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THE TECHNOGRAPH

PUBLISHED ANNUALLY

BY THE

ASSOCIATION OF ENGINEERING SOCIETIES

OF THE

UNIVERSITY OF ILLINOIS

VOL. XV.

1900-'01

UNIVERSITY OF ILLINOIS
CHAMPAIGN OR URBANA

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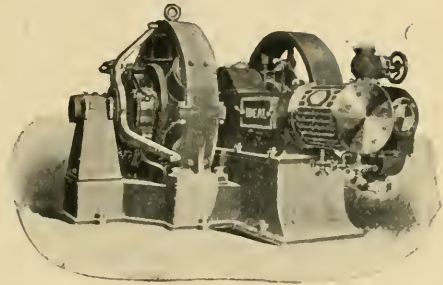
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VOL. XI.

1896-'97.

UNIVERSITY OF ILLINOIS,
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“The high end and aim of our profession is to consider and determine the economic use of time, power, and matter.”—*Don J. Whittemore.*

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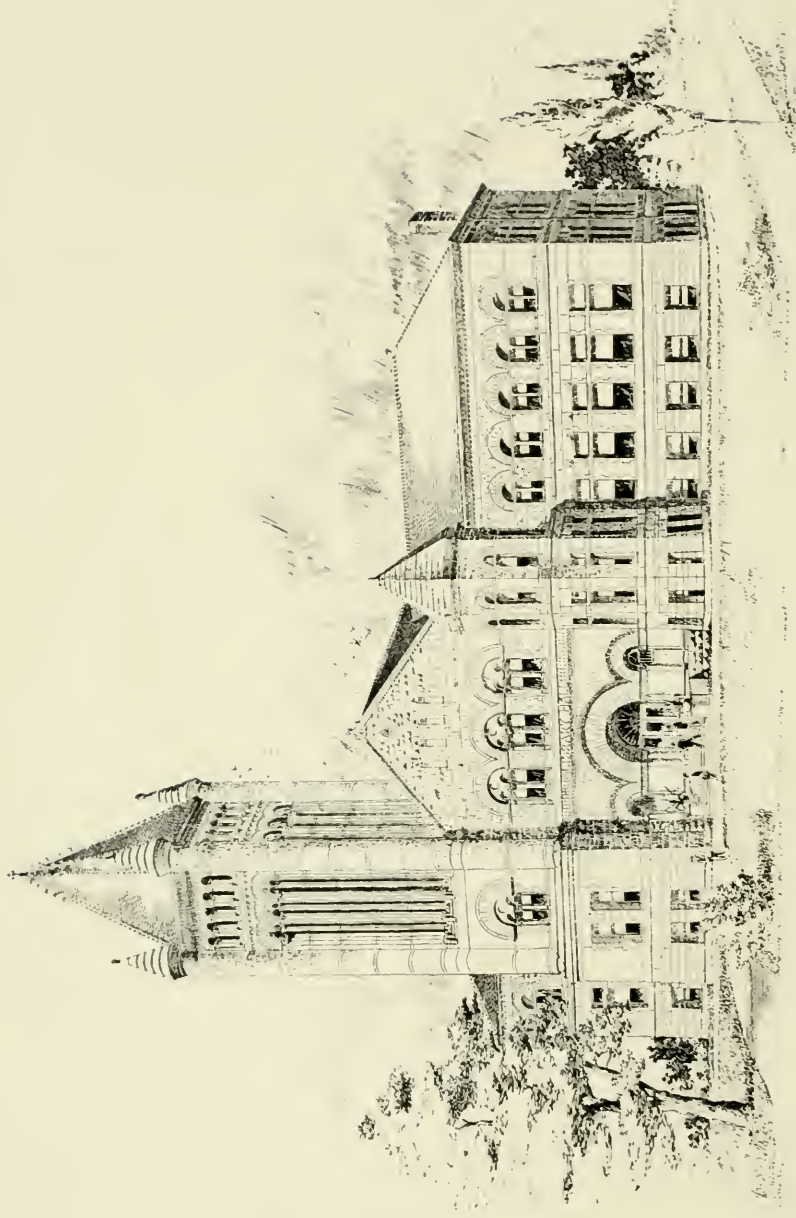
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OUR NEW LIBRARY.

BY JAMES M. WHITE, ASSOCIATE PROFESSOR OF ARCHITECTURE.

On the opposite page we present to our readers a view of the University Library, which is to be completed the first of June. The style of the structure is Modern Romanesque,—a style derived from that manner of building which prevailed throughout Western Europe from the fall of the Roman Empire until the rise of the Gothic Style, and was directly or indirectly inspired by Roman examples.

The walls are faced with a very hard pink sandstone from the Kettle River quarries in Minnesota, and the roof is covered with a deep cherry-red tile manufactured at Alfred, New York. The floors are constructed in accordance with the Expanded Metal System of Fireproofing. In this system concrete arches formed over arched channels, support a monolithic slab of concrete having expanded metal near its lower surface to resist the tension. The roof is similarly constructed, except that the concrete slab is supported on steel purlins instead of on arches. The roof tiles are nailed directly into the concrete. The partitions are of expanded metal fastened to steel studs. Where the partitions have no openings through them, a single row of channels lathed on one side only was used, the partition being plastered solid, making it two inches thick; but where there were openings, each stud was formed of two channels trussed apart to make a five-inch partition, which was then lathed on both sides.

Another article in this volume describes the heating and ventilating of the building and gives floor plans, which also

illustrate this description. The extreme dimensions of the building are 113 feet by 167 feet. The tower, which is entirely open between the mullions above the main cornice, is 132 feet high and forms the most imposing feature of the building. The entrance is through a massive archway which is beautifully enriched by carving. The entrance doors are of mahogany with frames of duplex electro-bronzed iron and a handsome grille in front of the transom. The main entrance hall is finished entirely in marble. The floor is of beautiful marble mosaic, the walls are marble arcades supporting the tunnel-vaulted ceiling, and the stairs and balustrades are likewise entirely of marble. The stairs to the second story, with the exception of the marble treads, are of electro-bronzed iron. The woodwork of the lower story is of oak, and that of the two principal stories is of cherry. The hardware throughout is of genuine bronze, Romanesque in design.

The rotunda is the central feature of the building and its walls will be elaborately decorated in color. It extends through the first and second stories and is surrounded by arcades on each floor, those of the second story opening on all sides into a gallery. Above the second story of arcades, and resting on an ellipse tangent to the four walls, is a domical ceiling of opalescent glass. The ellipse is supported by pendentives in the angles, on which will be painted winged figures emblematic of the four principal industries of the State,—Agriculture, Commerce, Manufactures, and Mining. The four lunettes between the pendentives will be covered by groups, each representing one of the four Colleges of the University. The paintings will be done in oil upon canvas and then fastened to the wall.

The delivery desk is placed at the south side of this rotunda, and the attendant on duty will be able to see nearly all parts of the reading rooms, as well as everyone who enters or leaves them. Immediately behind the delivery desk is the stack room, which at present contains three stories each seven feet in height, the middle floor being on a level with that of the delivery room. Each story will hold thirty thousand volumes. When future extensions are necessary, two more stories may be added in the space now assigned to the Art Gallery, making a total capacity of one hundred and fifty thousand volumes. Allowing eight books to the lineal foot of shelf, the capacity is equivalent to 2.6

volumes per cubic foot of space. The stacks are of the Library Bureau style with glass floors in the aisles. There is a book lift immediately in front of the door from the delivery room, and an electric freight elevator in one corner of the stack room communicating with the unpacking and cataloguing room below.

The "first story" is the one naturally assigned to the reading rooms, two of which are provided, since a single one would have required a higher story than would harmonize with the heights of the stories above and below it. Both rooms are splendidly lighted and are free from columns, the floor above being suspended from the trusses of the roof. Under these rooms are two others of similar dimensions which will be used as museums. The style of the building made a low basement desirable and necessitates placing the lower floor considerably below the grade. However, this is not a disadvantage for the museums, because it made it possible to set the windows high enough from the floor to permit the cases to be continuous around the walls.

It is impossible fairly to estimate the design of a building without first knowing the conditions which confronted the designer, and therefore a brief discussion of the problem is not out of place here. As the University is now growing rapidly, the building was designed to accommodate a much larger number of students than are now in attendance. The surplus space in the meanwhile will be utilized for the administrative offices of the University and for museums. It was necessary so to arrange the administrative offices that they may be accessible when the library rooms are closed. This is easily accomplished by locking the doors to the rotunda from the front and rear stair halls. When it becomes necessary to utilize the entire upper story of the building for library purposes, the partitions above the entrance hall may be removed so as to throw the Trustees' room and the President's reception room together into a periodical reading room, both wings being then used as seminary rooms. With the present arrangement of the periodical reading room, if the door between it and the large reading room be kept closed, the readers who frequent this room will not disturb students in the main reading rooms; and this arrangement will still be possible if the periodical room be transferred to the second story.

The work of designing the building was entrusted to N. Clifford Ricker, Professor of Architecture in the University, and

to the author. It is very gratifying to be able to say, now that the work has nearly reached a successful completion, that the draftsmen who assisted us, as well as the President of the Construction Company, are graduates or students of the University of Illinois.

The building will be dedicated the coming Commencement week, which is an especially appropriate time, because ground was broken for it with due ceremony on last Commencement Day.

UNITED STATES SURVEYS IN ILLINOIS.

BY J. A. OCKERSON, '73, SCHOOL OF CIVIL ENGINEERING, PRINCIPAL ASSISTANT ENGINEER, MISSISSIPPI RIVER COMMISSION.

The various surveys made by the general government have resulted in the establishment of many geodetic points and primary benchmarks in the State of Illinois. The writer has been closely identified with much of this work, and feeling that it is of great importance to the state, presents this brief account with the hope that it may awaken a new interest in the results, to the end that the points established may be more fully utilized and more carefully preserved.

The great prairie state is exceptionally well provided with bases from which to develop a thorough topographic survey of the territory lying within her borders.

TRIANGULATION. Illinois is nearly surrounded with a system of primary triangulation. Beginning at the northern boundary near the shores of Lake Michigan, it follows along the lake to the eastern boundary of the state. (See Fig. 2., page 9.) A chain of triangles extends from the lake nearly parallel to the eastern boundary, southward to Parkersburg. This system, comprising some fifty-one primary stations and two base lines, was laid out and measured by the U. S. Lake Survey operating under the Engineer Department of the Army. The triangulation extending from Chicago southward covers a distance of about 200 miles with thirty-five triangles. The discrepancy in the length of base as measured at Olney and as computed from the Chicago base through the triangles is 0.199 feet or 1 in 108 570. The angles were measured with 14-inch non-repeating theodolites reading with two micrometer microscopes to single

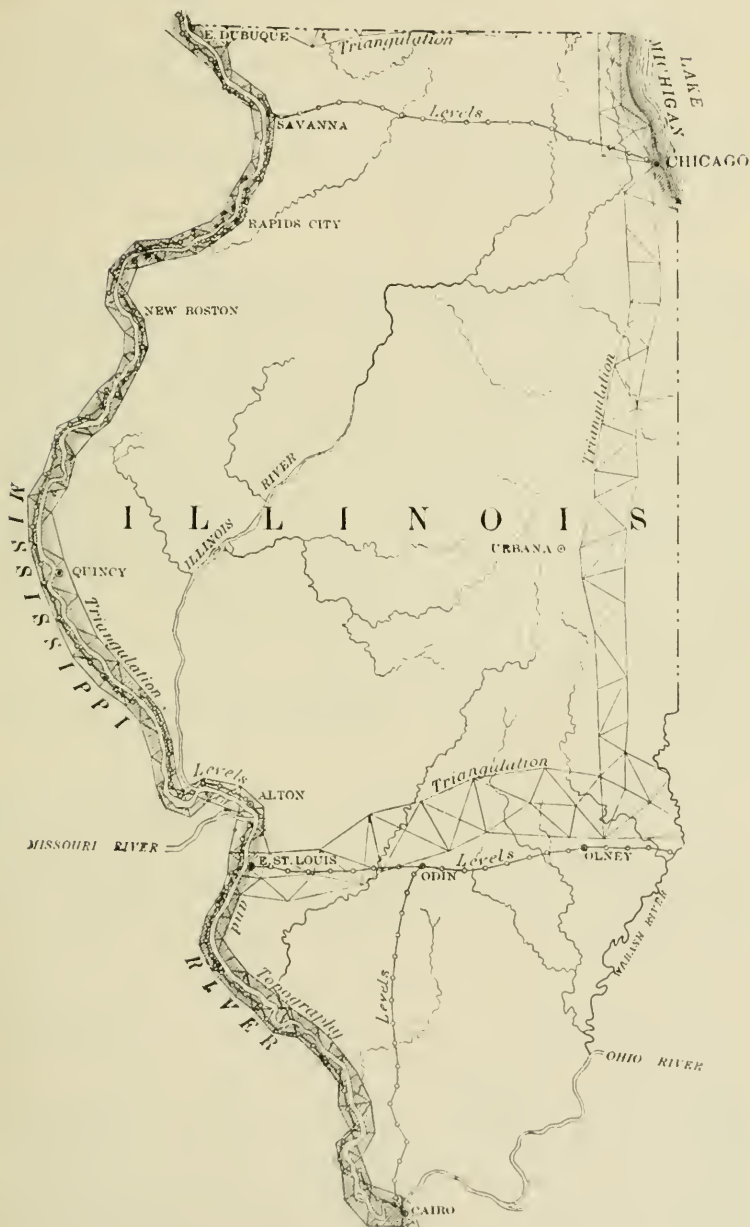


FIG. 2. U. S. SURVEYS IN ILLINOIS.

seconds. Some of the instruments were provided with three micrometers.

The U. S. Coast & Geodetic Survey triangulation crosses the Lake Survey system near the lower end and connects with it. This system extends across the state in a westerly direction to the Mississippi River and continues on toward the Pacific Coast. There are twenty-three primary stations and one primary base within the limits of the state.

The whole west front of the state is covered by a system of triangulation lying along the Mississippi River. In this system there are one hundred and forty primary stations, twenty-nine secondary stations, and five base lines. The angles in these triangles were measured with 10-inch theodolites reading with two micrometer microscopes to single seconds. While the lengths of the triangle sides in this system are such as to classify the work as secondary triangulation, yet the closure of triangles and general quality of the work has been well within the limits of error prescribed for primary work. For this reason it seems proper to apply the term primary to this system. This work has been done by the Mississippi River Commission, mostly under the supervision of the writer.

Along near the northern boundary of the state from the Mississippi River to near Lake Michigan is another Coast Survey system of triangulation with six primary stations in the state of Illinois.

In addition to the above, there are a great number of secondary points located in the vicinity of the triangulation systems, such as public buildings, land corners, the stone line benchmarks along the Mississippi River, etc. The positions of all of the above points in latitude and longitude are very closely determined.

LEVELS. There are several lines of primary levels, or precise levels, as they are sometimes called in contradistinction to the ordinary levels familiar to most engineers. These add another ordinate of position by giving elevations above sea level. One line extends across the state along the line of the Ohio and Mississippi Railway in about latitude $38^{\circ}45'$. Another line starts at the mouth of the Ohio and runs northward along the Illinois Central Railway to a junction with the first line at Odin. This work was done under the direction of the Coast and

Geodetic Survey. About thirty permanent benchmarks were established on these lines. These points are connected by precise levels with tide water at Sandy Hook, New York, and Biloxi, Miss. At these points automatic, self-recording tide gages are operated in order to determine the elevation of mean tide for a long period of time. The probable error of the Coast Survey line across the state is given as 0.1548 feet for the distance from Sandy Hook, N. Y., to St. Louis, Mo., some 1 100 miles.

Another line of primary levels has been run along the Mississippi River from Cairo to the Northern limits of the state. This line is not always on the east side of the river, but there are ninety-two permanent benchmarks in Illinois. Another line extends across the state from Savanna to Chicago, with thirty-seven permanent benchmarks along the line. There are on these lines, in addition to the above, twenty-nine permanent benchmarks on buildings, bridge abutments, etc. These lines were run under the supervision of the Mississippi River Commission. The allowable limit of discrepancy in the duplicate lines of levels was 5^{mm} distance between benches in kilometers. The line along the river is supplemented by two lines of ordinary levels run with great care and checking on the primary benchmarks. By this means three hundred and six benchmarks have been established in Illinois.

BASE LINES. Three primary and five secondary base lines have been measured at the following points: one primary base near Chicago and one near Olney by the U. S. Lake Survey; one primary base opposite St. Louis by the U. S. Coast and Geodetic Survey; one secondary base at Cairo, measured by the U. S. Lake Survey; four secondary bases measured respectively at East Louisiana, New Boston, Rapids City and East Dubuque. The lengths of these lines, reduced to sea level, are given in the following table:

| LOCATION. | HOW MEASURED. | LENGTH. FEET. |
|---------------------------|-----------------------------|------------------|
| Chicago Base..... | Repsold Base Apparatus..... | 24 648.6351 |
| Olney Base..... | “ “ “..... | 21 623.1545 |
| American Bottom Base..... | “ “ “..... | 23 841.7754 |
| Cairo Base..... | Wooden Rods..... | 5 402.8698 |
| Louisiana Base..... | “ “ “..... | 8 875.0796 |
| New Boston Base..... | Steel Tape..... | 18 065.7771 |
| Rapids City Base..... | “ “ “..... | 5 264.9940 |
| East Dubuque..... | “ “ “..... | 7 104.8508 |

Some idea of the refinement of the work will be derived by an inspection of the following results: Discrepancy between first and second measurements of the different sections of the Chicago base ranged from 0.0006 feet to 0.0082 feet, the probable error of the total length being 1 in 1 052 200. The probable error of the Olney base is 1 in 1 895 000. The discrepancy between the first and second measurements of the New Boston base, measured with steel tapes, was 1 in 750 000.

The rapidity with which base lines can be measured with steel tape makes this method of measuring preferable to any other except for an occasional initial primary base. It requires a large force of men several months to measure a primary base, while a base can be measured with a steel tape in a few hours and with a degree of refinement well within the limits of accuracy of the best angle measuring instruments. The first measurement of the Rapids City base was made with 300 ft. steel tape in 41 minutes, and the second in 28 minutes; discrepancy 1 in 594 917. The East Dubuque base required 68 minutes for the first measurement and 53 minutes for the second; discrepancy 1 in 346 965.

In order to secure the best results these measurements should be made on a day heavily overcast with clouds or before sunrise. Under average conditions, a base line a mile long can be made ready for measurement in two days time with a force of about ten men. This preliminary work involves clearing the line of brush, weeds or other obstructing vegetation; setting stakes on the line at intervals of 30 feet to support the tape; setting table and straining stakes at intervals of 300 feet, or end of each tape length; and carefully establishing the grade line of the entire length of base line at the points where tape is supported.

AZIMUTH OBSERVATIONS. Observations are usually made at each base line to determine its true bearing. Circumpolar stars lying near the pole are used in this work, the favorite stars being Polaris, δ Cephei, δ Ursae Minoris and λ Ursae Minoris. In primary observations five nights azimuth work are required to obtain the desired result. In secondary work two nights are considered sufficient. It is always desirable to observe one star at eastern elongation and one at western elongation each night. The probable error of the final result in primary work rarely exceeds a few tenths of a second.



PORTION OF MAP OF THE MISSISSIPPI RIVER

METHEUNICAL SIGNS AND LETTERS

SCALE 1:20,000

PLATE I



TOPOGRAPHY. A strip of topography averaging about a mile wide has been run along the entire Mississippi River front of the state. The outlines of the bluffs bordering the river bottoms have also been located accurately.

The area of the lands lying on the Illinois side of the river between the bluffs and the river amounts to some 1 200 square miles, nearly all of which is subject to overflow at high stages. This is protected by 148 miles of levee, as follows: below Alton, 54 miles; Snyder district, 54 miles; Quincy to Warsaw, 40 miles. The state of Illinois has a river front on the Mississippi River of 588 miles, the whole length of which has been surveyed.

The features embraced in the topographic belt, such as river banks, creeks, sloughs, ponds, lakes, fields, wooded areas, roads, houses, etc., have been located instrumentally in great detail. The locations of points are made in the field with transit and stadia. The errors of lengths read with stadia should not exceed 1 in 800. With short runs between check points this keeps the discrepancies so small as to be inappreciable on a plat of ordinary scale.

The relief of the country has been shown by means of five foot contours developed from numerous elevations determined by means of vertical angles. The levels carried by vertical angles are checked at frequent intervals on benchmarks established by means of wye levels. All of the transit lines are checked by connecting with points of a tertiary triangulation which in turn connects with the main system of triangles. The transit work is further checked by closing a series of circuits, and thus the discrepancies in the elements of distance, azimuth, and elevation are kept within very narrow limits. The number of instrumental locations averages about three hundred seventy per square mile of topography with three hundred twenty-five elevations in the same area. Soundings are taken in the Mississippi River in lines normal to the river and about 800 feet apart. The individual soundings on these lines are taken as rapidly as the leadsmen can operate, and about every fourth depth is located by reading the distance with a transit from a known point on shore to a stadia rod fixed in the sounding yawl near the leadsmen.

A strip of topography about half a mile wide has been run along the shore of Lake Michigan and includes the cities and

towns. The method used in this work is similar to that described above.

The U. S. Geological Survey has also done considerable topographical work along the Illinois River and along the Mississippi River from Rock Island northward. This work is largely compiled from the old land and other surveys supplemented by sketches made on the ground. The contour intervals are usually 10 and 20 feet. The methods used in this work give general results of sufficient accuracy to satisfy the wants of the geologist, but they lack much in the detail and accuracy required for a correct and satisfactory topographical map. In this respect they do not compare favorably with the results attained by other departments of the general government. Economy rather than accuracy seems to have been the controlling feature of this work, if current reports as to cost are true. The maps are admirably executed.

FIELD SKETCHING AND PLATTING. In the field, a careful record is made in suitable notebooks of the various points occupied and located, together with the distances, azimuths and elevations. These points are platted by the transitman before leaving the ground, and minor unimportant features not instrumentally located are sketched in proper position by pacing, or ranging in. This is the field sketch, and is usually a sheet 7 by 10 inches in size. As the platting on these sheets is done under many difficulties, it is not deemed best to use up the observers' time in attempting to do the work very accurately, as the field plat is made in the office, where all located points are re-platted with the greatest practicable accuracy.

These plats are generally made on tracing linen, and the scale of the work is 1:10 000. The tracing linen has the advantage of facilitating the transferring to the final map, and in the fact that blue prints can be made for immediate use if needed.

The projection lines, consisting of lines of latitude and longitude one minute apart, are first drawn. From these lines the geodetic points pertaining to the main triangulation are platted. This forms the base of the plat, and the transit courses are next platted and the various circuits closed to ascertain whether the work has been done with the required degree of accuracy. This is done in the field before the work is out of reach, so that if errors are found they may be located and corrected by the tran-

sitman. Filling in the side shots and completing the plats is generally left for winter work at headquarters.

OFFICE REDUCTION AND MAPPING. When the inclement weather of the winter sets in, the laboring force of the party is disbanded and the surveyors repair to headquarters, to reduce their notes, complete the field plats, and make the finished map. The elevations of side shots are worked up and locations platted. The details and contours are drawn in ink, the necessary notes as to locality, observer, notebook, etc., are entered on the plats and they are then ready to transfer to the map, which is usually made up of several field plats.

For the finished map, well seasoned and mounted paper is used. The projections, showing minutes of latitude and longitude and the limiting border lines, are first drawn. Then the transparent field plat is laid over the map, the corresponding projection lines being coincident, and the details are transferred to the map by means of faint carbon paper and a fine stylus. The lines thus transferred are inked in and then the lettering for the entire map, except title and notes, is done. After the lettering, come the conventional signs, representing the different characters of vegetation, etc. In the work of the Mississippi River Commission the lettering and sign work are done with mechanical appliances invented by the writer.

The title, authorities and explanatory notes are put on, and after a critical examination for errors or omissions the map is ready for re-production. This is usually done by photo-lithography, on a scale of one-half that of the original map. The character of the work done in this way is shown on Plate I. (opposite page 12).

SURVEY MARKS. The triangulation points, primary bench marks, and ordinary benchmarks are marked by stone posts or tiles and surface pipes. The latter are used on the work of the Mississippi River Commission and are the result of experience and development as the survey progressed. They were designed by the writer after testing several methods which failed in point of stability as well as durability. The ordinary stone post formerly used did not have sufficient bearing surface to maintain its elevation in loose wet soil; it is subject to disturbance by frost; the exposed portion is easily destroyed by a slight blow or by wild fires which cause the stone to crumble; they are also diffi-

cult and expensive to mark in a way that will make positive identification easy.

To obviate these defects a combination mark was decided on. This consists of a vitrified tile $4 \times 18 \times 18$ inches placed about 3 feet below the surface of the ground and a witness mark consisting of a 4-inch wrought iron pipe 4 feet long, which is set on the tile concentric with its center mark and plumbed over it. The top of the pipe is closed with a cast iron cap bearing similar marks to the surface of the tile. The position and elevation of the top of the cap are as well determined as the copper bolt in the tile, and until seriously disturbed can be used in lieu of the latter. If deemed necessary, the cap can be removed and the copper bolt reached through the pipe, or as a last resort the pipe can be dug up.

Before burning, the tile is easily marked in such a way as to identify it for all time to come, even when located among numerous other marks. In addition to the marks common to all points of the same class, the cap of the pipe is marked with the latitude, longitude and elevation above sea level, so that anyone having occasion to use them has all of the information required. This the writer believes to be an innovation introduced on the work of the Mississippi River Commission.

COST OF FIELD WORK BY THE MISSISSIPPI RIVER COMMISSION. The secondary triangulation with necessary base lines at intervals of about twenty-five triangles and azimuth work at each base, triangle sides averaging about three miles long, with geodetic location of stone line benchmarks at intervals of three-fourths miles, has cost an average of \$80.70 per mile of triangulation system.

Primary levels in which elevations are determined by duplicate lines run only when favorable atmospheric conditions exist, including the benchmarks, have cost an average of \$22.13 per mile.

Topography, with all important features located instrumentally as described above, has cost an average of \$47.05 per square mile; hydrography under same conditions, \$21.85 per square mile.

A valuable legacy has been left to the state in the way of geodetic points established with great care and at considerable

expense. It would be well for the engineering students and graduates of the University of Illinois, whose training makes them especially fitted to appreciate the value of the work described above, to take the initiative in a movement looking to its utilization and preservation. Suitable legislation should be enacted providing for the protection of the survey marks, with proper penalties for the wilful destruction of the same.

THE ACCELERATIONS OF THE LINKS OF A MECHANISM.

BY G. A. GOODENOUGH, INSTRUCTOR IN MECHANICAL ENGINEERING.

An interesting part of the subject of Kinematics is that relating to the accelerations of the moving parts of a mechanism. An outline of the principal theorems in this connection may be found in the *TASCHENBUCH DER HUTTE*, 16th Ed., pp. 149 to 154. A much fuller treatment is given in the introduction to *WEISBACH'S MECHANICS OF ENGINEERING AND MACHINERY*, Vol. III. The properties of the inflection circle are considered at some length in *WILLIAMSON'S DIFFERENTIAL CALCULUS*, 8th Ed., Chap. XIX.

It is the object of this article to apply these principles and constructions to one or two simple mechanisms, and thus to furnish concrete examples for the aid of those who may wish to study this important subject. Frequent references will be made to the authorities above mentioned.

For the first example, the ordinary four-link mechanism is considered (Fig. 1). Link CD is assumed to be fixed, links AD and BC are cranks rotating about points D and C respectively as centers, and link AB is the coupler whose motion is to be investigated. Lines AD and BC are prolonged and intersect at P, which is the instantaneous center of the motion of coupler AB with respect to fixed link CD. Conceive a rigid plane attached to the coupler and moving in the plane of the mechanism; then every point of this plane is for the instant rotating about point P as a center. As the coupler and attached plane move in space, every point of the plane describes a definite path. At any instant certain points of the plane have reached points of inflec-

tion in their paths. All such points lie upon the circumference of a circle called the inflection circle. (WEISBACH, § 16).

The location of the inflection circle is found as follows: Produce lines AB and CD to intersection K, and join points K and P. The line PK is called the *collineation axis*. Through point P draw PH parallel to DC until it intersects AB produced in point H. Finally, through H draw a line parallel to the collineation axis PK cutting lines BC and AD produced in points F and F'. Then a circle passed through points P, F, F' is the required inflection circle (TASCHENBUCH, p. 151). A second method of finding the circle is as follows (WEISBACH, § 17): Lay off $PB' = 2PB$. Then the four points B', C, P and F form a harmonic range, and the fourth point F may be found from the properties of the complete quadrangle. Through any point H draw rays HB', HC, HP, and through any point *e* on ray HC, draw diagonals Pf and B'd. The four points B', C, D and F form a complete quadrangle, and the intersection F' of sides fd and B'CP must be the harmonic conjugate of point C. Therefore F' is a point on the inflection circle. The point F' may be found in a similar manner.

Bobillier's construction (TASCHENBUCH, p. 152) may be used to check the accuracy of the work when either of the above methods are employed. The two points A and B of the moving plane describe paths whose centers of curvature are at D and C respectively. AD and BC are of course the radii of curvature of these paths. Let the line joining the given points A and B be prolonged until it intersects at point K the line joining the centers of curvature C and D. Then, as above stated, the line joining intersection K to the instantaneous center P is the collineation axis. This axis makes the angle θ with the radius BC, and according to Bobillier's construction, the line PT which makes the same angle θ with the other radius AD is the tangent to the centrode at the point P. If another pair of points should be chosen, a different collineation axis would be found, but the construction would give the same tangent PT. For example, suppose points A and X are considered. As before the center of curvature of A's path is the point D, while the center of curvature of the path of X is at infinity in the direction XP. The line joining the two points is AX, and the line joining the two centers of curvature is evidently JD parallel to PX. The point

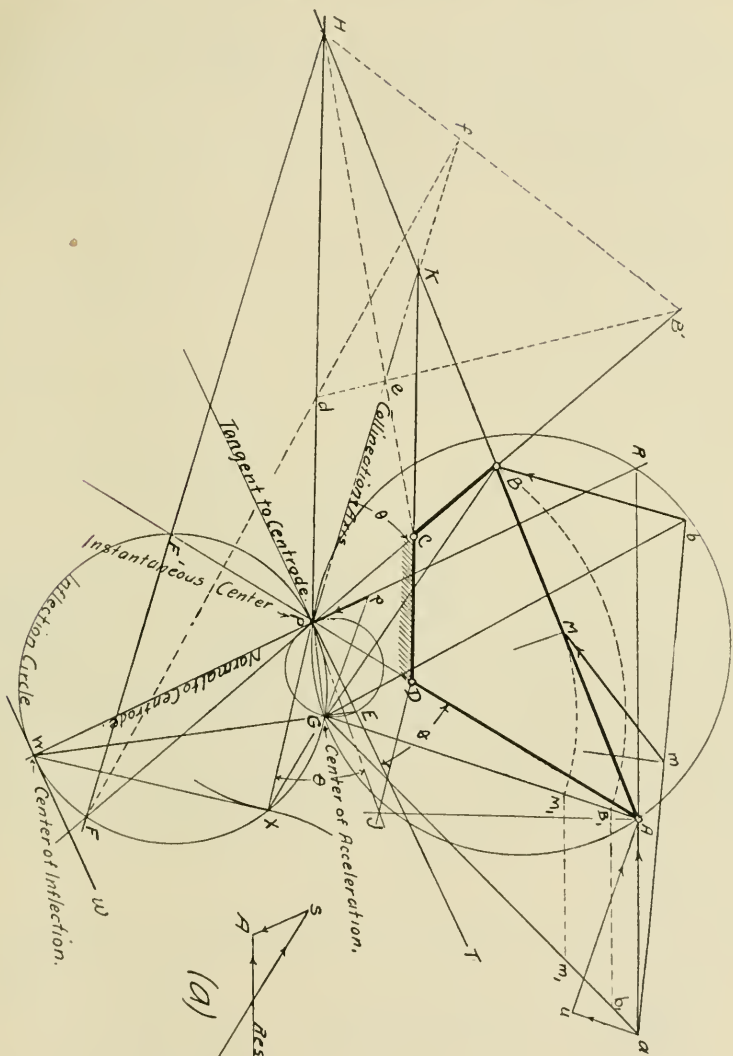
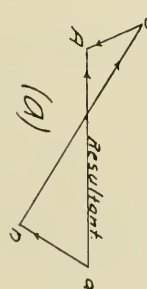


FIG. 1.

$AP = r$
 $AO = r\omega^2$
 $SM = r \frac{d\omega}{dt}$
 $AS = PP = u\omega$
 $AG = p$
 $AU = p \frac{d\omega}{dt}$
 $AU = p\omega^2$
 $Aa = p \sqrt{\omega^4 + \left(\frac{d\omega}{dt}\right)^2}$
 $PE = \frac{pu}{dt}$



of intersection is J, and hence PJ is the collineation axis of points A and X. The axis makes the angle θ with radius PX, and therefore PT makes angle θ with radius AD, as in the first case. The line PW perpendicular to PT at point P is the normal to the centrode and is also the diameter of the inflection circle (WIESBACH, § 20). The point W at the extremity of the diameter is called the *center of inflection*. To show definitely the point of inflection the path of point X has been plotted (Fig. 1).

In Fig. 2, the ordinary slider crank mechanism is shown. The instantaneous center of the motion of the rod AB is at point P and line PK is the collineation axis. Point K is the intersection of the line joining the points A and B with the line CZ which joins the centers of curvature of the paths of points A and B. Line PT is now drawn making angle BPT = angle APK. Then according to Bobillier's construction, PT is the tangent to the centrode, and PW perpendicular to PT is the normal at the centrode. The point B is constrained to move in the straight line BC. Hence the center of inflection must lie on the line BC (WEISBACH, § 20) and must therefore lie at the intersection W of lines BC and PW. The inflection circle is described upon PW as a diameter. Another method is to construct triangle ABF similar to triangle PAK; then F is a point on the inflection circle (TASCHENBUCH, p. 150). Still another construction is to lay off $PA' = 2PA$, and as in Fig. 1, points P, C, A', F form a harmonic range. The point F is found by constructing the complete quadrangle P, A', *mn*. Having found point F, the circumference of the inflection circle must pass through points F, B and P.

We consider now the problem of finding the acceleration of any point of the moving link. The following data is assumed:—

Length of Crank AC (Fig. 2) 9 in. = $\frac{3}{4}$ ft.

Length of Connecting rod AB 18 in. = $1\frac{1}{2}$ ft.

Velocity of Crank Pin, uniform 12 ft. per sec.

The acceleration of point A must be radial and of magnitude $\frac{\text{vel.}^2}{\Delta C} = \frac{12^2}{\frac{3}{4}} = 192$ ft. per sec. per sec. Let this accelera-

tion be represented graphically by the length AC of crank. On the drawing $AC = \frac{3}{4}$ in. Hence $\frac{3}{4}$ in. = 192 ft. per sec. per sec., or 1 in. = 256 ft. per sec. per sec., the scale of acceleration. The acceleration of point B must be in the direction of motion BC.

To determine its magnitude the *center of acceleration* of the motion of rod AB must be found. AC is the direction of A's acceleration, and BC is the direction of B's acceleration. They intersect at point C. The center of acceleration must lie on a circumference passing through points A, B, C (WEISBACH, § 21); it also lies on the circumference of the inflection circle (WEISBACH, § 15, 16). Therefore G, the intersection of these two circumferences, is the required *center of acceleration*.

Suppose a rigid plane lying in the plane of the mechanism is attached to rod AB; it will partake of the rod's motion and every point will have a definite acceleration. The magnitude of the acceleration is proportional to the distance of the point from the center of acceleration; and further, the direction of the acceleration of any point makes a constant angle ψ with the ray joining the point in question to the center of acceleration (WEISBACH, § 15). Thus:—

$$\frac{\text{accel. B}}{\text{accel. A}} = \frac{GB}{GA} \text{ and } \frac{\text{accel. P}}{\text{accel. A}} = \frac{GP}{GA};$$

angle GAC = angle GBC = angle GPW = ψ . This shows that the acceleration of the plane which coincides with the instantaneous center P is in the direction PW, the normal to the centrode. The length AC is taken as the linear representative of the acceleration of point A. To find graphically the accelerations of points B and P, lay off on line GA, the lengths GB' = GB and GP' = GP, and draw line GCH. Then B'e' and P'd' parallel to AC, represent to the same scale the accelerations of points B

and P respectively, since $\frac{B'e'}{AC} = \frac{GB'}{GA} = \frac{GB}{GA} = \frac{\text{accel. B}}{\text{accel. A}}$. In

this manner may be found the acceleration of any point of the moving plane.

By measurement, B'e' = 0.86 in., P'd' = 1.135 in.

Acceleration of B = 0.86 × 256 = 220.2

Acceleration of P = 1.135 × 256 = 290.6

It is of interest to find the angular velocity and angular acceleration of the moving plane.

Let ω = angular velocity,

Then $\frac{d\omega}{dt}$ = angular acceleration.

The velocity of point A is known to be 12 ft. per sec. Then

$$\omega = \frac{\text{vel. of A}}{\text{AP}} = \frac{12}{1.68} = 7.14$$

Let $\text{AG} = \rho$. The acceleration AC may be resolved in the direction AG and perpendicular to AG. The two components are

$$\text{Af} = \rho\omega^2, \text{ and } \text{Cf} = \rho \frac{d\omega}{dt}.$$

$$\text{Af} = 0.52 \text{ in.} = 0.52 \times 256 = 133.12 \text{ ft. per sec. per sec.}$$

$$\text{Cf} = 0.54 \text{ in.} = 0.54 \times 256 = 138.24 \text{ ft. per sec. per sec.}$$

$\text{AG} = \rho = 2.59 \text{ in.} = 2.59 \text{ ft.}$, since the scale of the drawing of the mechanism is 1 in. = 1 ft.

$$\omega = \sqrt{\frac{\text{Af}}{\rho}} = \sqrt{\frac{133.12}{2.59}} = 7.17.$$

$$\frac{d\omega}{dt} = \frac{\text{Cf}}{\rho} = \frac{138.24}{2.59} = 53.38.$$

Let the distance AP of point A from the instantaneous center be r . The total acceleration of A is the resultant of three component accelerations, viz:— $r\omega^2$ in the direction of r ; $r \frac{d\omega}{dt}$ perpendicular to r ; an acceleration $u\omega$ which is equal and parallel to the acceleration Pd of the point of the plane which coincides with the instantaneous center P (WEISBACH, § 14, 15).

In this last expression u is the velocity with which the instantaneous center traverses the centrode, and is likewise the velocity of the inflection center W. The directions of these three components and the magnitude of one of them are known and the direction and magnitude of the resultant is given by the line AC. From point A (Fig. 2 (a)), As is laid off equal and parallel to Pd ($= u\omega$), and AC is laid off equal and parallel to crank AC. The polygon is closed with the lines st and tC parallel and perpendicular respectively to radius AP. Then $st = r\omega^2$ and $tC = r \frac{d\omega}{dt}$. By measurement,

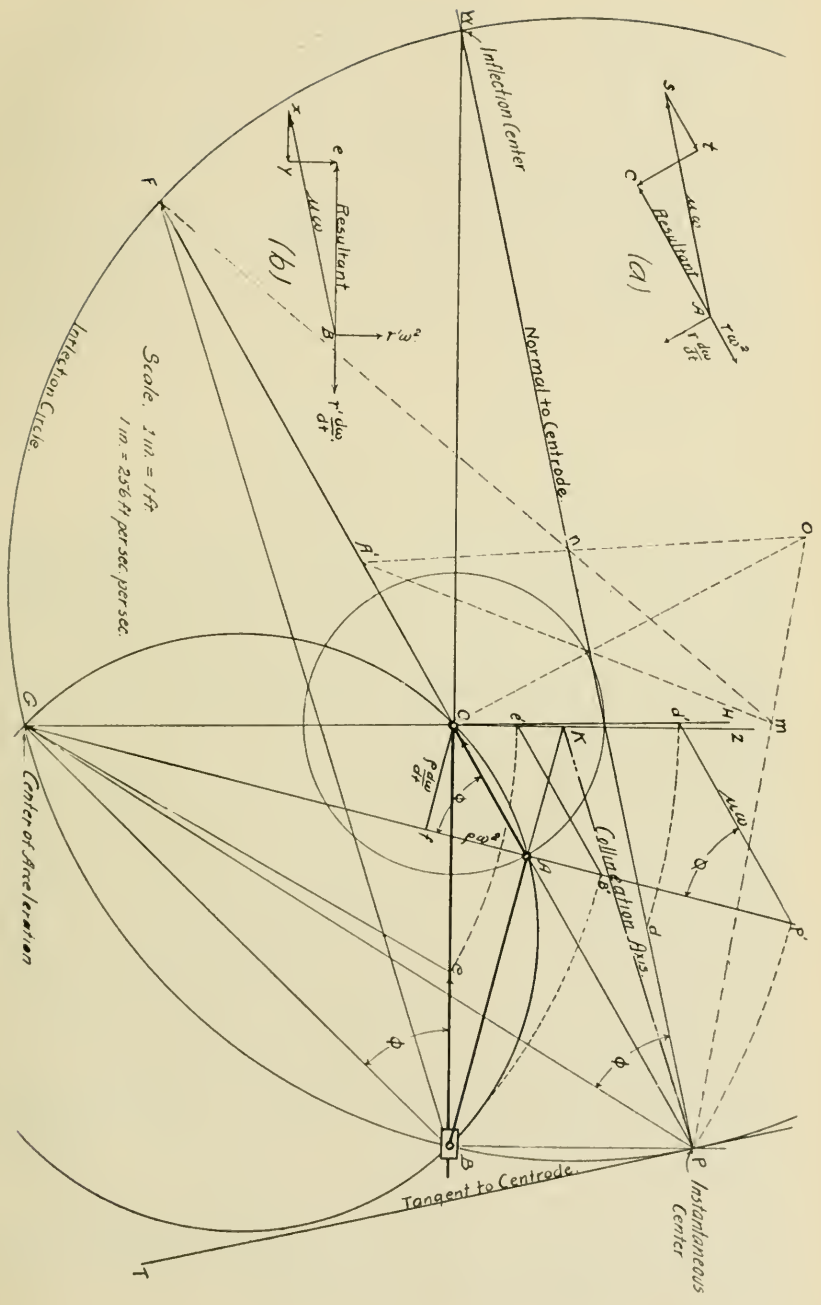
$$r = 1.68 \text{ in.} = 1.68 \text{ ft.}$$

$$st = 0.335 \text{ in.} = 0.335 \times 256 \text{ ft. per sec. per sec.}$$

$$tC = 0.35 \text{ in.} = 0.35 \times 256 \text{ ft. per sec. per sec.}$$

$$\text{Hence } \omega = \sqrt{\frac{st}{r}} = \sqrt{\frac{0.335 \times 256}{1.68}} = 7.16,$$

$$\frac{d\omega}{dt} = \frac{tC}{r} = \frac{0.35 \times 256}{1.68} = 53.33.$$



Scale. 1 in. = 1 ft.
 1 in. = 256 ft per sec. per sec.

FIG. 2.

Since $Pd = u\omega = 290.6$, $u = \frac{290.6}{7.16} = 40.6$ ft. per sec. $u = \text{vel.}$

of $W = PW \times \omega$. Therefore $PW = \frac{u}{\omega} = \frac{40.6}{7.16} = 5.67$ ft., which is verified by measurement.

In Fig. 2 (*b*), is shown the component accelerations acting on the point B. Let $PB = r'$. $Bx = Pd = u\omega$; then $ey = r'\omega^2$, and $xy = r' \frac{d\omega}{dt}$. The resultant is Be , equal and parallel to Be , Fig. 2.

$$\text{As above, } \omega = \sqrt{\frac{ey}{r'}} = \sqrt{\frac{0.245 \times 256}{1.22}} = 7.16$$

$$\frac{d\omega}{dt} = \frac{xy}{r'} = \frac{0.255 \times 256}{1.22} = 53.5.$$

In the mechanism of Fig. 2, the direction of point A's acceleration is determined by the assumed conditions, and the direction of the acceleration of B is fixed by the condition that B is constrained to move in the straight line BC. In the mechanism of Fig. 1, on the contrary, if the acceleration of point A be assumed in magnitude and direction, we have no knowledge of either the magnitude or direction of the acceleration of point B. But to obtain the center of acceleration, the directions of the accelerations of two points of the moving plane should be known. It was shown above that the acceleration of the point of the plane which coincides with the instantaneous center P must be along the normal PW to the centrode. If now aA is assumed as the linear representative of the acceleration of point A, the lines aA and PW intersect at R, and a circumference passed through R, A and P will contain the center of acceleration. Since this center lies also on the circumference of the inflection circle, it must lie at the intersection G of the two circumferences.

Having found center G, the accelerations of any other points of the coupler (as B and M) may be found by constructing the triangles BbG and MmG similar to triangle AaG . Then Bb (B_1b_1) represents the acceleration of point B, and Mm (M_1m_1) represents the acceleration of point M to the same scale that Aa represents the acceleration of point A. Points A, M and B lie in a straight line, and it is worthy of note that the extremities a , m and b also line on a straight line.

The total acceleration Aa may be resolved into two components, $au = \rho \omega^2$ in the direction AG, and $Au = \frac{\rho d\omega}{dt}$ perpendicular to AG, where $\rho = AG$ is the distance of point A from the center of acceleration. Again if $AP = r$, the total acceleration Aa may be considered as the resultant of three accelerations acting at point A, viz:— $r \omega^2$ in the direction AP; $r \frac{d\omega}{dt}$ perpendicular to AP; and $u\omega (= Pp)$ parallel to the normal PW. The polygon of these four accelerations is shown in Fig. 1 (*a*).

$$sA = Pp = u\omega,$$

$$sn = r \frac{d\omega}{dt}$$

$$an = r\omega^2$$

$$aA = \text{resultant, or total acceleration of point A.}$$

Since every point on the circumference of the inflection circle is for the moment moving in a rectilinear path, the radius of curvature is infinite, and the radial acceleration is $\frac{\text{vel}^2}{\text{rad.}} = \frac{\text{vel}^2}{\infty} = 0$. That is, a point on the circumference of the inflection circle has no radial acceleration. For example, the acceleration of point X Fig. 1, has no component in the direction XP, and must therefore be perpendicular to XP or in the direction WX (since PW is a diameter). Therefore the acceleration of any point on the circumference of the inflection circle is in the direction of the line joining the point to the center of inflection. Suppose a line WG be drawn connecting the center W with center G (Fig. 1). Let this line be prolonged to intersect the tangent TP at E, and let a circumference be passed through points P, G and E. From the geometry of the figure it is easily seen that angle GET = angle GPp. Hence the acceleration of point E is in the direction EP. It is also apparent, that the acceleration of any other point on the circumference also lies along the line joining the point to the center P. Therefore any point on this circumference has zero tangential acceleration (WEISBACH, § 15). As shown above,

$$PW = \frac{u}{\omega}$$

$$\text{From triangle } aAu, \tan aAu = \frac{au}{Au} = \frac{\omega^2}{\frac{d\omega}{dt}}$$

Angle $aAu = \text{angle } PWE$.

Hence, $PE = PW \tan PWE = PW \tan aAu$

$$= \frac{u}{\omega} \frac{\omega^2}{dt} = \frac{u\omega}{dt}$$

Since angle $GWu = \text{angle } GPW$, it follows that the direction of the acceleration of point W is along tangent Wu , that is, parallel to the tangent PT . Likewise the acceleration of every point on line GW is parallel to the tangent PT , and the acceleration of every point on line GP is perpendicular to the tangent PT , or parallel to the normal PW (WEISBACH, § 15).

NATURAL SELECTION IN ARCHITECTURE.

BY C. H. BLACKALL, '77, SCHOOL OF ARCHITECTURE.

A short time ago one of the students of the Massachusetts Institute of Technology conceived the idea of interviewing a number of prominent Boston architects to ascertain what in their opinion were the most needed qualifications for a successful architect. The young man was shrewd beyond his day, and after cogitating over the various replies he received, announced that as far as he could sum up the evidence, the chief requisite was that the architect should be a successful plagiarist and be able to steal his ideas without being found out. This is one way of expressing a natural misunderstanding of what architecture in these days very often means. We draw our ideas so largely from foreign sources that to one who looks upon the surface or who does not understand the processes of architectural evolution, it would seem as if the prime essential for an architect who is blessed with a large practice is the possession of a comprehensive and thoroughly classified collection of photographs of European work, with perhaps a few clever draughtsmen to aid in the plagiaristic concoctions which are paraded as original designs. We copy everything now-a-days. Our students roam the world in search of fresh fields and pastures of green, and there is no style ancient or modern but is copied in our buildings. We surely can not blame our kind friends and critics if they draw the infer-

ence that the most successful architecture is that which most closely resembles in external appearance its historic prototype.

When we consider, however, the true genius of architecture and appreciate more clearly the methods by which our best designers arrive at the desired results, the plagiaristic phase of architecture, so to speak, is not so manifest, and the reason for some of our close adherence to antique models is more apparent. There are two types of architectural designers. One includes those who strive to be original at all hazards, who abhor a copy and have a dread of doing anything in a manner that was ever done before, who scorn the academy, eschew Roman tradition and deny that true art has existed in this world since the sixteenth century. The other type of designer has the retrospective mind which does not appreciate the necessity of the worlds twice going through the same experience, but would profit by other people's mistakes and failures and use the materials which have been hewn out from the world's quarries, rather than to be original at the expense of being good or successful in design. Up to within a comparatively few years the designers of the first class were in the majority. Those were the days when Gothic ideas were considered not too bright and good for human nature's daily food, and the weight of the influence of men like Eastlake and Ruskin was thrown on the side of Romanticism and so-called eclectic design. Now it is a peculiar trait of the Anglo-Saxon race that we take a pride in doing what we do not want to do. We erect into a principle, procedures and methods which our heart and instinct disapprove and stick to that principle irrespective of innovations. Accordingly, the development from our medieval period of originality, though inevitable as an adjunct of our increasing national wealth and education, was slow and laborious at times, but since the Renaissance which this country experienced at the time of the Centennial Exhibition, and more extensively even, since our recent World's Fair, the academic, retrospective style of design has grown into more general favor. We are now in the midst of a peculiar period when the demands made upon our designers differ from anything which has existed in the past. Our acquirements are new. Even the methods of mere construction are in the line of radical departures. It is impossible for anyone to lay down exact prophecies of how our art is to develop. The future is a sealed book and naturally we can

turn only to the past for lessons. We can judge of what to do in the future only by what has been done in the past. The conflict between romanticism and the academy will always be with us. We shall never lack the warm adherence of originality at all costs nor those who advocate the extreme academic treatment for all problems, and while the true course undoubtedly lies between the two, if we can judge by what has developed in the past, we are safer in the hands of tradition than if guided by inspiration alone.

Architecture viewed in the light of academic training can be defined as the art of improving upon what has been done before. It is a pretty safe general rule when one has a task to perform, before beginning upon the work, to see how other people have solved the same problem, what difficulties they have encountered and how they have been enabled to overcome them. This rule would apply to every department of human industry and there surely is no reason why it should not be applied to architecture. The world never stands still, and though there are times when art seems to be on the wane and architecture debased rather than improving, yet in the course of centuries there has been a decided, long-continued progress from the rude huts and mud walls of the Egyptians to the present time. Broadly speaking, the civilized world owes its architecture to two nations, the Greeks and the Romans. The artistic spirit carried to so high a degree of perfection by the former, and the constructive and decorative principles of the latter have been the basis upon which all of our modern styles have been built, and for nearly seven centuries the world has been working over similar motives, experimenting with variations of the same styles of construction, and accepting the same general principles of planning as well as of taste. There have been countless variations from the dominant themes and the range of development has varied as widely as the twelfth century Gothic on the one hand, which retained only a shadowy hold on classic tradition, and the eighteenth century Spanish Plateresque on the other, in which the classic forms bloomed into a mad riot of imagination. Yet all the while the fundamental principles of classic architecture have never been entirely neglected and were constantly reasserted, each time with a renewed emphasis and a more perfect adaptability to the constantly changing conditions. Natural

selection built up the marvelous architecture of the Greeks from the crude work which marked the beginnings, to the final crowning glory of the Acropolis. There never was a more rigid, hide-bound system of art than existed in Greece, and yet in the age of Pericles it resulted in the greatest breadth of treatment, keen individuality, and a sense of freedom in detail, all within dignified, conservative lines. In exactly the same way a species of natural selection and survival of the fittest operated to develop the Roman baths, the triumphal arches and the enormous monumental structures with which the Romans adorned so lavishly the imperial city. It was by adhering to the type, by simply adopting the architectural baggage of his forbears that the Roman artist accomplished what he did. That he lost a certain delicate conception which the Greeks had does not argue that he did not bring something else into the world. The history of art in Europe affords an example of continuous growth from the eighth century B. C. up to the present period, with but one break, that caused by the downfall of Rome and the inundation of Europe by northern barbarians. The Gothic architecture which sprang up as a result of the revival of intercourse and education, was wonderful in its growth, exquisite in many of its developments, and expressed in a very large degree the character of the civilization and the needs of the people. However, Gothic architecture at the best was an innovation. It was an off-shoot resulting from barbarism, and the world resumed the line of selection which had been followed by the Greeks and Romans. The Renaissance period was the return to old ideas, to monumental design, and to coherent composition. The beauty of the Gothic work, its majestic cathedrals and magnificent color effects will always appeal to every artist, but the spirit of order, of tradition and precedent which the Romans impressed so strongly upon the world has never faded away. Our most enthusiastic admirers of medievalism have never quite shaken off the hold which the community as a whole has upon classic architecture. The artists of the Renaissance took motives from both Greece and Rome, united them with individualities of their own, and produced an architecture which is manifestly an adaptation of the past. It is without any question borrowed from Rome and Greece, but is none the less artistic and successful. If, then, the people of past periods met certain problems and solved them

aright in the lines of classic tradition, it would seem reasonable to infer that we can safely follow their lead, without undertaking to do over again all the work which was done so well long ago. We can profit by the successes and the failures of the past, accepting the vehicles of architectural expression which have stood the test of time.

Now architectural design is very largely a matter of temperament. Some minds like to be free and cannot bring their energies to the focus of set channels or systematic methods. Others welcome every method and mannerism which will reduce or eliminate blind groping after results. Some regret any loss of freedom and would wish each designer to be a law to himself. Others consider restraints and academic restrictions as the chain which will tie our art together and make it coherent and consistent. But the history of art in all periods shows that where individuals have broken radically away from the standard type the result has been almost always disastrous. It is impossible for anyone to outrank his generation. The most that can be expected is to make a slight improvement, to intensify conception a trifle, or introduce a few slight variations in motive. The growth and the gain come from improving upon what has been done in the past, from building up the type rather than making new ones, from all pulling together rather than striving for mere individuality, from a union rather than an opposition of forces.

In this country we have not yet found our true architectural bearings, and although the traditions of classic architecture have been preserved in our midst to a certain degree through the medium of our so-called colonial architecture, it is only within the past few years that we have had the means, the desires and the opportunities to apply to our work of to-day the reasonings, the precedents and the spirit of the master-builders of the past. Our architecture can be said to be in an amorphous condition. I believe it will ultimately crystalize into a condition which may be very different from that of the Romans and yet will be a development therefrom, which will lack some of the elements which Rome possessed just as she in turn did not take everything from the Greeks, but which will in turn be individual while following the line of historic development and which will add definitely and tangibly as well as ornamentally to the architectural history

of the world. We cannot afford to neglect the past. Rather we must keep our eyes open for the good from wherever it may come, using old ways if they are right and not wasting our energies in devising new processes, but rather striving to solve the new problems with the implements, the mediums within our reach. We need help badly enough at the best. It is quite probable that Robinson Crusoe would not have disdained a suit of clothes fresh from a European tailors simply because he happened to be in Juan Fernandez. So it seems to me we do well to help ourselves liberally to the architecture which has gone before. We are right in appropriating to ourselves and to our architecture the motives, the forms, the details, in fact, all we can use of our predecessors, as thereby we save just so much waste of effort and we can be so much more direct and really more natural. Think for a moment how powerfully the element of natural selection and survival of the fittest has eliminated useless conventional forms and mouldings. Nature abhors a vacuum no more than art abhors waste, and though the whole vegetable kingdom is around us to draw from and mankind have been at work conventionalizing plant forms ever since Adam, there are really only two forms which have survived and are in extended use to-day, namely, the honeysuckle and acanthus, and possibly the lily and clover. For mouldings we have the cyma recta and the cyma reversa, and with those two, combined with flat surfaces, nearly all architecture is composed.

We sharpen our pencils, we grind our paint, we stretch our paper and then we borrow our architectural baggage. This sounds like rank plagiarism, and if we look only on the surface it is such, but if we consider ourselves as part of the general development, if we use our acanthus leaf not just as the Romans did, not even as the Renaissance artist did, but use it in our own way, as means rather than ends, as implements rather than final results, and in spite of ourselves stamp our own mark upon it, if we look upon the vast wealth of architecture in the past as so many opportunities and helps which we must welcome and avoid, I think we can then well afford to disregard the idea of trying to do the original, and trust our improvement, trust our development to the natural order of selection.

PRACTICAL CONSTRUCTION OF RHEOSTATS FOR ELECTRIC ELEVATORS.

BY F. M. EVERETT, '96, SCHOOL OF ELECTRICAL ENGINEERING.

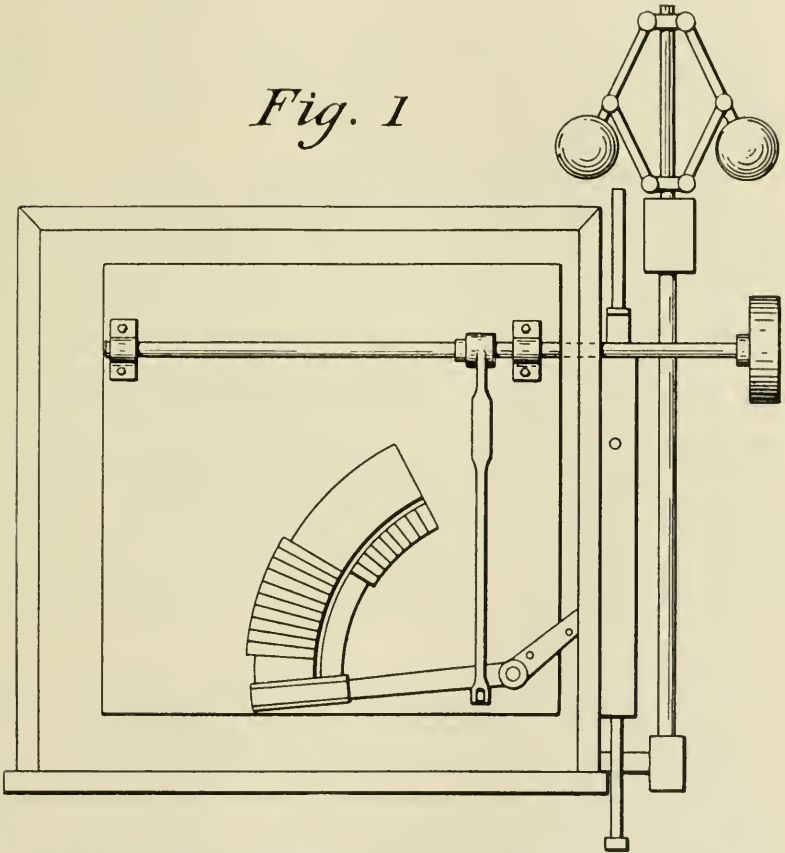
Apparatus used in modern elevator service and in connection with general hoisting machinery is, perhaps, subjected to more rigorous and straining tasks than in almost any other line of engineering practice. That it is expected to withstand these tests with less attention and repair than other machinery of similar intricacies, is evidenced by the character of the operators and attendants to which it is ordinarily entrusted. These reasons are sufficient to justify its claim upon engineering skill, large factors of safety, and competent and trustworthy inspection.

In considering the adaptability of the rheostat to the motor used in electric elevator work, we have first to consider its requirements and the existing conditions under which it is to operate. Its function is not only to be that of a motor starter serving to cut down the electro-motive-force until the counter electro-motive-force has been developed, but it is also to be, within certain limits, a speed controller. The action of the rheostat must be quick and positive; its mechanism simple and substantial; its materials economical and durable; and its location with respect to the rest of the apparatus convenient and such as to present a compact appearance. Its motor is to start always under load, must come up to normal speed quickly, must stop almost instantly, must be capable of being reversed, and should be as nearly self-regulating as practical. Inasmuch as it is probable that its operator is, in his own words, "afraid of 'blitzen' and ain't going to fool with it," its controller must be independent of him except in so far as the pulling of the lever is concerned.

Practice differs widely in the construction of rheostats for elevators and in the mode of controlling the motor. Some rheostats consist simply of dead resistance which is thrown in series with the motor armature whenever the machine is at rest, and is gradually cut out, automatically or otherwise, as the elevator

is started—the amount cut out depending upon the speed desired. Other rheostats consist not only of the resistance necessary as a motor starter, but also of auxiliary coils connected with the turns of the field spools in such a way that the brush of the contact-arm of the rheostat will regulate the magnetization of

Fig. 1



Crane Automatic Controlling Box

the field, and thus bring about more exactly the conditions of speed regulation which may be required in the particular installation for which the rheostat is designed.

To these essential features of the motor controlling box many auxiliary devices are sometimes added; for instance, a

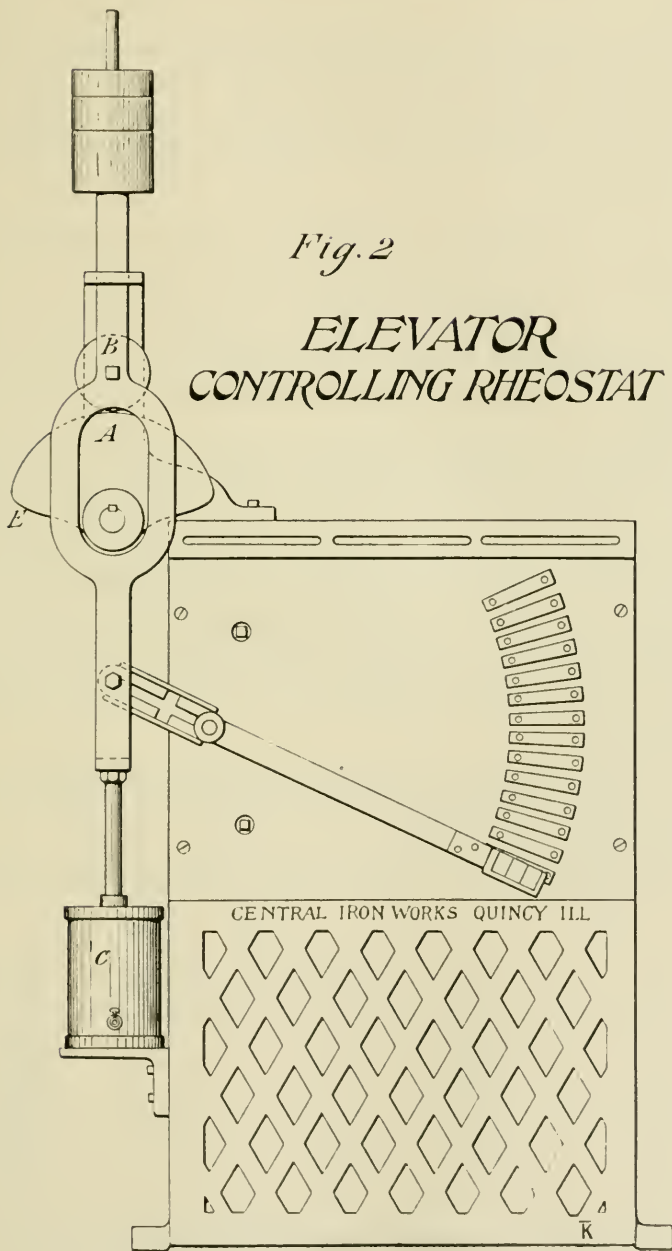
switch for shunting lamps across the fields just before the circuit is broken in order to protect the field insulation from the inductive force due to the breaking of the motor circuit; or, in accordance with the Requirements of the New York Fire Department,* electro-magnetic cut outs or circuit breakers to automatically break the circuit in case of a momentary interruption of the supplying circuit or in the case of an overload. These protecting devices are, however, not strictly the rheostat. Their design and construction is largely a matter of experiment and a discussion of the same does not come within the scope of this article.

The accompanying drawings illustrate types of rheostats used upon several modern electric elevator engines. Fig. 1, represents a controller built so that the regulation of speed may be effected by field alteration as well as by series resistance. Its general operating mechanism governs the action by centrifugal regulation.

The controller represented by Fig. 2, performs its function by interposing its resistance in the armature circuit, and thus acting as a dam or valve regulating the amount of energy delivered to the motor. Its governing mechanism is operated by the action of gravity and is controlled by the cam A, which is keyed to the shaft carrying the arm of the reversing switch. This construction renders it impossible to break the circuit without at the same time throwing the controlling resistance into circuit with the armature.

The curve of the cam upon which rests the roller B when the machine is not in operation, is concentric about the shaft center, so that the contact arm of the rheostat remains in the "all in" position until an instant before the switch is thrown. When the cam has been moved either to the right or to the left sufficiently far to release the roller B from the concentric portion of the cam, the weights descend, carrying the contact arm upward and causing the brush to sweep across the face of the rheostat, cutting out its resistance at a rate which may be fixed by the adjustment of the cock on the dash pot C. By the manipulation of the operating lever in the car, the roller B may be made to occupy any portion of the curve E, and consequently the con-

**Electrical World*, Vol. 29, p. 213.



tact arm retained in a position giving the motor the desired speed.

The mechanical construction of rheostats in this service generally consists essentially of a cast iron frame or box containing spiral coils of German silver wire, which are secured to the box by porcelain insulators. The contact arm and contact strips are ordinarily secured to a marble or slate slab constituting the face of the rheostat.

The exact amount of current which it would be judicious to assume as the safe maximum current for rheostat wire used in this service, is necessarily a subject of some speculation. There seems to be a dearth of data and information concerning the safe carrying capacity of iron and German silver wire under just the conditions which we wish to place them in the elevator motor rheostat.

The motor starting under heavy load, requires an immense starting current, but this abnormal current flows only for an instant. In our selection of the size of wire to be used in any particular case, we must be governed by the class and frequency of the work to be done, and guided by past experience. German silver wire is almost universally used in elevator rheostats. If we adhere closely to the few available tables* concerning the safe carrying capacity of German silver wire, we will find that a rheostat for a 500 Volt machine of any considerable size will be quite expensive.

The following table gives the results of observations of elevator motor rheostats which have successfully undergone constant use for several years.

SIZE AND QUANTITY OF WIRE IN RHEOSTATS FOR ELEVATOR MOTORS.

| MOTOR | | GERMAN SILVER WIRE. | | |
|-----------------|--------|---------------------|----------------------------|--------------|
| H. P. | VOLTS. | NO. OF LBS. USED. | NO. OF WIRE B. & S. GAUGE. | ARRANGEMENT. |
| 5 | 500 | 6 | 16 | Series. |
| 5 | 220 | 3 $\frac{1}{2}$ | 14 | Series. |
| 7 $\frac{1}{2}$ | 500 | 7 | 15 | Series. |
| 7 $\frac{1}{2}$ | 220 | 6 | 12 | Series. |
| 10 | 500 | 6 | 15 | Series. |
| 10 | 220 | 6 | 15 | Parallel. |
| 15 | 500 | 6 | 14 | Series. |
| 15 | 220 | 6 | 14 | Parallel. |
| 18 | 500 | 10 | 12 | Series. |
| 18 | 220 | 8 | 12 | Parallel. |

* See *Electrical Transmission of Power*, pp. 296 to 299, by A. V. Abbott.

The calculation of the requisite ohmic resistance for any given rheostat is extremely simple. In order to protect the armature from currents of undue magnitude, the rheostat should contain sufficient resistance when it is all in series with the armature, to limit the possible flow of current to that of the full load of the motor.

For example: Required the rheostat resistance for a 15 H. P. 220 Volt motor.

$$\frac{746 \times 15}{220} = 50.867 \text{ amperes} = \text{Full Load Current.}$$

$$R = \frac{E}{C} = \frac{220}{50.867} = 4.32 \text{ ohms} = \text{Resistance of Rheostat.}$$

If the rheostat is to be continuous series and of the same number wire throughout, the pounds required may be found at once by dividing the ohms required by the ohms per pound as given in the table.

For convenience this operation may be reduced to formula (3).

$$\text{From Ohm's Law, } R = \frac{E}{C} \text{ (1). Since } W = CE, C = \frac{W}{E}$$

(2). Substituting (2) in (1), $R = \frac{E^2}{W}$ (3). Where R = Resistance required for rheostat, E = E. M. F. of motor, and W = Watts output of motor.

To effect the most satisfactory speed regulation, that portion of the rheostat resistance near the "all out" position of the contact strips is usually sub-divided into coils of small resistance. A rigid conformation to the laws for maximum economy of conductor in rheostats, as given in a recent number of the *Electrical Engineer*, would not, in this service, be of much advantage.

When the starting load of a compound motor is fixed, the the necessary starting current is fixed, and a slow and uniform increase of current by the cutting out of rheostat resistance, will be of no special advantage in starting the motor; indeed, it will be of positive disadvantage so far as the adaptability of the rheostat is concerned. The cutting out of these coils will consume time and consequently delay the starting of the motor and will also decrease the available number of contacts for sub-dividing the rheostat resistance. Often an adjustment of the rheostat to the particular work at hand is made by the cutting

out of a few of its coils near the "all in" position, in case the resistance has been made slightly greater than that necessary to admit the required current to start the motor at the minimum load under which it is to operate.

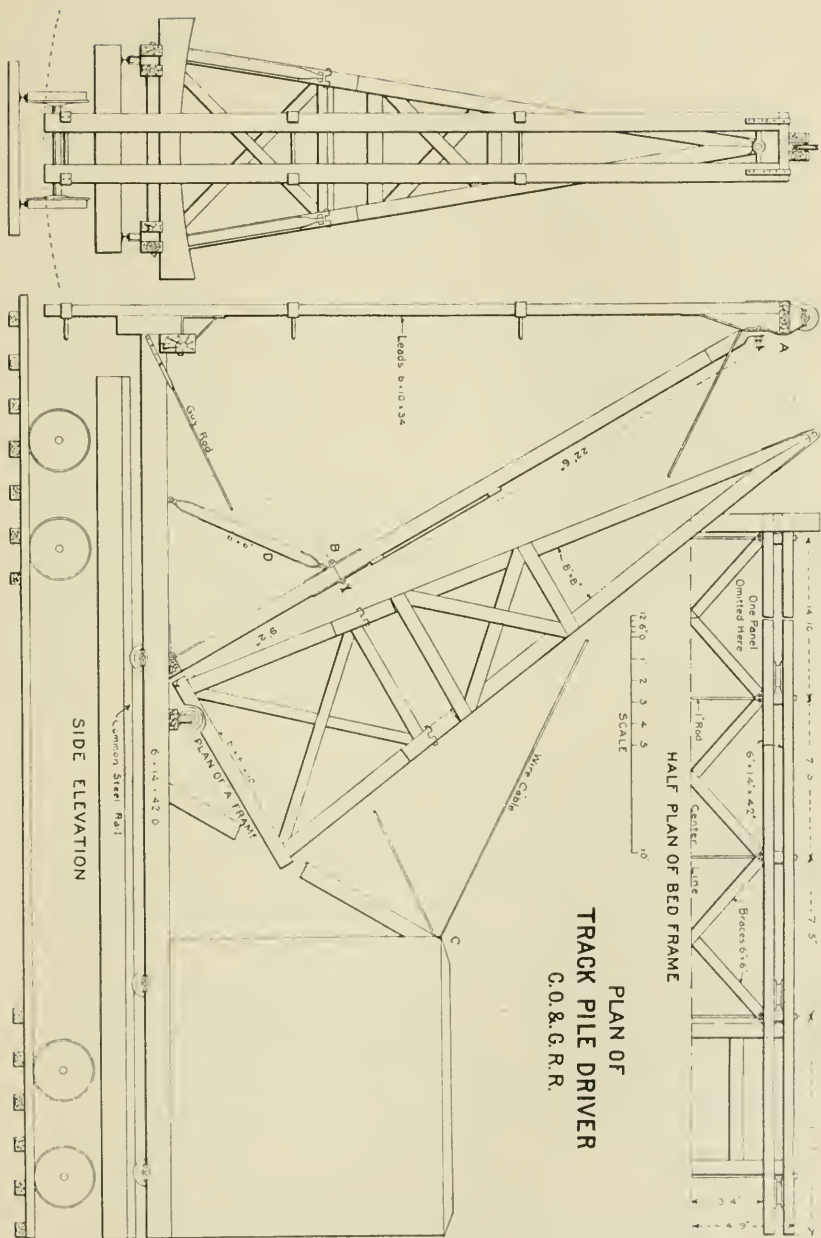
PLAN OF A TRACK PILE DRIVER.

BY HARLOW BACON, '93, CIVIL ENGINEER C. O. AND G. R. R.

The pile driver described in the following article was built in the shops of the Choctaw, Oklahoma and Gulf Railroad while the writer was in the employ of the company. It involves some points of design that the writer believes to be new and useful and therefore worthy of description.

The novel feature of the design is the mounting of the whole pile driving apparatus upon a set of six truck wheels which in turn run upon a pair of common steel rails spiked to the platform of the pile-driver car. Reference to the accompanying plate shows plainly the framing of the pile driver and the location of the truck wheels. The drawing gives side and front elevations of the driver, a half plan of the bed frame, one panel being omitted, and a plan of the "A" frame which supports the leads. The pile driver is mounted on trucks to enable the operator to drive piles a bent in advance of the car, as would be necessary in repairing a washout. The driver is easily and quickly run out the required distance ahead by means of an endless rope attached to the pile driver frame. This rope is carried around sheaves at the front and rear ends of the car and over a winding spool on the hoisting engine. The total "reach" of the driver ahead of the trucks of the car is about sixteen feet.

To enable the operator to drive the piles of a bent the necessary lateral distance from the center line of the track, the driver is constructed with a "pendulum lead"; i. e. the leads are free to swing laterally with a pendulum-like movement from the top of the "A" frame. The front view of the machine shows this feature of the construction. The leads are suspended entirely from the top of the "A" frame by the wire-rope guy, the circular beam at the bottom serving only to hold the leads in the required



PLAN OF
TRACK PILE DRIVER
C. O. & G. R. R.

position for driving piles off the center line. The movable frame and pendulum lead above described enables the operator to do track driving with great facility.

In order to fold the driver up for running on the road, the "A" frame is hinged at B, the strut D serving as a stiffener when the leads are in position. To fold the driver, the fastenings are removed from the front part of hinge B and strut D swung free at the foot. The hinge B then drops forward as shown by the dotted lines, describing an arc about the hinge at the foot of the "A" frame. This allows the head A to fold back at the point C on the front of the engine cab. While the leads are lowered the hammer rests on the knee braces which are attached to the leads just above the circular beam as shown on the side elevation. The leads are raised and lowered by means of the hoisting engine.

The hammer weighs 2,600 lbs. and is handled by a hoisting engine with an approved style of friction clutch. The pile driver has been thoroughly tried in actual service, and has been found to work successfully. The essential features of the design are by Mr. J. McFadden, formerly superintendent of bridges and buildings of the above mentioned road. Many of the details are omitted because of the limitations of this article.

CALCULATION OF SINKING FUND.

BY PETER MOGENSEN, '94, SUPT. DREDGING, MISS. RIVER COMMISSION.

When an engineering structure is planned, the engineer is usually required to estimate the cost of its construction, operation, and maintenance. In most cases there will be various methods, often differing considerably in cost, whereby a desired service may be obtained, and it seldom happens that the structure of lowest first cost will render the cheapest service. The engineer, however, seeks to make such choice and combination of parts that the whole structure fulfils its intended purpose at least expense, or gives the greatest commercial efficiency.

The annual cost of a structure, plant, or machine, may be divided as follows:

FIXED CHARGES.

- (a). Interest on capital invested.
- (b). Rent, taxes, insurance, etc.

OPERATING EXPENSES.

- (a). Wages.
- (b). Material.
- (c). Fuel, lubricants, minor repairs, etc.

MAINTENANCE.

- (a). Repairs, etc.
- (b). Sinking fund.

The commercial efficiency of a structure may be considered as the ratio of money produced to money expended. This ratio must be greater than unity in order to give a profit, and the engineer endeavors to make it as large as possible.

The nature of the several parts of the annual cost is indicated with sufficient clearness by their names, except perhaps the last—maintenance. To properly maintain a plant or structure it must be repaired when necessary. Besides these repairs a sinking fund must be provided equal to its depreciation in value, to meet the expenses of its reconstruction when worn out or when it has become antiquated and inefficient, or to refund the capital invested in its erection. The annual instalment to be set apart for this purpose will be the sum of the partial instalments required to replace the various parts of the structure under consideration, and the amount will depend upon the length of service of the parts and upon their value when new and when discarded. It is for the determination of these instalments that the adjoined table may be made useful. The conditions under which the sinking fund is accumulated are stated in the explanation of the formula employed in the computation of the table.

To illustrate, let it be required to determine the yearly instalment for the sinking fund of a manufacturing plant under the following conditions:

BUILDINGS AND FIXTURES.

- Value when new, \$20,000.
- Period of service, 25 years.
- Value after above period, nothing.

(It is assumed that the cost of removal is equal to the value of old material.)

MACHINERY.

- Value when new, \$15,000.
- Period of service, 15 years.
- Value when discarded, \$3,000.

BOILERS.

Value when new, \$5,000.

Period of service, 10 years.

Value when discarded, \$500.

The sinking fund is invested to bear an interest of 5 per cent per annum.

The partial sinking funds are as follows:

- (1). Buildings and fixtures, \$20,000, maturing in 25 years.
- (2). Machinery (\$15,000 — \$3,000), \$12,000, maturing in 15 years.
- (3). Boilers (\$5,000 — \$500), \$4,500, maturing in 10 years.

To find the annual instalment for (1) we look in the table for the quantity corresponding to an interest of 5 per cent and $n = 25$ years. This is seen to be 0.0208. Multiplying this quantity by the capital, C, the product, $\$20,000 \times 0.0208 = \416.00 , is the amount required. In the same manner the annual instalment for (2) is: $\$12,000 \times 0.0462 = \554.40 ; and for (3), $\$4,500 \times 0.0793 = \356.85 . The total annual instalment will therefore be, $\$416.00 + \$554.40 + \$356.85 = \$1,327.25$.

This sum then, set apart each year and invested to bear compound interest of 5 per cent per annum will provide for the ordinary depreciation of the plant.

If the interest, or the numbers of years, or both, should be intermediates of those given in the table, the corresponding value of $\frac{A}{C}$ can be readily found by interpolation.

When a value of $\frac{A}{C}$ is multiplied by 100 (the decimal point moved two places to the right) the per cent of the capital is given which, when yearly invested at the rate of interest indicated at the head of the corresponding column, will become equal to the capital in the number of years shown under n in the same row as the quantity considered. For example, engineers sometimes assume the yearly depreciation of an engine and a boiler to be 4 to 8 per cent of their respective costs. If an amount equal to this depreciation is placed at 5 per cent interest, and we examine the values $\frac{A}{C}$ (multiplied by 100) in the column under 5 per cent interest, we find that 4 per cent and 8 per cent of the costs imply "lives" of about 17 years and 10 years for engine and boiler respectively.

The table can be used in various ways. It will be seen from the formula that it is adapted for computations involving annuities.

Values of functions of r have been appended to facilitate checking of quantities in the table.

CALCULATION OF SINKING FUND.

Formula:— $\frac{A}{C} = \frac{r^2 1}{r^{2n} 1}$, when interest is added half-yearly.

Where A = annual installment, the first payable one year after investment, and the last one at the end of n years; C = capital invested; r = one dollar with one-half year's interest added; n = number of years from investment to maturity of sinking fund, when the latter is equal to the capital invested.

$\frac{A}{C}$ = a fraction which will amount to unity in n years. This fraction, or its equivalent $\frac{r^2 1}{r^{2n} 1}$, multiplied by C (the capital) will thus give the annual installment.

VALUES OF $\frac{A}{C}$ IN DECIMAL FRACTIONS FOR VARIOUS VALUES OF r AND n . IF THE DECIMAL POINT BE MOVED TWO PLACES TOWARD THE RIGHT THE PER CENTUM OF THE CAPITAL REQUIRED FOR ANNUAL INSTALLMENT WILL BE GIVEN.

| Int pr ann. | 1 % | 2 % | 3 % | 4 % | 5 % | 6 % | 7 % | 8 % | 9 % | 10 % |
|-------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| r | 1.005 | 1.010 | 1.015 | 1.020 | 1.025 | 1.030 | 1.035 | 1.040 | 1.045 | 1.050 |
| 2 | 0.4975 | 0.4951 | 0.4923 | 0.4903 | 0.4877 | 0.4853 | 0.4829 | 0.4803 | 0.4781 | 0.4756 |
| 3 | 0.3298 | 0.3292 | 0.3285 | 0.3199 | 0.3170 | 0.3138 | 0.3106 | 0.3076 | 0.3044 | 0.3014 |
| 4 | 0.2463 | 0.2425 | 0.2389 | 0.2353 | 0.2318 | 0.2283 | 0.2248 | 0.2214 | 0.2180 | 0.2147 |
| 5 | 0.1953 | 0.1916 | 0.1881 | 0.1845 | 0.1807 | 0.1771 | 0.1734 | 0.1699 | 0.1664 | 0.1630 |
| 6 | 0.1625 | 0.1585 | 0.1545 | 0.1506 | 0.1468 | 0.1431 | 0.1394 | 0.1358 | 0.1322 | 0.1288 |
| 7 | 0.1387 | 0.1345 | 0.1304 | 0.1265 | 0.1226 | 0.1188 | 0.1151 | 0.1115 | 0.1080 | 0.1046 |
| 8 | 0.1206 | 0.1165 | 0.1124 | 0.1084 | 0.1045 | 0.1007 | 0.0970 | 0.0935 | 0.0900 | 0.0867 |
| 9 | 0.1061 | 0.1025 | 0.0983 | 0.0943 | 0.0904 | 0.0867 | 0.0831 | 0.0795 | 0.0761 | 0.0729 |
| 10 | 0.0953 | 0.0913 | 0.0871 | 0.0832 | 0.0793 | 0.0755 | 0.0719 | 0.0685 | 0.0652 | 0.0620 |
| 12 | 0.0788 | 0.0745 | 0.0704 | 0.0664 | 0.0626 | 0.0590 | 0.0555 | 0.0522 | 0.0491 | 0.0461 |
| 15 | 0.0620 | 0.0577 | 0.0537 | 0.0498 | 0.0462 | 0.0427 | 0.0394 | 0.0363 | 0.0335 | 0.0308 |
| 20 | 0.0453 | 0.0411 | 0.0371 | 0.0334 | 0.0300 | 0.0269 | 0.0241 | 0.0215 | 0.0191 | 0.0170 |
| 25 | 0.0353 | 0.0311 | 0.0273 | 0.0239 | 0.0208 | 0.0179 | 0.0155 | 0.0133 | 0.0114 | 0.0098 |
| 30 | 0.0287 | 0.0246 | 0.0209 | 0.0177 | 0.0149 | 0.0124 | 0.0104 | 0.0086 | 0.0071 | 0.0058 |
| 35 | 0.0239 | 0.0199 | 0.0165 | 0.0135 | 0.0109 | 0.0087 | 0.0070 | 0.0056 | 0.0044 | 0.0035 |
| 40 | 0.0204 | 0.0165 | 0.0132 | 0.0104 | 0.0082 | 0.0062 | 0.0048 | 0.0037 | 0.0028 | 0.0021 |
| 45 | 0.0177 | 0.0139 | 0.0107 | 0.0082 | 0.0062 | 0.0046 | 0.0034 | 0.0025 | 0.0018 | 0.0013 |
| 50 | 0.0154 | 0.0118 | 0.0088 | 0.0061 | 0.0047 | 0.0032 | 0.0024 | 0.0016 | 0.0011 | 0.0008 |
| 60 | 0.0122 | 0.0087 | 0.0060 | 0.0041 | 0.0028 | 0.0018 | 0.0012 | 0.0007 | 0.0005 | 0.0003 |
| 70 | 0.0099 | 0.0065 | 0.0043 | 0.0028 | 0.0017 | 0.0009 | 0.0006 | 0.0003 | 0.0002 | 0.0001 |
| 80 | 0.0082 | 0.0051 | 0.0031 | 0.0018 | 0.0010 | 0.0005 | 0.0003 | 0.0001 | 0.0001 | 0.0000 |
| 100 | 0.0059 | 0.0032 | 0.0016 | 0.0008 | 0.0004 | 0.0002 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |

VALUES OF FUNCTIONS OF r .

| | | | | | | | | | | |
|-----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| $r^2 - 1$ | .010025 | .020100 | .030225 | .040400 | .050625 | .060900 | .071225 | .081600 | .092025 | .102500 |
| $\log r$ | .0021661 | .0043214 | .0064660 | .0086002 | .0107239 | .0128372 | .0149403 | .0170333 | .0191163 | .0211893 |

PRACTICAL TEMPERING OF STEEL.

BY W. B. BRAUCOER, '85. PROPRIETOR MACHINE SHOP.

The peculiarities of steel, which will be briefly described in this paper, were first noticed by the author seven or eight years ago, while working with several kinds of steel in the same set of knives, which were being re-sharpened and hardened. There were two or three kinds of tool steel—some made and stamped by Jessop & Sons—and common buggy tire steel. They were not affected the same upon being plunged into the hardening bath at the same apparent heat. It was also noticed that the thin knife edge would become brighter after it had cooled for a time.

Upon closer examination and comparison made in the dark, of one kind with another, a difference was found in the several brands in the action of cooling. The tool steel in cooling from a bright red, would gradually become darker to a certain point, then suddenly become much brighter, and then gradually cool down and become dark again, the pieces being so thin that the variation was quite noticeable. The tire steel in cooling would become much darker before it brightened, then it would gradually change its red by flashes, getting darker each time and then a little brighter, seeming to light up a few times after becoming invisible in the dark.

In hardening, the tool steel acted in a similar manner, sometimes hardening at a cherry red, and then it would soften at a bright red, while the tire steel hardened at a very dark red or even black.

This was puzzling for a time, but these observations suggested the thought that possibly there existed a fixed relation between this reheating of steel and its quality of hardening, and started the question of finding out the causes and conditions. The author has shown to a few persons the fact that steel will reheat after cooling for a time. They reluctantly admitted the fact after observing it once or twice, although refusing at first to consider it possible. A traveling salesman for Crescent steel said that he would investigate it further when he returned to the laboratory of the Crescent Works. Afterward there was noticed an article upon "The Recalescence of Steel," which appeared in *Sparks*. Others may have observed these

facts, though nothing else on the subject has come in the author's way, and this paper may lead someone who is in a position to make experiments, to interest himself in the subject and develop valuable information as to the proper treatment of steel.

A few questions may not be out of place here.

Why does steel reheat on cooling? Because in being heated it absorbs heat that is not used in raising its temperature, which may be called latent heat.*

What would the latent heat signify? That some internal change in the structure of the steel must take place when it is heated above the point where the latent heat is absorbed.

What change in the steel is caused by the latent heat? We don't know, and can only theorize as to that. It may be a chemical change, or a rearrangement of particles, or a change from the graphitic state of carbon to the combined state, or some other change.

Why should steel be heated slowly? Because it takes time to absorb its latent heat, and this must be allowed for.

What would be the effect of heating steel quickly? If the piece is large, the outside surface could be heated to the burning point in less time than is required for the whole piece to absorb its latent heat, as each layer takes some heat from the next layer inside, thus reducing its temperature below the point at which absorption can take place, and making it necessary to transmit heat to each successive layer several times.

What would be the effect of forging steel that has been heated rapidly? If it should be forged before it has completely absorbed its latent heat, there is danger of making checks and flaws which will be apt to show when the piece is hardened and thus may ruin the work.

Instructions for hardening and tempering steel usually refer to "cherry heat" and "cherry red." It is suggested that "hardening heat" would be a better term. If cherry red is a definite color it would be very unsatisfactory to work by in hardening steel, for the reason that the "hardening heat" is not, by any means, the same color in different steels. Again, it is the best

*Recalescence of steel is not generally known among practical men. It was probably first noticed by W. F. Barrett in 1873, who published the results of his experiments, in *Phil. Mag.*, Vol. 46, Dec., 1873. A very full discussion is found in the article by J. W. Langley in *Jour. Assn. Eng. Societies*, Vol. 12, April, 1894.—Editors.

practice to harden at as low a heat as possible. If the lowest heat at which a given steel will harden is called "cherry red," we find there is another heat the exact duplicate of it in color, but if the steel is plunged at this duplicate heat it will soften. It could be hotter and still soften.

How can the "hardening heat" be discovered for a given steel? Heat the piece until the scales begin to loosen, then hold it in a dark place and watch it cool. It will harden if plunged at this heat, or at any heat greater than that at which the latent heat becomes sensible, but of course the danger of flaws is increased at the higher temperatures. Note how long it takes to cool to the point at which the latent heat becomes visible and how low or dark red the steel becomes just before the latent heat becomes sensible. The color is only relative and depends on the light where we are observing the changes, so that the best results are obtained in a shaded or darkened place. We thus find the law of heating and cooling of the brand, and by remembering this as nearly as possible we heat and harden the steel, plunging into the bath just before the time for the latent heat to become sensible. Let it be understood that unless some tempering bath is used, the tools require drawing to the proper temper in the ordinary way.

The action of the forces within the steel to produce hardening might be explained theoretically as follows: Plunging in water accelerates the rate of cooling, and the outer layers of steel would be cooled so suddenly that they would pass their period of latent heat and contract upon the next layer just as it was being heated and expanded by its latent heat becoming sensible, and so on to the center. These intense forces act upon the particles in such a way as to compress them, making them dense and hard. Or this severe compression might produce enough extra heat to prevent the transformation of the combined carbon back to the graphitic state, thus leaving the particles in the hard state instead of soft.

A few trials have been made with self-hardening steel and it was found to possess some of the qualities of other steels. It will harden in water and also soften slightly, but the hardening heat is much lower than with other steels. On cutting some partially chilled casting it was found that the tool stood the work much longer and cut cleaner if hardened in water. Not

much attention has been paid by the author to the action with self-hardening steel.

There has always been more or less mystery about the working of steel, and it seems that this mystery is vastly increased and darkened by our competitive system of doing business, which compels a man to hold as trade secrets many, if not all, of his most important discoveries, hoping that he will thus derive an advantage that he is not willing to share with his fellow workmen. In this way some of the most valuable compositions and processes are kept secret to the use and profit of a few men, while the people at large are deprived of benefits which should accrue to them, as well as the opportunity of making further progress founded upon the knowledge thus derived.

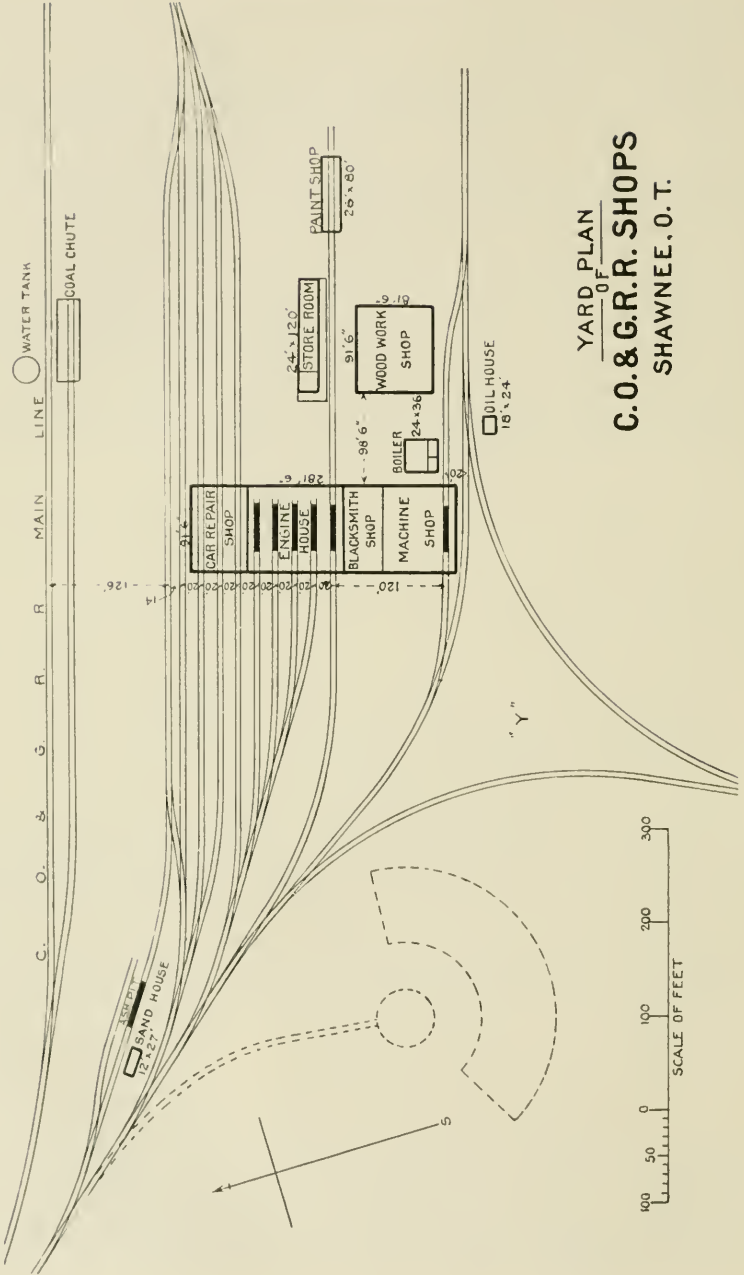
The above method of treating steel has been used by the author for several years with good results.

C. O. & G. R. R. SHOPS AT SHAWNEE, O. T.

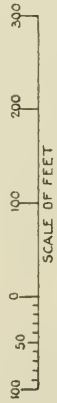
BY HARLOW BACON, '93. CIVIL ENGINEER, C., O. & G. R. R.

Since for the past two years the subject of railroad shops has been pretty thoroughly treated in the technical journals, the writer deems it unnecessary to give more than a general plan and a brief description setting forth the more important features.

On page 48 is given a "yard plan" of the shops now in course of erection by the Choctaw, Oklahoma and Gulf Railroad at Shawnee, O. T. The road in question is 216 miles in length, extending from the eastern boundary of the Choctaw Nation, I. T., westward to Fort Reno, Oklahoma. In the Choctaw Nation the road runs through rich coal fields, which are extensively worked. Originally the road was about 100 miles in length, but in 1895, 120 miles of new line were added, necessitating the construction of new shops. The problem was to build such shops as would be sufficient for present needs and also permit of extensions and additions as the requirements of the road demanded.



YARD PLAN
OF
C.O. & G.R.R. SHOPS
SHAWNEE, O. T.



The plan which was decided upon is shown in the accompanying drawing. The yards are connected to the main line at both the east and west ends. No turn-table is used, the engines being turned on the "Y."

The main building which is 91 ft. 6 in. by 291 ft. 6 in. contains an engine house of five stalls, separated from the other compartments by brick fire walls, a car repair shop and a blacksmith shop and machine shop partitioned off as shown. The five pits in the engine house and erecting pit in the machine shop are shown in solid black. The other buildings are: A wood working shop, 81 ft. 6 in. by 91 ft. 6 in.; an office and store room, 24 by 120 ft., the office being 20 by 24 ft.; a paint shop 26 by 80 ft.; a paint shop, 26 by 80 ft., and other minor buildings as shown on plan.

The construction throughout is of brick and stone. In the two large buildings, the stone work was carried up to the window, all above being brick. In the other buildings stone was used to the floor level with brick above. Walls are 18 in. thick in the two large buildings and 13 in. in the others. None of the roofs are trussed but in the large buildings are supported by interior posts. The construction in all cases is of wood, the covering being an inch sheathing and a prepared roofing composed of magnesia and asphalt pitch known as Carey's Magnesia Flexible Cement Roofing. The oil house, paint shop and engine house have concrete floors; in the others the floors are of wood. Steam for the engines in the different shops is supplied from a battery of boilers in the boiler house. The five tracks on the north side of the yards are to be used for car repair tracks. Water for the entire plant is furnished from an elevated tank shown on plan.

For future extensions ground is reserved at the west end of the yards. The proposed site of the turn-table and round-house is shown by broken lines. The round-house will be erected when needed and the main building turned into a machine shop.

The general plan, together with the design and details of the buildings, was worked out by the writer, with the coöperation of F. A. Molitor, Chief Engineer, and Jas. Cunningham, Master Mechanic. The cost of the plant complete, exclusive of the water supply, was approximately \$40,000.

EFFECT OF PIPING ARRANGEMENTS ON THE
INDICATOR DIAGRAM.*

BY D. T. RANDALL, '97, SCHOOL OF MECHANICAL ENGINEERING.

Prominent engineers have for a long time believed that only short indicator connections to the cylinder give accurate results. Much attention has been given to this subject within the past three years, and a great deal has been written in regard to it. In a paper by Mr. E. J. Willis, who took up the subject as to its effect on the resulting areas without discussing the form of the cards, he says: "When cord movement is correct and the instrument is in good adjustment, I have never failed to get practically the same results from long and short connections." This statement led to much experimenting. The well known journal, *Power*, took up the question, and in discussing the results obtained by Mr. Willis, criticised his method of taking the cards and explained that when both long and short connections were open from the cylinder at the same time, the long pipe clearance influenced the results on the short connected indicator. It was pointed out that when the diagram was taken on the short pipe, the long pipe should be cut off by a valve. Two engineers connected with *Power* made some experiments following out this idea. An ingenious combination of pipes and valves was used, and the results show that the same indicator on an engine of constant load gives different results in the following cases: (1) When indicator has short direct connection; (2) when indicator has short direct connection with a clearance space beyond; (3) when indicator has long pipe connections. Of the many who have made experiments along this line, few others have taken the precaution to avoid the error in the cylinder card due to the effect of the clearance of the long pipe.

That this error is considerable is shown in Fig. 4, page 52. These diagrams were taken on the engine described below. They were secured in connection with some other experiments which will not be discussed in this article. Fig. 4 shows

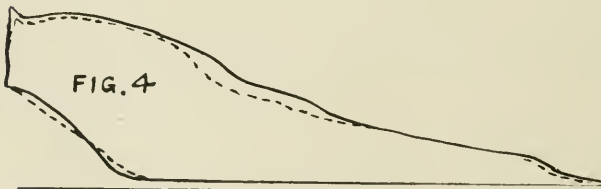
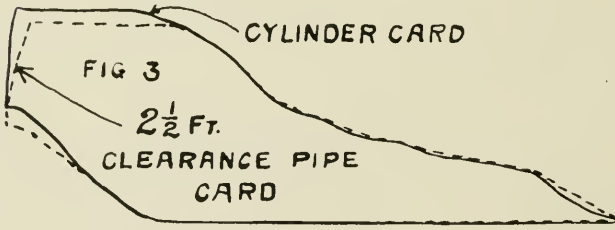
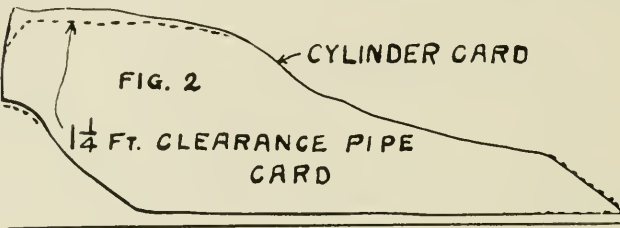
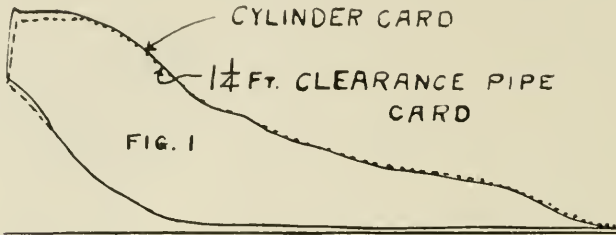
*The data for this article was selected from results obtained in a thesis on the subject by J. R. Saylor and the author. University of Illinois, 1897.

the effect of opening a clearance pipe one-half inch in diameter and ten feet long, connected to the cylinder and entirely independent of the short connection which lead to the indicator. A diagram was first taken with the long pipe open. It is shown by the dotted line of the figure. A gate valve in the pipe close to the cylinder was then closed and a diagram taken; only the short connection to the indicator being open to the cylinder. This diagram is shown by the full line of the figure. These cards were taken with a Crosby indicator; spring, 60 lb. per in. The boiler pressure was 70 lb. A number of these cards were taken, all being similar to the figure.

The subject of long connections has been so thoroughly discussed that there is little occasion to say more; but on another subject, closely allied to it, little has been written. It is on the effect of a clearance pipe beyond the indicator. Rigg, in his work, *THE STEAM ENGINE*, published in 1878, recognized this source of error, and says of pipes leading from the cylinder to the indicator: "It is necessary to have them continuous to indicator without any length being open beyond the indicator. Such a *cul de sac* has the effect of distorting the apparent pressures altogether." It is not uncommon to see the two ends of an engine cylinder connected to one indicator cock. In most such cases the indicator is placed on a tee near the middle, and pipes lead to each end of the cylinder where angle valves are placed in the bend of the pipe for the purpose of cutting off the communication to either end, as may be desired. Such an arrangement subjects the diagrams to two sources of error, that due to the length of pipe from the cylinder to the indicator, and that due to the length of pipe open beyond the indicator.

In a series of experiments, over one thousand diagrams were taken to determine the effect of piping arrangements. Nearly two hundred of these were to determine the effect of a clearance pipe beyond the indicator. The data given on pages 54 and 55 was obtained from cards taken on a 8x10 in. Ball engine, running at 290 R. P. M., with boiler pressure of 70 lb. gage. A special head was used, the upper half being tapped for pipes. The clearance amounted to 9.28 per cent of the piston displacement. All cards were taken with a Crosby indicator which was calibrated with a 50 lb. spring, used in these experiments. The piping was as follows: A short nipple and a tee formed the

shortest possible connection from the cylinder to the indicator. A nipple connected the tee with a gate valve into which was secured the various lengths of pipes forming a clearance space be-



yond the indicator. All pipes used in connection with the experiments given in this article were the commercial 0.5 in. size. The reducing motion was a four part pantograph, and the cord

lead horizontally to a pulley and then at an angle of about twenty degrees to the indicator. In taking cards, steam was first admitted to the long pipe which was covered to prevent condensation as much as possible, then condensation was drained from a cock in end of pipe and a diagram taken. The gate valve was next closed and a card taken with only the short connection open to the cylinder. In some cases one card was taken over the other, as shown in the figures, and in other cases the card was shortened and separate diagrams were taken for convenience in measurement. In part of the experiments a constant load was maintained, in some cases by a friction brake and in others by using the line shaft for a load. Many experiments were made while the engine was furnishing power to the shops. The load on the engine did not vary greatly during parts of the day, and diagrams as a rule gave uniform differences. In fact, with two persons working on the experiment the two diagrams could be taken within a very short time. In these experiments four lengths of pipe were used: 1.25 ft., 2.5 ft., 5 ft. and 10 ft. As the shorter lengths are of more practical importance, diagrams of the shorter pipes only will be given.

Figs. 1 and 2, are representative cards, showing the differences in diagrams taken with 1.25 ft. of clearance space beyond the indicator, and diagrams taken with only the short connection open to cylinder. These diagrams were selected for the purpose of showing the effect of cut-off as obtained in the different experiments. Fig. 3 shows the effect of a clearance pipe 2.5 ft. in length, the experiment being conducted in the same manner as those corresponding to Fig. 1 and Fig. 2.

Such data has been selected from the several experiments as will best show the differences in results obtained under various conditions of cut-off and pipe lengths. Table 1 shows the results of four experiments, with as many different lengths of pipes forming a clearance space beyond the indicator. Three cards in each experiment are considered separately. The cut-off in each case was as great as one-third. Table 2 gives average results of three cards in each of four experiments, the cut-off being less in each case than in Table 1.

TABLE I.

| No. | LENGTH OF CLEARANCE PIPE IN FEET. | APPARENT CUT-OFF CYLINDER CARD. | MEAN EFFECTIVE PRESSURE. | | PER CENT DIFFERENCE. CYL. CARD TAKEN AS BASE. |
|-----|--|--|--|---|---|
| | | | SHORT CON- NECTED OR CYLINDER CARD. | CARD WITH CLEARANCE BEYOND THE INDICATOR | |
| 1 | 1.25 | 0.40 | 31.0 | 30.9 | — 0.4 |
| | | 0.39 | 29.7 | 29.6 | |
| | | 0.40 | 30.4 | 30.2 | |
| 2 | 2.50 | 0.43 | 31.2 | 30.0 | — 4.4 |
| | | 0.43 | 31.2 | 30.0 | |
| | | 0.44 | 31.9 | 30.1 | |
| 3 | 5.00 | 0.33 | 29.4 | 25.9 | — 11.1 |
| | | 0.33 | 29.3 | 26.2 | |
| | | 0.33 | 29.1 | 25.9 | |
| 4 | 10.00 | 0.33 | 30.6 | 22.5 | — 24.9 |
| | | 0.33 | 30.0 | 23.0 | |

TABLE II.

| No. | LENGTH OF CLEARANCE PIPE IN FEET. | APPARENT CUT-OFF CYLINDER CARD. | MEAN EFFECTIVE PRESSURE. | | PER CENT DIFFERENCE. CYL. CARD TAKEN AS BASE. |
|-----|--|--|--|--|---|
| | | | SHORT CON- NECTED OR CYLINDER CARD. | CARD WITH CLEARANCE BEYOND THE INDICATOR. | |
| 1 | 1.25 | 0.21 | 21.9 | 21.8 | — 0.4 |
| 2 | 2.50 | 0.25 | 22.9 | 22.5 | — 1.7 |
| 3 | 5.00 | 0.13 | 17.4 | 17.9 | + 2.9 |
| 4 | 10.00 | 0.10 | 18.5 | 17.2 | — 7.5 |

Table 3 shows the results of experiments under conditions similar to those which exist when the indicator is connected to the ends of the cylinder by pipes leading to a tee, with angle valves, etc., as already described. In these experiments an 8-in. pipe lead from the cylinder to the indicator, and lengths of pipe beyond the indicator gave clearance effect. Except that the indicator was eight inches from the cylinder, these experiments are similar to the others described.

TABLE III.

| No. | LENGTH OF CLEARANCE PIPE IN FEET. | APPARENT CUT-OFF CYLINDER CARD | MEAN EFFECTIVE PRESSURE. | | PER CENT DIFFERENCE. CYL. CARD TAKEN AS BASE. |
|-----|--|---|---|--|---|
| | | | CARD WITH 8-IN CON- NECTION TO CYLINDER. | CARD WITH CLEARANCE BEYOND THE INDICATOR. | |
| 1 | 1.25 | 0.62 | 32.6 | 32.5 | - 0.3 |
| 2 | 2.50 | 0.40 | 34.9 | 35.2 | + 0.8 |
| 3 | 5.00 | 0.43 | 33.3 | 31.8 | - 4.5 |

It will be seen from the tables that the clearance pipe as a rule gives the smaller diagrams, but that in Table 2, the clearance pipe 5 ft. in length for the given cut-off, gives a larger mean effective pressure than the cylinder card; and in Table 3 the clearance pipe 2.5 ft. in length also gives results slightly larger than the cylinder card.

Evidently the cut-off has an influence on the resulting diagram, and these results seem to indicate that greater cut-offs give greater relative differences in the diagrams. For comparatively short lengths of pipe the error in mean effective pressure is not great, but the form is slightly changed.

Owing to the fact that the clearance volume, size of cylinder, speed, steam pressure and other conditions are seldom the same in different engines, these results can be considered to apply only to the engine on which they were obtained, or to other cases having like conditions. The results show that general conclusions can not be drawn from a few experiments, and with those of other experiments point out the fact that accurate results can be obtained with certainty only when the connection from cylinder to indicator is short and direct.

The following references are given for those who desire to make a further study of this subject:—

“Effect of Pipe Connections on Indicator Diagrams,” by E. J. Willis—*Amer. Mach.* Nov. 23, '93.

“Direct and Indirect Indicator Connections,” *Power*, Sept., '94; Oct., '94; Nov. '94; and Feb., '95.

“The Effect upon the Diagrams of Long Pipe Connections,” by W. F. M. Goss—*Am. Soc. Mech. Engrs.*, May, '96, and *Power*, June, '96.

BOILER WATERS.

BY S. W. PARR, PROFESSOR OF APPLIED CHEMISTRY.

If any apology is due for discussing the somewhat perennial subject of boiler water, it might be fair to say, perhaps, that the matter is coming to be treated in a more rational manner; that much of the quackery and mysticism that has so long prevailed is being superseded by a more scientific and sensible consideration of the problem. The study of some phases of the subject has been under more or less continuous investigation in the Department of Applied Chemistry for the past two years, and while much of the data still awaits further confirmation, some points have been developed that may be worthy of notice at this time. It is not our purpose now to enter into a discussion of difficulties and dangers attending the use of certain boiler waters further than to make such enumeration as shall serve in a general way to classify the waters producing harmful results.

The first and largest class of course includes those waters of a scale forming tendency. These may be subdivided into (*a*) those that are both scale forming and corroding, (*b*) those that deposit their mineral salts in the form of scale, and (*c*) those that throw out their salts as suspended or non-cementing particles, forming a mud or sludge. Another and much smaller class of waters are those that are chiefly corroding in their nature with little if any tendency to form a scale. And still another class are such as have a tendency to "rise" or foam, especially as the salts in solution become more concentrated.

Giving attention now to the first class, we shall need to know something of the chemical nature of the ingredients that are responsible for the difficulties. If all waters held in solution the same kind of salts with little or no variation in their chemical behavior, it would be a comparatively simple matter to make a classification for determining the grade of a water based simply on quantity of scale forming material. Indeed such a classification has been widely adopted as a result of the action of the Association of Railway Chemists. The classification, based on

the number of grains, per gallon, of scale forming material, is as follows:

| | | |
|--|---|-------------|
| Below 15 grains per U. S. gallon—good. | | |
| 15—20 | “ | “ fair. |
| 20—30 | “ | “ poor. |
| 30—40 | “ | “ bad. |
| Over 40 | “ | “ very bad. |

While this serves in a general way as an index to the value of a water for boiler purposes, many cases arise where quality or property of the constituents and not quantity is the prime thing to be considered. Take as an illustration certain waters referred to further on, having 8 to 18 grains of scale forming material per gallon, and yet in actual practice entirely non-scaling in behavior.

This evidently necessitates an understanding of the particular compounds present and their properties. The ingredients we need especially to take note of in this first general class are the various compounds of calcium, magnesium and sodium. These may be combined as carbonates, sulphates, chlorides or nitrates.

First, the carbonates of calcium and magnesium, if in solution, are in the loosely held bicarbonate form, for example $\text{CaH}_2(\text{CO}_3)_2$. This when raised to the temperature of boiling water disengages CO_2 and leaves the insoluble calcium carbonate. It should be noted now that the heat necessary to accomplish this is such as exists throughout the mass—hence the particles of calcium or magnesium carbonate may therefore be disengaged at indefinite points throughout the boiling water and not necessarily altogether at the points of contact with the hotter surfaces of the flues. When thus disengaged as above described they continue to float so long as the water is in active circulation. They readily settle out as a muddy deposit when the boiler becomes quiet.

We should note in this connection that sodium, if present in a similar form as bicarbonate, also breaks up into the normal carbonate, Na_2CO_3 , and in this condition is able to attack the calcium and magnesium in whatever soluble form they may exist and throw them out as insoluble carbonates at the boiling temperature. Here again this action is not confined to any special locality and as before, when solid particles are set free in

the midst of the mass they continue free, or at the most, in times of quiet settle out as mud or sludge.

Next the sulphate, what properties exist here? Calcium sulphate, the most commonly occurring compound under this head, has the peculiar property of increasing in insolubility with an increase of heat so that particles in solution, entering the boiler so, might still remain in solution, but coming in contact with the more highly heated surfaces of tubes and plates are thereby rendered insoluble at that particular point and thus become located as scale. This action carries along with it of course some carbonate of lime simultaneously affected, and so little by little we have built up chemically or mechanically or by combined processes the scale on the surfaces of the more highly heated plates and tubes.

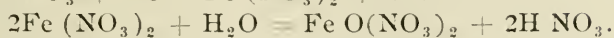
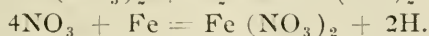
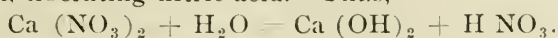
The next compound to interest us is magnesium chloride. Calcium chloride may also be included as of similar property though in much less degree. The unstable nature of magnesium chloride may be well illustrated by igniting some of the salt in a porcelain crucible having mixed in with the same a quantity of clean sea-sand. Now upon heating the crucible over the flame of a Bunsen lamp and occasionally stirring the contents so that the oxygen of the air may have access to the mass, hydrochloric acid is disengaged very easily and copiously, so long as any moisture remains, and after the point of complete dryness has been reached, chlorine gas is evolved. A ready test in proof of the above may be had by smelling the vapors or by holding near, a rod wet with strong ammonia solution. The chemical reactions taking place may be represented by the equations:—



It will be evident from this illustration that where magnesium chloride exists it may by decomposition and liberation of free acid exert a corroding influence. Such action would be especially promoted under the case illustrated by the first equation where the water and iron came in contact, and in the second case under scale that had an admixture of magnesium chloride or oxychloride present.

The remaining possible compound is that of the nitrates. These salts are all unstable, breaking down with more or less

ease in both the wet and dry condition under the influence of heat, liberating nitric acid. Thus,



The first two equations represent the fact that as between metallic iron and nitrates of calcium, etc., the nitric acid will leave the lime and attack the iron. Further, having first dissolved the iron as ferrous iron it again passes by successive stages into a higher form of oxidation as illustrated by the third equation, again liberating more nitric acid to eat more iron.

It must be evident from the foregoing that the first essential in judging of the action of boiler waters is an accurate knowledge of the ingredients of the water and a correct determination of the forms they are most likely to assume. This has necessitated much work along the line of the most accurate as well as expeditious methods of analysis of a boiler water. It was soon found that by the ordinary methods some peculiarities of behavior on the part of certain waters remained unaccounted for and much experimenting was carried on in search of explanations. The most profitable have come from a study of waters taken from steam boilers as long as possible after a clean out so that the maximum of concentration should be reached and all the primary decompositions effected.

In illustration of this point a few examples may be cited taking the above types of water in which some form of salt in combination predominates and gives character to the water, such character, as indicated above, being more positively identified in the water drawn from the boiler after the concentration that results from prolonged generation and use of steam. A type in which the carbonate form predominates is found in the city water of Champaign and Urbana, and in the other wells of the vicinity that reach the same strata from 135—165 feet in depth. Of course the degree of concentration varies and no two samples from boilers will show the same amount of salts. However, a sample drawn from the stationary boiler at the Illinois Central round-house yields.

| | | | | | |
|-----------------------------------|-------|--------|-----|-------|--------|
| Silica..... | .70 | grains | per | U. S. | gallon |
| Sodium carbonate..... | 24.65 | “ | “ | “ | “ |
| Sodium chloride and sulphate..... | 3.12 | “ | “ | “ | “ |

| | |
|---------------------------|------|
| Calcium or magnesium..... | none |
| Nitrates | none |

Here it is evident that the great excess of sodium carbonate easily accounts for the absence of lime or magnesia or any scale forming compound; consequently, as we would expect, these substances are thrown out of solution as a fine powder and not in the form of scale. The natural constituents of the water before entering the boiler are as follows:

| | |
|--------------------------------------|------------------------|
| Silica..... | .472 grains per gallon |
| Fe ₂ O ₃ | .612 " " |
| CaCO ₃ | 5.205 " " |
| MgCO ₃ | 6.611 " " |
| Sodium sulphate..... | .349 " " |
| Sodium carbonate..... | <u>3.381</u> " " |
| Total..... | 16.630 |

Of this, all but the last two constituents are ordinarily classed as "scale forming ingredients." It has been a matter of considerable interest to find this type of water somewhat widely distributed throughout the state, though by no means always from the same geological formation as at this place. At Burnside, on the Illinois Central Railroad, at a depth of 450 feet, a water of the following composition is found:

| | |
|-------------------------|------------------------|
| Silica..... | .455 grains per gallon |
| Alumina..... | 1.669 " " |
| CaCO ₃ | 4.332 " " |
| MgCO ₃ | 1.403 " " |
| MgSO ₄ | .391 " " |
| Sodium chloride..... | 1.418 " " |
| Sodium carbonate..... | <u>3.800</u> " " |
| Total..... | 13.468 |

Here again the sodium carbonate is far in excess of the amount required for complete precipitation of the scale forming ingredients, and we would expect to find the same conditions as to behavior as with the city water at this place. Unfortunately, however, the Burnside water is mixed with Lake Michigan water in use. However, a parallel boiler running exclusively on Lake Michigan water furnishes an interesting comparison. In each case the boiler had been in operation six days from the time of

the last wash-out. The amounts in grains per gallon for the two main ingredients are as follows:

| BOILER WITH LAKE WATER ONLY. | LAKE AND BURNSIDE WATER MIXED. |
|---------------------------------------|--------------------------------|
| CaSO ₄ | 29.16 7.68 |
| Na ₂ SO ₄ | 5.80 27.12 |

It will thus be seen that the excess of sodium carbonate of the Burnside water has performed the work of transforming about 75 % of the scale forming calcium sulphate into insoluble calcium carbonate, the sodium sulphate being correspondingly increased over four times.

Another water of this type is found at Wenona. The well supplying the city is 1,750 feet deep, and has a composition as follows:

| | |
|---------------------------------------|------------------------|
| SiO ₂ | .705 grains per gallon |
| Al ₂ O ₃ | .507 " " |
| CaCO ₃ | 9.173 " " |
| MgCO ₃ | 3.199 " " |
| Na ₂ SO ₄ | .469 " " |
| Na ₂ CO ₃ | 1.216 " " |
| NaCl..... | <u>62.117</u> " " |
| Total solids..... | 77.386 " " |

Of this, 13.584 grains only would be classed as scale forming.

Another water of even more positive characteristic as to the excess of sodium carbonate is found at Carbondale, Ill., at the electric light and power station. The depth of well is 260 feet. The analysis shows the following constituents:

| | |
|---------------------------------------|------------------------|
| Silica..... | .898 grains per gallon |
| Fe ₂ O ₃ | .268 " " |
| CaCO ₃ | 12.422 " " |
| MgCO ₃ | 1.399 " " |
| Na ₂ CO ₃ | 12.874 " " |
| NaCl..... | 35.563 " " |
| Na ₂ SO ₄ | <u>3.964</u> " " |
| Total..... | 67.368 " " |

Many other samples of similar characteristics have been worked with, but these are extremes both of type and locality.

It should be noted as perhaps the chief points of interest in this type of water, first, that regardless of the ingredients usually classed as scale-forming, i. e., all compounds other than sodium or potassium, none of this class of waters is scale form-

ing at all, even though the compounds listed under this head range from 8 to 18 grains per gallon. The second point of interest lies in the fact that such waters are more widely distributed throughout the state than was at first supposed.

With regard to the type of water in which the calcium sulphate plays an important part it is by far the one most commonly met with. Such waters drawn from the boiler and analyzed show a high ratio of calcium sulphate with little or no carbonate of lime or magnesium present. They are the most abundant of all and to such the table for classifying according to the quantity of scale-forming material given at the outset is fairly well adapted.

In such waters however special note should be taken of the amount of chlorides and nitrates, for the latter, especially when present in sufficient quantity, has strongly corroding properties. An example is given below of a water with excessive scale-forming properties and at the same time with marked tendency to corrosion. The water is from the Mattoon electric light plant. The well is 315 feet deep.

| | | | | |
|--------------------------|--------|--------|-----|--------|
| Silica..... | .308 | grains | per | gallon |
| Ca CO ₃ | 12.254 | " | " | " |
| Ca SO ₄ | 27.354 | " | " | " |
| Mg SO ₄ | 4.844 | " | " | " |
| Sodium chloride..... | 13.130 | " | " | " |
| Calcium nitrate..... | 1.686 | " | " | " |
| Total..... | 59.576 | " | " | " |

An interesting comparison may here be made with this water drawn from the boiler after six days' running from time of last wash out:

| | | | | |
|--------------------------|---------|--------|-----|--------|
| Silica..... | 1.865 | grains | per | gallon |
| Ca SO ₄ | 30.316 | " | " | " |
| Mg SO ₄ | 25.652 | " | " | " |
| Mg CO ₃ | 3.446 | " | " | " |
| Mg Cl ₂ | 2.764 | " | " | " |
| Sodium chloride..... | 251.456 | " | " | " |
| Calcium nitrate..... | 21.687 | " | " | " |
| Total..... | 337.186 | " | " | " |

The points of interest to be noted here are that according to the sodium chloride which would remain unchanged, the con-

centration has been less than 20 times (19.3). Now noting the amounts of calcium salt in the water from the boiler they are approximately the same, hence, approximately, eighteen times the original quantity has been thrown out, chiefly as scale. The magnesium constituents have taken other forms but about ten times the original amount has been lost, presumably as scale. As to the nitrates, about seven times the original amount has been lost, and as this would only come about by decomposition the corrosive properties of this water are thus abundantly accounted for in accordance with the equations above given. The point should be made here also that the calculation of the nitrates to calcium nitrate is not arbitrary. Indeed experiments indicate that just as properly could they be assigned to the sodium—giving the calcium the equivalent of chlorine, for the reason that sodium nitrate seems possessed of corrosive properties equally with calcium nitrate, corrosion being effected artificially by sodium nitrate in the absence of calcium nitrate.*

Another similar water with scale-forming and corroding properties is from the flowing wells, 128 feet deep, at Gilman, Ill. The water is from the stationary engine at the Illinois Central round house, two weeks from the last wash out:

| | | | | |
|---------------------------------------|---------|--------|-----|--------|
| Ca CO ₃ | 3.306 | grains | per | gallon |
| Ca SO ₄ | 29.194 | " | " | " |
| Mg SO ₄ | 1.160 | " | " | " |
| Na ₂ SO ₄ | 63.626 | " | " | " |
| Na Cl..... | 18.052 | " | " | " |
| Na NO ₃ | 28.594 | " | " | " |
| Total | 143.932 | " | " | " |

In this water the amounts of calcium as sulphate and carbonate would indicate for it an especially bad character as a scale forming water while the high ratio of sodium nitrate indicates a seriously corroding tendency, both of which characteristics are abundantly verified in the switch engine and other boilers using this water exclusively.

That method of analysis which would more nearly duplicate the boiler processes and reactions would seem to be the best. Working along this line the following procedure has been adopted.

*See thesis by A. E. Paul, '97.

A litre of water is taken and evaporated in a 5 or 6 inch porcelain dish resting on an iron plate with a $1\frac{1}{4}$ inch hole drilled through the center. The flame strikes the dish through this opening and keeps the water in gentle ebullition, care being taken toward the end to avoid loss. When the contents are reduced to about 25 c.c. the dish is removed. A separation of the soluble from the insoluble part is now effected by washing with successive portions of boiling water, draining through a hardened filter and finally bringing as much of the insoluble part onto the filter paper as possible. The volume of the wash water need not exceed 100 c.c. though the washing should be complete. This process while being far more rapid than the usual method of evaporation in platinum dishes on the water bath, has the advantage of reproducing quite accurately the conditions that are brought about in the boiler, with reference especially to the combinations assumed by the alkalies, sodium and potassium and the presence or nonpresence of magnesium and calcium. Of course to formulate any definite standard based on the forms of the ingredients thus found in the soluble portion demands a vast amount of data supplemented by actual experience in the use of the same waters. However, in general it may be said that: 1st, if the carbonates of the alkalies predominate such waters may be pronounced good; 2nd, if only the alkalies are found in the soluble portion as chlorides or sulphates with little or no amounts of magnesium or calcium, such waters are safe so far as corrosive properties are concerned, their grade as to scale-forming properties being determined from the results obtained from the analysis of the insoluble portion; 3d, if the soluble portion shows the presence of nitrates in any considerable quantity, even in the absence of magnesium or calcium, such a water will prove strongly corrosive; 4th, if alkalies are found in the soluble portion and also magnesium and calcium with abundance of sulphates, chlorides or nitrates, such waters are extremely objectionable, increasing in the order named. The first form, without appreciable quantities of the other two, because of scale-forming quality; the last two in any case, because of corrosive tendency.

Further corroboration of the proposition under "3" above is had in the case of experiments carried on by means of a small steam digester running at a pressure of 75 pounds and contain-

ing porcelain beakers in which were placed finely divided iron with solutions made up to duplicate these as well as all other possible or likely conditions.

The methods for determining the constituents in the two portions, the soluble and the insoluble parts, do not vary greatly from those in common use. It may be said, however, that each portion is titrated with standard hydrochloric acid solution and the sulphates of the soluble portion determined. In fresh portions, total sulphates, chlorides and nitrates (Crum's method) are determined and from the data thus at hand the various constituents are calculated. It may be said further that after careful experiments it has been found that this method of rapid evaporation is without loss, and the sum total of the ingredients gives quite as satisfactory a result for "total solids" as the usual method of evaporation and ignition in platinum.

With regard to remedies the great majority of waters could undoubtedly be brought artificially under the form indicated above where sodium carbonate predominates by addition in proper amount of that reagent. This is simply common "soda ash." The argument is sometimes advanced that this is a corroding agent. Where corrosion occurs it is due to some other ingredient already in the water, as has been shown above. This is also verified by all the boilers using the above waters. When artificially applied, however, the method of application is a matter of much importance. As usually applied it is done quite regardless of all chemical principles involved. To take up this phase of the matter would involve an extended discussion of the subject which must be left for some other time. So far it may be said our experiments have not found that corrosion which is due to the presence of nitrates is materially reduced by addition of soda ash. Such treatment is of course effective where the difficulty is due to free acid as in the case of mine waters.

With regard to boiler compounds, their name is legion, and they include an almost endless list of substances from treacle, potatoes and old shoes on the one hand to quite refined and respectable chemicals on the other. Without doubt there is some virtue in those substances which form the insoluble sucrates and tannates, but the charge sometimes made that soda ash is objectionable because of corrosive properties seems to be disproved by our experiments.

THE WORLD'S COLUMBIAN EXPOSITION.

A CONSTRUCTIVE PROBLEM, AND ITS VALUE AS A CRITERION.

BY ARTHUR PEABODY, '82, ARCHITECT, CHICAGO.

THE GENERAL DESIGN.

The design of the Universal Exposition held at Chicago in 1892-3 has been pronounced superior to any previous attempt. This opinion is held not only by the people of America, but of the world at large. The artistic and useful purposes for which it was created, were subserved in a degree quite beyond the expectation of the most sanguine. So persistently have its glories been sung that we have even grown a little weary of them. Something may be learned, however, by those whose interest has not entirely waned, from the simple narration of its building, together with a few criticisms on the various parts or phases incident to it. Having been connected with the Exposition during the entire constructive and operative periods, from April 1, 1891, to May 1, 1894, I may not be thought impertinent for venturing a few opinions which, though not infallible, at least are based on personal observation.

That a clear idea of the original design may be obtained, a short discussion of the several parts is essential.

In a general way the design may be said to have been composed of a number of great fields of activity, to some of which exclusive territory must be assigned; to others joint use of a common area, for different purposes.

The first elements to be considered were, naturally, the site, the character of the ground, its accessibility, etc., in short, the treatment demanded by physical conditions. For such work a contour map was used, and upon it the outlines of the several fields were determined. Here the groups of buildings were studied from the point of view of the landscape artist, the architect,

and the engineer. Preliminary sketches were made, showing in elevation and perspective the vague results of imaginings, the first gropings after detail. The final result followed quite closely after the general lines of the grand design, which, however, no map can adequately illustrate.

The several fields may be summed up as The Spectacular Field, The Exhibit Field, The Amusement Field, The Field of Service, as constituting the major elements in the design, with the Field of States and Foreign Countries as the principal minor element.

So much applause has been awarded to the glories of the Spectacular Field that criticism can detract but little. Whether the change from the thirteen columns of the original design to the Peristyle, with its giant shafts and rich pavilions on either hand, was wise, remains a question. One thought in connection with it was to create a "Principal Entrance." It was intended also to treat architecturally other "Gateways," but at the eleventh hour designs were abandoned and only a high board fence with turn-styles, great and small, and barnyard gates, gave evidence of the limits of the city of wonders.

Of the spectacle in general, the most notable criticism is that the buildings of which it was composed were so large that they could not be seen. By this I mean that, in order to obtain a comprehensive idea of an entire building, it must be viewed from a point so remote that detail was quite lost. Nor, in many cases, could such a view be had at all; as was instanced in the building for the exhibit of Fine Arts. This was not all, either, that tremendous size entailed. On account of the actual dimensions of subordinate parts, principal features were sometimes dominated by lesser elements, as in the case of Machinery Hall. Here the north-east corner pavilion, viewed from any practicable distance, quite overshadowed the remaining mass—towers, porticos, and all.

From these results an opinion might be hazarded that the buildings were too large, in an artistic sense, to be satisfactory. Their size was incomprehensible except by some accidental scale of measures. During the burning of the Casino and Peristyle, firemen put up ladders and mounted to the roof. At once the size of the buildings was magnified, in the imagination, some

two or three times. The figures on the parapet, about fifteen feet high, diminished the apparent size of the buildings in the mind of a spectator, by serving as units of measure.

Gigantic scales and heroic statues were of course inevitable. But having reached a certain dimension, the greatest that the mind is able to grasp, the buildings remained apparently stationary in size, no matter what their actual measures might become.

It is not my intention to convey the idea that the buildings should have been smaller. On the contrary there was not room enough in them to contain the exhibits. But viewed as objects of art they were open to the above objection. In some cases, too, the statues were larger than originally contemplated, a fact which went further to confuse the mind. Such a fault would, of course, be remedied in permanent work.

Coming to the second division, the Exhibit Field, the principal fault was contrary to that found with the Spectacular Field. Instead of being too large, by this meaning that waste spaces were encountered, the demand for room out-ran the areas provided. In but one department, that of Electricity, which should never have been quite divorced from its essential partner, Machinery, was there excess of area. Even the gigantic "second growth" of the Exposition was inadequate; insomuch that, although the Manufactures and Liberal Arts Building was increased one-half its area, by the roof over the great court, the important industry of Leather Working, and the notable science of Anthropology, were exhibited in separate buildings of three and four acres area respectively. These buildings, erected in the last part of the construction period, in a remote location, quite separated the above mentioned exhibits from their classes, and militated seriously against their success. The wholesale expansion of original buildings, by annexes, etc., encroached upon areas intended for accessory or external exhibits, crowding them into insufficient spaces, to their manifest disadvantage, and to the harm of the Exhibit Field as a whole.

It is probable that the original treatment of this field was quite nearly perfect, so far as an ideal amount of exhibit space is concerned. The dictum of Prince Jerome Napoleon, perhaps not far wrong, allotted seventy-five acres as a maximum. The

space actually occupied at the Exposition of '93 was double this amount, divided as follows:

| DEPARTMENT. | AREA IN ACRES. |
|---|--------------------------------|
| Agriculture, Forestry, Dairy, Stock | 35 |
| Horticulture | 5 ¹ / ₂ |
| Manufactures and Liberal Arts | 52 |
| Machinery and Electricity | 29 ¹ / ₄ |
| Mines | 8 ¹ / ₄ |
| Transportation | 14 |
| Total for the field | 144 |

To examine, even casually, the exhibits in such an Exposition, required an average exploration of fifteen and one-half acres per day for ten days (the average stay of most visitors)—something appalling to people "gone a'pleasuring."

The Amusement Field consisted of two distinct branches. The first included ordinary intellectual and gastronomic pleasures, music, and the like. To satisfy these requirements, pleasure boats and electric launches were put in commission, bands and orchestras engaged, and pleasure palaces built. The beautiful Music Hall and Casino were erected, as well as the Choral Hall near the Horticultural Building. Of these three buildings, Choral Hall achieved a fair measure of success. Large enough for great gatherings, it accommodated the less without losing interest by reason of its size. A great organ was here installed for concert and recital work, and the stage was made sufficiently ample for great choruses and orchestras. Music Hall and the Casino, the one built for holding high class musical functions, the other for the leisure of wealthy visitors, proved to be failures. Both were closed before the middle of the Exposition Period;—neither attracted the class for which it was provided. Two reasons might be cited for this disaster. First, lack of novelty. People in America are accustomed to classical music, and to high living. Second, situation. Pleasure is usually taken after the more earnest work of exploration. The most novel and varied array of pleasures was situated at the other side of the grounds, on the Midway Plaisance. Competition, too, was severe. At old Vienna, classical music, good fare, novelty, position, all combined when the tired brain and body demanded rest and play, to draw the people away from the restaurant and the music hall on the lake front. The Turkish drum and the reed pipe drowned, for the time, the strains of Wagner and Liszt.

The second branch of the Amusement Field, commonly dubbed the "Midway," was extremely well located, easy of access by train or other means, separated from the rest of the Exposition by the peculiar shape of the grounds, and was extravagantly successful. Beside the quality of a country fair, with its fakirs and clowns, there was here collected all the unique, far country exhibitions, under the system of "concessions;" sufficient in themselves to occupy at least two of the days previously given as the average visit of the sight-seer.

The provision for great functions did not receive much attention in the original design. What they might be had not yet developed. Processions, and the like, were not conspicuously successful for this reason, and provision for public comfort at pyrotechnic displays, for which the surface of the lake was fortunately available, was not adequate.

The Field of Service, including all things pertaining to the access of visitors to the grounds, their comfort and protection during the day, and their safe exit when the time of departure came, was from the nature of things a serious problem. More opportunity for error existed here than in any other division, for upon what basis should the attendance be estimated? In what manner would people come? What means of transportation would be most popular? What remedies could be applied for failures? Extensive preparation was made for local transport, by land or water. The Illinois Central Road was elevated above the streets, and special express trains put in service, in addition to the regular suburban service from the city. An "elevated" steam railway extended its lines into the grounds. Two electric surface roads were built from the west. All these did excellent service, and, in point of fact, the entire work of transportation. Looking back upon the scope of the Exposition, it seems incredible that any serious attempt should have been made to provide for long distance excursions by railroad. The single reason was that a day, or a series of days, at intervals, was a wholly inadequate method of exploring so great a city of wonders. At all events the large railroad yards, and the Terminal Station, were a complete failure. Save by the wandering private car of some railway magnate, or the occasional train from the north-west side of the city, the tracks were innocent of use. Toward the end of the Exposition Period, the Illinois Central Suburban Ex-

press Trains were diverted into the grounds, by a long detour, annoying alike to passengers and to the company, and a semblance of use was thus made of the Terminal Station. As a long distance excursion facility it was, however, needless, and its existence was a cause of derision on the part of the public prints.

Service inside the gates was in many respects ideal. Fire and police forces, scavenger work, transportation within the grounds (both by land and water), ordinary restaurant and toilet service, and hospital service, were adequately given to the people. No serious accident involving loss of life to any visitor, or extreme hardship, through the fault of this branch, was reported.

The Field of States and Foreign Countries was not one capable of special treatment, and but little attention, perhaps too little, was given to it. The informal distribution of State Buildings upon winding alleys was not productive in itself of much effect, nor were the buildings of such a character as to warrant the attempt to arrange them in a formal manner.

THE EXPOSITION BUILDINGS.

From the discussion of the general plan of the Exposition the mind naturally turns to the buildings and other features which composed the individual parts of the great design. Remarks under this head will not include an academic description of them, but reference is here made to a series of articles in the *Century Magazine* of the year 1893, by Mr. Henry Van Brunt of Kansas City, in which the principal buildings are treated in a thorough and scholarly manner.

In a general way, the buildings were well adapted for exhibition purposes. Very light, with numerous entrances and exits, the great areas were divided into spaces by walks and alleys, so that, usually, the exhibits were capable of perfect display. Galleries, however, were found objectionable for many reasons. On account of the labor of climbing stairs there was a disposition on the part of visitors to avoid them. Continuous effort was necessary, not always successful it must be confessed, to induce visits to the galleries, where, indeed, some most interesting objects were exposed. A further objection was the consequent darkening of spaces underneath, especially in the event of the

gallery being situated in the central part of the building. This was shown in an extreme degree in the Manufactures and Liberal Arts Building, under the galleries in the great court, where artificial light was at all times necessary.

The lighting of such buildings is at best difficult. Excessive areas of skylights were found to render certain parts too bright for the exposition of some classes of goods. This fault must then be corrected by draperies, velums, and the like. It was further discovered that all glass surfaces must be coated with lime-wash, to exclude in some measure the cumulative effects of the heat rays of a mid-summer sun.

The use of skylights is of course imperative in exposition buildings to secure equal illumination to all sides of each exhibit. Enormous glass areas, however, are very difficult of management, especially in roofs of great height, on account of the danger attendant on operation and repairs, and the peril to visitors from falling fragments of glass, loosened by the action of high winds and the variation of temperature.

Surprising results were obtained from skylights, no less in small areas than in large. Choral Hall, which was the auditorium for miscellaneous orchestral and choral festivals, all of which were held during the day, was lighted by a circular opening in the roof whose area was about 450 square feet, or about one one-hundredth of the 44 332 square feet of gross area of the building. Windows upon the sides lighted the corridor around the outer part, but the auditorium obtained its illumination altogether from the roof.

In other buildings skylight areas were, with regard to floor space, as follows:

| BUILDINGS. | GROSS AREA. | SKYLIGHTS. | PROPORTION. |
|-------------------------------------|-------------------|------------|----------------------|
| Manufactures and Liberal Arts. | 1 327 669 sq. ft. | 589 170 | 1 to 2 $\frac{1}{2}$ |
| Machinery Hall | 579 280 " | 278 613 | 1 " 2 |
| Agriculture | 400 000 " | 180 000 | 1 " 2 |
| Horticulture | 188 300 " | 130 650 | 1 " 1 $\frac{1}{2}$ |
| Mines..... | 248 900 " | 75 000 | 1 " 3 |
| Transportation. | 246 000 " | 75 000 | 1 " 3 |
| Electricity..... | 265 200 " | 55 000 | 1 " 5 |

It is not intended to place Choral Hall in actual competition with other buildings erected for purely exhibit purposes, and yet the thought arises, in this connection, as to whether they were not lighted in excess. They may not have been *too light*, but it

seems apparent that, when a building is of nearly the same brightness as ordinary daylight, increase of skylight area will not intensify the brightness in a degree commensurate with the increased glass surface. It can add, however, to the heat of the interior in a wonderful manner. This is precisely what happened. I fancy that by experiment it might be shown that the power of a skylight increases more rapidly than its area, up to a certain point, after which the light effects halt, while the increase of temperature from dark heat-rays continues.

Provision for installation of exhibits would seem to claim attention here, in the discussion of the several buildings. In nearly all cases openings were provided for the entrance of freight cars, under the supposition that loaded trains of cars would be admitted to the interior. In practice this was not found to be desirable, nor in some instances possible. Machinery Hall and Transportation Building were exceptions to this rule, but in other cases cars were left at entrances, and their contents discharged into wagons and hand-trucks. Freight tracks for the transfer of materials, in building, and for conveyance of exhibits in cases, were of course essential; but for various reasons, which would recur again under similar circumstances, tracks in buildings were not found practicable. In other respects the buildings generally were above criticism. Trifling details were perhaps not quite perfect, as the ephemeral character of the work would indicate. The universal comment, at all events, was more complimentary than critical.

CONSTRUCTION.

Viewed in the light of events, Constructive Architecture at the Exposition was a brilliant success. Such was the apparent strength and dignity of the great buildings that many people were deceived into believing them sufficient to last indefinitely. But little demonstration is required to show the fallacy of that idea. The fire of July 7, 1894, served only to accelerate their downfall, which, under the action of storm, rain and frost, was a question of months, rather than of years. And yet those of us who saw them rise, bit by bit, out of the wild marsh and sandy waste; who watched their growth in beauty until the day when all was finished; we, too, felt a certain sharp regret that so much grandeur and seeming strength should fade so quickly.

It may be interesting, at least to the student of architecture, to recount, briefly, the ways and means by which those shadowy dreams of art were transmuted into something like realities. I say "something like," because the buildings were but representations of great "palaces and piles stupendous." Theirs was the glory of the passing vision, certain to flee away at the breath of morning. During the development of the general design, by the Consulting Architect, the organization of the "Board of Architects" was effected. This was composed of ten leading American architects, whose names are too well known to need repetition here. By this board, under a program of mutual agreements, arrived at under the advice of the Consulting Architect, designs for ten principal buildings were produced. For their execution the branch of "Constructive Architecture in the Department of Construction" was created. In connection with farther development of the grounds and buildings, the services of landscape designers, engineers, artists, sculptors, and decorators were required, and, in connection with the great work, fire, police, hospital, and scavenger forces must be maintained. The brief time, two years, in which everything must be completed, made imperative the greatest possible efficiency of those concerned, and consequently most careful organization. A complete diagram of the Department is unnecessary, and would occupy too much room in a paper of these limits. A brief outline may be useful.

Under the Chief of Construction, who derived his authority from the Committee on Buildings and Grounds of the Exposition Company, the entire forces of the Construction Department were marshalled, substantially as follows:

| | | | | |
|--|--|--------------------|---|--|
| CHIEF OF CONSTRUCTION AND ASSISTANT CHIEF. | Constructive Forces. | DESIGNER IN CHIEF. | Constructive Architects | } Chief Draughtsman. Five Asst. Chiefs. Fifty Draughtsmen. |
| | | | | |
| | | CHIEF ENGINEERS | } Civil Engineers Mechanical Engrs. Electrical Engrs. Sanitary Engrs. Structural Engrs. | |
| | | | | SUPERINTENDENTS | } Supts. of Bldgs. Supt. of Exterior Covering. Master Carpenter. |
| Service Forces. | } Police Force. Fire Dept. Hospital Service. Scavenger Force. | | | |

It will be seen that the Chief Draughtsman, who stood at the head of the architectural force, derived his authority directly from the Chief of Construction. His action, however, was subject to the advice of the Landscape Architects and the Designer in Chief. Structural Engineers were subject to the advice of the Chief Draughtsman or his Assistant Chiefs, wherever their work was subordinated to architectural requirements. To each of the Assistant Chiefs a sufficient number of draughtsmen was assigned to carry out the special work entrusted to him. Every age, from sixteen to sixty, nearly every nationality, and certainly every grade of ability, was represented in the fifty draughtsmen. School men were in minority, nor did ability prove always consequent to the training they were supposed to have had. Perhaps I may be pardoned for stopping here to point out the vital necessity to any undergraduate of *learning to draw*. In competition with graduates of office boys' positions, this faculty will be of more service than any one thing in the whole catalogue of draughtsman's duties. It seems reasonably certain that a year's exclusive work in free-hand drawing, during a college course, would advance a young man's earning power more than two years' drill in the routine of office work; which is, beside, the first thing encountered on entering upon preliminary service in some architect's office. By free hand drawing I refer to the execution of classic ornament, and architectural decorative motives, to such an extent that a fund of them is accumulated in the mind, and the hand is ready to dash them off at instant notice.

It was in no sense creditable to school men to be instructed on such points by the Assistant Chiefs, however excusable in cases where such training had not been previously enjoyed. I am of the opinion that college men excelled somewhat in construction, although among my own best assistants, were men whose experience had been obtained wholly in offices. Few of the draughtsmen were, in any sense, masters of classic architecture, or of construction, and for that reason an undue amount of labor was thrown on the men in charge, especially during the first six months of the construction period.

Among the five Assistant Chiefs the several designs for great buildings were distributed for execution. These designs were exhibited by plans, elevations, and sections, drawn at the scale

of sixteen feet to the inch. Similar drawings are shown in any important competition for large buildings. In them the intention of the designer was shown with great care. Suggestions of methods of construction were very properly omitted.

It was this matter of the construction for which the Department of Constructive Architecture was organized. Its aim was to create uniform methods, to evolve general or typical schemes of construction, and, in short, to reduce everything so far as possible to a science. Time was always limited and in many instances so brief that continuous effort at high tension, extending each day's labor well into the night, was the sole means of keeping the department abreast of its duties. Beside the drawings made directly from the originals, numerous detail sheets were required to illustrate constructive problems; engineering diagrams must be incorporated in the general set, specifications written, etc., so that, from a general setting forth of intention on the part of the designer, there was developed and set down in detail the whole duty of the contractor.

The office system soon became crystallized into definite form. When a design was received the drawings were examined with greatest care, notes of errors and omissions were made, and the various sheets compared, numbered and listed. In consultation with the Structural Engineers a constructive scheme was then thought out. The building when completed partook of three distinct parts; first, a real building, more or less suited to the needs of exhibitors and the public in general. It must therefore be provided with the many necessities of modern life; protected, so far as possible, against danger of fire, and arranged to fulfill the prime object of its existence. Second, a real envelope, made up of rigid walls, substantial towers, domes, porticos, entrances and the like. Third, a false envelope, the glorifying mantle thrown over the giant frame of wood and steel, transforming their brute strength and enormous mass into the monument of classic architecture contemplated in the original design. Composed mainly of plaster of Paris, this covering was fragile in the extreme, requiring support and defense at every point.

With these three elements in view, the constructive architect and the structural engineer sat down together to map out their campaign. Such a building as Machinery Hall required preliminary study of this nature for nearly a month before a

line was drawn. When the main lines of action were determined upon, forces were marshalled for the general assault. As many draughtsmen as could possibly be employed on the drawings were detailed to assist the men in charge, and work was pushed with all energy to execute what were known as the "Contract Drawings." In such work as this, in the case of Machinery Hall, sixteen first-rate men were engaged for a period of seven weeks. Ordinary sheets of contract drawings were limited in size to four feet by seven, by the fact that the largest hektograph pad, then in use, was of those dimensions. A careful record was kept, in which each sheet was indexed by number and date of completion. When a drawing was finished and signed by the draughtsman, it was carefully examined and countersigned by the Assistant Chief and sent at once to be reproduced.

Except engineers' diagrams, which were best copied in blue print, the hektograph was used for all reproductions. Among the manifest advantages of this process were: the reproduction of color as well as lines; the use of manilla paper; the possibility of obtaining copies at night, or in stormy weathers, in great numbers. The hektograph was used during the whole constructive period, for full size as well as scale drawings, and, by printing in sections, sheets as large as 12 feet by 28 feet were produced. When a sufficient number of drawings had been copied to enable the specification writer to form an intelligent idea of the building, he began his labors, and by the time the entire list was done, his work also was finished. The specifications, however, were quite general in character, dealing exhaustively with technical points, but referring to the drawings for all detail information. For this reason a good number of notes on the drawings was necessary, to explain character of materials, etc.

The work of receiving estimates, letting contracts, and issuing certificates, was done by the Assistant Chief of Construction, who was in short the Business Manager. During the month of April, 1892, there was erected what was known as the "Service Building," at Jackson Park. All branches of the Department were then removed from the Rookery Building, in Chicago, to that place; this became the scene of the greatest achievements of the "Builders of the Fair." The Service Building, which many visitors remember, was erected in about three

weeks' time, at a cost of nearly \$50,000, by three sets or "shifts" of men, working day and night. Work in the department after this time consisted primarily of detailing, at $\frac{3}{4}$ inches to the foot, and at full size, what had already been placed under contract, and was in course of erection. Other buildings for various purposes, were designed and executed by the Department under the direction of the Chief of Design. Among them were three main Exposition Buildings, thirty-two other large buildings, sixty-two for operatic purposes, one hundred and seventy-six for concessionaires and others, seventy-eight decorative features of various sorts, including band stands, fountains, obelisks, rostral columns, bridges, and the docking around lagoons; in all more than three hundred and fifty structures. It will be seen that the number of completed drawings, being about thirty times reproduced by the hektograph in each case, was truly enormous. What their total number was, is of course not obtainable; at the close of the Department's work, however, one hundred and twenty boxes, of about 20 cubic feet capacity, were filled with drawings and sent to store, beside a nearly equal volume distributed among foreign countries, educational institutions and societies, or sent to the dump. Thus ended the labors of the Constructive Architects.

To the designers of the Exposition high honor has been given, and rightly. If those, to whom the almost equal task of executing their designs was entrusted, remain unsung, what wonder? Their work was so uniformly excellent and so great in volume that the natural inference is, "It must have been very easy." Whether or not it partook of the nature of a holiday I leave to the fair-minded reader. In two years a force of five men under a single chief, with the assistance of some fifty draughtsmen and about ten engineers, executed the necessary drawings for 364 buildings and other architectural features, of which 300 were designed by the Chief Designer or, under his direction, by the men in charge. Of the designs entrusted, by other architects, to the Department, no one lost character in consequence. Of the whole number of buildings twenty-seven were of large size, aggregating about 175 acres of floor area, and demanding extraordinary constructive skill, as well as thorough training in classic architectural style. No building failed in strength, none of those constructed by the Department was lost

by fire, nor did a single visitor during the entire time for which the Exposition was open suffer injury or death by reason of them.

It would be in questionable taste to include in an article distinctively architectural in its trend, anything like a technical discussion of the work of the various engineers, artists, and so forth, which went to supplement the architectural treatment. There remains the subject of Building Superintendence, which was performed quite in the ordinary way by a fairly competent force of men. Daily reports were made to the Chief of Construction, who held a council each morning for that purpose. Attendance on this council was made imperative not only on the Superintendents of Buildings, but upon each engineer in charge of a special line of work, such as electricity, grades and surveys, etc., and upon the officers of each service corps. In this way a degree of unity was preserved quite beyond what would have been otherwise possible. For the exterior decoration, or "staff covering," of buildings in general, a special superintendent was employed; and for the execution of temporary works, the repair of wooden bridges and roads, and the thousand and one "odd jobs," a Master Carpenter, with a considerable force of men, was appointed.

CONSTRUCTIVE MATERIALS AND METHODS.

I have referred in the previous section to the frame of wood and steel which served to enclose the real building and to support the architectural envelope. From its adaptability and for economical reasons, wood became the chief material used in building. Very large members, and parts exposed to concentrated strain, were commonly of steel. Of the real building little need be said. Its construction was simple and such as ordinary architectural practice would suggest. The enclosing frame, before referred to as the "real envelope," was more difficult. It consisted of walls without weight, though frequently of unusual thickness, domes, towers, pediments, and porticos, equally devoid of natural stability. As if to render the task more impossible, pinnacles were crowned with winged statues of gigantic proportions, exposing their great areas to the wind. Into all this must be infused the element of stability. It was as if inertia, as an attribute of nature, had been suddenly taken away

and other natural forces left to work their will. Something must be substituted for the lost quality or the first buffet of the storm would lay the buildings prostrate. What that something was may presently appear.

The underlying soil consisted of beach sand, overlaid, in some parts, with black loam. No difficulty, therefore, was experienced in support for foundations. These were in general of wood. Layers of two-inch plank were covered with rows of square timbers, crossed and drift-bolted together, diminished toward the top to a size convenient for the reception of the load intended. Such foundations formed of steel beams and concrete filling, are common under permanent buildings. The same method of calculation, as cantilevers, applied to the wooden beams, using a proper fibre strain. Piles were driven under buildings which projected over water, as at the Peristyle and the Agricultural Building, and in a few other cases. The dome of the Horticultural Building rested on piles which supported the load and resisted any tendency to lateral movement. Light walls were constructed on sills. All timber supporting load was estimated to be stressed to 1200 pounds per inch. Foundations imposed not more than $1\frac{1}{4}$ tons per square foot of ground. Ordinary floors supported 100 pounds per square foot. Mines and Transportation Buildings had floors adequate for 150 pounds, and Machinery Hall 200 pounds, per square foot. Except in Machinery Hall, these floors were constructed of ordinary joists covered with two-inch plank. In the section devoted to the exhibit of steam engines, oak was used in mill-constructed style. Upon the wooden pier foundations, above described, were set the supports for roof trusses, and the spaces intervening, filled with studding, constituted the frame of the walls. The surface of ordinary roofs, about the clerestories, was 60 feet above the ground, and, except for the galleries at about 20 feet above the main floor, there was no intermediate brace in the height. Full advantage, therefore, had to be taken of the gallery floor which was treated as a horizontal truss from point to point. In most cases the clerestory construction rested directly on the wood foundation, and, being of the nature of a braced arch, was quite capable of resisting horizontal thrust. To this the exterior work was therefore tied in such a manner as to relieve it of the danger of overturn. Truss-posts were made quite rigid laterally,

either by building them in the form of braced columns, as in the Agricultural Building, or by fishing beams together with bolts and keys, as in Machinery Hall. Between them, to relieve the studding of excessive length, were placed horizontal girders. The flat roofs also were trussed horizontally in the same manner as the gallery floors.

From the above description it will be seen that wind was considered the greatest difficulty to be overcome. Load, except in a number of isolated cases, was of small consequence. Such structures as Machinery Hall towers tested the ability of engineers as much as did any single thing. Here the tendency toward overturn or up-rooting, in the loose sand, was rather formidable. I remember, too, that the winged figures of Victory required steel rods four inches in diameter to receive the wind pressure transmitted by their great surfaces.

Where no clerestory occurred to serve as an anchor, other means were resorted to, such as building very deep braced posts to which sway rods were secured from the lower chord of the trusses. Such provision was made in the end pavilions of the Horticultural Building.

A student of architecture or of civil engineering would have found the array of trusses used at the Exposition a profitable and interesting study, and no doubt many took advantage of it. From the simple rafter and tie-rod of the Annex to the Transportation Building, to the stupendous braced arches of the building for Manufactures and Liberal Arts, the entire gamut was run, unless an exception be made of what is known as ecclesiastical timber work. Very interesting constructive problems occurred in special features, such as domes, corner pavilions, entrance porticos, and the like. Surprising loads were sometimes developed by the use of statuary in groups or upon pediments. The frame of the building being developed in all parts gave room for the consideration of the covering.

Flat roofs were covered with metal or with roofing felt and gravel. Corrugated iron was used in some cases, notably upon the roof of the Manufactures and Liberal Arts Building. Great areas of roof were covered with skylight glass, set in ordinary galvanized iron frames. Experience proved that all such areas should be guarded underneath by wire screens, to prevent accident from falling fragments of glass, broken out by vibration

during storms, or by expansion of the steel frame of the building.

Nearly all roofs were vented by louvres, which served to decrease the temperature of the interior and to relieve the tendency of confined air to lift up the roof covering. Transportation Building was an exception to the general rule of top ventilation and in consequence suffered injury from every storm of wind. Louvres are not quite satisfactory as vents, especially when located just above flat roofs. No louvre with fixed boards can, in such positions, exclude the rain. Rain falling on a flat roof rebounds or splashes, and the minute particles of water forming a sort of heavy mist will enter the most scientifically constructed louvre situated within a few feet of such a surface.

Exterior surfaces such as are usually built of stone or similar material, were covered with "staff." To receive this "outside skin," a fairly continuous surface was necessary. This was formed of inch boards set diagonally upon the studding and spaced about ten inches apart. On the inside surface of the studs a similar stripping of boards was set, using about half as much material, so that the open sheathing formed a considerable item of strength to broad surfaces. Upon this the exterior staff covering was laid in convenient sheets and secured by flat headed wire nails. For each cornice, moulding, and enrichment a suitable "furring" was provided, similar to that used for exterior sheet metal.

"Staff," the material used to convey architectural character to the buildings, was a mixture of plaster of Paris, strengthened by the addition of manilla fibre and moulded into various ornamental forms. As a building material it was quite new in America and an outline of its manufacture may not be wearisome. The fibre, cut into short lengths, was first beaten with a stick until the strands were quite separated and the bunch stood up in a feathery mass. A convenient amount was then grasped in the hands and plunged into a vat of liquid plaster and, when well drenched, was placed in the mould and pressed firmly to place. In this way the fibre penetrated every part, while the plaster, being fluid, filled all the outlines and presented an unbroken surface. As soon as the plaster had become set the mould could be emptied, and the process repeated.

Moulds were obtained from artists' models, either in plaster, or, in case of deeply undercut ornament, by the use of gelatine,

which from its flexible nature was very advantageous. It was unfitted for work which needed an extraordinary number of copies however, as the heat evolved by the hardening plaster gradually destroyed the delicate outlines obtained from the model. Such work where not too difficult, was copied from moulds carved in wood and put together in sections.

When the staff had been put in place, the joints and nail heads were "pointed" with plaster, and the surfaces covered with ordinary white lead paint, colored as desired. Certain qualities of staff as a building material were soon discovered. It could be easily cut with the saw or hatchet, quickly set in place, and produced wonderfully gratifying effects. Nothing, however, could be fastened to it, such as flashings and joints with gravel roofs, nor had it any available strength. In short as a covering it was admirable and it was otherwise useless. It possibly to some extent served as a protection against fire. At any rate it served to confine fire in such a manner that it could neither be extinguished from the outside, nor could it burst out until the local supports were burned away from within, allowing the staff to drop off. This was a noticeable feature of the great fire of July 7, 1894. More confidence was placed in provisions for extinguishing fire than in any quality of this material to resist it, however. To this end hydrants and hose reels were placed at regular intervals, patrol walks were provided at every point in all buildings, and where special danger was anticipated, as in the boiler house at Machinery Hall, metal was used exclusively. The Pumping Station and the Museum of Fine Arts were constructed with brick walls; and in other ways were above the standard of Exposition Buildings.

It would stretch the limits of this paper to describe the color decoration of the buildings, but a word about it may be proper. Aside from frescos and other distinctly local artistic efforts, no serious color scheme was attempted; Transportation Building being the only exception to this rule. Gold was used sparingly and with effect on one or two buildings, but in general, exteriors were kept very nearly the color of the plaster. Interior surfaces of walls and ceilings were given a coating of lime wash by means of a hose pipe. A mixture of the coloring matter was thrown from the pipe by the use of compressed air, which broke the liquid into minute drops as is accomplished by the atomizer.

The method was very rapid and promised to be very satisfactory. It was probably the only way in which the interiors could have been colored in the space of time available.

Lime wash is lacking in adhesive powers, and with this quality complete satisfaction with the interior coloring was not enjoyed. The constant rain of lime dust during the exposition caused some damage and great annoyance. Had something like an aniline stain been used, better results might possibly have been attained.

At the beginning of the previous section I referred to the World's Exposition structures as "representations of buildings." If anything needs to be added to what has already been said, perhaps the item of cost will convey to the mind the accuracy of this definition. The comparison with buildings of permanent character was suggested by a query on the part of one of the architects of the Designing Board.

Assuming twenty cents per cubic foot as a fair estimate of the cost of permanent buildings of great areas, and thirty cents per cubic foot for those with areas divided into rooms, great and small, the cost of permanent buildings is calculable. Of course the prices per cubic foot made use of are empirical, and yet the total for ten buildings may not be far from correct:

COST OF BUILDINGS.

| BUILDING. | CONTENTS CUBIC FEET. | ESTIMATED COST. | | ACTUAL COST. | |
|-------------------------------|-------------------------|-----------------|-------------|--------------|-------------|
| | | TOTAL. | PER CU. FT. | TOTAL. | PER CU. FT. |
| Administration | 5 626 529. | \$ 1 687 958 | 30 cts | \$ 493 901 | 8.8 cts |
| Gallery of Fine Arts. | 10 781 700. | 3 034 340 | 30 cts | 541 795. | 5.0 cts |
| Agriculture | 23 049 100. | 4 609 820 | 20 cts | 563 840 | 2.4 cts |
| Manufactures. | 168 043 315. | 33 608 663 | 20 cts | 1 837 601. | 1.1 cts |
| Machinery. | 35 978 028. | 7 195 604 | 20 cts | 1 370 084. | 3.8 cts |
| Mines | 15 458 408. | 3 091 681 | 20 cts | 265 447. | 1.7 cts |
| Transportation | 18 787 100. | 3 757 420 | 20 cts | 312 324. | 1.7 cts |
| Horticulture | 11 013 479. | 2 202 695 | 20 cts | 268 850. | 2.4 cts |
| Fisherles. | 3 166 325. | 633 265 | 20 cts | 216 333. | 6.8 cts |
| Electricity | 20 454 789. | 4 090 959 | 20 cts | 432 675. | 2.1 cts |
| Total for ten buildings | ..... | \$63 912 405 | ..... | \$6 302 850 | ..... |

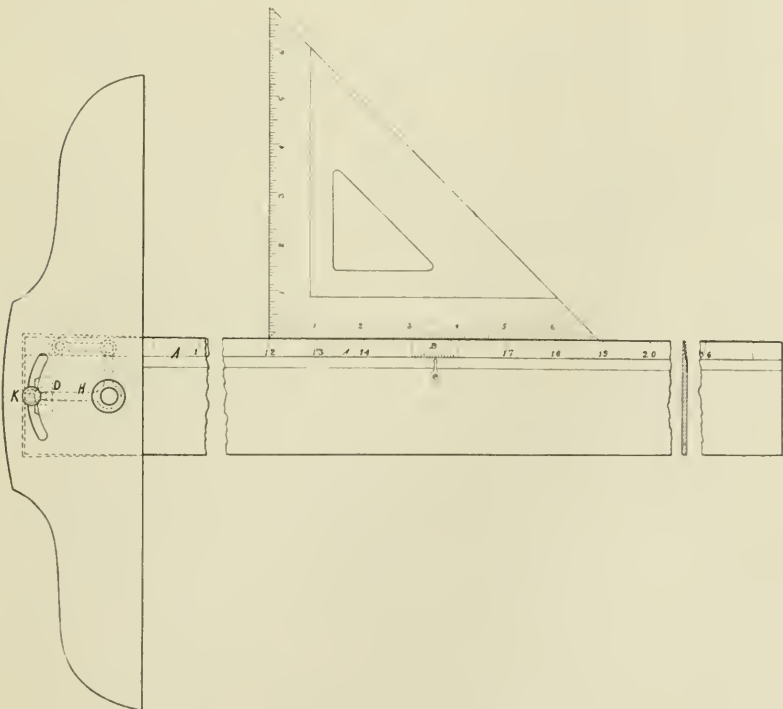
A final comment might be ventured on the Exposition Grounds and Buildings as one great work, namely: that it was brought about by two principal causes, of which the first was design, the second execution. Which was most wonderful may

not be important to discover. Like Faith and Works they were inseparably united for a common result. One is of course most apparent to the public eye. As with a victorious army, the generals win the battles and bear the decorations, while the soldiers "get their pay." May the Master Architects wear their medals with a kindly remembrance of the yeoman service rendered by the "boys in the Construction Department."

AN IMPROVED T SQUARE.

BY C. R. CLARK, '98, SCHOOL OF ARCHITECTURE. AND M. J. HAMMERS, '98, SCHOOL OF MECHANICAL ENGINEERING.

This square was designed to conveniently combine the scale and T square, and admit of the speedy manipulation of both. With this instrument points can be located and distances taken with greater accuracy and rapidity than by the ordinary method.



Pocketed in the transparent working edge of the blade is a movable scale A, graduated to inches for the greater portion of its length; one inch B, near the center, is graduated for the fractional parts, over which is a fixed pointer. The scale is movable endwise by an angled lever H fulcrumed in a chamber of the head. To facilitate accuracy, a guide graduation is placed on the working edge of the blade. The blade is made adjustable by means of a clamp nut D in the head. Graduated strips are attached to an ordinary triangle for vertical measurements.

To lay off a horizontal distance the square is placed on the paper and the scale shifted until an inch mark comes even with the initial point on the paper. The whole number of inches is then observed on the scale, the knob K is moved to carry the scale the required fraction as indicated by the pointer, and the line is then ruled. Vertical measurements and vertical ruling are made directly along the triangle without moving the T square.

MECHANICAL ENGINEERING SHOPS OF THE UNIVERSITY OF ILLINOIS.

BY L. P. BRECKENRIDGE, PROFESSOR OF MECHANICAL ENGINEERING.

The new shops of the Mechanical Engineering Department are situated about one hundred feet south of old Machinery Hall (now called Engineering Laboratory).

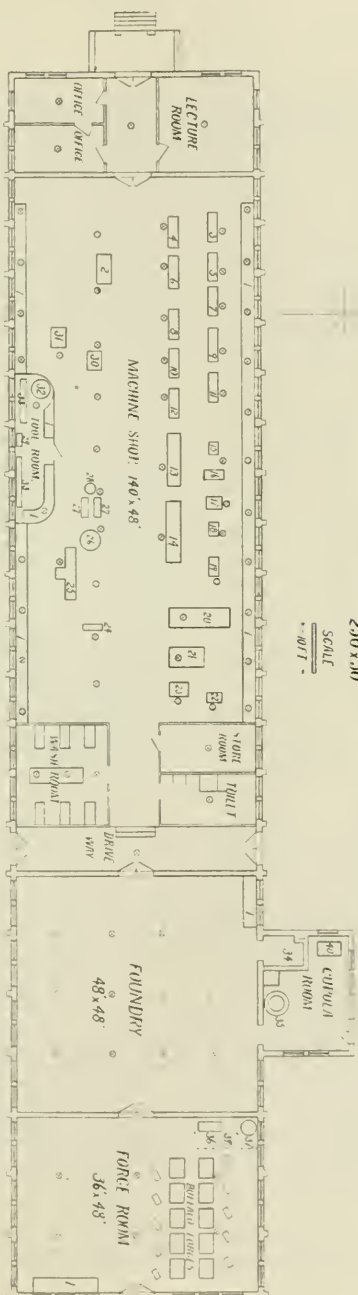
A view of the new Machinery Building is shown opposite page 88. It is a one-story brick building 250 x 50 feet. The slate roof is supported on steel trusses spaced 10 feet in the machine shop and 12 feet in the foundry and forge shop. The light is excellent, fully 75 per cent of the side walls being glass area. The arrangement of the rooms is clearly shown by the floor plans on page 87, and a study of this cut will explain the arrangement better than any detailed description.

An interior view of the machine shop is shown opposite page 89. The floor of this shop is $1\frac{1}{4}$ -inch hard pine laid on 3" x 4" joists placed 12-inch centers. The joists are supported on 12-inch steel I-beams resting on brick piers 10 feet apart. Several of the larger machines are placed on independent piers. The benches on each side of the shop are of 3-inch maple carried on the Brown & Sharpe patent cast iron leg. They are fully sup-

UNIVERSITY OF ILLINOIS,
MECHANICAL ENGINEERING DEPARTMENT SHOPS.

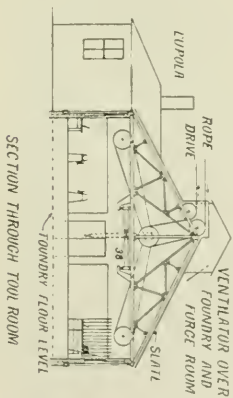
250 x 50

SCALE
1" = 10' 1"



⊙ ELECTRIC LIGHTS

- | | | | |
|----|----------------------------|----|---------------------------------|
| 1 | WORK BENCHES | 21 | 22", 25", 41" PUTNAM PLANER |
| 2 | TABLES | 22 | 16" HINLEY SHAPER |
| 3 | 17" RANTS LATHE | 21 | POWER HACK SAW |
| 4 | 16" POWELL LATHE | 23 | B-S OUV HAT GRINDER No. 2 |
| 5 | 14" TEAFLATHER LATHE | 26 | CUTTER - RUBBER GRINDER |
| 6 | 14" PITTSBURGH LATHE | 27 | SPEED LATHS |
| 7 | 14" FLATHER LATHE | 28 | SENSITIVE DRILL |
| 8 | 16" BLAISDELL LATHE | 29 | TWIST DRILL GRINDER |
| 9 | 14" FLATHER LATHE | 30 | B-S PLAIN MILLING MACHINE No. 2 |
| 10 | 16" FLATHER LATHE | 31 | BRENNERD OUV MILLING MACHINE |
| 11 | 14" FLATHER LATHE | 32 | REVOLVING TOOL RACK |
| 12 | 16" GOULD-FERRIARROT LATHE | 33 | TOOL RACKS |
| 13 | 20" TAYLOR LATHE | 34 | CORE OUVEN |
| 14 | 27" T-F REED LATHE | 35 | CUPOLA - SMITHING No. 1, 27" |
| 15 | EMERY WHEEL | 36 | STURTEZANT FAN |
| 16 | GRIND STONE | 37 | STACK |
| 17 | WATER EMERY GRINDER | 38 | 12 TON CRANE - 3 TONS |
| 18 | 20" BRANLIS VDR DRILL | 39 | EXHAUST FAN FOR FORGCS |
| 19 | 28" UPRIGHT DRILL | 40 | 27" x 36" RATTLER |
| 20 | 30" x 30" S-CRAY PLANER | | |



SECTION THROUGH TOOL ROOM

plied with drawers having combination dial locks. Power is taken to the shops by a 30 H. P. rope drive from engines in the Mechanical Engineering Laboratory. The jack shaft is situated above the lower chord of the roof truss, and from this the line shafts on either side are driven by belts on tight and loose pulleys. The line shafts are supported by 18-inch self-oiling drop hangers fastened directly to the lower chord of the roof truss, which is formed of two 8-inch channel irons spaced 1 inch. The hangers are 10 feet centers carrying a 2½-inch turned shafting which makes 125 R. P. M. The line shaft on the north side extends through the foundry and forge shop.

The floor of the machine shop is 3 feet above the driveway at the east end of the shop, and the crane extending over the driveway furnishes excellent facilities for loading or unloading materials and machinery. In the wash room are 96 lockers provided with dial combination locks.

In the foundry the light is excellent, the window sills being 6 feet from the floor. The cupola room is 18 x 24 feet outside, and the core oven is large and convenient. Two heats a week are usually taken and a very large percentage of the work done is used in the machine shop. Castings weighing 2 000 lbs. have been made.

The forge shop is provided with 10 Buffalo down-draft forges and the usual equipment of small tools. Some additional forges and a steam hammer will soon be added to this equipment.

The wood shops of the department occupy a part of the second floor of the Engineering Laboratory.

The shops are lighted by 130 incandescent lamps. The entire lighting plant was constructed last year (1896) by students in the shops.

The heating is by means of 1¼-inch pipe coils under the benches and overhead in the machine shop, while in the foundry and forge shop all of the heating surface is placed on the walls beneath the windows. The total heating surface in the building is 2 900 sq. ft. The steam is supplied by boilers in the laboratory through a 4-inch main about 120 ft. long.

The cost of the building was \$17 000. It is believed that the general arrangement and plan of this building are superior to any technical school shop in the country.



EXTERIOR VIEW OF MACHINE SHOP, UNIVERSITY OF ILLINOIS.



INTERIOR VIEW OF MACHINE SHOP, UNIVERSITY OF ILLINOIS.

SOME MODIFICATIONS IN THE USE OF THOMPSON'S CALORIMETER.

BY PROF. S. W. PARR, DEPARTMENT OF APPLIED CHEMISTRY.

There is presented herewith in tabular form the analysis of a number of Illinois coals. Much of this data has resulted from work that the Chemical Laboratory has been called upon to perform in connection with boiler tests conducted by the Department of Mechanical Engineering.

With regard to calorimetric determinations, it is to be regretted that we have been restricted to the use of a Thompson's calorimeter. Perhaps it should also be said that it is unfortunate that an apparatus so susceptible to errors from so many sources should ever have come into the degree of use or acceptance accorded this device. It has been found by experiment, however, that some of the errors may be very materially lessened by observing some conditions not heretofore made note of in directions for using this apparatus. Much depends upon the fineness of division of the charge, but more especially upon the degree of fineness taken in conjunction with the ratio of quantity existing between the coal and the chlorate mixture. Take for example a sample of coal that has been ground to pass through a sixty mesh sieve. Now upon mixing and burning with the usual KNO_3 and KClO_3 salts (1:3) in the ratio of two grams of coal to ten grams of the oxidizing mixture as usually directed, the combustion is so vigorous that much carbonaceous matter is thrown out of the cartridge unburned, and the too rapid passing of the gases through the water causes further loss of calorimetric units. Now by increasing the quantity of chlorate mixture the carbonaceous material is thereby diluted and the combustion retarded, a maximum reading being reached with coal of this fineness when the ratios are two grams of coal to eighteen grams of the chlorate mixture. For example under the above conditions, using the same coal, results were as follows:—

| | |
|---|-----------------|
| Ratio of 2 : 10 the calorimetric reading gave | 10 800 B. T. U. |
| “ “ 2 : 18 “ “ “ “ | 11 520 B. T. U. |

With this latter ratio there was still found great irregularity in the readings, hence from the same sample, coal was ground to pass through a forty mesh sieve. Uniform readings

now were obtained by using a ratio of 2 : 15 giving for the same coal 11 430 B. T. U. With this latter ratio and by addition of one-half gram of Na_2O_2 , thoroughly mixing and tamping well in the cartridge, uniform readings of 12 150 B. T. U. were obtained. Grouping them for comparison:—

ATHENS, ILLINOIS, LUMP COAL.

| | | |
|---|-----------------------|-----------------|
| Ratio 2 : 10 | Through 60 mesh | 10 800 B. T. U. |
| “ 2 : 18 | “ 60 “ | 11 520 B. T. U. |
| “ 2 : 15 | “ 40 “ | 11 430 B. T. U. |
| “ 2 : 15 and $\frac{1}{2}$ g. Na_2O_2 | “ 40 “ | 12 150 B. T. U. |

This last ratio was found also to complete the burning in that length of time found to give the best results, namely: not less than three-fourths nor more than one and one-fourth minutes. It should be said that close tamping retards, while loosely charging accelerates the burning.

Another kind of coal gave uniform readings as follows:—

ODIN, ILLINOIS, PEA COAL.

| | | |
|---|-----------------------|-----------------|
| Ratio 2 : 18 | Through 60 mesh | 10 980 B. T. U. |
| “ 2 : 15 | “ 40 “ | 11 340 B. T. U. |
| “ 2 : 15 and $\frac{1}{2}$ g. Na_2O_2 | “ 40 “ | 11 700 B. T. U. |

These comparative readings were continued on a number of samples from various sources and a very constant difference obtained in favor of the coal and chlorate mixture reduced to pass through a forty mesh sieve and using the last ratios given in the tables above. The increase due to the use of one-half gram of Na_2O_2 is quite constant in amount (360 to 400 B. T. U.). The heat of solution of this substance for one-half gram is found by experiment to be quite constant at 135 B. T. U.; whether the additional increase is due to heat of further chemical combination as $\text{Na}_2\text{O} + \text{CO}_2$, etc., or whether due to more perfect combustion of the coal has not been determined. The ash is very satisfactory and free from carbonaceous residue.

Even granting that the increased reading is due to chemical combination of the resulting compounds, the reading is legitimate and nearer the truth, since this heat of combination is an offset to balance the heat absorbed by decomposition of the chlorate mixture. The calorimetric readings in the table on page 91 were obtained as above described. The water used was uniformly six or seven degrees below the temperature of the room, the final reading being six or seven degrees above the room temperature.

ANALYSIS OF ILLINOIS COALS.

For methods of analysis employed, see pages 89 and 90.

| COAL. | DATE. | MOISTURE. | VOLATILE COM- BUSTIBLE. | COKE. | ASH. | CALORIMETER IN B. T. U. |
|--|--------------|-----------|----------------------------|-------|-------|----------------------------|
| Fairmount Screenings..... | Dec. 10, '96 | 10.67 | 36.46 | 39.85 | 13.02 | 11 340 |
| Odin Slack..... | Dec. 9, '96 | 8.00 | 34.45 | 42.26 | 10.43 | 11 160 |
| Odin Lump..... | Nov. 14, '96 | 7.92 | 38.39 | 45.57 | 8.12 | 12 240 |
| Odin Lump..... | Nov. 27, '97 | 8.11 | 35.73 | 44.62 | 11.54 | 11 475 |
| Du Quoin..... | June 15, '96 | 9.14 | 34.61 | 50.87 | 5.40 | 11 700 |
| Sangamon Lump..... | Feb. 20, '97 | 12.47 | 35.44 | 40.54 | 11.52 | 10 980 |
| Odin Lump..... | Nov. 6, '96 | 7.24 | 40.76 | 45.76 | 6.23 | 12 240 |
| Odin Pea Coal..... | June 11, '96 | 5.09 | 37.93 | 42.30 | 14.68 | 12 150 |
| Odin Pea Coal..... | Oct. 6, '96 | 7.28 | 41.25 | 45.27 | 6.24 | 11 700 |
| Paradise Lump..... | Oct. 6, '96 | 10.72 | 34.56 | 48.33 | 6.38 | 11 700 |
| Athens Lump..... | Mch. 25, '97 | 12.11 | 33.18 | 41.95 | 10.76 | 12 150 |
| Odin Pea Coal..... | Mch. 29, '97 | 7.71 | 35.43 | 42.44 | 14.42 | 11 700 |
| Moneaquia Lump..... | Dec. —, '95 | 8.77 | 36.57 | 45.57 | 9.09 | ..... |
| Moneaquia Lump, Vein No. 2..... | Dec. —, '95 | 7.08 | 42.80 | 42.14 | 7.98 | ..... |
| Moneaquia Lump, Vein No. 5..... | Dec. —, '95 | 8.00 | 39.53 | 46.00 | 6.47 | ..... |
| Du Quoin Lump..... | Feb. 27, '95 | 7.43 | 39.81 | 45.10 | 7.66 | ..... |
| Odin Lump..... | Feb. 23, '95 | 6.32 | 37.73 | 44.45 | 11.50 | ..... |
| Mt. Olive..... | April—, '95 | 7.99 | 38.59 | 44.51 | 8.91 | ..... |
| Moneaquia Lump..... | Jan. 1, '95 | 9.18 | 39.58 | 43.75 | 7.49 | 11 700 |
| Bloomington Lump..... | Jan. —, '96 | 3.80 | 43.10 | 43.50 | 8.80 | ..... |
| Odin Lump..... | Jan. 23, '95 | 6.20 | 40.25 | 46.02 | 7.53 | 11 880 |
| Odin Lump..... | April 9, '96 | 7.10 | 34.90 | 48.09 | 9.91 | 11 250 |
| Du Quoin Lump..... | Oct. 29, '95 | 7.59 | 35.77 | 47.53 | 9.11 | 11 250 |
| Paradise Lump—I.C. Coal & Salt Co..... | June 24, '96 | 9.63 | 37.00 | 51.10 | 2.27 | 11 970 |
| Muddy Val. Lump—I.C. Coal & Salt Co..... | June 24, '96 | 7.11 | 40.37 | 48.73 | 4.29 | 11 880 |
| Odin Lump..... | Feb. 9, '97 | 8.55 | 36.10 | 41.15 | 11.20 | 11 430 |
| Odin Pea Coal..... | Mch. 4, '97 | 4.20 | 36.22 | 44.23 | 15.35 | 11 790 |
| Odin Lump..... | Feb. 4, '97 | 8.40 | 34.03 | 49.85 | 15.70 | 11 790 |
| Odin Lump..... | Jan. 26, '97 | 3.50 | 38.30 | 47.35 | 10.85 | 12 330 |

ELECTRIC LIGHTING BY GAS ENGINES.

BY F. W. RICHART, '91, SCHOOL OF MECHANICAL ENGINEERING.

The term gas engine in the title is intended to be used in its broadest sense, including all engines operating on the Otto cycle, whether they obtain their power from gas, gasoline, or kerosene.

Engines using gasoline or kerosene have some means of vaporizing the fluid just before or after it has entered the cylinder, and are hence as truly gas engines as those which bear that name. The operation is essentially the same; the construction usually differs in but a few details.

The gas engine, having but one working stroke in each two revolutions of the crank-shaft, necessarily gives somewhat of a pulsating motion. This is one of its most objectionable characteristics, and it is for this reason that its fly-wheels are made exceptionally heavy for the power they produce. For electric lighting it is especially desirable that the motion be uniform, as a pulsating light is disagreeable. Means for alleviating or overcoming this difficulty will be mentioned later on.

The choice of the most desirable engine for an isolated lighting plant is by no means an easy task. It must be remembered that in most instances the plant is placed in inexperienced hands and expected to run for hours at a time, after starting, with no attention whatever. For these reasons the machine should be simple, have large bearing surfaces and reliable lubricating devices, and should be made so it is impossible for the valve mechanism to get out of time.

Whether the gas, gasoline, or petroleum engine is to be chosen may depend upon circumstances. Gas and gasoline engines are usually so made that they are readily convertible, one into the other, by making a few changes. Gasoline will produce somewhat more power than gas when used in the same engine. Petroleum engines are distinctly different. Petroleum being much more difficult to vaporize, requires different management from gasoline. It has a decided advantage in point of safety, over either gas or gasoline, in that the fluid is not ignited at ordinary temperatures, except it be taken up by some absorbent.

There are two general methods of igniting the mixture of

vapor and air after it has been compressed: hot tube and electric spark. The hot tube is the most reliable in causing explosions to occur, but has not, as ordinarily made, a long life. Some foreign builders have made tubes of porcelain that give good results. In this country they are usually made of a short piece of gas pipe which costs but a few cents and may be quickly replaced. Electric igniters are more economical of fuel, requiring no burner to keep them hot, but it seems that the majority of builders do not consider them reliable, preferring to sell a machine having a tube igniter or one having both. A third method of igniting the charge is by the heat of compression; that is, the mixture of vapor and air is compressed to such degree that, with the aid of heat from the vaporizing chamber, ignition is effected. This method is not as far as I know used in any engine, except, perhaps, the Hornsby-Akroyd petroleum engine. The author's experience in the use of this method has been very satisfactory. There is no burning out of tubes nor misfires from weakened batteries or damaged electrodes. This method is not known to have ever been tried with any other fuel. Detail description will be given later on.

There are two methods of governing gas engines. That most commonly used is the "hit and miss." In this case, if the demand for power is less than the capacity of the engine, the governor cuts the supply of fuel entirely off till the speed drops enough to allow the feeding mechanism to come into action again. This is manifestly undesirable for electric lighting, for the engine may have to run for four or six revolutions between explosions, causing too great fluctuations in speed to be readily overcome by ordinary methods. The second method is by adjusting the amount of the charge to the work to be done, and having the explosions occur regularly every other revolution. With gas engines the force of each explosion is easily controlled by connecting the governor to the gas valve. With gasoline and petroleum engines it may be accomplished either by admitting or pumping a variable quantity (depending on the power required at that instant) into the vaporizing chamber, or by pumping a definite quantity and operating a by-pass or overflow valve with the governor.

In order to obtain the greatest efficiency from the engine, only that amount of air necessary to completely consume the

charge should be admitted. The hot tube igniter requires a full cylinder of gas and air to force the mixture far enough into the hot tube to cause an explosion. It is for this reason that we find the "hit and miss" method of governing used on the greater number of tube igniters. The exceptional cases require a timing valve to admit the mixture into the tube at the proper moment. There is a considerable range of mixtures at which gases will explode, and little attention is given by most builders to proportioning the mixture exactly, the point aimed at usually being to be certain the fuel is completely burned. If the amount of gas is too great for the quantity of air, a burning mixture instead of an explosive mixture will result, which is not only poor economy, but gives a small amount of power. As a matter of actual economy, there would probably be but little saved by such an arrangement. It is, however, very important that combustion shall be complete, for any incomplete combination of the charge and the oxygen of the air does not result in a complete combustion of part and leave the remainder unaffected; but the whole charge is burned to a condition of smoke and unconsumed particles, or soot, mixes with the lubricating oil of the cylinder clogging the rings on the piston and very seriously interfering with the running of the engine.

One serious fault with some governors is that the sudden impulse given to the engine when an explosion occurs causes it to act so violently as to entirely cut off the following charge, thereby causing a momentary loss in speed. In such cases better results will be obtained by the addition of a dash-pot which is able to dampen the sudden movements of the governor.

The amount of water required to keep the cylinder cool is about ten gallons per brake horse power per hour. Where a constant flow of water cannot be had a large tank may be used, and in fact this is the prevailing practice. A tank having a capacity of 100 gallons for each brake horse power will give good results. Smaller ones are usually used. By some authorities about 160° F. is the limit given that the water should reach. Practically as long as lubrication in the cylinder is all right there is no great harm done if the water boils. I have seen installations where the water had to boil to cause a circulation. This is wrong; there should be a complete circuit of water so that circulation may begin on the slightest generation of heat in the engine

cylinder. Rain water should be used if possible where cooling tanks are employed. When rain water is not obtainable, well or hard water may be used if care is taken to draw off part occasionally and fill up with fresh, thus keeping the amount of dissolved mineral salts to a low enough degree to prevent deposit on the walls of the water-jacket.

In the operation of gas engines in general, there are a few points worth calling special attention to. They have the reputation of sometimes suddenly stopping without apparent cause, or where an attempt is made to start them, they refuse to go, until, perhaps, after many trials they start off with no apparent change of conditions. This, no doubt, is a false charge. In the first place all bearings must be properly lubricated. Especial attention is called to the fact that cylinders often need a special grade of oil to work well—a moderately light oil with a high flash point. If the cylinder becomes blackened and the rings clogged, do not lay the blame on poor combustion unless you are sure the oil is all right. Poor combustion will always show itself by a smoky exhaust. Failure to explode may usually be attributed to one of three things: failure of charge to enter the cylinder, failure of ignition apparatus to operate (especially the electric), or failure of valve mechanism to operate thus allowing the charge to escape before explosion can take place. With gas engines proper, there is no chance for failure of the charge to enter, except the pipe be stopped up or the valve closed. With gasoline or petroleum engines, the charge may fail to enter by reason of an empty tank, a clogged pipe, leaky pump or check valves, or clogged nozzle. With tube igniters, ignition will not fail if the tube is hot enough and the charge forced up into it. Electric igniters may fail by reason of a weak battery, broken circuit, corroded contact points or electrodes, or in some engines where it is possible for water to leak through packing into the cylinder space, water may short circuit the electrodes and stop the engine.

The installation of a gas engine lighting plant, usually carries with it the idea of cheapness of operation, and therefore, cheap attendance. To fulfill this requirement, the dynamos should have self-oiling bearings, radial carbon brushes, run practically sparkless, and be slow speed. Dynamos now built have in general self-oiling bearings, but there is a desirable fea-

ture that but few small machines have, and that is this: There should be a cap over each bearing, hinged or removable, that is large enough to enable both rings to be plainly seen. The small glass gages on the sides of the bearing, are practically worthless to show the proper amount of oil. When the rings may be plainly seen it is an easy matter to pour in oil, until the rings carry an abundant supply to the bearing. There is then no excuse for flooding the bearing and running oil all over the machine, and it takes but a glance to see that the bearing is properly supplied with oil at any time.

Radial carbon brushes are very desirable for this class of work, mainly because it is impossible to get a brush wrongly set. Non-sparking is for the same general reason desirable because the commutator will require a minimum of attention.

One other topic demands discussion, and that is the various means of lessening or overcoming the fluctuations that necessarily occur when using gas engines, by reason of the intermittent application of the energy. The majority of engines operating on the Otto cycle receive but one impulse in two revolutions, and are therefore the most difficult to deal with. There are three methods of reducing the fluctuations one-half, that is, securing an impulse every revolution: first, coupling two engines on one shaft; second, putting two cylinders in tandem and exploding alternately; and third, so constructing the engine that there is an explosion in one cylinder at each revolution. For an example of this latter engine see *Am. Mach.* Jan. 7, '97.

To return to the subject proper, there are several ways of lessening the fluctuations of speed of the dynamo, three of which will be mentioned. First, adding revolving weight; second, using a very heavy belt; and third, making a flexible connection between the dynamo pulley and shaft. When used for electric lighting, gas engines are provided with two heavy fly wheels, but this is usually the case when used for any other purpose. A heavy fly wheel added to the dynamo shaft will add steadiness to the motion, or if it is not desirable to put additional weight on the dynamo shaft the same object is attained by introducing a counter shaft between the engine and dynamo, and placing a fly wheel on it. The above are the usual methods employed. Except for very small machines, or for long distances (twenty feet or more) between centers it will in all cases be found desirable

to use leather link belts, for the two reasons that they are heavier than flat leather or rubber belts, and they will not flap. A flapping belt, especially on a short drive, will cause slipping on the dynamo pulley and greatly aggravate the very trouble that it is so desirable to overcome. The object of a flexible or spring connection between the dynamo pulley and the shaft is to relieve the sudden jerk at the time of the explosion. To obtain the most desirable results from the ordinary Otto cycle engine it is recommended to use heavy fly wheels on engine, a leather link belt, a rigidly connected fly wheel on dynamo shaft and a flexibly connected driving pulley. Some engines may advantageously be run at a higher rate of speed than that at which they are rated. An increase of ten per cent in speed will decrease the intensity of the pulsations in running, twenty per cent.

As regards first cost, petroleum engines are twenty to thirty per cent more expensive than gas or gasolene engines. Prices vary as widely with this class of engines as with steam engines, and the variations in quality and desirability are equally as great. The total cost of a power plant, whether gas or steam engine, will probably be about the same for like quality.

The operating expense for gas engines depends on the price of fuel. Gas engines consume seventeen to twenty or more cubic feet of gas per B. H. P. hour. Gasoline engines use about one pint (U. S. measure) per B. H. P. hour. Petroleum engines burn about one pound (one pint Imperial measure) per B. H. P. hour. Of course the quality of the fuel will affect the consumption to a certain degree. The great saving in cost of operation as compared with steam engines, is the fact that only a small amount of attention is required, and less expense of repairs.

The size of the engine does not affect the efficiency greatly, as is the case with steam engines. Moderate sized engines are practically as efficient as large ones. Very small engines (five H. P. and less) have a somewhat lower efficiency.

The following description of a plant installed by the author may be of interest. The results noted may be easily duplicated by a similar installation, and by giving more particular attention to the points already noted, better results may easily be attained.

The conditions to be met were, lighting a general store, with clerks to operate the plant and but little attention given by

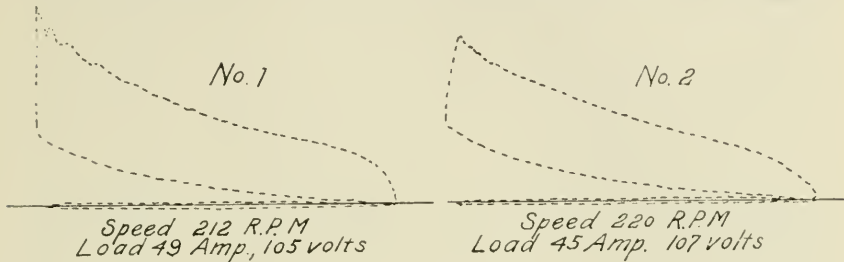
them. To prevent a higher rate of insurance the plant had to be located away from the building, but in reality a kerosene lamp is a more hazardous risk than the whole lighting plant.

The problem of choosing an engine was not a simple one. Engines governing by the "hit and miss" plan were avoided, heavy fly-wheels, and a simple, effective, and reliable igniting apparatus being desirable. The Hornsby-Akroyd oil engine was chosen. The size is ten B. H. P. having a cylinder eleven inches in diameter and a stroke of fifteen inches. The rated speed is 210 R. P. M., but it was found to give much steadier light and better regulation to run at 225 R. P. M. The kerosene is held in a tank which is cast in the sub-base of the engine. From this tank it is pumped into a hot chamber, called the vaporizer, which is bolted to the rear of the cylinder. There is a filter placed in the oil tank at the point where the oil leaves it to prevent the escape of dirt or grit, which would damage the check valves of the pump or prevent them from seating. The oil is injected into the vaporizer through two very small holes in the vaporizer valve box. This valve box is water jacketed to keep it cool. It is provided with a check valve that prevents the jar of the explosion from being communicated to the oil pipe or pump. This valve box is also provided with the by-pass valve that is operated by the governor. The oil flowing through this valve returns to the tank in the engine bed.

To start the engine, it is necessary first to heat the vaporizer. This is accomplished by burning about one and one-half pints of kerosene in two lamps, under the vaporizer. The fire is urged by a small blower. Six or seven minutes is sufficient time with this engine to heat the vaporizer so it will run; but after starting, it takes about ten minutes for the vaporizer to get hot enough to work its best. As soon as the oil is all burned out of the lamps the pump is worked by hand till the oil overflows at the by-pass valve. A lever is then moved that prevents the governor from coming into action till the proper speed is attained, and on turning the engine over, it starts. There are no igniting devices save the heat from the vaporizing chamber and the heat of compression. There are no adjustments to be made except to alter the volume of the cylinder (which varies the amount of compression) by two very simple means. This change is necessary to adapt it to different oils.

With properly adjusted compression the explosions invariably occur on the dead center. Changing the temperature of the vaporizer from a black red to a bright cherry red, does not, so far as could be observed by the indicator, change the time of explosion.

The accompanying indicator cards were taken with a sixty pound spring, but an eighty pound spring would be better adapted



to the work, because the pressure sometimes rises too near the limit at which it is safe to use the lighter spring. Card No. 1 is a good card and shows average working results. Card No. 2 shows the explosion line inclined instead of vertical. This condition prevails when there is too much oil injected in the cylinder, or when compression is not great enough. It indicates a slow burning, instead of an explosion as in the case of the vertical line.

CEMENT LABORATORY NOTES.

BY MILO S. KETCHUM, 95, ASSISTANT IN CIVIL ENGINEERING.

LABORATORY INSTRUCTION.

Instruction in the Cement Laboratory is given as part of the instruction in Masonry Construction. The students devote one period of two hours per week for fourteen weeks to laboratory work in cement testing. The time is by no means sufficient to make the students expert cement testers, but the results have been very gratifying, the students becoming quite proficient after performing the first six or seven experiments.

The Cement Laboratory occupies two pleasant rooms, 20x36 ft. each, on the ground floor of Engineering Hall. The west room is used for the storing of cements, sand, etc., and as a weighing room; the east room as the laboratory proper. The cement, sand and crushed quartz are stored in galvanized-iron cans holding about a barrel of loose cement. The weighing is ordinarily done on Fairbanks scales reading to decigrams; in the experiment to determine the fineness of cement, however, the weighing is done on a more delicate scale reading to centigrams. The mortar is mixed on slate tables 3x4 ft., of which there are six in the east room. These have proved to be much more serviceable than glass slabs.

For hand-molding the laboratory is supplied with two gangs of brass molds having a capacity of thirty briquettes each, and with twenty-four individual brass molds of a special design so as to be adapted to machine-molding as well as to hand-molding. The special individual moulds referred to above are also used in a Boehme hammer apparatus and in a Russell lever machine. All molds are of the form recommended by the American Society of Civil Engineers. The laboratory has one brass individual and a gang of seven cast-iron molds for flexure specimens. The briquettes are stored in zinc trays 12x13x3 inches, the water not being allowed to remain in the pans for more than a week.

The laboratory is supplied with a Riehle cement testing machine with a capacity of 1 000 lbs.; an Olsen machine with a capacity of 2 000 lbs., and having attachments for making compressive and flexure tests; and a Fairbanks machine with a capacity of 1 000 lbs. The Riehle machine, being supplied with rubber-tipped grips, is the most satisfactory machine to use, the

briquettes broken on this machine failing uniformly in the smallest section.

The equipment also includes a "hot test apparatus," a glass tank for storing pats when tested for soundness; a Vicat needle, two sets of Gillmore needles, and two German needles, for determining activity; cement and sand sieves; trowels, graduated cylinders, etc.

RESULTS OF TESTS.

In Tables I and II following are given some of the results of tests made in the laboratory by the members of one class in the fall term of 1896.

In Table I (page 102) are given the percentages of water for neat cement mortar, the tensile strength of neat cement mortar, and the fineness of different cements. The results given under the head of "Mean per cent of water" are the means of values obtained by two or more pairs of students. The results for tensile strength represent the values obtained by one or more pairs of students, each pair making six briquettes each of four different cements in a single laboratory period, using the percentage of water which they had determined in a previous experiment. The mortar was pressed into molds with the thumbs. The results for fineness represent the work of one or more pairs of students.

The probable errors of the mean tensile strengths given in Tables I and II were obtained by the formula $p. e. = 0.6745 \sqrt{\frac{\sum v^2}{n(n-1)}}$ where v is the difference between the mean and the tensile strength of each briquette, and n is the number of briquettes tested.

In Table II (page 103) are given the results obtained by different students for the tensile strength of neat Dycherhoff-Portland, and Utica, and "Black Diamond" Louisville-Rosendale cement mortar. This table shows a few of the individual results used in compiling Table I, and presented in Table II to show the variations in the results by different operators. The students made all the briquettes placed opposite their initials during a single laboratory period; the briquettes made by different pairs, however, were made and broken on different days. The work was new to all, none of the students having had any previous experience in making or breaking briquettes. All the experience they had in cement testing had been obtained in performing the

five previous experiments. The work was all done under the direction of the writer in accordance, as nearly as possible, with the specifications for the testing of cements recommended by the American Society of Civil Engineers. These results show what can be done by inexperienced men working under definite instructions. That the variations are mostly due to accidental errors is made evident by the fact that the probable error of the "final mean" is very much less than the mean of the probable errors for each cement.

While it is a fact that the students had had no previous experience in testing cements, they brought with them to the work the knowledge and experience gained by three years of technical training, and should by no means be considered inexperienced men. These results seem to show that when definite specifications are adopted for the testing of cements and technically trained men are put in charge of the tests, engineers will cease to complain of the unreliability of cement tests.

TABLE I.
STRENGTH AND FINENESS OF VARIOUS CEMENTS.

| BRAND. | TENSILE STRENGTH OF NEAT CEMENT MORTAR; HAND MOLDED; 1 DAY IN AIR, 6 DAYS IN WATER. | | | | | | PROB. ERROR MEAN. | NO. OF TESTS. | FINENESS. | |
|-----------------------------------|---|------------------|------------------|------|------|-----------------|-------------------|---------------|------------|--|
| | MEAN PER CENT OF WATER. | NO. OF BRIQUET'S | LBS. PER SQ. IN. | | | PER CT. PASSING | | | | |
| | | | MAX. | MIN. | MEAN | 50 SIEVE. | | | 100 SIEVE. | |
| | | | | | | | | | | |
| PORTLANDS— | | | | | | | | | | |
| Star Stettin | 21 | 18 | 727 | 520 | 616 | 10.0 | 1 | 99.8 | 91.0 | |
| Dyckerhoff | 21 | 28 | 572 | 418 | 494 | 5.2 | 1 | 99.7 | 86.1 | |
| Heyn | 23 | 5 | 544 | 402 | 480 | 15.0 | 1 | 99.6 | 86.3 | |
| Hilton's | 22 | 16 | 486 | 335 | 437 | 8.3 | 1 | 97.7 | 83.7 | |
| Dufosseze | 22 | 6 | 642 | 503 | 584 | 13.0 | 3 | 99.8 | 84.3 | |
| Alpha | 21 | 14 | 612 | 386 | 516 | 14.0 | 2 | 99.5 | 90.5 | |
| Saylor's | 22 | 12 | 545 | 376 | 477 | 11.0 | 3 | 98.9 | 89.6 | |
| Buckeye | 22 | 11 | 366 | 254 | 305 | 6.3 | 1 | 99.5 | 90.0 | |
| ROSENDALES— | | | | | | | | | | |
| Utica | 38 | 23 | 221 | 100 | 172 | 3.7 | 2 | 92.8 | 77.7 | |
| Milwaukee | 34 | 11 | 159 | 73 | 118 | 6.7 | 3 | 95.6 | 81.5 | |
| Louisville Black Diamond | 36 | 22 | 193 | 130 | 158 | 2.3 | ..... | ..... | ..... |  |
| Louisville Star Brand | 35 | 10 | 235 | 176 | 197 | 3.5 | 2 | 85.1 | 70.0 | |
| Akron | 28 | 12 | 253 | 151 | 182 | 7.0 | 1 | 93.3 | 78.7 | |
| New York and Rosendale | 28 | 5 | 159 | 121 | 140 | 5.3 | 4 | 95.9 | 81.3 | |

TABLE II.

VARIATION OF TENSILE STRENGTH BY DIFFERENT OBSERVERS.

Briquettes hand-molded and stored 1 day in air and 6 days in water.

| INITIALS OF STUDENTS. | PER CENT OF WATER. | NUMBER OF THE BRIQUETTE. | | | | | | MEAN TENSILE STRENGTH, LBS. PER SQ. INCH. | PROB. ERROR. |
|---|--------------------|--------------------------|-----|-----|-----|-----|-------|---|--------------|
| | | 1 | 2 | 3 | 4 | 5 | 6 | | |
| Neat Dycerhoff Portland Cement. | | | | | | | | | |
| A. & B. | 21 | 495 | 436 | 532 | 482 | 485 | 468 | 483 | 8.6 |
| G. & P. | 21 | 418 | 497 | 539 | 455 | 417 | 566 | 482 | 18.0 |
| H. & J. | 21 | 543 | 491 | 520 | 550 | 519 | ..... | 525 | 6.9 |
| K. & V. | 21 | 472 | 433 | 478 | 455 | 465 | ..... | 458 | 6.6 |
| S. & W. | 21 | 572 | 510 | 511 | 545 | 505 | 542 | 531 | 7.2 |
| Final Mean | | | | | | | | 491 | 5.2 |
| Neat Clark's Utica Cement. | | | | | | | | | |
| A. & B. | 37 | 172 | 181 | 180 | 187 | 169 | 189 | 180 | 2.1 |
| S. & W. | 37 | 140 | 200 | 148 | 178 | 169 | ..... | 167 | 7.1 |
| H. & J. | 38 | 184 | 131 | 196 | 167 | 100 | 128 | 151 | 10.1 |
| B. & N. | 35 | 172 | 192 | 201 | 169 | 190 | 221 | 191 | 4.8 |
| Final Mean | | | | | | | | 172 | 3.7 |
| Neat "Black Diamond" Louisville Cement. | | | | | | | | | |
| A. & B. | 35 | 161 | 179 | 142 | 152 | 152 | 170 | 159 | 3.6 |
| K. & V. | 36 | 163 | 143 | 143 | 152 | 151 | ..... | 150 | 2.3 |
| H. & J. | 37 | 165 | 176 | 170 | 130 | 152 | ..... | 159 | 5.3 |
| B. & H. | 37 | 130 | 167 | 156 | 153 | 186 | 193 | 164 | 6.3 |
| Final Mean | | | | | | | | 158 | 2.3 |

CAPACITY OF CEMENT BARRELS.

Having recently received a number of barrels of cement for use in the Cement Laboratory, the writer measured the cubic capacity of each, and in Table III, page 104, presents the results along with all the data on the subject available to him in engineering literature.

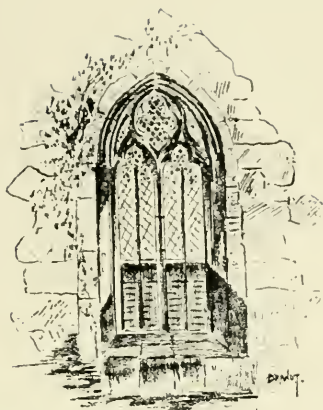
The cements had been received directly from the manufacturers or importers, and should be fairly representative barrels.

TABLE III.

CAPACITY OF CEMENT BARRELS.

| BRAND. | LOCALITY. | VALUES GIV- EN IN ENG. NEWS, FEB. 20, 1890. | COMPUTED VALUES. |
|-----------------------------------|-----------|--|---------------------|
| Portland. | | | |
| Alsen's | German | 3.33 | 3.46 |
| Dyckerhoff | " | | 3.23 |
| Hamborg | " | | 3.75 |
| Heyn | " | | 3.17 |
| Lagerdorfer | " | | 3.36 |
| Star Stettin | " | | 3.30 |
| Dufosse | Belgian | | 3.22 |
| Hilton's | English | | 3.32 |
| West Kent | " | | 3.32 |
| White Bros | " | 3.16 | |
| Francis | " | 3.38 | |
| Johnston's | " | 3.38 | |
| Alpha | American | | 3.64 |
| Buckeye | " | | 3.52 |
| Commercial | " | | 3.72 |
| Saylor's | " | 2.85* | 3.60 |
| | | Mean= | 3.49 |
| Rosendale or "Natural." | | | |
| Akron | American | | 3.37 |
| Clark's Utica | " | 3.75 | 3.55 |
| Louisville, "Black Diamond" | " | 3.75 | 3.41 |
| Louisville, "Star" | " | | 3.40 |
| Milwaukee | " | | 3.80 |
| New York and Rosendale | " | | 3.58 |
| | | Mean= | 3.52 |

*This value is apparently erroneous, but is certainly correctly quoted.



PENCIL SKETCHES MADE BY THE CLASS IN ARCHITECTURAL PERSPECTIVE,
UNIVERSITY OF ILLINOIS.
About 1/4 Size.



Astronomical Observatory, University of Illinois.

THE ASTRONOMICAL OBSERVATORY.

BY G. W. MYERS, DIRECTOR.

In compliance with a request of the board of trustees, the legislature appropriated to the University, during the spring of 1895, the sum of fifteen thousand dollars (\$15,000.00) to build and equip a students' astronomical observatory. The professor of astronomy being in Europe on leave of absence at the time of the appropriation, the work of erecting the building was somewhat delayed, nothing beyond the letting of contracts having been done until the spring of 1896. Ground was broken for the observatory building in April of that year, and about the same time a contract was let to Warner and Swasey for the following instruments: A 12-inch Equatorial Telescope, a 3-inch Combined Transit and Zenith Telescope, a good Chronograph.

The optical parts of these instruments were to be made by J. A. Brashear.

At the same time a contract was let to Saegmüller for the following: A 4-inch equatorial, a 2-inch Transit, a cheap Chronograph.

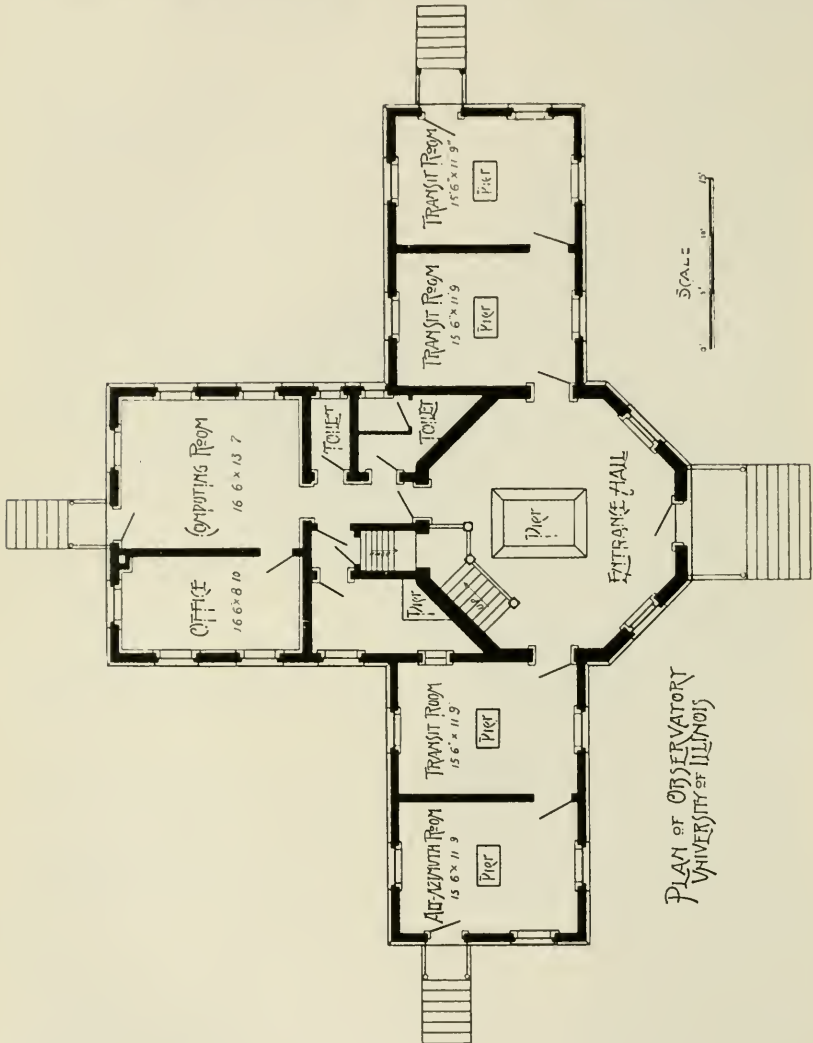
The last of these instruments was furnished to the observatory during the latter part of February, 1897, and so far as can be judged until systematic and prolonged tests can be made, they are all the makers claim for them.

Besides the items enumerated above, the following have been recently added to the equipment: A Riefler clock, a Green's barometer, three Green's thermometers, a Hough observing chair.

The sum total of purchases for the observatory equipment up to date amounts to \$8,340.00. This of course does not include minor facilities and appliances for practical work.

Instruments which were formerly owned by the University are: A 2-inch alt-azimuth, two sextants, two chronometers, a 1½-inch astronomical transit with zenith attachment and two mercurial horizons. A 4-inch equatorial by Newton & Co., which has long constituted the chief equipment of the astronomical department, is still used for observing variables, estimating position, angles, etc., etc. A switchboard with the usual elec-

trical connections has been installed in the observatory, and the building is lighted by the lines of the Urbana and Champaign street railway company. Numerous minor appliances for facili-



tating the work of theoretical and practical instruction have been purchased by the department during the past winter.

The observatory building is situated on an elevation about five minutes' walk south of University Hall, and commands as

good a horizon as can be had in the neighborhood. It is constructed in the form of the letter T, of repressed brick, and faces the north. The accompanying floor plan gives a good idea of its dimensions, and the half-tone reproduction of a photograph represents its general appearance quite well.

The dome has a clear internal diameter of 24.5 ft., revolves on trucks rolling upon a circular rail, and is turned with the hand by means of a rope and sheave. The slit has 44 inches clear opening, extends beyond the zenith and is closed by a single shutter. The latter is carried on rollers at both ends and can be completely opened or closed in five seconds.

The east and west wings contain two transit rooms each, provided with slits 26 inches wide in walls and roof for meridian transit observation. The openings in the side walls are closed by windows which drop into pockets in the walls. Each slit has a masonry pier placed centrally under it and isolated from the floor.

Small transits for students' use are mounted in the two west rooms. The 3-inch combined transit and zenith telescope stands on the pier of the east central, and the alt-azimuth on that of the east room. The Riefler clock is placed against a brick pier in the small room adjoining the east central transit room, and so situated as to face the 3-inch transit instrument. The chronographs are placed in a small room south of the clock room; the barometer is in the entrance room and thermometers are distributed throughout the observatory.

The total cost of the building and dome was \$6,680.

DESCRIPTION OF PRINCIPAL INSTRUMENTS.

THE 12-INCH EQUATORIAL.

This instrument is a refractor of 12.4 inches clear aperture and of 15 ft. focal length. It is mounted on a rectangular cast-iron column of two tons weight which rests on the masonry pier shown in the sketch. The polar and declination axes are cylinders of steel three inches in diameter. The greater part of the weight of the instrument is carried by a pair of friction rollers near the top end of the polar axis, and the rest is borne by a ring of balls at the lower end of this axis. The tube consists of seven cylinders riveted together, six of about 2.5 ft. length and the

seventh somewhat shorter. The sheets of steel composing the cylinders are $\frac{1}{16}$ to $\frac{3}{32}$ inches thick. The mechanical work is of the finest character throughout. The optical parts are by J. A. Brashear of Alleghany City, the curves used being those of Professor Hasting's formulæ. The optical properties of the lens are good and the character of the mounting leaves nothing to be desired.

There are two verniers each in right ascension and declination. The right ascension circle is 17.1 inches in diameter, is graduated on silver to minutes and read by two verniers to 5 seconds. The declination circle is 16.5 inches in diameter, graduated on silver to 10 minutes and read by two verniers to half minutes. In addition to these graduated circles, the instrument is further provided with another of 18.1 inches diameter, graduated to 5 minutes for coarse setting in right ascensions, and one of 30 inches diameter graduated to single degrees for the same purpose in declination. The graduation marks of these coarse circles are streaks of white paint on a black back ground and are easily legible from the eye end of the tube in any position of the instrument.

The instrument is further provided with a driving clock, a setting dial, positive and negative eye pieces of powers from 130 to 720, and with a low power eye piece.

Its filar position micrometer consists essentially of a position circle 6.3 inches in diameter, graduated on silver to half degrees and read by two verniers to tenths of a degree and a very accurately threaded screw, carrying a light frame holding the micrometer wires. Whole revolutions of the screw are read by a toothed wheel and fractional parts are given by a drum of 2.5 inches diameter whose circumference is graduated to hundredths. Tenths of divisions are readily estimated. The micrometer box is movable in position angle, the entire system of threads fixed and movable is carried "in distance" by a screw without graduations and the eye piece is adjusted to the centre of the field by a still different screw.

The instrument is provided with a helioscope, a finding telescope of 3.2 inches aperture and 4.5 ft. focal length and with the customary facilities and appliances for the electrical illumination of verniers and micrometer wires. It may be added that

no further work on the mechanician's part is needed to adapt the instrument to photographic and spectroscopic work.

THE 4-INCH EQUATORIAL.

The smaller equatorial has an aperture of 4 inches and a focal length of 6 feet. It is provided with graduated circles of 6 inches diameter in both right ascension and declination, the former reading by two verniers to single minutes and the latter, also, by two verniers to five minutes of arc. It is further supplied with driving clock and finder and is mounted by means of a circular cast iron column 6 feet high which rests on a masonry pier, the whole being covered by a shed carried on rollers which may be easily and quickly pushed entirely away from the instrument.

THE 3-INCH TRANSIT AND ZENITH TELESCOPE.

The combined transit and zenith telescope has a Brashear objective of three inches diameter and a focal length of 37 inches. It has two graduated circles, one of 12.5 inches diameter, graduated to half degrees and read by verniers to minutes, and the other of 12 inches diameter, graduated to 10 minutes and read by verniers to 10 seconds. Delicate striding and zenith telescope levels, together with a micrometer which may be used either in right ascension or declination render the instrument capable of yielding very excellent data whether used as a transit instrument or as a zenith telescope.

The larger part of the weight of the horizontal axis, which by reason of its system of circles, levels, etc., is subject to considerable flexure, is borne by a pair of friction rollers, held by springs against cylindrical bearings at either end and about $2\frac{1}{2}$ inches within the pivots. Only enough weight is allowed to come upon the pivots to make them rest firmly in the wyes.

By a suitable combination consisting of a level, a graduated circle and a reversing apparatus the west pivot may be brought into the east wye and the instrument reset upon the same star with extreme quickness and perfect safety. In addition to the above mentioned facilities, the instrument is supplied with a mercurial horizon, a complete set of eye pieces, including a collimating and a zenith eye piece. All in all, this instrument leaves little to be desired either in point of convenience or of completeness.

THE 12-INCH ALT-AZIMUTH.

This instrument was made by Troughton and Simms, has an aperture of 2 inches and a focal length of 20 inches. Its horizontal and vertical circles are each 12 inches in diameter, graduated on silver to 5 minutes and read by two reading microscopes to single seconds. Tenths of seconds are readily estimated. It is provided with both fine and coarse levels for adjustment to place, an accurate striding level, and a very complete set of eye pieces. The reticle consists of nine vertical and three horizontal cross hairs, illuminated by a lamp at the end of the axis. Both the vertical and horizontal circles shift for position, this instrument being the first to have a shifting vertical circle and among the first to have a shifting horizontal circle.

THE SIDERIAL CLOCK.

The Riefler clock has two interesting characteristics. The first consists in the peculiarly simple and effective compensating pendulum, and the second in the mode of suspending the pendulum.

As is well known, any good compensating pendulum should have as few parts as possible, should take up changes of atmospheric temperature with equal rapidity in all its parts, should have its compensating material extending as nearly throughout the length of the pendulum as possible, and finally should be heavy and have an appropriate form. How nearly Riefler's pendulum satisfies these conditions can be inferred from the following description:

It consists of a hollow steel tube 4 ft. 2 in. long, 0.65 of an inch inside diameter, with its walls 0.04 of an inch thick. The tube is filled with mercury to a height of about two-thirds of its length. At the lower end is attached, by a screw with a milled head, a heavy lens-shaped mass of brass whose form permits it to cut its way through the air with almost no resistance. Below the lens are smaller disk-shaped masses whose number and position may be varied for somewhat finer regulation of the rate than can be effected with the milled head. These disks are also used for regulating either to sidereal or mean solar time. At about two-thirds of the height of the pendulum is a light brass cup for the reception of small weights which may be put on or taken off for the most delicate alterations of rate, without disturbing the vibrations of the pendulum.

The second special feature is the peculiar mode of suspending the pendulum. Its weight is carried by a frame resting by knife edges on agate surfaces. By means of a pair of thin steel springs the two parts into which the pendulum tube is divided near its point of suspension are connected at a distance of about one-half inch apart. Through these springs the oscillations of the pendulum communicate a rocking motion to the frame and also to an arm extending downward, terminating in a fork either prong of which carries an agate pin. These pins engage alternately into the toothed wheel of the escapement. The rest of the mechanism of the escapement offers no features especially different from the ordinary form. By means of a pair of screws at the extreme top of the pendulum, the relative lengths of to and fro vibrations may be regulated. The clock is also provided with break circuit attachments and chronographic connections.

Lack of space prevents a more detailed description of these instruments and any discussion whatever of the rest of the equipment. A word as to the work contemplated at the observatory may perhaps be not out of place here.

The presence in our atmosphere of clouds and dew, as also its lack of transparency and steadiness, require that whatever research work we undertake shall be selected from those lines least influenced by atmospheric conditions. Double and variable star work offer considerable promise of practical results and it has been thought therefore that aside from double star measures, something would be attempted in the study of the light changes of faint variables. Our chief work, however, is and will continue to be, instruction in the use of instruments and in the methods pursued in a working observatory. All research work must of course be subordinated and subservient to this end.

BROKEN ASHLAR MASONRY.

BY W. W. BEACH, '98, SCHOOL OF ARCHITECTURE.

In preparing a paper on this subject I feel that I am entering an almost unoccupied field. Professor Baker and Professor Ricker, in their respective works on masonry construction, each

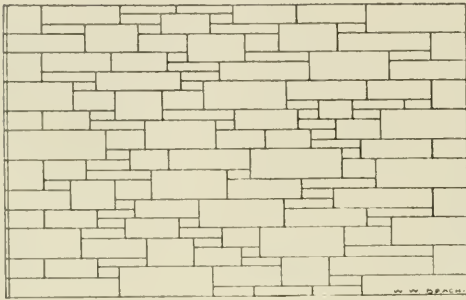


FIG. 1.
BROKEN ASHLAR.
4, 8 AND 12" COURSES.

I was called upon to design the broken ashlar masonry for the walls of the University Library building, I was unable to find, by diligent search, any other reference to the subject than that given by Kidder, and was thrown on my own resources. Whatever I have compiled and am prepared to offer on this subject is elaborated from data gathered by the observance of buildings in different cities, from the study of photographs, and from the personal experience gained in designing the masonry for the library building.

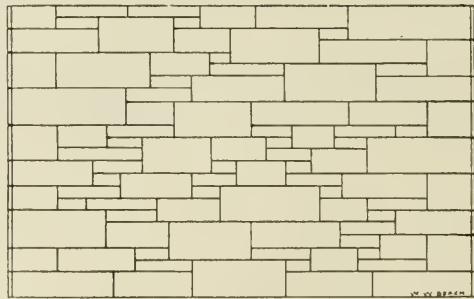


FIG. 2.
BROKEN ASHLAR.
5, 10 AND 15" COURSES.

Mr. Robert Anderson, in "The Brickbuilder" for September, 1896, says: "The trouble is now that if the architect makes

give definitions of broken ashlar, but neither attempts to give assistance in designing it. Mr. F. E. Kidder, in "Building Construction and Superintendence," goes somewhat further in describing broken ashlar, but still gives little that would help an inexperienced person in its design. When

a drawing of a certain piece of wall, he must either invent the variations which naturally come in rubble work, or else make a conventional representation of the design. If he does the latter—and almost all drawings are of such description,—the workmen tend to imitate the hardness which is inevitable in the design thus presented. The little accidents, which make the work so charming and flexible in its look, are eliminated by them, as far as possible, in order to make the work look like the drawing.

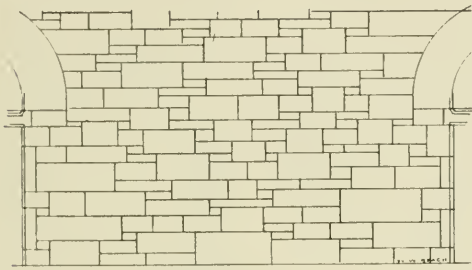


FIG. 3 FROM V. OF I. LIBRARY RICKER & WHITE
4' 6" x 10' 18" IN 14 AND 16 COURSES

ing." What Mr. Anderson says is true also of broken ashlar work whenever the architect, which is rarely the case, attempts to design it. Generally he has had insufficient experience with that branch of design to enable

him to dictate to the mason.

It is very easy for an architect to specify "random range," "broken ashlar," or "coursed rubble," using a term that should give him a wall of a style that is about what he has in mind, but it is vastly different for him to tell the mason exactly how he shall build that wall. The infinite number of variations that can be made in such work render detailed instructions a difficult and endless task. In any event it is necessary to know the exact meaning of the various terms used in specifying stone work. The term "ashlar" is sometimes applied to any stone-work having dressed joints, but it

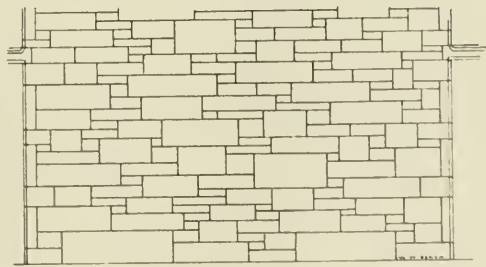


FIG. 4 FROM V. OF I. LIBRARY RICKER & WHITE
4' 6" x 10' 18" IN 14 AND 16 COURSES

would seem better to confine it to rectangular stone-work where all joints are dressed. Ashlar may be either "range" or "broken"; in the former horizontal joints are continuous on

the face of the wall, and in the latter the horizontal joints are broken at frequent intervals. The latter is also termed indiscriminately, "random range," "jagged range," and "random ashlar."

I have said that broken ashlar is capable of an infinite variety of treatments. Stone masons, however, generally confine the term to work built of stone cut in three different heights,

viz., four, eight, and twelve inches. Where then is your variety? Evidently the architect must find it for himself. However, he must be able to design a wall as a stone mason would build it, and must know or discover the rules that govern the ar-

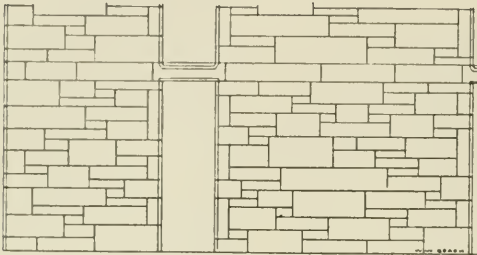


FIG 5. FROM U OF I LIBRARY. CRICKER WHITE. 4" 8" 10" 12" 14" COURSES.

angement. In Fig. 1 is shown a wall built of four, eight, and twelve-inch stone, and in Fig. 2 a similar wall using five, ten, and fifteen-inch stone. These are laid up according to stone masons' methods, while the walls shown in Figs. 3, 4, and 5 are laid up with greater freedom with stone of varying heights. All these figures are drawn to a uniform scale so as to be readily compared. It will be

seen that the work for the University Library building is quite different in size and arrangement from that in Fig. 6, which is drawn from a photograph of one of H. H. Richardson's buildings. I do not know whether Richardson himself designed

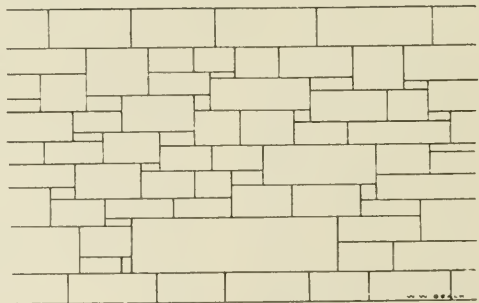


FIG 6. FROM AMES LIBRARY. H H RICHARDSON. VARYING COURSES.

the masonry for his buildings, or whether that was left to the masons, so it is impossible to say how far he influenced the design of the ashlar used. By studying Richardson's work we no-

tice that the designs vary greatly in different parts of the same building. In a few walls square stones predominate, while in others long ones are more numerous, the contrast between small and large stones being much greater in some walls than in others. This makes it impossible to gain a correct conception of Richardson's ashlar from a single diagram; but it is plainly evident that this ashlar violates three principles that seem to be

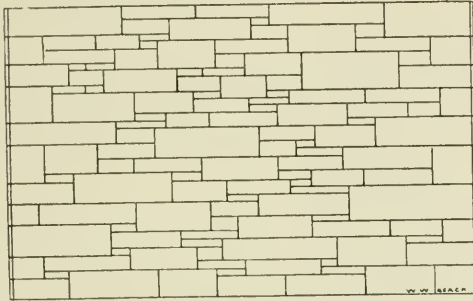


FIG 7. BROKEN ASHLAR. 3 & 9" AND 15" COURSES.

important guides in the design of broken ashlar. These principles may be stated as follows:— (1) Never have more than three stones meeting at a vertical joint. (2) Have no stone shorter than twice its height. (3) Have no stone sufficiently large to attract attention to

itself. Minor rules I found it well to follow are:— Have no stone longer than five times its height. Have no horizontal joint noticeably long, say over seven or eight feet. Use large stones on corners, alternating stretchers and headers, having the latter not less than twelve inches on bed. Avoid having the ashlar form a stepped arrangement. Avoid bunching large or small stones, keeping all sizes equally distributed. Avoid the appearance of filling in with small stones. Rather have each ashlar an intentional part of a harmonious whole. Fig. 7 shows a wall in which these rules have been carefully observed, with the exception that

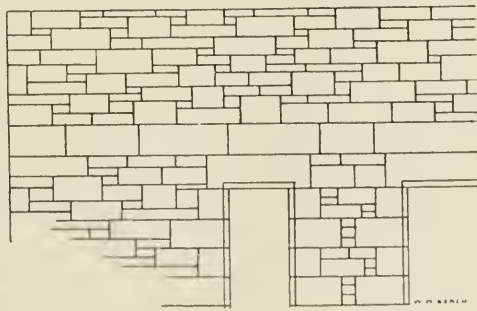


FIG 8. FROM BUILDING IN EDINBURGH. VARYING COURSES.

some of the horizontal joints are too long. One should endeavor to follow these rules until the general design of broken ashlar is thoroughly understood. Having the subject well in hand it is

possible to branch out and adopt an individual style as did Richardson. The attempt to successfully imitate a style without any previous knowledge of the subject is almost sure to lead to difficulties which make it unlikely that the charm found in the original will be reproduced.

Another point upon which it would be well to lay stress is that of keeping the work uniform on all parts of the building.

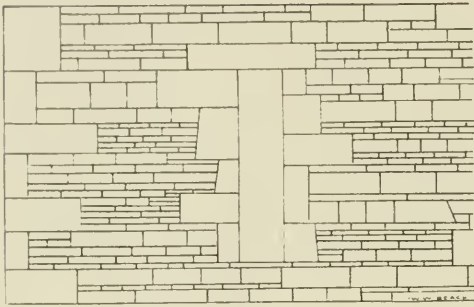


FIG. 9 FROM WITHINGTON MANOR BARN

Fig. 9 I have shown a bit of ashlar used in an old barn at Withington Manor, England. This would be a good style to use in a rural district where a poor grade of stratified sandstone, limestone, or shale was abundant. A better grade of stone could be used for quoins, jambs, sills, caps, and other trimmings, and the wall filled in with native stone as is shown in the diagram. Fig. 10 is from the tower of the First Presbyterian Church, St. Louis, and is one of the few good examples I have noted in that city. Even in this, the continued repetition of three sizes of stone grows monotonous. Some unexpected mistake would be a relief.

In order to do this it is essential that the same man design the whole work, not, as is often done, allowing each mason to work independently.

Fig. 8 shows a portion of the wall of an Edinburg building. It is a good pattern and worthy of study. In

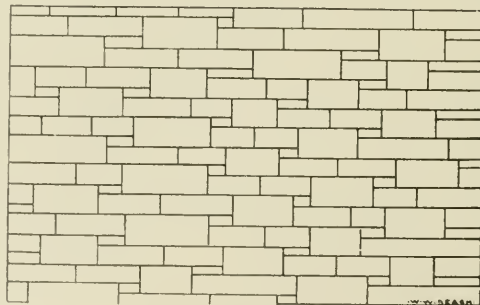


FIG. 10 FROM FIRST PRES. CHURCH ST. LOUIS J. G. CAIRNS. 4" 8" AND 12" COURSES

Since we build so much in stone and have so many oppor-

unities for picturesque treatment of broken ashlar walls where we cannot afford dressed stone, why should we not give the subject more study? It is certainly capable of wonderful possibilities if properly handled by a skilled designer, and even the ordinary architect could improve his buildings with a little study. It is a pity that he deems his whole duty performed when the mill-work and carving have been detailed, leaving all else to the tradesman and mechanic.

MAGNETIC DISTRIBUTION IN SHORT IRON CORES.

BY W. G. CAMPBELL, '96, SCHOOL OF ELECTRICAL ENGINEERING.

The design of a transformer having a closed magnetic circuit for a given voltage is a comparatively easy matter. The laws of the magnetic and electric forces in the different parts are well determined, and a vast amount of data is available showing the best dimensions of core and coils. But to design and calculate a transformer having an open magnetic circuit for producing a given electromotive force, is a much more complicated problem. Especially is this true when a high electromotive force is desired, for there is the additional requirement of keeping the primary and secondary coils widely separated. The author of this paper has had the problem of designing and building an open magnetic circuit transformer to give an electromotive force of from twenty-five thousand to thirty thousand volts. It has been desirable for several reasons that this coil should be built upon the general plan of the Ruhmkorf induction coils. At the outset two questions arose which have required experiments for their solution. These were:— what percentage of the total lines of induction produced at the middle of the primary core, passes through the windings of the secondary coil; and what magnetizing force is necessary to produce the required induction in the core. The results of these experiments form the subject of this paper.

The inductions were determined by the currents induced in an exploring coil, the induced currents being measured with a ballistic galvanometer. For measuring the magnetizing currents in the primary coil a Kelvin balance was used in most cases. An ammeter which had been recently calibrated was

used to measure some of the larger currents. The magnetizing current was obtained from a large battery of storage cells. Most of the work was done at night when the storage cells were not otherwise in use, so that a very constant current was secured. For regulation of the current, a large water rheostat was used and found to work excellently. The ballistic galvanometer was calibrated for each set of readings, Lord Kelvin's method with a long solenoid being used.

To investigate the first question, a solenoid with an iron core was taken, and its magnetic field was explored with different secondary coils. The iron core, built up of iron wires, was 14 inches long and $1\frac{3}{4}$ inches in diameter, and was wound with two layers of No. 8, B. & S. copper wire. The secondary coils were placed symmetrically over the primary coil. Their dimensions are given in columns 1, 2, and 3 of Table I. The last column in this table gives the mean induction passing through a turn of the secondary coil, this induction being expressed as the percentage of the total induction across the middle section of the primary core. Thus with a secondary coil of $2\frac{1}{4}$ in. internal diameter and $2\frac{3}{4}$ in. external diameter and a length of 14 in. (total length of the primary), the mean induction in the turn was 72.5 per cent of the total induction through the middle cross section of the primary core.

TABLE I.
MEAN INDUCTION THROUGH A SECONDARY TURN.

| DIMENSIONS OF SECONDARY COIL. | | | PER CENT INDUCTION. |
|-------------------------------|---------------------|--------|---------------------|
| Di | De | l | |
| 2 $\frac{1}{4}$ in. | 2 $\frac{3}{4}$ in. | 14 in. | 72.5 |
| " | " | 12 " | 79.5 |
| " | " | 10 " | 84.0 |
| 2 $\frac{3}{4}$ in. | 3 $\frac{3}{4}$ in. | 14 " | 71.5 |
| " | " | 12 " | 78.0 |
| " | " | 10 " | 82.0 |
| 3 $\frac{3}{4}$ in. | 4 $\frac{3}{4}$ in. | 14 " | 69.5 |
| " | " | 12 " | 75.0 |
| " | " | 10 " | 80.0 |
| 4 $\frac{3}{4}$ in. | 5 $\frac{3}{4}$ in. | 14 " | 68.0 |
| " | " | 14 " | 73.5 |
| " | " | 14 " | 78.0 |

The next step was to determine what magnetizing force was necessary in the primary solenoid to produce a given induction

at the middle point of the core for different ratios of length and diameter. Five cores with different ratios of $\frac{l}{d}$ were used in these experiments. To get the magnetic properties of the core which was made of iron wires, a single wire was taken and welded into a ring by an alternating current. The curve of magnetization, Fig. 1, was determined for this sample by the ordinary ballistic galvanometer method.

The five cores used in the experiment were compact bundles of wire wound with double cotton covered magnet wire, No. 25,

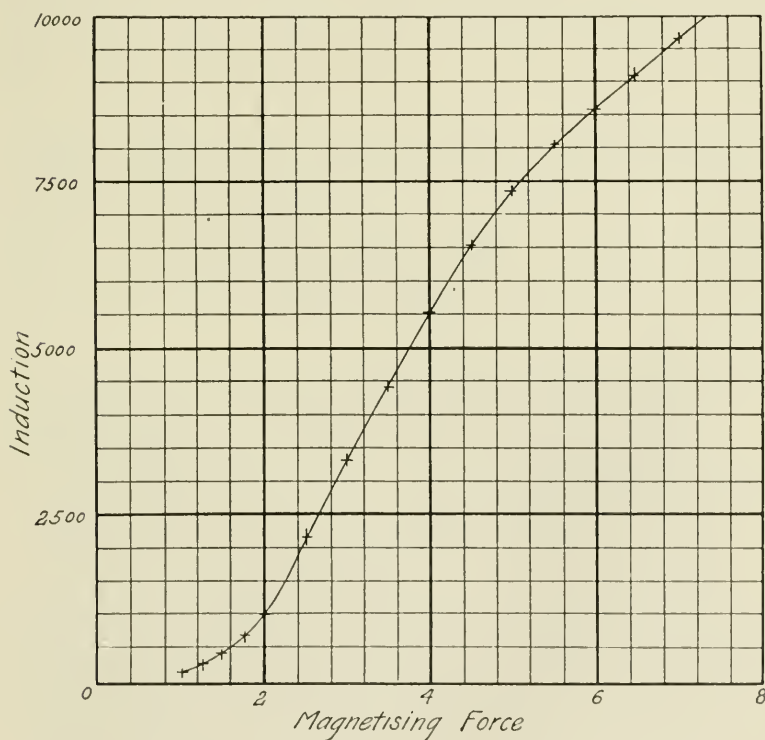


FIG. 1.

B. & S. gage. One layer was sufficient for the smaller cores, and two layers for the larger cores. Five such cores were used, each being 14 inches long and built up of wires having a diameter of 0.628 in. Different numbers of wires gave different ratios

of $\frac{l}{d}$. The diameter used in the magnetic calculations was of course not that of the bundle, but $2\sqrt{\frac{A}{\pi}}$ where A is the actual iron area of cross section. The secondary coils were eight in number for each core. These were placed one inch apart beginning at one end, having one coil at the end and one at the middle of the core. Since the core was symmetrical it was not thought necessary to put secondaries its whole length.

The method of work was first to find the primary current necessary to produce a given induction through the middle section of the core, and then to determine the induction through the cross section at each of the other secondary coils corresponding to the given induction through the middle cross section. The primary current necessary to produce the required induction through the middle cross-section was carefully determined with an error of not over one-half of one per cent. This is probably less than the error due to other sources. After the desired primary current was ascertained it was kept constant and the induction through each of the other secondaries was obtained by the method of reversals. Thus a value of the induction through different sections of the core was ascertained, corresponding to a given induction through the middle section. Fig. 2 gives these

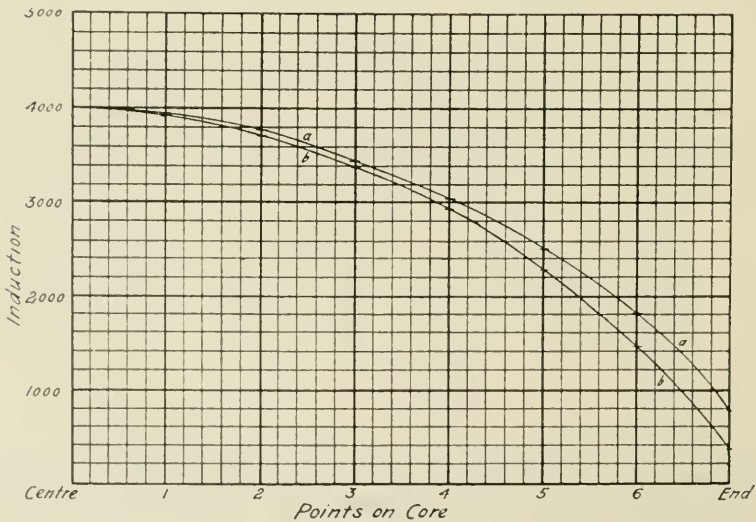


FIG. 2.

results for $B=4000$, for values of $\frac{l}{d} = 9$ (curve *a*), and $\frac{l}{d} = 51.1$ (curve *b*). The curves for the other cores were found to lie between these curves. Experiments were also made for induction of 2000 and 10000, showing that these curves are in general the same for all low inductions. Thus dividing by two the ordinates of the curve corresponding to $B=4000$, gave the ordinates for the experimental curve corresponding to $B=2000$. Let H_1 represent the magnetizing force due to the solenoid. Then $H_1 = \frac{4\pi Si}{10l}$ where $S =$ total turns and $l =$ length of coil. This is only an approximate formula, the true value being $H_1 = \frac{4\pi Si}{10l} \cos z$, where $\tan z = \frac{d}{l}$.* This gives

$$H_1 = \frac{4\pi Si}{10l} \frac{1}{\sqrt{1 + \left(\frac{d}{l}\right)^2}} = \frac{4\pi Si}{10l} \left[1 - \frac{1}{2} \left(\frac{d}{l}\right)^2 + \dots \right]$$

For $\frac{l}{d} = 9$ this differs from $\frac{4\pi Si}{10l}$ by only one-half of one per cent, and accordingly $\frac{4\pi Si}{10l}$ was used.

From Fig. 2 we find the induction for each point along the coil. From the BH curve for the iron we get the corresponding values of the true magnetizing force. By averaging these we get the average value H of the true magnetizing force for the core. Call BH'_1 the demagnetizing force of the core at an induction B . Then $H'_1 B = H_1 - H$ or $H'_1 = \frac{H_1 - H}{B}$, if we can assume these forces as approximately in the same straight line. H'_1 is then the demagnetizing effect of the core for unit induction. This value is given in Table 2 for cases where $B = 2000$ and where $B = 4000$. It was found that H'_1 , or rather $1000 H'_1$, is practically constant for all values of B for the same core. For example, in the case of $\frac{l}{d} = 51.1$ it did not vary one per cent. from $B = 2000$ up to $B = 10000$.

*Fleming, *Alternating Current Transformer*, Vol. 1, p. 21.

TABLE II.
DEMAGNETIZING FORCE FOR VARIOUS CORES.

| N. | A. | $d = 2 \sqrt{\frac{A}{\pi}}$ | $\frac{l}{d}$ | H_1 | | $1000 H'_1$ | | |
|-----|--------|------------------------------|---------------|---------|--------|-------------|-------|-------|
| | | | | For B = | | 2000 | 4000 | 10000 |
| | | | | 2000 | 4000 | | | |
| 19 | .380 | .605 | 51.1 | 4.306 | 7.126 | 1.11 | 1.10 | 1.10 |
| 31 | .620 | .881 | 40.0 | 5.631 | 9.839 | 1.77 | 1.77 | ..... |
| 55 | 1.103 | 1.185 | 30.0 | 7.745 | 14.110 | 2.81 | 2.83 | ..... |
| 124 | 2.477 | 1.776 | 20.0 | 13.600 | 25.630 | 5.73 | 5.71 | ..... |
| 613 | 12.250 | 3.950 | 9.0 | 41.410 | 80.920 | 19.61 | 19.53 | ..... |

Here we have—

N = number of wires composing the iron core.

A = aggregate area of cross-section of wires.

d = equivalent diameter of solid iron core.

$\frac{l}{d}$ = ratio of length of core to diameter.

H_1 = magnetizing force of the solenoid.

H'_1 = demagnetizing force of the core for unit induction.

Curve *a* of Fig. 3 shows the relative values of $\frac{l}{d}$ and 1 000

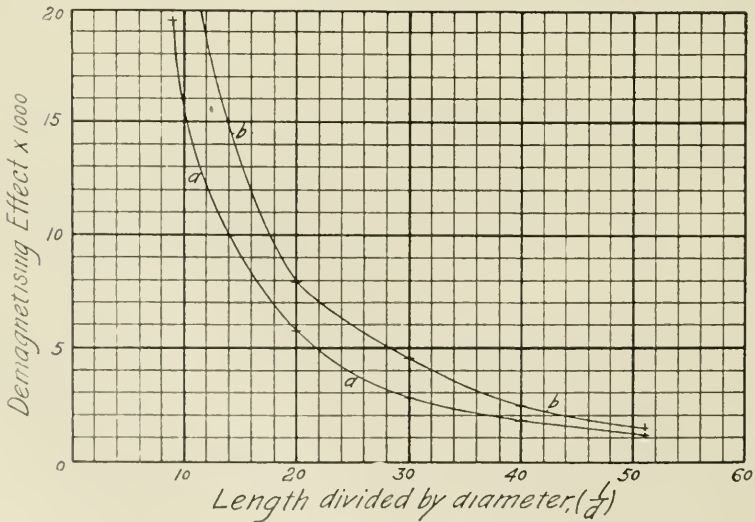


FIG. III.

H'_1 as experimentally determined. Ewing has given values of H'_1 for $\frac{l}{d} = 200$, $\frac{l}{d} = 100$, and $\frac{l}{d} = 50$, the assumption being

that the effects of the ends are the same as for ellipsoids.* He says this is very nearly correct for values of $\frac{l}{d}$ equal to 200 and 100, but that it is not true for values of $\frac{l}{d} = 100$ and $\frac{l}{d} = 50$ is readily shown by Ewing's curves. For we find for the induction $B = 10\,000$, that where $\frac{l}{d} = 50$, H is less than 1, and where $\frac{l}{d} = 100$, H is about 2. Thus the value of H for the first length is twice that for the second. Fig. 2 shows that shorter cores in the present experiments have had the higher average induction. If we can infer that the true magnetizing force is proportional to the induction, this result for the smaller values of $\frac{l}{d}$ is exactly opposite to that found by Ewing for larger values of $\frac{l}{d}$. Fig. III, curve *b*, is the value of H calculated for corresponding ellipsoids, using the formula $N = 4\pi \left(\frac{1}{e^2} - \right) \left(\frac{1}{2e} \text{ nat. log. } \frac{1+e}{1-e} - 1 \right)$.†

Tanakadate§ has done considerable work on the magnetization of short cores; but he used a magnetizing coil longer and larger in diameter than his cores, and also used the magnetometer method, obtaining what he calls the mean intensity of magnetization. Since the conditions are so different from those given above, only an approximate agreement with our results can be expected.

In Table III we have gathered together results calculated from experiments described above, and also some calculated from the published data of Ewing‡ and of Tanakadate.‡ The last two cores were made of different iron from the other cores used in the work described in this paper. Tanakadate's results were expressed in terms of intensity of magnetization, and these have

*Ewing, "Magnetic Induction in Iron and other Metals," p. 78.

†Ewings' Magnetic Induction, etc., p. 25.

‡Paper read before the British A. A. S. meeting, Sept., 1888. See *London Electrician*, Nov. 2, 1888.

‡See reference cited above.

been reduced to induction in the cases cited. In some cases the B H curve of the iron has had to be assumed. The 1 000 H_1 calculated from formula is by the same method used by Ewing.* The last column gives results from an empirical formula $H_1 = .8 \left(\frac{d}{l} \right)^5$. This effect depends upon some other function of $\left(\frac{l}{d} \right)$ than that expressed by this formula, but as this is simple and fairly accurate, it may be useful for much work.

This work has been done in connection with thesis work under the direction of Professor A. P. Carman, in the electrical laboratory of the University of Illinois.

TABLE III.
DEMAGNETIZING EFFECTS FOR SEVERAL VALUES.

| l | $\frac{l}{d}$ | B | H_1 | H | $H \dagger$ | 1 000 $H_1 \dagger$ | 1 000 $H_1 \ddagger$ | 1 000 $H_1 \S$ | OBSERVER. |
|-------|---------------|-------|--------|-------|-------------|---------------------|----------------------|----------------|------------|
| ..... | 200.0 | 4 000 | 1.85 | ..... | 1.30 | 0.125 | ..... | .117 | Ewing |
| ..... | 100.0 | 4 000 | 3.10 | ..... | 1.38 | 0.430 | ..... | .370 | Ewing |
| 35.6 | 51.1 | 4 000 | 7.13 | 2.70 | 1.46 | 1.420 | 1.10 | 1.130 | Campbell |
| ..... | 50.0 | 4 000 | 6.60 | ..... | 1.00 | 1.550 | ..... | 1.180 | Ewing |
| 35.6 | 40.0 | 4 000 | 9.84 | 2.70 | 0.10 | 2.430 | ..... | 1.77 | Campbell |
| 6.0 | 39.4 | 3 780 | 11.50 | 2.60 | ..... | ..... | ..... | 2.35 | Tanakadate |
| 5.0 | 32.0 | 3 780 | 15.00 | 2.60 | ..... | ..... | 3.28 | 2.480 | Tanakadate |
| 35.6 | 30.0 | 4 000 | 14.10 | 2.76 | ..... | ..... | 2.83 | 2.760 | Campbell |
| 4.0 | 26.3 | 3 790 | 20.00 | 2.70 | ..... | ..... | ..... | 4.57 | Tanakadate |
| 35.6 | 20.0 | 4 000 | 25.60 | 2.80 | ..... | 7.970 | ..... | 5.71 | Campbell |
| 3.0 | 19.7 | 3 800 | 28.00 | 2.70 | ..... | ..... | ..... | 6.64 | Tanakadate |
| 9.0 | 15.0 | 3 810 | 46.00 | 2.80 | ..... | ..... | 11.34 | 8.770 | Tanakadate |
| 2.0 | 13.1 | 3 820 | 47.50 | 2.80 | ..... | ..... | 11.67 | 11.000 | Tanakadate |
| 35.6 | 9.0 | 4 000 | 80.90 | 2.80 | ..... | ..... | ..... | 19.53 | Campbell |
| 4.5 | 8.8 | 1 000 | 26.90 | 1.80 | ..... | ..... | ..... | 25.10 | Campbell |
| 5.0 | 4.4 | 2 000 | 122.20 | 2.20 | ..... | ..... | 60.00 | 67.700 | Campbell |

*See Ewing, Magnetic Induction, etc., p. 32.

†Calculated for ellipsoid from formula cited.

‡Calculated from observations by method given above.

§Calculated from empirical formula $H_1 = .8 \left(\frac{d}{l} \right)^5$.

THE HYDRAULIC LABORATORY.

BY PAUL CHIPMAN, '94, ASSISTANT IN THEORETICAL AND APPLIED MECHANICS.

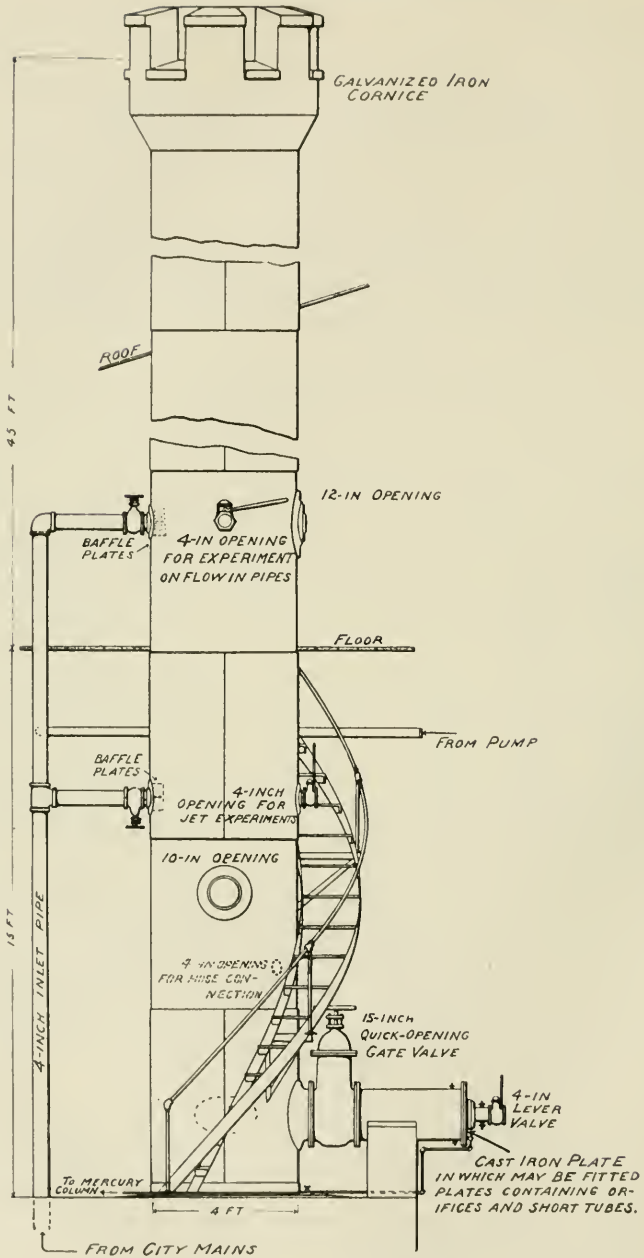
The hydraulic laboratory now occupies the north room in the Engineering Laboratory Building and the room on the second floor directly above. Many improvements have been made in the past year in the facilities for experimenting along various lines of hydraulic investigation.

A steel stand-pipe four feet in diameter and sixty feet high has been erected in the east end of the laboratory. It rests on a concrete foundation seven feet in diameter and five feet deep. Its largest opening is a short distance above the lower floor, where a quick-opening 15-inch valve leads to a 15-inch cylinder 3 feet long. In the end of this cylinder may be fitted plates containing orifices and short tubes of various forms and sizes. One of these plates being in position, a 4-inch lever valve is bolted on. This valve is then closed, and the 15-inch valve opened. The flow from the orifice may then be started by a single movement of the lever valve and stopped as readily, the 15-inch valve being used only when the orifice-plate is to be changed. At other points in the stand-pipe, openings are provided for connecting hose in the investigation of friction in hose and discharge from nozzles, for experimenting with jets, and for connecting pipe for the study of flow of water in pipes. Other openings have been provided for future needs. The head of water is measured by means of a mercury column.

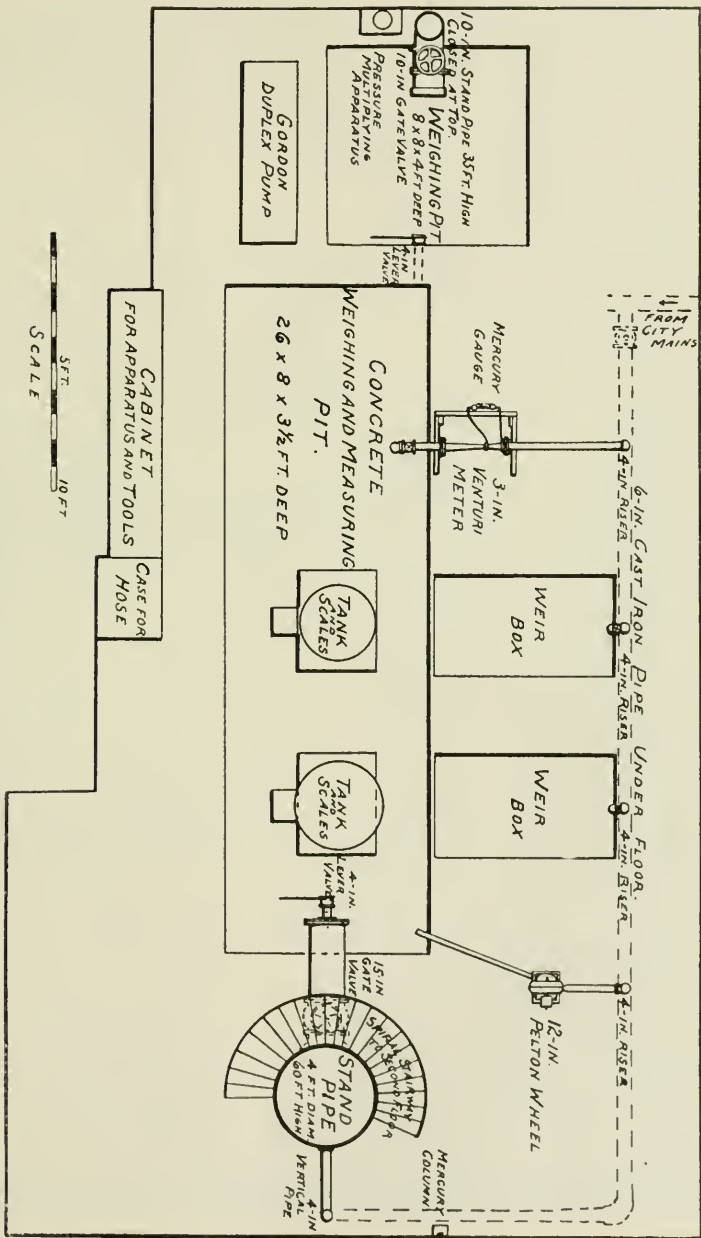
In front of the stand-pipe is a concrete pit 26 feet long, 8 feet wide, and $3\frac{1}{2}$ feet deep. In this pit are tanks and scales for measuring the quantity of water discharged. The pit itself is also used for measuring larger quantities of water, the increase in depth being determined with a hook-gauge.

Water is supplied to the stand-pipe direct from the city mains through a 6-inch pipe running near the north wall and under the floor. Four vertical 4-inch pipes rise from this main and supply water for tests of weirs, meters, motors, etc. The water discharged is weighed in the tanks in the pit.

A 3-inch Venturi meter is connected with one of these risers



HYDRAULIC LABORATORY STANDPIPE.



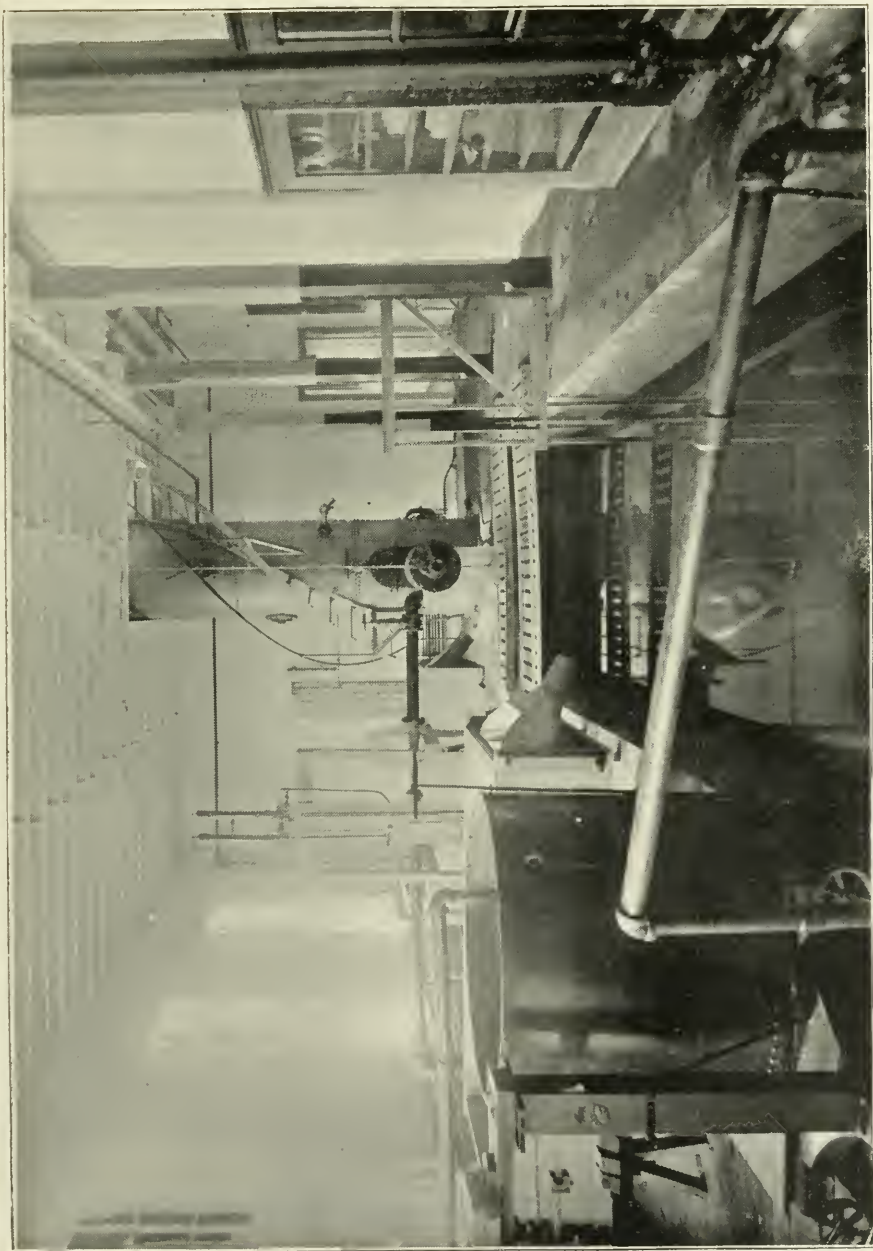
FLOOR PLAN HYDRAULIC LABORATORY.

for purposes of testing. The difference in pressure at the throat and at the entrance is measured with a mercury gauge made especially for this purpose. It consists of a U-tube with one arm longer than the other, the long arm being connected with the piezometer at the throat of the Venturi, and the short arm with the one at the entrance.

At the west end of the laboratory is a 10-inch stand-pipe 35 feet high, connected at the top with a 6-foot wooden tank. At the bottom suitable provision is made for attaching orifice plates, or for making other connections.

A Gordon duplex pump enables the water to be pumped from the pit to the stand-pipe or to the wooden tank, and thus to be used again. High pressures are obtained by an apparatus in which water from the city mains is admitted to an 8-inch cylinder under a piston which is connected with another piston working in a $1\frac{1}{2}$ -inch cylinder. This apparatus has recently been used in making tests of the strength of sewer pipe by subjecting them to internal pressure. Arrangements not yet completed are being made for testing small turbines.

Among the appliances of the laboratory other than those mentioned above are a number of orifice plates with round, square, and rectangular orifices of different sizes; short tubes, both straight and converging, of various sizes; rectangular, trapezoidal and triangular weirs of different dimensions; various makes of water meters; a 12-inch Pelton wheel; 200 feet of fire-hose with play-pipe; set of calibrated nozzles, for use in measuring quantities of water; and numerous piezometers and other gauges.



INTERIOR VIEW—HYDRAULIC LABORATORY, UNIVERSITY OF ILLINOIS.

SPECIFICATIONS AND NOTES ON RAILWAY TELE-
GRAPH CONSTRUCTION.

BY J. H. YOUNG, '98, SCHOOL OF ELECTRICAL ENGINEERING.

The following specifications were used for the construction work of the T. H. & B. Ry. Telegraph Line between Welland and West Brantford, Canada.

POLES.

SIZE.—Poles shall be 25 ft. long except as hereinafter designated, not less than 6 in. at the top for 25 ft. and 30 ft. poles and 7 in. for 35 ft. and longer, of first class cedar, reasonably straight butted and entirely stripped of bark, and knots well and closely trimmed.

Where it is necessary at farm crossings, road crossings or railways, the poles shall be of sufficient length to carry the wires on the lowest cross arm at least 23 ft. above the rails for railway crossings, 15 ft. above road crossings, and 13 ft. above farm crossings. Long poles shall also be used where necessary to keep the line properly evened up as directed by the Engineer.

FRAMING.—All poles shall be properly roofed at the top and three gains 4 in. wide, 1½ in. deep, and 24 in. apart, and the top of the upper gain 8 in. from the peak of the roof of the pole, shall be properly cut so as to bring the cross arms square with the pole and properly in line with each other.

SPACING.—Poles shall be placed at least 35 to the mile on straight runs and correspondingly closer on curves and angles and railroad and other crossings in order to give the line uniform strength.

LIGHTNING ARRESTER.—A lightning arrester consisting of No. 6 wire, of the same quality as used on the line, shall be run as directed by the Engineer not oftener than one to the mile and shall be run to the ground and properly fastened to the pole by 2 in. galvanized staples, placed not more than 3 ft. apart. The upper end of the wire shall project 3 in. above the peak of the roof of pole, and the lower end have at least 3 ft. coiled up and properly stapled to the butt end of the pole, before being placed in the hole.

LABOR.—Poles shall be properly set in the ground and guyed where necessary, 25 ft. and 30 ft. poles being placed not less than 5 ft. in soil and not less than 3 feet in solid rock, and other lengths correspondingly deeper. On curves and angles the poles must be set bracing or leaning to correspond with and compensate for the curve or crossing. Where anchor poles or guys are used they shall be properly set and fastened. Poles shall be set so that the cross arms on adjacent poles shall face in opposite directions except when otherwise directed. Poles must be well tamped and holes well filled with earth, and the loose earth thus used must be well tamped around the poles above the natural surface so that when the earth settles it will be somewhat crowning so that the poles will stand securely when the wires are strung thereon.

In cities and villages and in crossing railroads, other telegraph lines and other roads the poles are to be of such length and the work of such character as

may be required by the Railway Company's or by the officials of said cities and villages. At points of crossing with other lines the poles shall when practicable be of sufficient height to carry the wires of the lower cross arm, when erected, above all foreign wires, and when this is impracticable and it is found necessary to carry the wires under the foreign wires, then a suitable guard wire or wires must be provided and strung so that any foreign wire shall not come within 18 in. of this Company's wires. When the wires are run above those of a foreign company's the poles shall be placed as near as possible to such foreign wires so as to avoid contact.

TRIMMING.—Any trimming shall be done in a neat and workmanlike manner; in no case shall the limbs be left hanging on the trees.

The line shall be trimmed out in good shape, sufficient to clear the wires at least 2 ft. in the clear through forest trees; in shade or fruit trees the trimming shall be done to leave the wires not less than 18 in. in the clear.

CROSS ARMS.

Cross Arms shall be of first class, clear, well seasoned, white pine, free from sap and shakes, and no knots over 1 in. in diameter, and no loose knots of any size allowed, with upper face properly rounded to shed water, except where it fits the gain in the pole, where it shall be left square. The cross arms shall be painted with two coats of red mineral paint.

SIZE.—The cross arms shall be 6 ft. x 3 in. x 4 in. with holes bored for four $1\frac{1}{4}$ in. pins, spaced 22 in. apart center, 22 in. apart at sides and 3 in. from end.

NUMBER.—One cross arm shall be fastened to each pole at the upper gain with two improved lag screws with a suitable washer to each screw.

FITTING.—Both cross arms shall be fitted with four pins which shall be fastened in the cross arm by driving a ten-penny cut nail through the pin and the cross arm.

PINS.

The pins shall be $1\frac{1}{4}$ in. smoothly turned, sound, well seasoned, white oak. Shoulder not less than $\frac{1}{4}$ in, not less than 5 in. length above the shoulder, and 4 in. below shoulder threaded to fit standard glass insulators, well and smoothly cut, so that not less than one and one-half complete turns of insulator shall be necessary to remove it from the pins.

LAG BOLTS.

The lag bolts used in fastening the cross arms to the poles shall be $\frac{1}{2}$ in. improved lag bolts 7 in. long.

WASHERS.

Washers shall be of proper size to fit the bolts, one being placed between the head of each bolt and the cross arm.

INSULATORS.

The insulators shall be of the best standard quality of glass of a pattern approved by the Engineer.

WIRE.

QUALITY.—The wire shall be No. 8 galvanized iron wire, of quality approved by the Engineer, after proper tests have been made, and must be at least up to the following specifications:—

1. The wire to be soft and pliable and capable of elongating 15 per cent without breaking, after being galvanized.
2. Great tensile strength is not required, but the wire must not break under

a less strain than 2.5 times its weight in pounds per mile. Tests for tensile strength will be made by direct applianee of weight or by means of a single lever, at the option of the inspecting officer.

3. Tests for ductility will be made as follows:— The piece of wire will be gripped by two vises, 6 in. apart, and twisted. The twists to be reckoned by means of an ink spiral formed on the wire during the torsion. The full number of twists must be distinctly visible between the vises on the 6-in. piece. The number of twists on the 6-in. piece must not be under fifteen.

4. The electrical resistance of the wire in ohms per mile at a temperature of 60 degrees Fahrenheit, must not exceed the quotient of the constant number 5500 when divided by the weight of the wire in pounds per mile. No. 6 should have a resistance not exceeding $5500 \div 550 = 10$ ohms per mile. A wire of 388 pounds (No. 8) 14.1 ohms. A wire of 365 pounds 16.4 ohms per mile.

5. The wire to be cylindrical and free from scales, inequalities, flaws, and splits and all other imperfections and defects. Each coil must be warranted not to contain any weld, joint, or splice whatever in the rod before drawn.

6. It is desirable to obtain the wire in coils, all of one piece, of about 150 pounds each. If this cannot be undertaken, the contractor may tender for the supply of wire with two pieces only to the coil, joined by the ordinary twist joint and carefully soldered. It should be stated in the tender whether there will be one or two pieces in each coil.

7. The wire must be well galvanized and capable of standing the following test:— The wire must be plunged into a saturated solution of sulphate of copper and permitted to remain one minute and then wiped clean. This process will be performed four times. If the wire appears black after the fourth immersion it shows that the zinc has not all been removed and that galvanizing has been well done: but if it has a copper color the iron is exposed, showing that the zinc is too thin.

STRINGING.—Two wires shall be strung as directed by the Engineer, and shall be well tied with proper ties of same wire as the line wire. Every possible precaution shall be taken to prevent kinks in the wires and in no case shall a kink be allowed to pass.

SPLICING.—Whenever it is found necessary to splice a wire such splice shall be in a style and manner approved by the Engineer and the joint properly soldered.

COMMENTS.

In the course of the construction of this telegraph line, the following notes were taken.

POLES.

SPACING.—Longer spans than 35 to the mile may of course be used when necessary, but the strain upon the poles and cross arms is increased and in case of a break near a long span the cross arms are likely to be pulled off or broken by the extra strain put upon them.

SIZE.—Twenty-five foot poles are generally used with an allowance of about 10 per cent for 30 ft. and 35 ft. poles unless a careful survey of the line is made and the exact number of each size ascertained, but this is seldom done in railway work.

FRAMING.—In framing, one man can generally keep ahead of six men raising. In one case two men framed 14 poles in 4

hours, or about 3.5 poles per hour. This was rather slow work, however. The gains in the pole are cut on the inside of the bow when the pole is crooked, so that when the pole is set, the straightest side is seen as one looks down the line and not as one looks at the side. This may seem a small matter, but the difference in the appearance of the line is well worth what little trouble it may take to set the poles properly.

LABOR.—The poles are generally distributed from the train while moving at the rate of two or three miles per hour, though this sometimes results in a broken pole if it happens to fall wrong. This method has the advantage of being much quicker and less expensive, taking everything into account.

One rule for setting poles is that the depth of the hole in earth shall be one-sixth of the length of the pole. The holes are generally dug with a bar for loosening the earth and a spoon for removing it. The bar is of 1 in. hexagonal steel 7 or 8 ft. long, and the handle of the spoon is about as long as the bar and about $1\frac{1}{2}$ in. in diameter. The rate at which one man can dig holes is, in mixed clay and gravel, on an average, about four per day, and in mixed gravel and sand about eight holes per day.

Guy wires are generally put at the ends of curves and should always be put on both sides where a line is tapped or an abrupt change in direction is made. In raising, seven men can, under favorable conditions, raise forty or forty-five 25 ft. poles per day. This is where they do not do any of the digging, but simply set the poles and do the filling in.

WIRE.

STRINGING.—In stringing wire the spans are pulled up nearly straight, and the frost of the first winter is allowed to do its work in finding flaws and in putting the proper amount of sag in the line. Twelve men on this work at one time strung a little over twenty miles of wire in about three days.

The tie wires are about 15 in. long and either of the same wire as the line or a size smaller (generally the latter) and are wrapped about three times around the live wire.

SPLICING.—The splice used is the regular American Telegraph Splice, all joints being soldered. The soldering on most of this line was done without the use of acid, by a process which consists of first dipping the joint in the pot of melted solder and

allowing it to heat somewhat. It is then taken out and pulverized sal ammoniac rubbed on the joint by means of a soft rag or a bunch of cotton waste. The joint is again dipped, and on removing is found to be better soldered than when acid is used. It is claimed that the dry sal ammoniac does not have the corrosive effect which the acid often does.

CABLES.—Two cables were used on this work, one a submarine cable for crossing the Welland Canal, and the other an aerial cable through the city of Hamilton. The submarine cable was a seven-wire Kerite standard telegraph cable. In laying this a trench was dug from the base of the terminal poles to the water's edge on each side of the canal. A wire was then pulled across where the cable was to go and the end of the cable fastened to it. The latter was then pulled across and after the slack had settled the trench was filled in and the ends of the cable were run into the cable boxes on the terminal poles. The lightning arrester used was of a type somewhat similar to Bunnell's Cable Lightning Arrester with fusing wire.

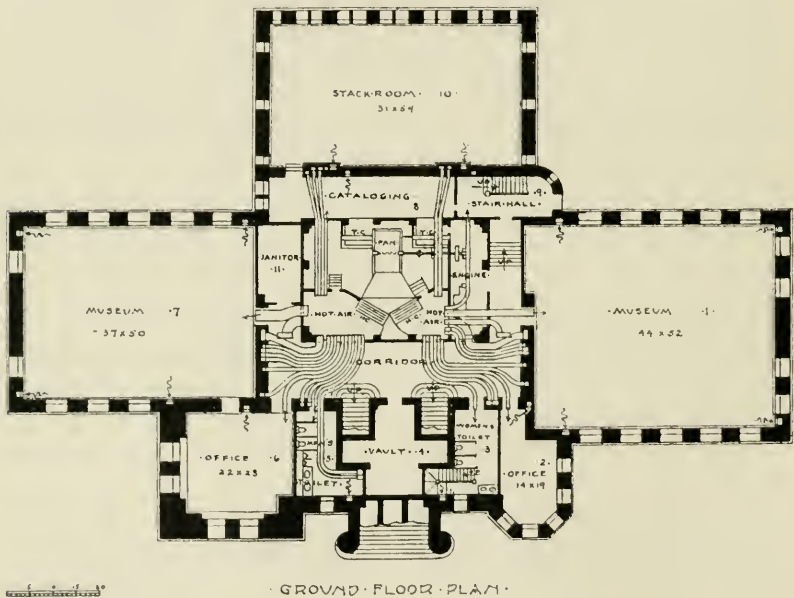
The aerial cable was of the usual form of seven-wire Kerite telegraph cable and was strung by first placing in each pole a large screw-eye, made from a long $5\frac{3}{8}$ in. lag bolt, and to these fastening the suspending wire for the cable. The latter was then hung from this wire by wooden clips and No. 11 galvanized iron wire. The length of cable in the tunnel was suspended in a similar way, the suspending wire being fastened to similar eyes of drive bolts in the brick walls.

BATTERY.—The Battery used was of the usual gravity form and was placed at each end of the line. There were forty cells at each end or about one cell for each mile of line. These batteries used up about one pound of copper sulphate per cell every three or four weeks and were thoroughly cleaned once in six months.

THE HEATING AND VENTILATING OF THE UNIVERSITY LIBRARY.

BY JAMES M. WHITE, ASSOCIATE PROFESSOR OF ARCHITECTURE.

The system adopted for this building is the one generally known as the "Plenum," or fan system. It was designed and installed by the B. F. Sturtevant Co., of Boston, through Foss

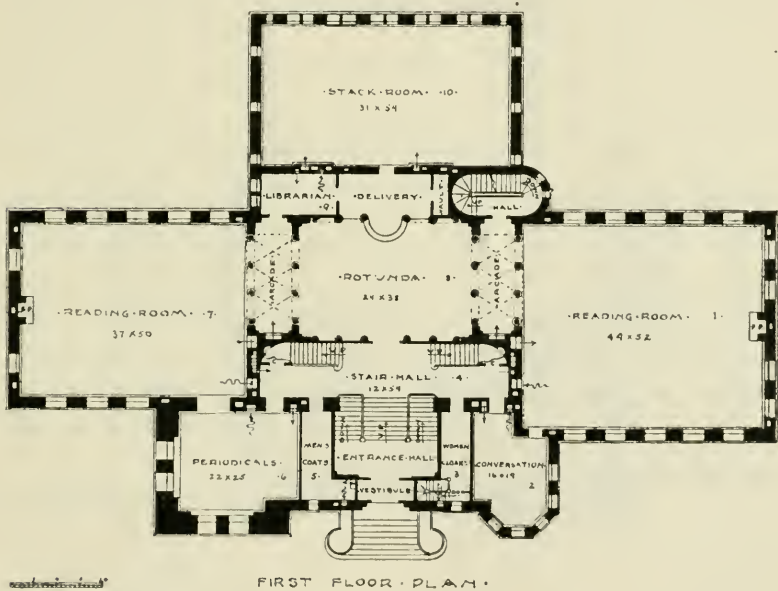


& Noble, their Chicago representatives, and under the direction of Prof. N. Clifford Ricker and the author.

We believe that this system is the only one which will adequately meet the requirements in a building which is continuously occupied by a large number of persons. Other methods will give results at certain times or seasons or under certain conditions, but where a large quantity of air is to be continuously supplied it must be *put* and not merely allowed to go. No other method than that of impelling air by direct means is inde-

pendent of natural conditions. At the same time it is easily controlled to suit all demands.

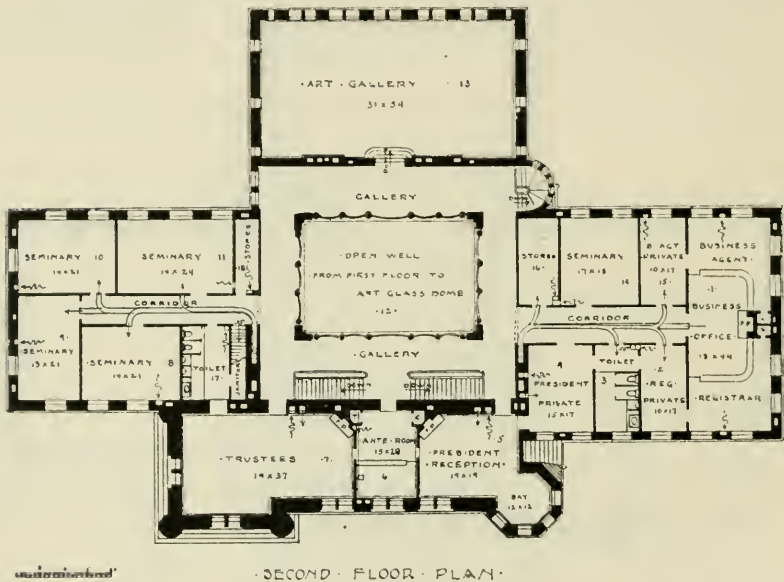
The designers of this plant were required to comply with the following conditions: the temperature in all parts of the building must be maintained at seventy degrees when the temperature of the external air is ten degrees below zero; the temperature in all rooms except halls, toilet and cloak rooms must be controlled by thermostats which will not permit a variation of more than two degrees; the air is to be introduced and removed



from the room without noise and without producing injurious draughts; the following velocities are not to be exceeded—in ducts 1 200 to 1 500 feet per minute, in risers 600 to 800 feet per minute, outlet velocities for large registers 500, and for small ones 350 to 400 feet per minute; the maximum pressure is to be $\frac{1}{2}$ ounce; the air in the room is to be changed every ten minutes and in the halls every twenty minutes; the galvanized iron pipes connecting the hot air chamber with the vertical ducts must be so arranged as not to disfigure the rooms of the ground floor.

The last condition was complied with by concealing the pipes above a false ceiling in the basement corridor. The rooms

in the wings of the second story were reached by lowering the ceilings of the wing corridors and running the pipes in the space thus obtained. In these cases, the hot air inlets to the rooms come quite near the ceiling, but in all other places the inlets are eight feet above the floor. The outlets are placed at the floor and where possible are nearly under the inlets. With this arrangement, the warm air enters the upper part of the room with sufficient velocity to carry it across and it spreads out and returns along the floor to the outlet. The vent flues, with the ex-



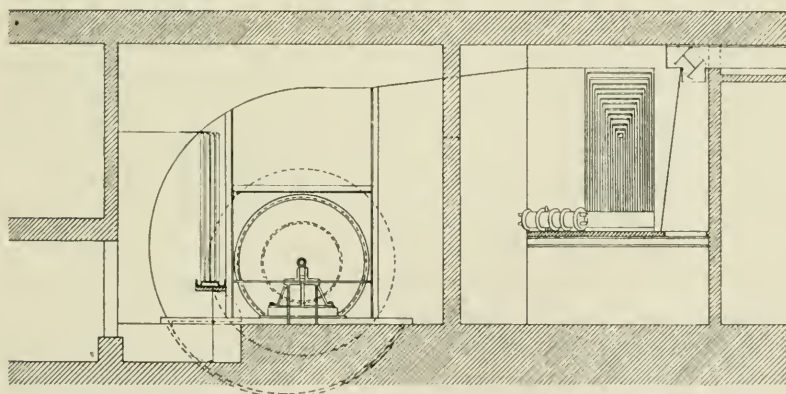
ception of those from the toilet rooms, terminate in the attic, from which the air escapes through louvres. The plenum created in the building by the fan not only causes the air to flow out through these flues, but largely counteracts the inward draughts around doors and windows.

The fresh air chamber is formed under the cataloguing room at the back of the fan by raising the floor $4\frac{1}{2}$ feet above the level of the fan chamber. Tempering coils, marked T. C. on the plans, are set at each side of the fan and boxed in with galvanized iron, so that all air before reaching the fan may be made to pass through them. Under the tempering coils as shown by the section is a horizontal damper, which may be opened to ad-

mit air under them in moderate weather when they are not needed.

The fan is an 8' x 4' B. F. Sturtevant blast wheel with three-quarter steel plate housing, and intended to run at 147 revolutions per minute. It is operated by a horizontal low pressure engine, having a cylinder 15 inches in diameter and a stroke of 8 inches. Steam is to be supplied from the Central Heating Station of the University at a pressure of at least 20 pounds,

In front of the fan is an air chamber divided horizontally by a platform four feet from the floor. On this platform are set the heating coils, marked H. C. Each of the two banks has $3\frac{1}{2}$ sections of 967 linear feet of one-inch pipe each, which, with the two sections of the tempering coil, make a total of 8 703 linear



SECTION THROUGH HEATING AND VENTILATING ROOM

feet of pipe. By referring to the section, it will be seen that the fan is so placed with reference to the platform in the air chamber that the air as discharged from the fan may pass with equal readiness above or below it, but that which passes into the upper chamber has to pass through the heating coils. The space below is the tempered air chamber, and that above, the hot air chamber. Each pipe leading to a room controlled by a thermostat has a connection to both of these chambers. A pair of dampers at the inlet to each of these pipes is so connected that a quantity of air equal to the full capacity of the pipe will always be passing, but the air may be at any temperature in-

intermediate between the temperatures in the two chambers, depending upon how these dampers are set. The amount of air from the fan which will pass above or below this platform is therefore dependent upon the position of these dampers. The halls and toilet rooms receive hot air only and the supply is controlled by the valves in the register faces.

The dampers are controlled by the Powers system of temperature regulation. The thermostat, which is placed in each room, consists of two discs concave towards each other, enclosing a corrugated metal diaphragm which moves freely between them. A small quantity of volatile liquid, having a boiling point below 60 degrees, is placed in one compartment. When the temperature is below 60 degrees, the liquid is condensed and the metal diaphragm is close to the side. When heated above 60 degrees, vapor is formed, the pressure of which varies with every change of temperature and amounts at 70 degrees to four pounds to the square inch. This tends to force the diaphragm over and to expel the air from the other side. The thermostat is connected both to the levers of the mixing damper in the end of the pipe supplying air to the room and to an air reservoir in which a ten-pound pressure is maintained by means of an automatic compressor. The expansion of the vapor in the thermostat opens a valve which permits the air at ten pounds pressure to operate directly upon the dampers, which it shifts to the position necessary to maintain the desired temperature in the room. The automatic regulation is also applied to the steam supply. Separate connections are made to each pair of heater sections and each is controlled by a thermostat, which will cut off steam from the coils in succession as the outer air becomes warm enough to make them unnecessary.

The glass area of the building is 5 246 square feet, figuring the entire stone opening in each case. The exposed wall surface, exclusive of the above glass area, is 14 717 square feet. In rooms having the outside walls partly underground, only half the area below grade is included. No allowance has been made for loss through the ceiling of the second story, because the large quantity of air discharged into the attic at 70 degrees, through the vent flues, will keep it quite warm. The total number of cubic feet of space heated is 395 763. Of this amount, 19 212 cubic feet is in vaults and unoccupied rooms used for storage, in which

but one change an hour is figured; 128 250 cubic feet is in halls and corridors, in which the air is to be changed three times an hour; and 248 301 is in occupied rooms, requiring a change of six times per hour. This makes a total of 1 893 768 cubic feet of air to be delivered per hour, or about 31 563 cubic feet per minute. The 8' x 4' fan is estimated to handle 31 800 cubic feet when running at 147 revolutions.

The radiation must be sufficient to make good the loss through the walls and the glass and by ventilation. According to Wolff's diagram of Loss of Heat from Walls, 17 heat units are lost per square foot per hour through a 24-inch wall, when the difference between inside and outside temperatures is 80 degrees. This makes the loss through the walls 250 189 heat units per hour. The loss through windows according to Peclet for the same difference of temperature is about 81 heat units per square foot per hour, or a loss of 424 926 heat units. The loss by ventilation will be the number of heat units which are contained in the air passing out the vent flues in excess of the number of heat units contained in the air drawn in by the fan. If the air leaves the room at 70 degrees and enters the fan at -10 degrees, then the loss will be the number of heat units necessary to raise the total volume of air required per hour through 80 degrees. If one heat unit will raise 50 cubic feet of air one degree, then the total volume of air divided by 50 and multiplied by 80 will give the number of heat units lost by ventilation: $1\ 893\ 768 \times 80 \div 50 = 3\ 050\ 029$ heat units. The total loss then from the three sources is 3 725 144 heat units per hour. The air delivered by the fan will, under maximum conditions, enter the heaters at a temperature of -10 degrees and will pass over them with a velocity of 900 feet per minute. The heaters contain 8,703 linear feet of 1-inch pipe and under the above conditions about 75 pounds of water will be condensed per minute, which is nearly 2 pounds per square foot of surface per hour and the temperature of the air will be raised about 115 degrees. In one pound of steam, at a pressure of 10 pounds above the atmosphere, there are 1 186.5 heat units, while in 1 pound of water of condensation there are 213 heat units, leaving 973.5 units which are given off by the heating surface. The heat units given off per hour by the condensation of 75 pounds of water per minute would therefore be $75 \times 60 \times 973.5 = 4\ 380\ 750$ heat

units, which provides about 15 % in excess of the amount required.

An approximate rule for determining radiating surface in linear feet of 1-inch pipe for hot blast apparatus is to multiply the quantity of air handled per minute by the difference between inside and outside temperatures, and divide by 300. This would give $31\,563 \times 80 \div 300$, which is nearly 8 417 linear feet, and is a satisfactory check on the 8 703 provided. According to Mill's Rule, the building would have required 5 338 square feet. This is nearly double the 2 901, which is the equivalent in square feet of the 8 703 linear feet provided, but one square foot of radiation in front of a fan will condense nearly four times as much steam as a square foot of ordinary radiation, so we have in reality the equivalent of a little more than twice the surface required by Mill's Rule, but this surplus is necessary to provide for the large quantity of heat lost by ventilation, as Mill's Rule takes into consideration only about one change of air per hour.



BOOK REVIEW.

THEORY AND CALCULATION OF ALTERNATING CURRENT PHENOMENA. By CHARLES PROTEUS STEINMETZ with the assistance of ERNEST J. BERG. W. W. Johnson Company, New York.

The author of this book is the engineer of the General Electric Company and as such he has had a large experience in designing the most recent types of alternating current machinery. His book has on this account special interest for the engineering student. The topics treated are first the general and fundamental phenomena of alternating currents such as found in a number of our current text-books, and later such advanced topics as theory of induction, motors, synchronizing alternators and motors, higher harmonics in alternating circuits, and various problems in polyphase systems. The elementary topics are not treated with the clearness required by the beginner and the book can not be recommended to one not already familiar with other books on the subject. But in the more advanced topics the author's presentation is excellent and stimulating. His use of the complex variable, a development of his paper before the Chicago Congress of 1893, is particularly interesting and valuable. The book is a substantial contribution to the literature of alternating current theory, and should be in the hands of all advanced students.

LOCOMOTIVE TESTS BY THE UNIVERSITY ON THE ILLINOIS CENTRAL R. R.

The students of the Mechanical Engineering department are to be congratulated upon the excellent opportunities now open to them for doing practical testing work on locomotives.

Through the kindness of Mr. Renshaw, Superintendent of Machinery of the Illinois Central R. R., the department has had three standard locomotives equipped for complete road tests. A series of tests has been in progress during the spring term on engines No. 409, Standard Freight; No. 962, the fast passenger of the American type recently designed by Mr. Renshaw and built by the Brooks Locomotive Works; and engine No. 623, a new engine designed for use on the Mississippi division of the road. The locomotives have been carefully arranged for testing by Mr. Pollard, master mechanic, at Centralia, and by Mr. Whitney of the Champaign shops, in consultation with Professor L. P. Breckenridge of the Mechanical Engineering department. The usual run is from Champaign to Centralia, a distance of 125 miles, returning the next day. The testing crew consists of six men under the supervision of Mr. Wood or Mr. McKee, assistants in the Mechanical Engineering Laboratory.

Various modifications have been made from time to time in the steam distribution, method of regulation, type of exhaust nozzle, kind of coal, etc., in order to bring out the advantages or economy of each special arrangement. Certain results have been checked by tests made in the round house, and careful measurements and weights have been taken of all parts of the engines. Carefully prepared reports are being compiled, and it is believed that much information of value will be furnished to the company.

With the facilities now at hand for work of this nature, the opportunities for special work in railroad engineering at the University are certainly exceptional.

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VOL. XII

1897-'98

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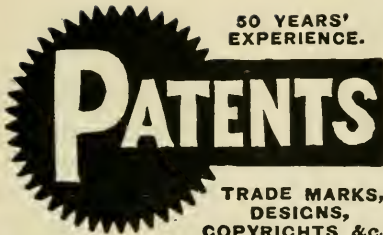
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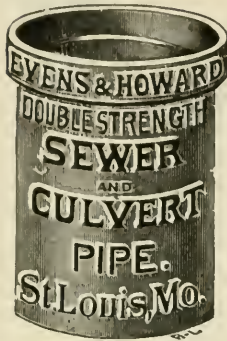
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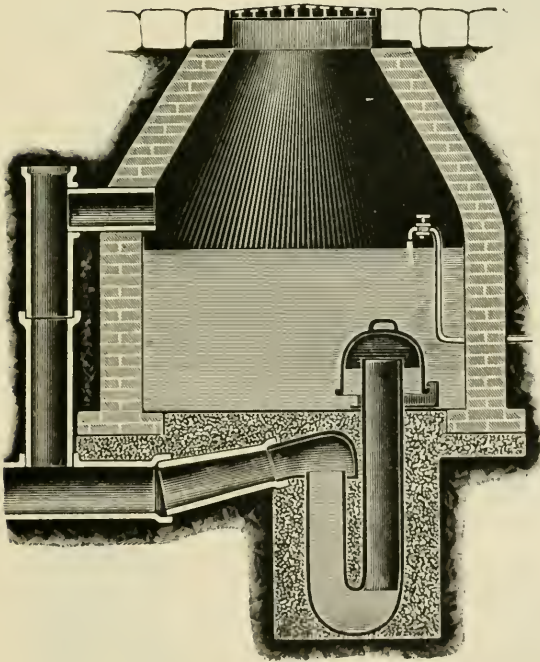
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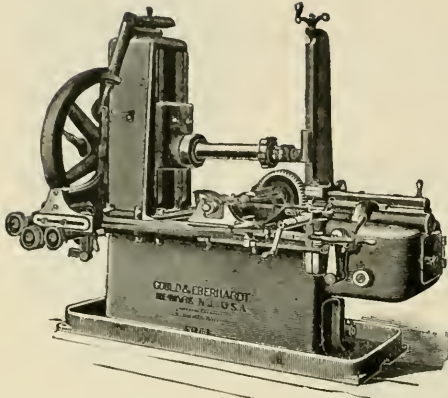
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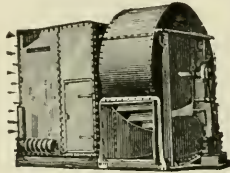
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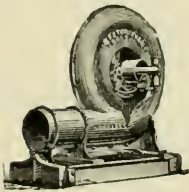
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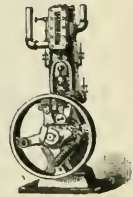


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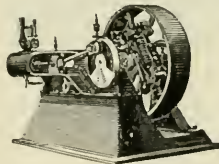


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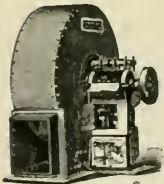
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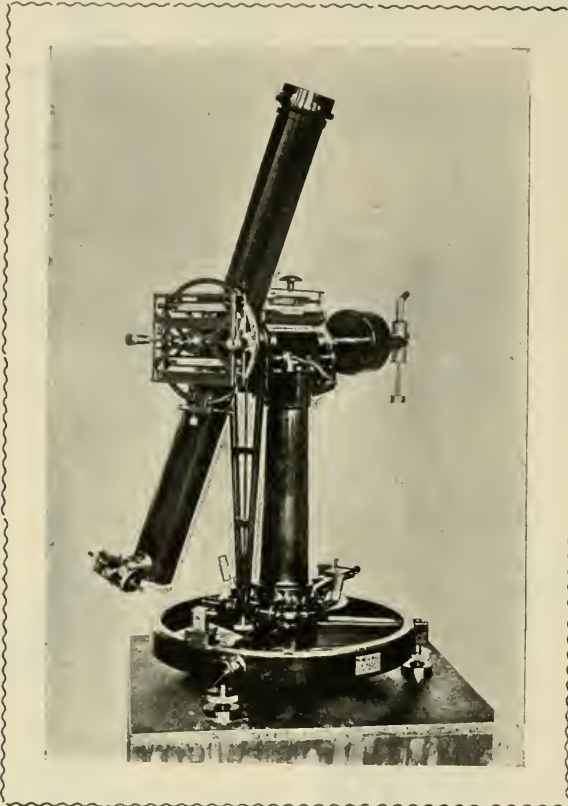
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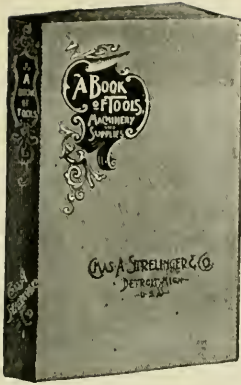
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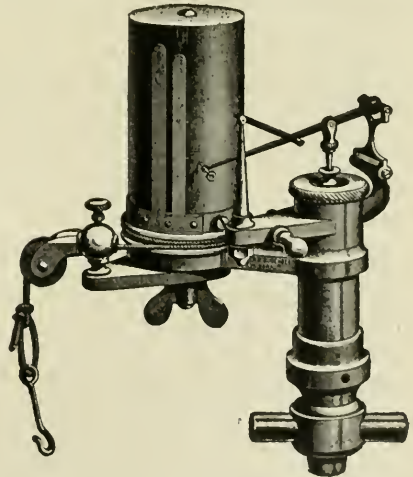
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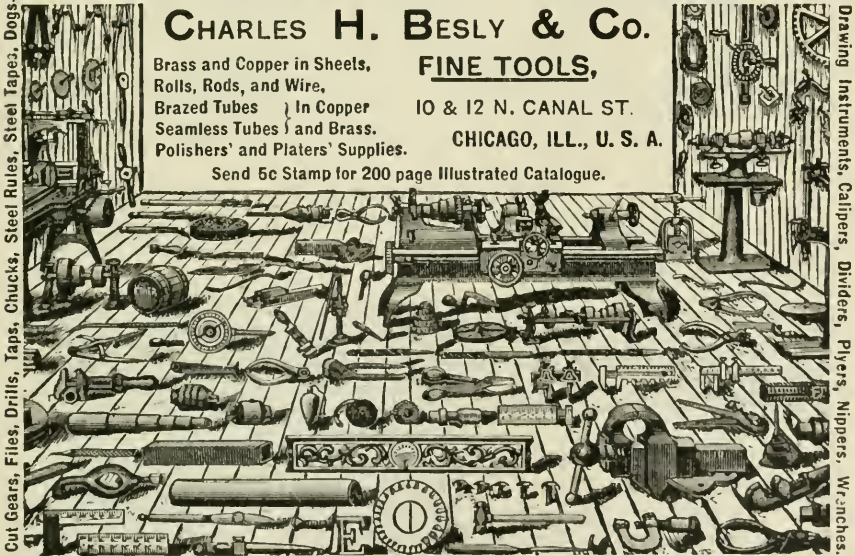
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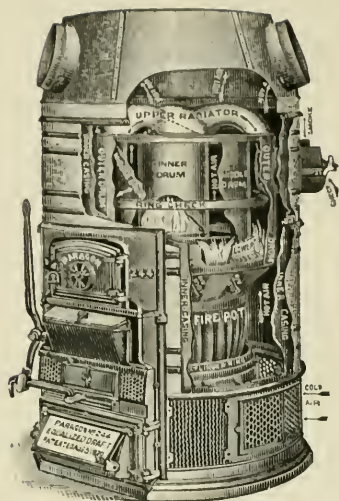
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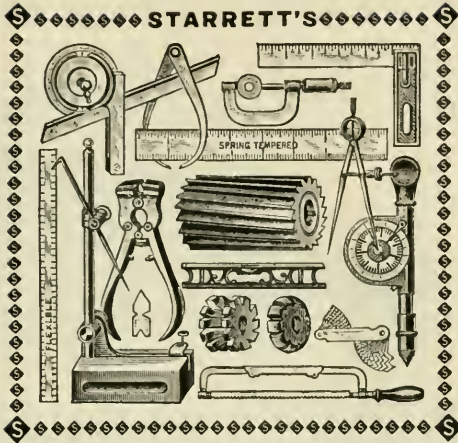
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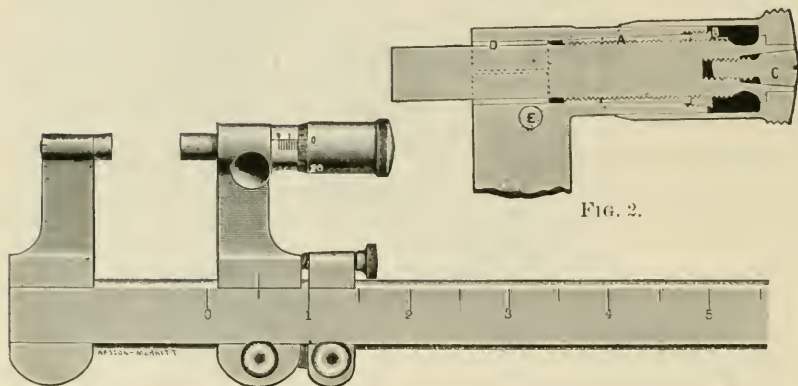


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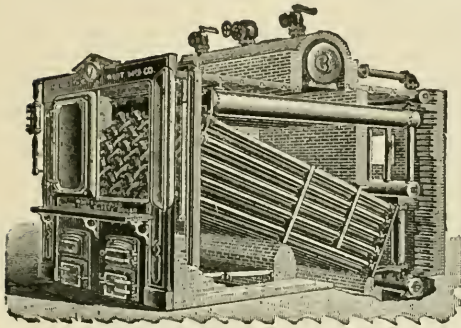
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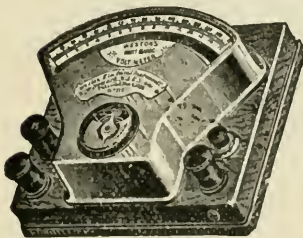
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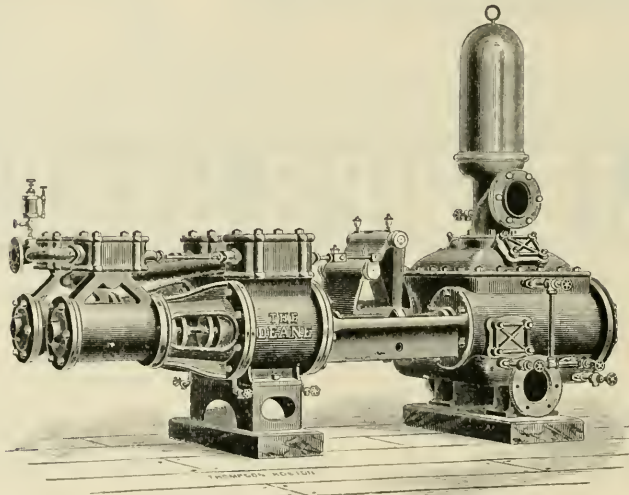
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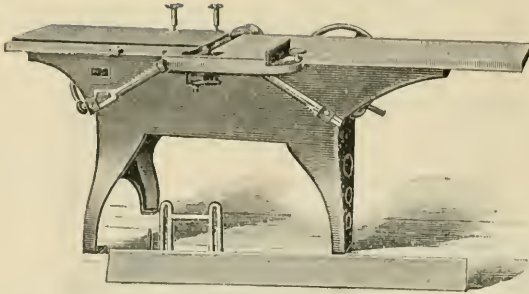
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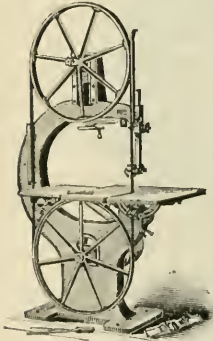
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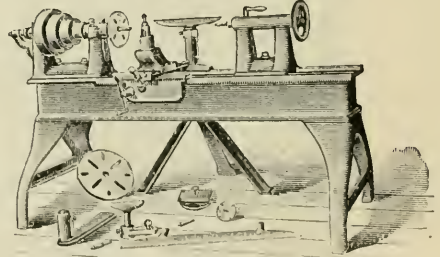
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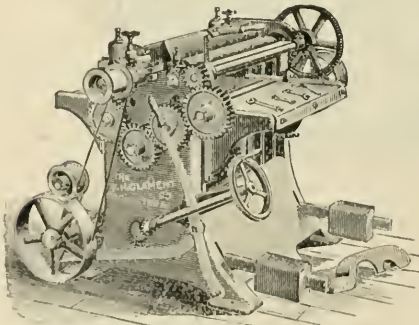
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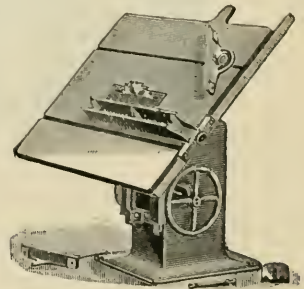
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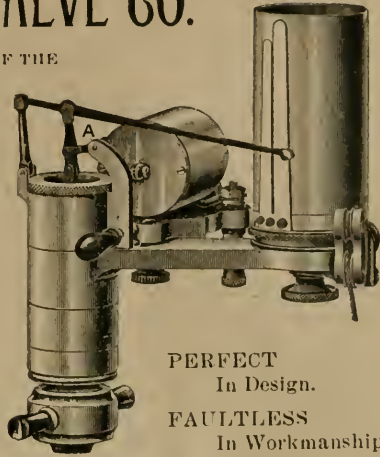
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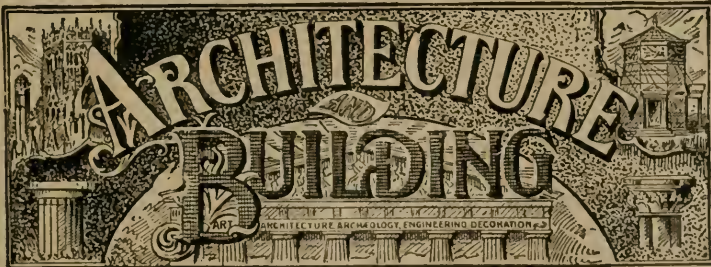


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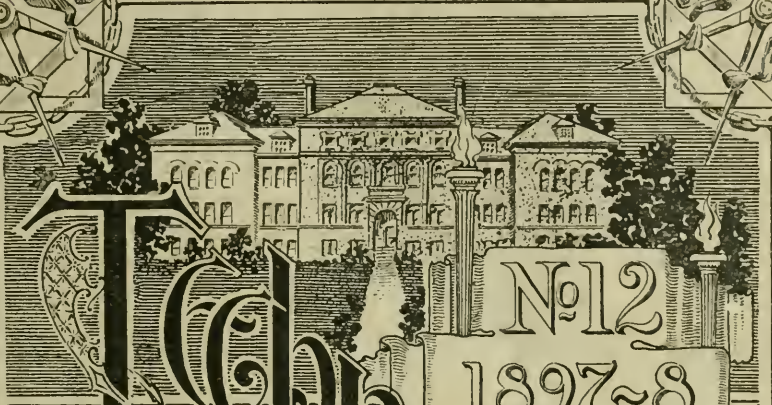
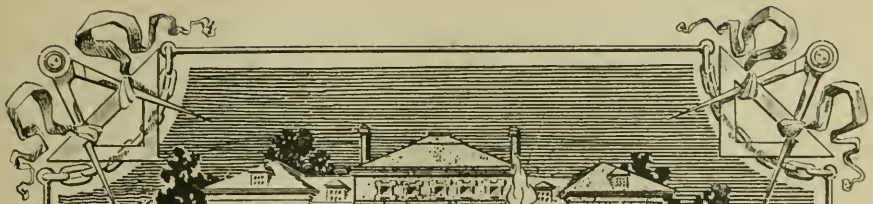
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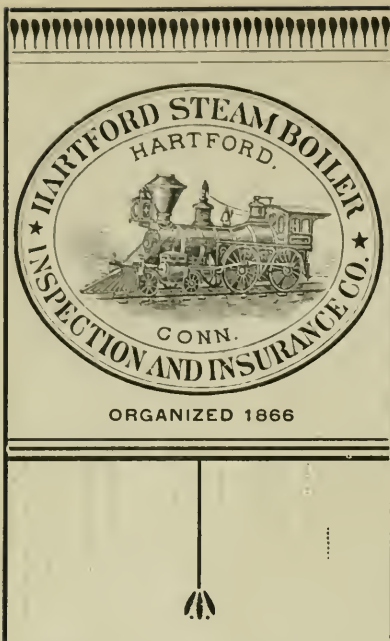
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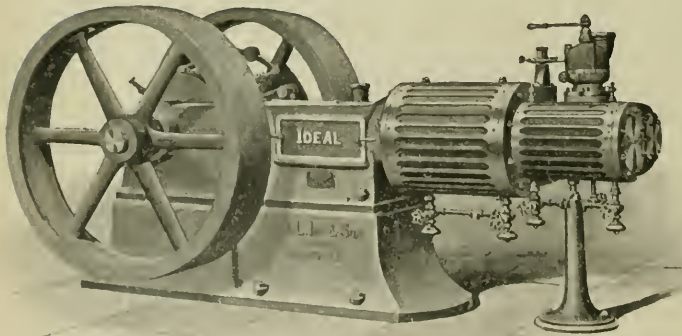


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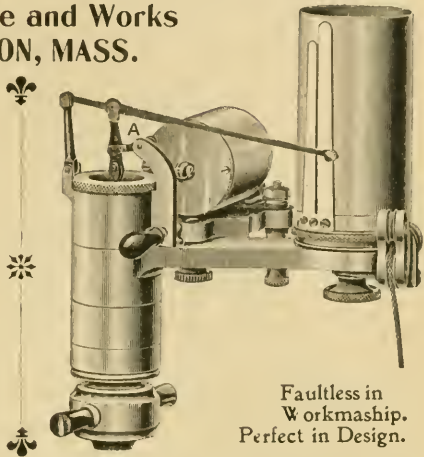
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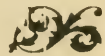
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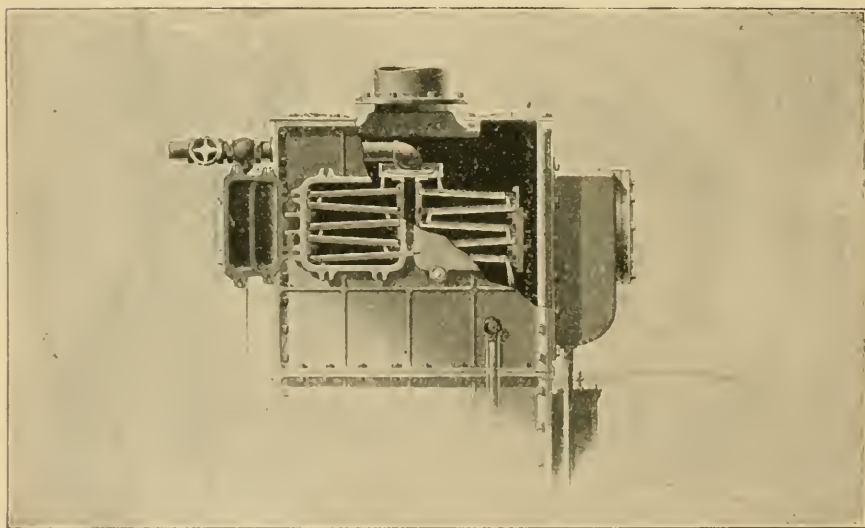
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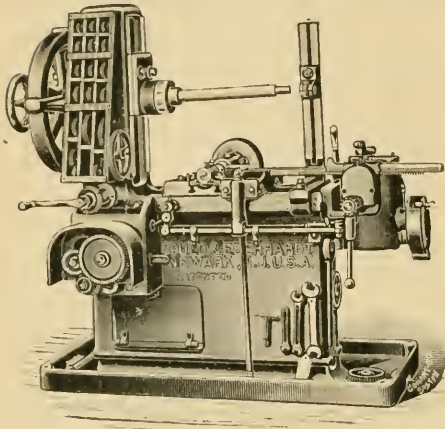
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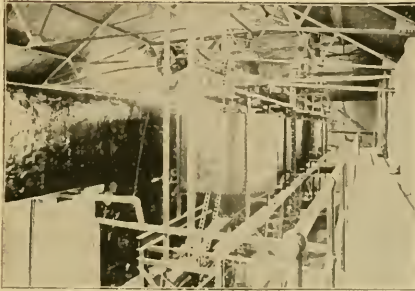
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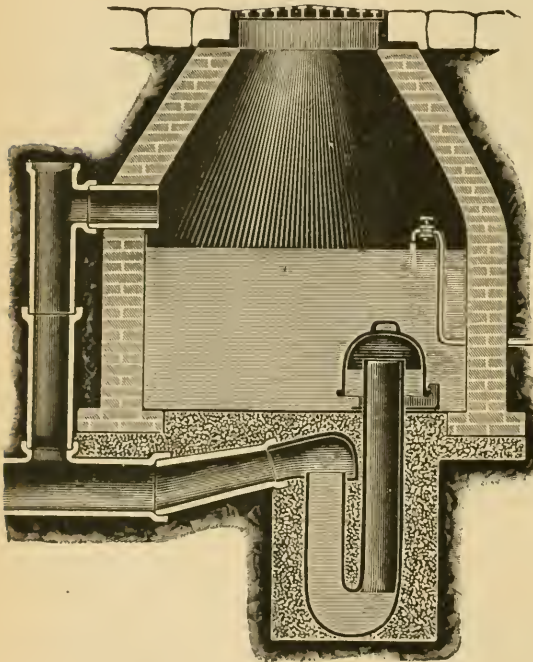
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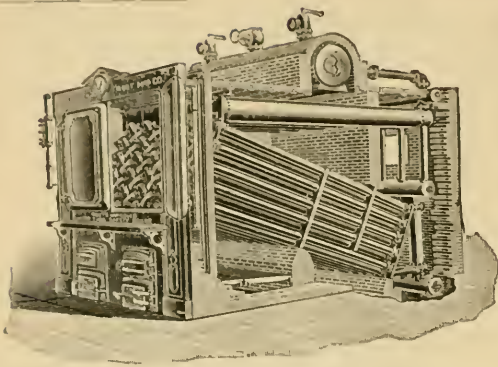
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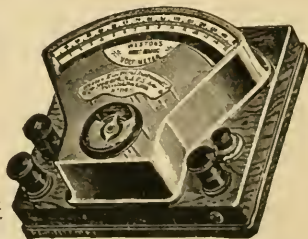
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1897-98.

NOTES ON SKETCHING.

ADDRESSED PRINCIPALLY TO ARCHITECTS.

BY FRANK FORREST FREDERICK, PROFESSOR OF ART AND DESIGN.

I would not have consented to contribute to the columns of a technical journal, where I fear I shall be but a cat in a strange garret, had I not felt that there were two matters upon which I could speak to the advantage of architectural students.

I. The reason why the art of sketching is not so general as formerly, and suggestions for a return to its practice.

II. The reason why the methods and mediums employed should depend upon the subjects, and suggestions for more artistic sketching upon the part of architects.

I.

It is, fortunately, no longer necessary for the student of architecture to study in foreign schools in order to learn the elements of his art, but no architect deceives himself by thinking it unnecessary to travel abroad. To study in Europe, and sketch its famous buildings, should be the ambition of every architect—an ambition easily attained in these days of cheap and rapid traveling. This need of study is very generally realized as the number of architectural traveling scholarships offered, and the number of applicants for them—to say nothing of the far greater number who go unaided—testifies. At least one large architectural school offers a summer course which takes the student to Europe upon a sketching trip, and in almost every European city there are clubs

of architects who make pilgrimages for the purpose of study by means of drawing. Notwithstanding, among students in schools and other amateurs, the practice of sketching is not so general as formerly, and to account for this there are several reasons.

The wonderful developments in the art of photography have made it possible for anyone to secure pictures of almost every building now standing; and the traveler is met at the door of every structure by a vender of photographs who, for a small sum, will furnish him with pictures of every crack and cranny in the place. These photographs are generally excellent, often taken under the direction of architects, and many times taken under the most favorable conditions of light or air—conditions which may occur but once or twice in a year. And if the traveler is particular to secure a certain view of a certain thing, he has but to "press the button" of his own pocket camera and it is his. Compared with buying photographs and taking snap shots, the art of sketching seems tedious and a waste of time, and the young architect, especially if he hails from the Hustling States of America, goes merrily on to the music of his kodak click.

The development of the art of photography has made possible the various reproductive processes by which reproductions of drawings, paintings and photographs are made with great rapidity and slight cost. As a result, illustrations which a few years ago could not be produced for the wealth of the world, are now given in the ten cent magazines, and the majority of architectural journals depend almost entirely upon their illustrations to arouse interest in their columns. To lose the art of reproducing drawings would set the cause of art back some centuries, yet the blessing of cheap and unlimited illustrations works some harm to the cause of art, for, with every book, magazine and pamphlet full of illustrations, the young architect thinks it unnecessary to make drawings himself.

The drawings which are reproduced, especially in architectural journals, are generally so excellent that the student is discouraged when he compares his work with that which is published. He forgets that many drawings look better in the reproduction than in the original, that many drawings are made at large scale and are reduced in size in the process of reproduction—giving the impression of very fine work, beyond the power of the most skilled

draughtsman to copy. The journals themselves must be blamed for much discouragement on the part of students, for, in the race for variety and attractiveness they often publish as sketches works which are not sketches, but highly finished studies. And methods are employed in the reproductions, as rouletting, tinting, etc., which improve the illustrations but were lacking in the original sketch. It is to be expected that the amateur will be deceived and will be discouraged when he sees his own attempts.

Furthermore teachers are many times responsible for the lack of ability, and therefore of interest, in sketching. Their favorite method of sketching may be with charcoal, or pencil, or oil, according to their favorite class of subjects, and, not realizing that a medium very successful and useful in the hands of one student may be useless in those of another, they do not instruct their students in the methods of handling the various materials used in art study. For example: A stick of charcoal may be the best possible medium for sketching a Norman tower appearing above a mass of foliage, but it is certainly not suitable for an accurate drawing, at sketch book scale, of the ornament about the doorway of the tower. Yet, by many art teachers, charcoal is held to be the only medium to be used in art study, and it is to be expected that their students will try to do all kinds of sketches in that one medium and fail in the attempt. No architect can expect to acquire the knowledge of paint, crayon, pastel, etc., held by the artist who devotes his entire time to their study and use, but it is a simple matter to learn enough of these mediums to use them successfully in sketching.

A sketch is "a rapid or off hand presentation of the essential facts of anything: — a delineated memorandum; a slight indication of an artist's thought, invention or recollection." To sketch is "to present the essential facts of, with omissions of details; to describe or depict in a general, incomplete and suggestive way." Sketches are not works of art for exhibition purposes, but are notes or memoranda, and this the amateur seldom realizes. The difference between a sketch and a study is also not generally understood. A sketch presupposes not haste, but the rapidity of execution which comes from thorough knowledge of the subjects sketched — "The art of leaving out is the proof of perfect acquaintance with the art of putting in." A study is "a sketch executed

as an *educational exercise*, as a memorandum or record of observations or effects, or a *guide for a finished production*."

So many rules upon selection of subject, point of view, sketchy treatment, suggestive line, etc., etc., have been laid down (probably by those who could write better than sketch) that the average amateur regards sketching as something beyond the power of any but the genius, and is frightened away from the practice of one of the easiest, quickest and most satisfactory methods of securing and preserving information. It is not even necessary to be a good draughtsman to be able to make valuable sketches; that is, valuable to the one who made them, if to no one else; but a good drawing always tells the truth, and is therefore of more value, even if it be immediately erased. Let the architectural student then draw anything and everything (and the range of choice is wide), but let him make studies as well as sketches of the things he draws, and think of their beauty and value — not of the pictures he is making. Let him be "practical" if he wishes, and draw only those things which he knows he can use immediately in his profession. Let him draw anything (nothing is too small or simple), so long as he draws at all, for in the drawing he is cultivating his sense of proportion, his appreciation of beauty, and his skill of hand. The architectural student in the vacation time of his school days, or the practicing architect on a holiday, who sketches and studies, returns to his drawing table and T square with a clearer eye, with imagination stimulated, and with a deeper appreciation of the dignity of his profession.

II.

It is needless to say that the holder of a traveling scholarship, or any student who will spend the time and money necessary to travel for study, will realize the value of drawing. It is customary for these travelers, upon their return, to exhibit their sketches at the school or club which may have granted the scholarship, or privately, or in the columns of architectural periodicals. It is interesting to note that every good draughtsman has a style or manner of his own — a very desirable thing, for without individuality art would be dead indeed — but it is not so interesting to note that ninety-nine out of a hundred architects not only have a style or manner of their own, but do *everything* in their one method.

Some affect black ink on rough paper, a lead pencil on smooth paper, some put a wiry and crooked line around everything, and others end each line with a small black blot; and whether they are sketching a minaret standing dark against the moon-lit sky, or the dome of Saint Paul's in a London drizzle, they try to adapt the subject before them to their own little way of doing things.

Hence, when an artist looks over the portfolio of the architect he has a feeling of missing something—the sketches do not tell enough—they seem exercises in technique only, and it seems a pity that opportunities to secure valuable material should have been missed—lost because they were beyond the power of the medium and method employed. If it is said that the architect does not see things as the artist sees them, the answer must be that it is the architect's loss, and his first duty should be the cultivation of an artist's point of view. Who more than the architect should appreciate the beauty of the silhouette of a spire against the sky, or the color of buildings and bridges old and new, or the composition made by buildings and their surrounding trees or lesser buildings, or the building and the river bank upon which it may by chance stand? Each of these beauties, and many others, can be best suggested by some one method or combination of methods. Why not use the color box for the old buildings, a value of charcoal for the spire? And if necessary even the line with the little black blot at the end of it will best express the subject.

Your old traveler smiles when he hears the man who has crossed the ocean once say that he simply puts a tooth brush in his grip and starts. The old traveler's trunks are the terror of cabbies, and if he is an Englishman he even takes his bath tub. In the same way the veteran draughtsman goes prepared to sketch whatever may appeal to him, whether it be a poplar tree of Normandy, the vibrating color of Saint Mark's facade, or the detail of a bit of ornament from some iron bound chest of old Germany. He does not, like the amateur, attack the art of Europe with one lead pencil and a block of paper.

The drawings here reproduced were selected from my portfolio in the hope that they would arouse interest in the art of

sketching, and to illustrate the statement that the method and medium should depend upon the subject. The originals will be gladly shown to anyone interested to compare them with the reproductions.

Before speaking of the drawings, the two methods employed in their reproduction must be described and compared. New methods are discovered daily, and every craftsman has methods of his own; but, briefly, a line drawing (Plate II *), is reproduced as follows: A photograph of the drawing is made of the size it is to be upon the printed page. From this negative a print is made upon a sensitized metal plate coated with albumen, bitumen, or gelatine. This coating, when exposed to the light, becomes hard and remains upon the plate when the remainder is washed away. It will be remembered that in a negative the parts that are to be white are opaque and the darks transparent, therefore the sensitized plate is affected by light only where darks are wanted in the picture, and when the plate, after washing, is immersed in acid, the unprotected areas are eaten away, leaving the protected lines at their original elevation. If an inked roller is passed over the plate it will come in contact with the raised lines and these will print upon the paper the desired reproduction of the original.

The photograph, and all the drawings not in line (as Plate I *), were reproduced by the half-tone process. In this process a sheet of glass or gelatine, ruled with very fine lines, is placed between the original and the lens. This is photographed upon the negative with the picture and is the flat tint appearing in all half-tones. The object of this film is to cut the masses of value, which would otherwise all reproduce as black, into lines to permit the action of the acid upon the plate in the later stages of the process.

In the first process, called zinc-etching, since the plates used are generally of zinc, nothing but lines can be reproduced—no tints, gradations, or masses other than blacks. In the half-tone process the presence of the photograph of the film makes white an impossibility, and, except in very carefully made and printed plates, blacks are so reduced by the film as to print as grey.

* The several plates of this article are found in order between pages 14 and 15.

PLATE I, (original size $6\frac{3}{8}$ in. \times $9\frac{1}{4}$ in., an unfinished drawing of an aisle in Westminster Abbey), may be said to be both a study and a sketch, for the vaulting was carefully and fully worked out, while the lower part was merely suggested or sketched. It was drawn on very rough water-color paper with sepia. Warm sepia was selected simply because it is to me a pleasant medium, but it was put upon the rough paper with a dry brush for the reason that the crumbling age of the old stones could by that means be best expressed. The wall of the choir, seen between the piers to the left, was put in with a wet brush, for I did not wish to represent detail, character of surface, or anything beyond the fact that the wall was there.

PLATE II, (original size 3 in. \times $9\frac{1}{4}$ in., a sketch of the Houses of Parliament), was executed in ink on tracing paper placed over an unsuccessful sketch in wash. This building is "Perpendicular Gothic," with all the vertical paneling, shallow buttresses, pinnacles, finials, etc., that characterize the style. The effect at a distance, especially the sky-line, is of a forest of spires clearly outlined and full of detail. To express this in a few lines in a few moments, in other words to sketch the building and lose none of its character, was the problem. Pencil was too weak, charcoal too clumsy, a brush used wet or dry was too soft, but ink lines drawn with a pen in short vertical touches gave the desired effect—to me at least. It will be noticed that the style of line changed to suggest the low flatness that characterizes Westminster bridge.

PLATE III, (original size $4\frac{1}{4}$ in. \times $9\frac{3}{4}$ in., a street in the old town of Canterbury), was sketched upon gray crayon paper. The drawing was made with a soft pencil and washed over with a tint of ivory black. The shadows were washed again with a darker tint. The dark accents were worked out with the point of the brush with pigment taken directly from the pan, and the lights were added with Chinese white. This is an exceedingly quick method of getting effects, and was employed partly for that reason, but more because it gave the feeling of the scene. The grey town had been well washed by a brisk shower, and the sun, shining on the wet surface, gave a brilliancy that could have been best suggested with the contents of the color-box. But colors were out of the question, for trains leave town whether

sketches are finished or not, and so this method was used. A pencil or a pen drawing would have given no satisfaction, for they could not express enough of the elements in the scene that appealed to me.

PLATE IV (original size $8\frac{1}{2}$ in. \times $9\frac{3}{4}$ in.) is a sketch of the entrance to Canterbury Close. The drawing was made with quite a soft pencil upon water color paper and partly washed with a tint of ink (Higgins' Waterproof, diluted with water). The darks were picked out with ink directly from the bottle. The sky, foreground, and parts of the walls and roofs were left of the original whiteness of the paper, but in the reproduction the photograph of the film gives a flat tint that rather improves this particular sketch. Sketches of this kind, on account of their effectiveness and the rapidity with which they can be made, are very useful in studying composition — several sketches of the subject to be studied can be made from different distances or positions, the propositions settled, the darks blotted in, etc., and the best selected for more careful work. This was the method of sketching generally employed by the old masters — Rembrandt, especially, used it continually. Turner, in his early work, used it constantly in architectural sketches, and to such good advantage that these have never been surpassed.

PLATES V AND VI, (original size $6\frac{3}{4}$ in. \times $6\frac{3}{4}$ in., it will be noticed that all the drawings were made quite large) are two reproductions from the same sketch. After finishing the sketch on Plate IV, I moved nearer the entrance and made a more detailed drawing, for I felt that the detail, which could not be shown in the first sketch, was of sufficient interest to be noted. The drawing was made upon smooth white paper with a very soft pencil. As I look at the sketch I see that I must have started with the lead well pointed and finished with it worn and somewhat flattened. The drawing looked flat and uninteresting when finished, and so some of the lines were strengthened with ink (the ever useful fountain pen), as can be seen in the reproduction. By making the shadow darker under the awning, I brought that forward, and the darker touches upon the gateway itself accented the weather-worn stonework and gave the whole thing solidity. Plate VI is a zinc-etching from the same sketch introduced here for comparison. It will be seen, contrary to general

belief, that pencil lines, if drawn with vigor and clearness, will reproduce as dark as pen lines—in fact it is impossible to distinguish them. While the vigor of white contrasting with black, as seen in Plate VI, is very desirable, it does not make up for the delicacy and truth seen in Plate V, which is lost in the zinc-etching.

PLATE VII (same size as original sketch) is a sort of "short hand" method of drawing which I fancy will not meet with approval among architects. It is, however, a very useful method where considerable is to be suggested in a short time. This was sketched with a fountain pen upon a sheet of the paper sold with the reversible covers at the University blue-print room. Under the circumstances the only method which could have been used in place of the pen would have been the pencil, but the result would not have been so satisfactory for the nervous, "touchy," technique forced upon me by the uncertainty of the length of time at my disposal would have resulted, in pencil, in a mess.

The photograph reproduced upon Plate VIII is a snap shot taken from the west front of Amiens Cathedral. It seemed to me a very pleasing composition, but, not having time to sketch it, I made the memoranda (also reproduced upon Plate VIII), from which, with the assistance of the photograph, I could make a study in color which would be quite truthful. It is a common practice among artists to use photographs and memoranda in this way, and there is no reason why it would not be a method of equal value to the architect.

The Dover-Calais boat, original size $5\frac{1}{2}$ in. \times $9\frac{1}{4}$ in. (Plate VIII) was drawn with a brush on Whatman's cold pressed drawing paper. It appears slight and hasty enough to be the merest sketch, but is really a careful study. Picture a sky as blue as ever spanned that turbulent channel. The white chalk cliffs of the Dover shore. The group of hotels and houses upon the curving beach. The green water with a heavy ground swell that twisted and broke the reflection of the black iron hull of the steamer into strange and ever changing shapes. And then add the fresh sea breeze—so refreshing after a hot ride from London—and, if you will, the odors of "Lun-ch now bee-ing served, sir, honly three and six, sir;" and then think of the nerve of any one who would try to draw. An Englishman would never have attempted it unless he had time

to go into the thing thoroughly. A Frenchman would have taken some charcoal and secured the values—the relative dark and light of the sky, cliff and water, if he had done nothing else. A German would have drawn the proper number of bricks in the hotel chimney even if he had left out the boat. A Japanese would have looked for the most striking and telling line or spot in the composition and noted it. He might have seen the shore line and drawn its great sweep—in which case he would have put it in a horizontal rather than a vertical rectangle. Or, he might have seen, as I did, trying to put myself in the spirit of the Japanese, the boat and its reflection and made that the prominent feature, with all else subordinate. Japanese art is much studied, because their artists possess the ability to seize the important elements and let the rest go. They have the power of characterization, can analyze, and have learned the value of style. A Japanese draughtsman would not have tried to represent that reflection just as it appeared at any one time, but by study would have determined the general character and style of such a reflection upon such a sea and would have tried to represent a type.

The pen sketch of the towers of Westminster Abbey, Plate VIII, is one of two reproductions made from the same drawing. Plate IX is reproduced the same size as the original, while the reduction is one ninth the original area. It is hoped that the opportunity to compare the two will be of assistance not only to students of methods of sketching but to students of the technique of pen work.

The first drawing on Plate X (original size $5\frac{1}{4}$ in. \times 8 in.), was in soft pencil on German drawing paper—a paper having considerable grain, but not so rough as Whatman's. The reproduction by the half-tone process did not do the study justice. The flat tint upon the areas left white in the drawing prevented the contrasts desired between them and the darks and there was a monotone effect—something almost never desired. There is, of course, no such thing as color in anything not executed in colors, yet we are so accustomed to associate certain values or tones with colors that we sometimes say, as in the case of this reproduction, that it lacked color. The proper balance of light, half-tone, and dark was, however, very nearly secured by "tooling" or cutting away the surface of the plate, as the sky, the glass in the nearer window, and the edge of the sidewalk, which secured white.

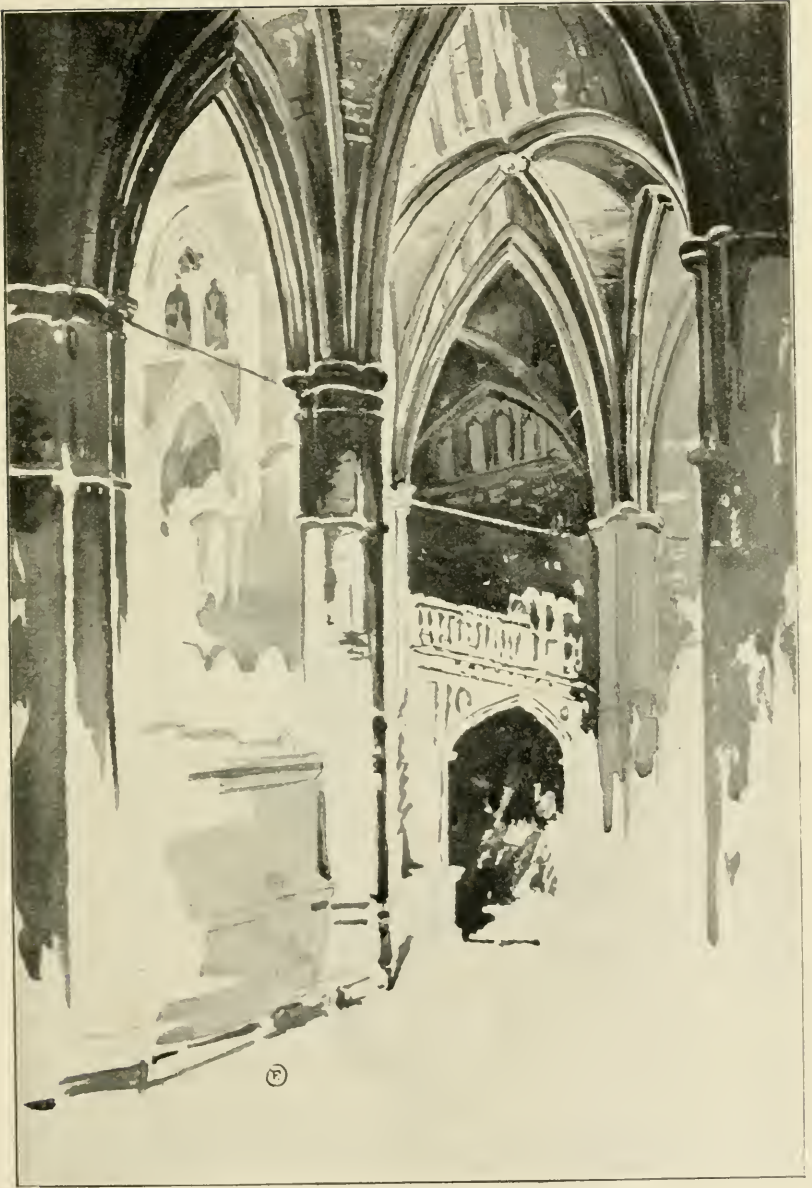


PLATE I — IN WESTMINSTER ABBEY.



PLATE III—STREET IN OLD CANTERBURY.



PLATE IV — ENTRANCE TO CANTERBURY CLOSE.

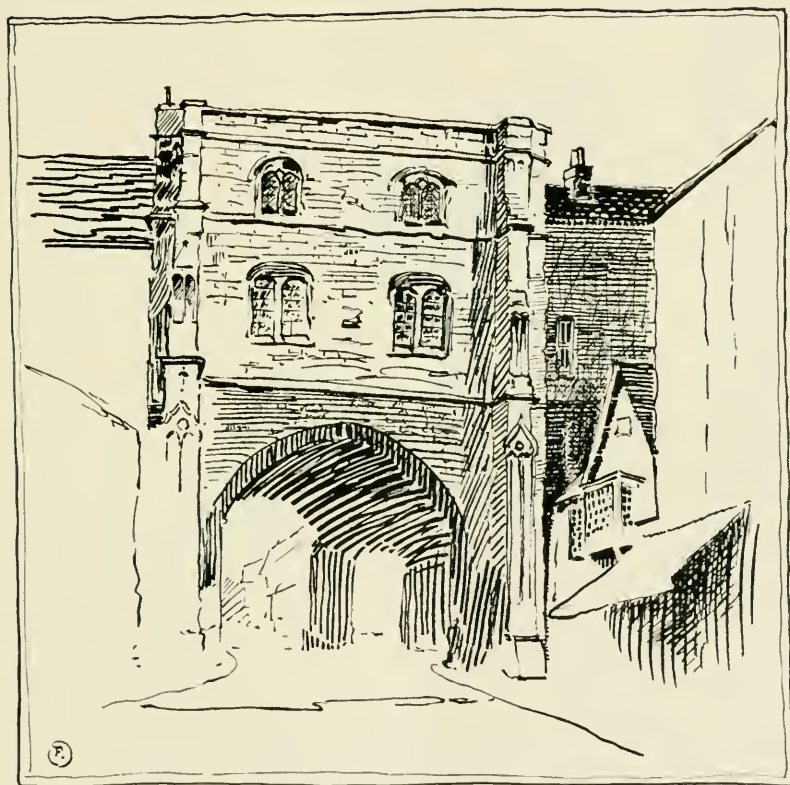


PLATE VI — ENTRANCE TO CANTERBURY CLOSE.
(IMPROPERLY REPRODUCED.)



From the top of a 'Buss.
Had the blockade been longer
My sketch had been stronger ~

(F)



PLATE IX — WESTMINSTER TOWERS.

R. F. F.



PLATE X—"THE OLD CURIOSITY SHOP."
TRAFALGAR SQUARE AT NIGHT.

Between the windows is printed in as large letters as possible: "The Old Curiosity Shop Immortalized by Charles Dickens." This was left out for obvious reasons.

Plate V. could have been greatly improved by cutting out the sky, foreground, awning, and some lights upon the buttresses, but it was left as it is to better illustrate the difference between the two processes.

The last drawing selected to illustrate these notes is a sketch, original size 4 in. \times 4 $\frac{5}{8}$ in. of a corner of Trafalgar Square, made one evening just before the long London twilight turned into night. It was very foggy, and, while not raining, the air was so full of moisture that umbrellas were a necessity. The rays from the street lights seemed to be stopped by the almost solid atmosphere, though the clock face of "Old Tom" in the Parliament House tower, being higher, showed as a clear circle. Landseer's granite lion at the foot of Nelson's monument seemed like polished ebony in silhouette against the grey sky, and the people went hurrying by—the only loafers being two men, one of whom was a policeman. On such a night as that no one could be charged with negligence even if he did leave his sketching traps at home, yet when I saw this effect I lost interest in "The Yeoman of the Guard" (and the Gaiety Theater, I think it was) and felt that to make a sketch suggesting the scene and the circumstances was the only thing to be done. But pockets were empty—excepting my pen, and all the paper available was the wrapper about a book just purchased. This paper was the dark greyish-brown kind which seems to be universal in London. It proved to be just the right tone and a touch of the pen showed the ink to be in true contrast. I could have said then, but did not: Where, devotees of shiny white paper and B. B. (beastly black) pencils, are you now? What could you do, you who wade in the mud of Sepia, or smirch good paper with the end of a "charred log of wood"? For once the fates were with me and my hobby—the material and the method should depend upon the subject. My wrapping paper and my Waterman were enough for me. But, fearing that some one may have read the preceding with care, I must add that the whites were put in after I got home.

STANDARD METHODS OF TESTING PAVING BRICK.

BY ARTHUR N. TALBOT, PROFESSOR OF MUNICIPAL AND SANITARY
ENGINEERING.

The extensive use of brick for street paving purposes in our interior cities has made the adoption of standard methods of testing paving brick a matter of interest alike to engineers and manufacturers. The present diversity of practice does not permit an accurate understanding of the requirements of any set of specifications.

"Best paving brick" and "To the satisfaction of the engineer" are not sufficient. Rattler tests with miscellaneous foundry scrap will not permit a comparison of the results of tests by different engineers. Manufacturers who have to deal with many municipalities are entitled to know exactly what grade of brick is wanted, and specifications should be definite and precise and the tests should be made by uniform methods. In discussing methods it must be borne in mind that tests must be largely relative or comparative, and that they are made in order to secure materials with the same properties as brick in pavements which have stood the test of time and also to insure obtaining materials as good as the samples submitted by the bidder before the contract was let.

To make a durable pavement, brick must have, to the requisite degree, toughness and hardness, strength, and imperviousness to liquids. Acceptable methods of testing paving brick must be easy and convenient to make and must give similar results when repeated, and the apparatus must be easily and cheaply duplicated anywhere. Such tests must determine the qualities of the brick, must distinguish soft from hard, and brittle from tough, and must do justice to both large and small brick.

The test commonly used to determine toughness and hardness is known as the rattler test, or impact and abrasion test. Abrasion machines are unsatisfactory, because they do not include a test of the impact effect. The rattler test gives the impact

and abrasion effect, but there is such a great variation in size of rattler, in speed and duration of test, and in the amount and kind of foundry shot used that the adoption of a uniform method and uniform conditions becomes a matter of great importance.

Two societies have had under consideration for three or four years the matter of standard tests of paving brick—the Illinois Society of Engineers and Surveyors and the National Brick Manufacturers' Association. The committee of the National Brick Manufacturers' Association, known as the Commission on Paving Brick Tests, made a very comprehensive set of tests and secured a large amount of valuable data. Their work is certainly a valuable contribution to engineering literature. A recommendation of the Commission, adopted by the Association, was that the rattler test be made the principal test, and that it be made without foundry shot; i. e., with a charge of brick alone. Among the specifications adopted are the following: That the standard rattler shall be 28 inches in diameter and 20 inches in length, but that machines having diameters between 26 and 30 inches, and lengths from 18 to 24 inches may be used; that the cross section of the barrel shall be a regular polygon of from twelve to sixteen sides; that the shaft shall not extend through the chamber; that the charge shall consist of a number of brick of one kind nearest equal in bulk to 15 per cent of the bulk of the rattling chamber; that the per cent of loss of weight be determined for 1800 revolutions at a speed of 30 revolutions per minute; and that the average of two distinct and complete tests made on separate charges of brick shall be used as the official result.

The efforts of the Illinois Society of Engineers and Surveyors have been to secure the adoption of some standard form and amount of foundry shot which may easily be exactly duplicated and which will give the proper relation between the impact and the abrasion effect, in place of the miscellaneous foundry scrap so commonly used. Favorable consideration has been given to the shot used by the writer in the Laboratory of Applied Mechanics of the University of Illinois, in tests made for the Department of Public Works of Chicago, and known as the University of Illinois standard. This standard shot consists of cast-iron blocks of two sizes, a larger size, $2\frac{1}{2} \times 3\frac{1}{8} \times 5\frac{1}{4}$ inches, with edges rounded to $\frac{1}{2}$ -inch radius, weighing about eight pounds each, and a

smaller size, $1 \times 1\frac{1}{2} \times 2\frac{1}{2}$ inches, with rounded edges, weighing about one pound each. After experimenting with various mixtures, a mixture of even parts of large and small blocks was chosen. A large proportion of 8-pound shot gives too great impact action and a smaller proportion gives too little. 7 to 10 per cent of the volume of the rattling chamber may be occupied by the shot. For the 24×36 -inch rattler, 150 pounds of 8-pound shot and 150 pounds of 1-pound shot makes a good charge.

Space does not permit of a description of the data obtained in determining the limits of variation with this test, but the range of conditions giving quite uniform results is quite wide in reference both to speed and to size of rattler. An advantage in the use of the iron mixture is that a few bricks or several may be tested without affecting the conditions materially. Thus, for the charge and size of rattler above mentioned, from 5 to 14 bricks may be tested at one time and the percentage of loss will remain nearly constant. This method easily distinguishes soft and brittle brick, and is fair to large as well as to small brick. The writer is of the opinion that the use of a standard amount of a standard form of cast-iron shot such as that used in the tests at the University of Illinois and mixed in such proportions as to give a proper relation between the impact and the abrasion action offers the best method of making the rattler test on the score of convenience, fairness, ease of securing standard material, detection of soft brick and measurement of toughness and ability to stand both impact and abrasion. The National Brick Manufacturers' Association Commission abandoned the use of cast-iron shot on the ground that the impact effect exceeded the abrasion effect; that the wear and tear on the rattler was prohibitory; and that the results did not give a good characteristic curve. It is to be regretted that this decision was reached on such meager data and that a second form of foundry shot was not used. With the shot herein described, the abrasion effect is sufficiently marked, the wear on the machine is not excessive, and the characteristic curves are regular and uniform as shown by the curves illustrated in this article.

However, the general adoption of a uniform method of testing paving brick is of such importance to engineers and manufacturers

that the particular method selected is not essential, provided it fulfills the requirement of uniformity, fairness and thoroughness. If the National Brick Manufacturers' Association standard is satisfactory in these respects, the writer is quite willing to aid in securing its general adoption. The objections made to this method are that it requires a large number of brick for the test, too many to detect lack of uniformity if averages be taken; that a slight decrease in the number of brick below the number required to make 15 per cent of the volume will seriously affect the results of the test; and that the method will not sufficiently distinguish soft and brittle brick. The last objection, if found to be true, would show a serious defect in the method.

To find whether the rattler test of the National Brick Manufacturers' Association does sufficiently distinguish differences in texture of brick known to be different in character, and also to compare the results of this method with those obtained with the standard cast-iron shot of the University of Illinois, a series of tests was made in the Laboratory of Applied Mechanics.

Four kinds of brick were used. Brick No. 1 was a repressed shale paver selected from the product of one of the best known manufactories, and an excellent brick. Brick No. 2 was also a repressed shale paver of excellent qualities. Brick No. 3 was a surface clay brick, well burned and a good article. It may be said, however, that its structure, appearance and wear, and also its life in pavement under ordinary conditions, go to show that it is inferior to Brick No. 1 and Brick No. 2. Brick No. 4 may be ranked as a high-grade sewer brick or building brick. All were selected by the makers, and as the individual bricks were weighed during the tests, their uniformity is known from the data collected. The size of Brick No. 1 is $2\frac{1}{2} \times 3\frac{7}{8} \times 8\frac{1}{8}$; of Brick No. 2, $2\frac{7}{8} \times 3\frac{7}{8} \times 9\frac{1}{4}$; of Brick No. 3, $2\frac{1}{8} \times 3\frac{5}{8} \times 7\frac{5}{8}$; and of Brick No. 4, $2\frac{1}{8} \times 3\frac{7}{8} \times 7\frac{3}{4}$. The absorption test gave the following amounts in 48 hours, only rattled brick being used for the test: Brick No. 1, 0.5 per cent; Brick No. 2, 2.2 per cent; Brick No. 3, 3.0 per cent; Brick No. 4, 4.7 per cent.

The rattler used was the 24 × 36-inch rattler of the Laboratory of Applied Mechanics of the University of Illinois. A movable partition allowed this to be shortened to 18 inches. Although this diameter is 2 inches less than the minimum allowed by the

Manufacturers' recommendation, the variation will not affect the comparison made in this discussion.

Each make of brick was tested by the Manufacturers' test; i. e., without foundry shot and with a charge of brick equal in volume to 15 per cent of the volume of the rattler. Experiments were made both with the full length rattler and with a length of 18 inches. The speed was about 30 revolutions per minute.

Each make of brick was also tested with the form of shot known as the University of Illinois standard, cast-iron blocks, $1 \times 1\frac{1}{2} \times 2\frac{1}{4}$ inches, and $2\frac{1}{2} \times 3\frac{1}{8} \times 5\frac{1}{4}$ inches, with rounded corners and edges as described in THE TECHNOGRAPH No. 10. For the full rattler, 150 lb. of the large and 150 lb. of the small shot were used, and for the 18-inch length, one half of this amount. The speed was about 20 revolutions per minute. Twelve bricks were used in the full rattler and six in the half length.

The brick were weighed at the end of 200, 400, 600, 800, 1 000, 1 500 and 1 800 revolutions. The results have been platted and are shown in Diagram I, page 21, the abscissas representing the number of revolutions and the ordinates the per cent of loss in terms of the original weight. It will be noted that the curves, now generally called characteristic curves, are quite similar, and that the Manufacturers' curve is above the Illinois curve in Brick No. 1 and Brick No. 2, crosses it in Brick No. 3, and is below it in Brick No. 4. To make a comparison of the two methods, Diagram II was constructed. The loss of Brick No. 1 was taken as unity, and the losses of the others were expressed in terms of this and platted as shown.

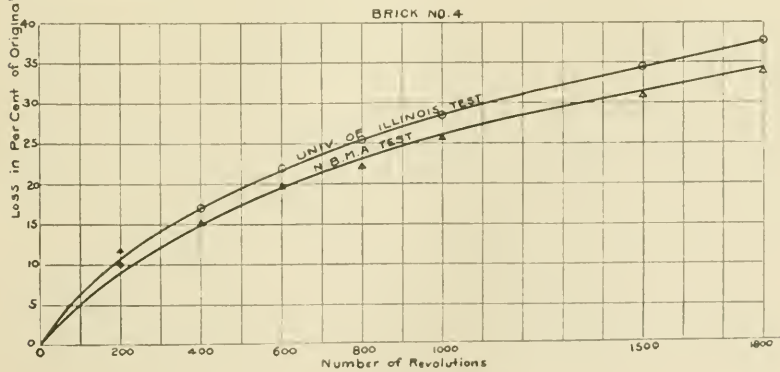
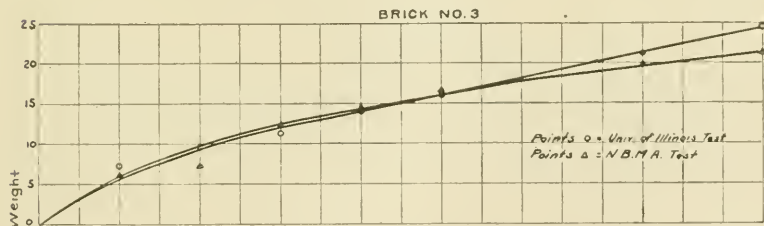
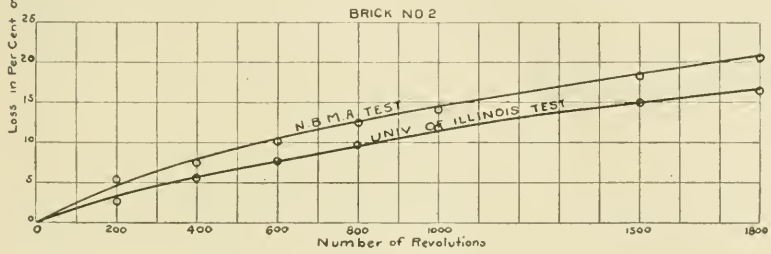
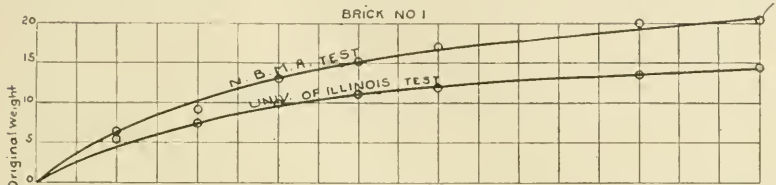
Two things may be seen from Diagram II, page 22:

1. The Manufacturers' test makes Brick No. 3 as good as No. 1 and No. 2, when, as has been stated, it is manifestly inferior.
2. The loss in Brick No. 4, which is unfit for pavement, is much less distinctly marked in the Manufacturers' test than in the Illinois test.

If these conclusions are borne out with other makes of brick, the Manufacturers' test has serious defects. It does not sufficiently distinguish between hard and tough brick and soft and brittle brick. A satisfactory method of testing paving brick must show the difference between bricks of the nature of No. 1 and No. 2. and such as No. 3, and will make a more marked distinction between bricks like No. 4 and hard and tough bricks.

DIAGRAM I.
 RATTLER LOSSES OF BRICK.

COMPARISON OF UNIVERSITY OF ILLINOIS AND NATIONAL BRICK MANUFACTURERS' ASSOCIATION STANDARD TESTS.



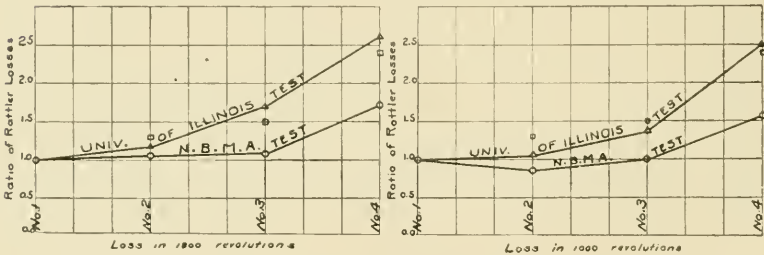
The ratios of the reciprocals of the moduli of rupture of the different makes to that of Brick No. 1 are shown in Diagram II, by the points enclosed in squares. It will be seen that these ratios increase much as the ratios of rattler loss by the Illinois standard. The values of the moduli of rupture were the averages of five brick, and there was no great variation in individual cases.

The tests described above were verified partly by repetition and partly by comparison with results obtained with the same brick heretofore, and it is thought they are representative of the makes of brick used. It may be added that in the Manufacturers' test, a charge of soft brick soon broke, and thereafter the loss was much lighter. In general, the impact effect of the test was insufficient to test the toughness of the brick. The results are quite different from those anticipated by the writer.

DIAGRAM II.

COMPARISON OF RESULTS.

RATIO OF RATTLER LOSSES TO LOSS OF BRICK NO. 1.



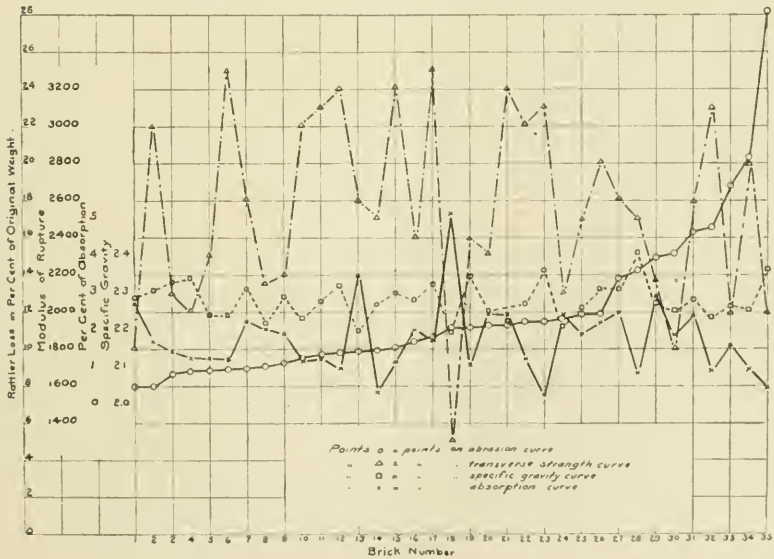
While the tests described are not extensive enough to warrant rejecting the standard method of the National Brick Manufacturers' Association, they show that the method should not be adopted without further investigation. It is hoped that engineers having opportunities to make such tests will contribute to the general knowledge of the subject. If these results shall prove to be representative, the method of using a charge of brick alone can not properly be adopted as a standard by engineers.

The recommendation of the National Brick Manufacturers' Association abandoning the absorption test and not recommending the cross-bending test will not be acceptable to engineers. It is true that the limit of absorption has frequently been placed too

low, that overburned brick are as bad as underburned, and that uniformity of brick is more important than low absorption. With a moderately low limit, as 3 or 4 per cent, and a definite time of say 48 hours, brick which pass the rattler requirement but which have high absorptive qualities would be cut out. The cross-bending test adds another precaution. The results are indicative of shearing and crushing strength—qualities which are necessary in a pavement having heavy traffic. It takes the place of the crushing test, which is difficult to make.

As a matter of interest on the topic of tests of paving brick, Diagram III, page 23, is presented. The data are from tests made in the Laboratory of Applied Mechanics of the University of Illinois, on thirty-five makes of paving brick from Ohio, Indiana, Illinois, Iowa and Missouri. They are platted in the order of loss by the rattler test, the different properties of the same brick being shown on the same vertical line. These may be said to be picked brick, and among them are the best paving brick of the country. It will be seen that while there is a considerable variation in the modulus of rupture, in a general way the value decreases as the rattler loss increases.

DIAGRAM III.
RESULTS OF TESTS OF PAVING BRICK.



THE EFFECTS OF TEMPERATURE ON INSULATION MATERIALS.

BY WILLIAM ESTY, ASSISTANT PROFESSOR OF ELECTRICAL ENGINEERING.

The tests described below form a part of a thesis investigation made last year under the direction of the writer in the electrical laboratory of the University of Illinois by Messrs. M. E. Chester and C. V. Crellin of the Class of 1897. During the progress of the experiments many valuable suggestions were offered by Dr. A. P. Carman.

The proper insulation of electrical conductors and apparatus is of the utmost importance to successful operation, and therefore the behavior of insulating materials under different physical conditions is of great interest to the electrical engineer.

The electrical properties of any material may be determined by tests upon insulation resistance, and its behavior under the disruptive influence of high voltages. On the other hand, its physical properties may be investigated by means of hygroscopic, temperature, bending, and pressure tests. The former qualities are known to depend largely on the latter, and in testing any material, the specific conditions under which it is used, should be reproduced as closely as possible. The influence of temperature and of the amount of moisture present is perhaps the most important.

Whenever in the operation of electrical apparatus there is a loss of electrical energy, it appears in the form of heat, which affects insulating substances by contracting, expanding, charring, burning, and disintegrating them according to the degree of heat and the character of the insulating material employed. Thus in the normal running of dynamo-electric machines, heating of the parts is always present to a greater or less extent, but if kept within certain well defined limits is not of serious consequence. There is, nevertheless, the possibility that at any time an overload, a short-circuit, or a ground may occur which will cause

abnormal and excessive heating of the armature and field coils, hence it is necessary in constructing these machines to provide such insulation of the conductors, cores, etc., as will withstand high temperatures. Great progress has been made in the insulation of electrical machinery and apparatus, but until recently no scientific investigations on insulation appear to have been published. Mr. C. P. Steinmetz has made a valuable contribution to the subject in his paper read before the American Institute of Electrical Engineers, on "The Disruptive Strength of Dielectrics."* Mr. T. T. P. Luquer has published † results of tests showing effects of moisture on silk and cotton covered wires, and Messrs. Canfield and Robinson have described some tests on disruptive strengths of insulators. ‡

It is quite well known that the resistance of insulating materials, in general, decreases with a rise in temperature, but until recently no definite measurements have been published, showing the relative change of resistance with temperature.

At the May meeting of the Institute of Electrical Engineers in 1896, Messrs. Sever, Monell and Perry presented a paper giving results of tests "On the Effect of Temperature on Insulating Materials." § In the discussion which followed, Mr. C. F. Scott quoted the results of some tests made by Mr. C. E. Skinner of the Westinghouse Co., which, in some respects, were contradictory to those of the previous paper. Messrs. Sever, Monell and Perry, for example, obtained a maximum insulation resistance for paper and cloth at about 75° C., while Mr. Skinner found the resistance to be a minimum at about the same temperature. The discrepancy in these results would seem to be due to the difference in the conditions of the tests, which could be accounted for by the difference in the forms of apparatus used, one allowing the escape of moisture more rapidly than the other. Mr. Skinner placed the material to be tested between two cast-iron plates 10 inches in diameter, while the other experimenters wrapped the insulation around a brass cylinder three fourths inch in diameter and three inches long, and then wound it with a number of turns of bare copper wire. The moisture would evidently have a better

* *Trans. Am. Inst. Elec. Eng.* Vol. x, p. 85, (1893).

† *Electrical Engineer*, Vol. xiv, p. 613, Dec. 28, 1892.

‡ *Electrical Engineer*, Mar. 28, 1894.

§ *Trans. Am. Inst. Elec. Eng.*, Vol. xiii, p. 223.

chance to escape quickly in this apparatus than when the material was confined between large plates. The form of the curve would also depend on the rate of heating, but this was about the same for the two cases, being from 100° C. to 120° C. in 30 minutes.

The present tests were undertaken with a view to adding to the rather limited data on the subject, for which purpose average samples of the ordinary insulating materials used in the construction of electrical machinery were obtained from the leading electrical manufacturing companies.

APPARATUS.

The heating apparatus consisted of an oil bath which completely surrounded a cast-iron box in which the material under test was placed. Ordinary cylinder oil was used for the bath which was contained in a cast-iron vessel and heated by three Bunsen burners. The lid of the iron box was held down by six one fourth inch cap-screws; the surfaces of the joint were faced, and a packing ring of manilla paper was used to make the joint tight. The leads were brought out through short iron tubes screwed into the lid and the thermometer was introduced through a third tube at the center of the lid. The arrangement is shown in Fig. 1, which gives a cross-section of the complete apparatus.

The above method of heating was adopted in preference to the more usual electrical method, because it was thought that the temperature could be maintained more accurately where there was no chance for sudden variations in temperature.

The material under test was placed between plates as shown in the figure. The plates were made of steel, one fourth inch thick and accurately ground so as to present a smooth, plane surface for contact. The lower plate was six inches in diameter and the upper one four and one half inches. The latter was surrounded by a ring of the same material one half inch wide, an air space of a quarter of an inch separating the ring and the plate. The object of the ring was to eliminate any error due to leakage over the surface and edge of the insulating material from one plate to the other. The ring was connected as shown in Fig. 2 so that the leakage current, if present, would be shunted around the galvanometer. The effect of leakage, however, was not no-

ticeable with the E. M. F. used in the tests, for no disconnecting the ring, no change in the galvanometer deflection was observed.

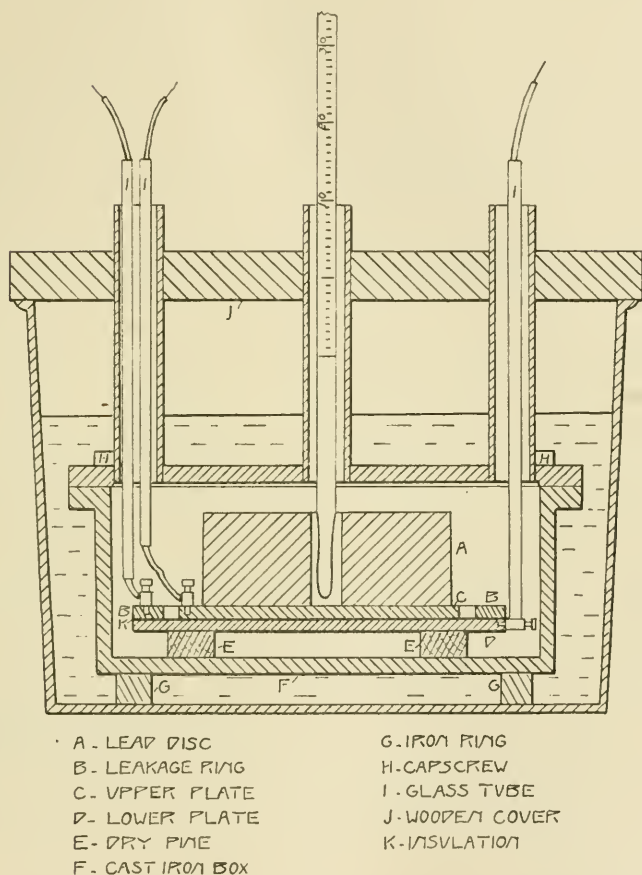


FIG. 1. CROSS SECTION OF HEATING APPARATUS.

The upper plate was held in close contact with the insulating material (which was cut into circular discs, four and one half inches in diameter and having an area of 16.14 sq. in.) by a lead disc weighing six pounds. It was found that if tin foil was placed between the plates and material, the contact was very much improved so that the same E. M. F. produced a larger deflection.

The plate device for obtaining contact with the insulating material was adopted in preference to the cylinder method

described on page 25, because it seemed probable that more uniform contact and pressure with the different specimens could be obtained in this way. The wire band would make contact only with a small part of the whole surface, and there would, moreover, be a tendency for the wire to embed itself in the insulating material, this tendency depending on the texture of the latter and on the tension of the wire when wound. The plates do not allow the escape of moisture so readily, but this is not objectionable because the rate of drying is only relative in any case, since it depends on the initial moisture present and also on the rate of heating.

For measuring the temperature of the insulating material two mercury thermometers were used, one graduated from 0° to 120° C., and the other from 0° to 200° C. The former was used for the first hundred degrees because its long stem enabled it to be read above the iron tube without raising it, (see Fig. 1). Moreover since its divisions were farther apart it could be read with greater accuracy, especially when the rate of change of resistance with the temperature was most rapid. When changing thermometers the one to be introduced was heated to about the temperature of the other, so that it soon gave a correct reading. The bulb of the thermometer was placed in contact with the upper plate through a hole in the centre of the lead weight. The bulb was thus closely surrounded by a mass of metal having approximately the same temperature as the insulating material between the iron plates.

A Thomson square-pattern reflecting galvanometer having a resistance, with all four coils in series, of 5 596 international ohms at 20° C. was used to measure the current passing through the material. An adjustable resistance box was used as a shunt to the galvanometer in order to reduce the larger deflections to readable amounts.

The source of E. M. F. first tried was a small 500-volt Edison motor run as a generator, but owing to the unsteadiness of the driving steam-engine and the consequent fluctuation of the dynamo E. M. F., the deflections of the galvanometer were erratic and unreliable. This action seemed to be due to the varying dynamo E. M. F. acting in conjunction with the electrostatic capacity of the insulated plates, which charged the galvanometer case and needle system with a static charge, and thus disturbed the normal deflections. Putting the galvanometer parts to ground would decrease the effect but not completely eliminate it.

Four hundred small lead accumulator cells of the Planté type, made for this work, were finally substituted for the dynamo and proved satisfactory.

All the apparatus was highly insulated to prevent any possible leakage current affecting the galvanometer. The latter, together with its shunt box, key, etc., was placed on plate glass. The reversing key in the galvanometer circuit consisted of a block of paraffine bored with holes and filled with mercury for the connections. All leads were made as short and direct as possible and suspended in air from glass rods. Quarter ampere fuses were inserted in the circuit to protect the apparatus in case of short circuit.

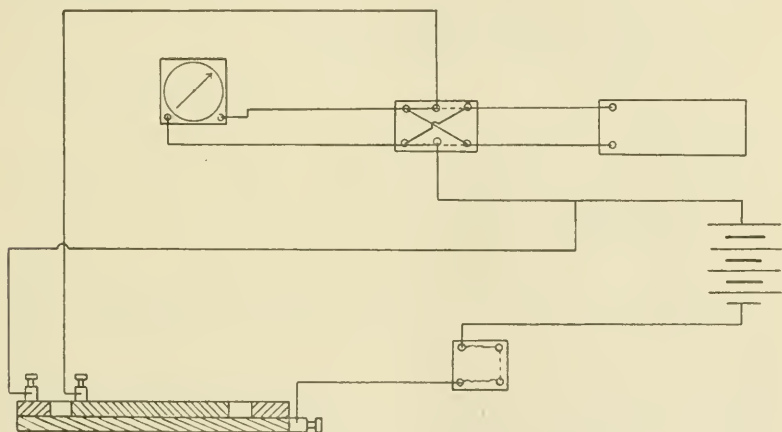


FIG. 2. DIAGRAM SHOWING CONNECTIONS.

METHODS OF TESTING.

The simple and direct method known as resistance measurement by substitution was used for measuring the insulation resistance of the different materials. The method involves two observations of the galvanometer deflection: (1) when a large known resistance is in circuit with the galvanometer, and (2) when the unknown insulation resistance is substituted for the known.

The connections, shown in Fig. 2, are so made that current can flow only by passing through the insulation to be measured; that is, the resistance to be measured is inserted in series with the galvanometer, battery, etc. Now, since the deflections of the

galvanometer are proportional to the currents flowing in the circuit, and since these currents for a given E. M. F. are inversely as the total resistances in the circuit at the time, it follows that the deflections give an inverse measure of the total resistances in circuit.

The formula used for the reduction of the observations to absolute resistance in megohms is given below :

$$X = \frac{E_x r m d}{E m_x d_x} *$$

* For deduction of the formula see page 00.

where X = insulation resistance of material in megohms ;

E = E. M. F. applied when known resistance is in circuit ;

r = known resistance in megohms ;

d = deflection when r is in circuit ;

$m = \frac{G+S}{S}$ = multiplying power of the shunt when r is in circuit.

G = resistance of galvanometer ;

S = resistance of shunt ;

E_x, m_x, d_x = the same quantities after X has been substituted for r .

Further, for the sake of better comparing the results of tests on the various kinds of materials, both among themselves and with those of other experimenters, the absolute resistances calculated as above, were reduced to "specific" or unit resistances. The unit of specific resistance chosen for this standard of comparison was megohms per sq. in. per mil of thickness, and is computed thus :

$$\text{Since Resistance} = \frac{\text{Specific Resistance} \times \text{Thickness}}{\text{Area}},$$

$$\text{we have} \quad \text{Megohms per sq. in. per mil} = \frac{\text{Total Resistance in Megohms} \times \text{Sq. In.}}{\text{Mils.}}$$

For example, in one test on Manilla paper at a certain temperature, the absolute resistance was found to be 324.8 megohms ; the thickness was .0077 in.; and the effective area (equal to that of the upper contact plate, see Fig. 2), was 16.14 sq. in., find its specific resistance.

By the equation above we have :

$$\text{Megohms per sq. in per mil} = \frac{324.8 \times 16.14}{7.7} = 682.5.$$

In the accompanying plates of curves the specific resistance as defined above is plotted as ordinates.

Two kinds of heating tests were made : (1) The material was heated from the temperature of the atmosphere up to 200° C., readings being taken about every five degrees up to 100° C., and thence upwards, every ten degrees ; (2) the material was heated up to 100° C., and readings taken every five degrees ; the box was then tightly corked and the insulation allowed to cool, readings being taken till the resistance became too high to measure. The insulation was again heated, after it had cooled down to atmospheric temperature, up to 200° C., thus bringing out the effects of moisture on the material.

It was found that the resistance depended a good deal upon the pressure to which the insulation was subjected, and some experiments were made along this line. The curves in Fig. 7 show this effect of pressure very plainly. It is difficult to say, however, just how much this decrease is due to the better contact with the plates, and how much to compression of the material. It would seem to be principally due to the latter effect because pressure had very little effect on paper whose pores were filled with oil.

The method of producing changes in the pressure applied was by placing cast-iron weights on top of the plates. Weights were added up to 200 pounds, and then decreased by steps to zero.

DISCUSSION OF TESTS ON MATERIALS.

PLAIN MANILLA PAPER.—After the resistance at the temperature of the air was carefully noted, the temperature was gradually increased at the rate of about 100° C. an hour. Curve A of Fig. 3 shows the results of the first test on this material. It rapidly dropped off from about 700 megohms at 20° C. to 2 megohms at 60° C. It then remained below this value till it reached 120° C., at which point it began to rise and remained between 20 and 30 megohms from here out to 200° C.

The next test on this same material, see Fig. 3, curve E, was to heat it up to 105° C., at which point the moisture was all driven

off. The resistance had fallen from 84 megohms at 20° C. to 0.13 megohms at 105° C. It was then allowed to cool and the resistance rose slowly till the temperature fell to 80° C., and then more rapidly, till it was 108 megohms at 62° C. (curve F). After it had cooled down to 24° C., it had a resistance of 3 129 megohms. It was again heated up as at first, and the resistance dropped rapidly and reached a minimum of 4 megohms at 120° C., again increasing from this point as in the first case, see curve G. The reheating curve G was similar to the curve A taken in the first case, Fig. 3, except that the drop was not as rapid, which shows that when moisture is present, the resistance drops much more rapidly and reaches a minimum at 60° C. If the material is dry this minimum is at 120° C.

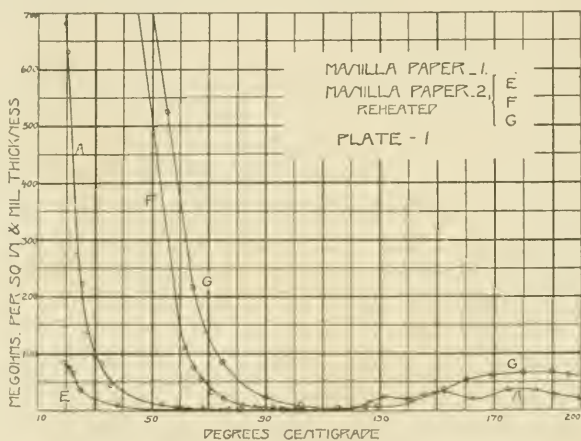


FIG. 3. RESISTANCE OF MANILLA PAPER.

OILED PAPER.—Two samples of oiled paper were tested in the same manner and gave the same form of curve as the dried Manilla paper, except that it continued to decrease steadily to 200° C. (Fig. 4, curve A), but gave practically the same resistance at 110° C. as the dry paper. On cooling (curve not shown), it increased, following about the same curve as when it decreased, but it did not rise so quickly. On reheating, the resistance came down in practically the same curve as it did on the first heating, which seems to show that oiled paper does not absorb moisture as rapidly as plain paper, and in cooling it does not recover immediately its former resistance.

PLAIN COTTON DUCK CANVAS.—Two samples of this material were tested and they gave the same general results and form of curve as the plain paper. (Fig. 5, curve A.)

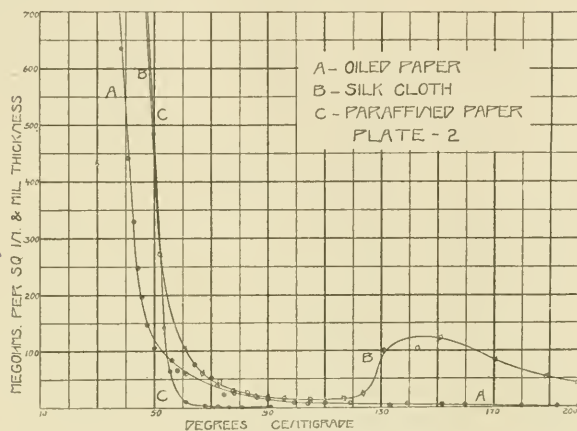


FIG. 4. RESISTANCE OF PAPER AND CLOTH.

SHELLACED CANVAS.—This was a sample of the plain canvas well saturated with shellac. Its curve dropped off the same as before but continued to decrease up to 200° C., as in the case of oiled paper. The application of shellac did not seem to increase the resistance at all, but lowered the specific resistance. (Fig 5, curve B.)

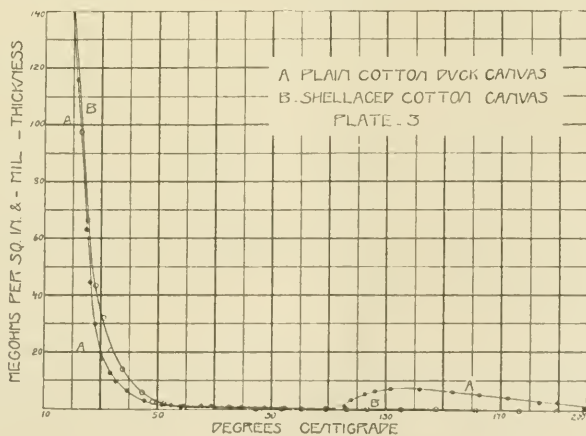


FIG. 5. RESISTANCE OF CANVAS.

HEAVY LINEN CLOTH.—This showed results similar to the cotton duck in that its resistance came down much slower on reheating (curve B, Fig. 6), dropping from 10 290 megohms at 48° C. to 1.7 at 100° C., while before reheating it had a resistance of only 40 megohms at 48° C. (curve A, Fig. 6). From this action then it is evident the moisture factor was very prominent.

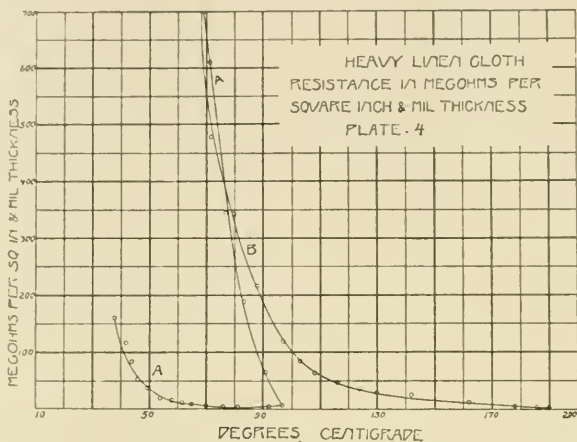


FIG. 6. RESISTANCE OF LINEN CLOTH.

SILK CLOTH.—This gave the same general form of curve (Fig. 4, curve B) as the duck canvas, but showed a much higher specific resistance, and decreased more slowly in heating. At 20° C. it had a specific resistance of 16 800 megohms, and at 106° C. it had dropped to 11 megohms.

MUSLIN CLOTH.—This showed a lower resistance, at 20° C. of 20 megohms, and from 48° to 110° C. it remained below 2 megohms, and at 110° C. it began to rise till at 140° C. it was 240 megohms, and then it rapidly decreased till it was 12 megohms at 200° C. (Curve not given.)

PARAFFINED PAPER.—This showed a very high initial resistance at 20° C., which could not be measured till it was at 38° C. It then dropped off very rapidly to 60° C., the melting point of the paraffine. (curve C, Fig. 4.)

EFFECTS OF PRESSURE ON INSULATION RESISTANCE.

The effect of pressure was tried upon Manilla paper, oiled paper, and cotton duck canvas, but the curves for the latter only are given. See Fig. 7.

The plain paper had a resistance of 5 600 megohms with 0.5 pound pressure, and with 88 pounds pressure it was 470 megohms, and from this point on it decreased slowly to 300 megohms with 200 pounds pressure.

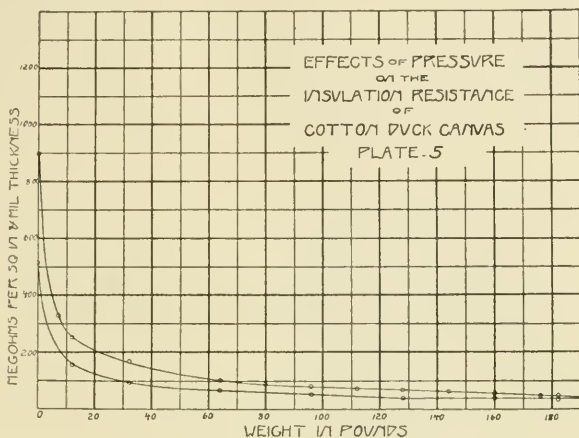


FIG. 7. EFFECTS OF PRESSURE.

The following table is arranged to facilitate comparison between the various materials tested:—

TABLE I.

VARIATION OF SPECIFIC RESISTANCE OF VARIOUS MATERIALS WITH TEMPERATURE.

| MATERIAL. | TEMPERATURE IN DEGREES CENTIGRADE. | | | | | |
|-----------------------------|------------------------------------|--------------|-------|-------|-------|-------|
| | 20 | 40 | 60 | 100 | 140 | 200 |
| Silk cloth..... | 16 860 | 2 200 | 120 | 11 | 102 | 40 |
| Oiled paper..... | 16 580 | 500 | 60 | 8.5 | 5 | 0.4 |
| Oiled paper, reheated... | 34 000 | 550 | 70 | 2.4 | 0.6 | 0.3 |
| Manilla paper, 1..... | 682 | 40 | 4 | 0.8 | 25 | 22 |
| Manilla paper, 2..... | 84 | 9 | 1.4 | 0.13 | ..... | ..... |
| Manilla paper, 2, reheated | 5 000 | 2 000 | 300 | 10 | 16 | 61 |
| Canvas, 1..... | 160 | 6.6 | 1.5 | 0.5 | 7 | 1.4 |
| Canvas, 2..... | 40 | 2.7 | 0.5 | 0.16 | ..... | ..... |
| Canvas, 2, reheated . . . | 2 000 at 31 | 304 | 20 | 3 | 5.5 | 2 |
| Canvas, shellaced..... | 146 | 12 | 1.1 | 0.17 | 0.6 | 12 |
| Linen cloth..... | ..... | 120 | 12 | 6.0 | ..... | ..... |
| Linen cloth, reheated . . . | ..... | 10 290 at 48 | 1 200 | 100 | 20 | 1 |
| Muslin..... | 25 | 5 | 2.3 | 2 | 236 | 20 |
| Paraffined paper..... | ..... | 12 980 | 9 | ..... | ..... | ..... |

In removing the weights in the same order in which they were put on, the resistance did not attain its initial value for the same pressure.

Cotton duck canvas showed about the same results as the plain paper, the curve, however, dropping more rapidly at first. Curve A, Fig. 7 shows the effect of adding weights, while curve B that of diminishing the pressure.

Oiled paper differed from both the preceding in that it showed but little variation in resistance with pressure.

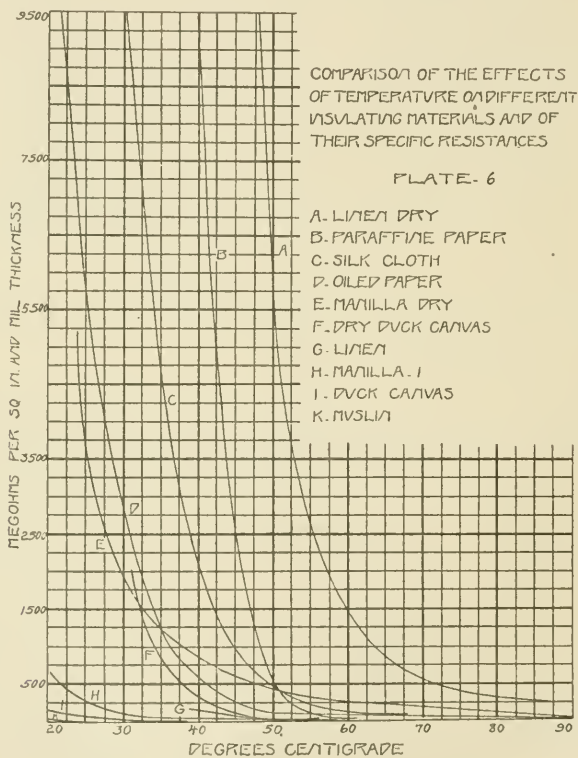


FIG. 8. COMPARISON OF RESISTANCES.

The comparison of the specific resistance of the different materials, showing their relative values under the ordinary working temperatures obtaining in practice, i. e., from 20° C. to 90° C., is most clearly shown by the curves of Fig. 8.

These show that they have fallen comparatively low at 60° C., a fact of special significance, as this is the ordinary working temperature of electrical machinery. It must be remembered, however, that high resistance, as we have been considering it, is not the only important quality of insulation, for its ability to stand high potentials without breaking down, is of equal, if not greater importance. Insulation may offer a high resistance to leakage and at the same time have a low disruptive strength, or vice versa. This distinction between the qualities of an insulating material suitable for practical construction purposes was well brought out by Mr. Steinmetz in the discussion of the paper already referred to.* He said: "In medium potential circuits, as, for instance, the primaries of alternating circuits, disruptive strength is generally of much greater importance than insulation resistance, and as I have shown in a previous paper, † these two qualities do not always go together, but high disruptive strength may be combined with comparatively low insulation resistance, as in mica, or inversely, as in air. In disruptive strength, pure mica ranges above fibre and all other organic substances. When coming to very high voltages, as in long distance transmission, still another phenomenon becomes of importance, which again changes the relative value of insulating materials, namely, surface leakage. Mica, for instance, while very good indisruptive strength, is not very satisfactory to guard against surface leakage, but a high potential will leak or creep over quite a long distance of mica or porcelain surface, while organic compounds are frequently much superior in this respect. Thus insulating materials can not be discussed generally in their relative value, but only with regard to the practical application they have to meet."

Coming back now to the curves in Fig. 8, they together with other similar curves obtained but not there shown, indicate that the treated materials, like oiled and paraffined paper, have a smaller insulation resistance than the untreated fibrous substances when at a temperature of about 60° C. From this fact the conclusion might be drawn that it is worse than useless to employ materials other than those of a dry, untreated, fibrous nature. It is well recognized, however, that reliability is the prime consid-

* *Trans. Am. Inst. Elec. Engs.*, Vol. xiii, p. 230.

† *Ib.* Vol. x, p. 85.

eration in the choice of an insulating material, and since the untreated substances are hygroscopic, they become unsafe to use under the variations of temperature and humidity to which electrical machinery is exposed in practical operation. Hence, treatment with oil, Japan, paraffine, or shellac, etc., fills the pores of the dry untreated materials, and renders them less likely to absorb moisture.

The above effects are plainly illustrated by the curves in Fig. 5 and 8, but more extended experiments showing the effects of absorbing moisture,* and the influence of moisture and temperature on disruptive strength, would be of great interest and value. It would also be of interest to have further data on the deteriorating effect of continued heating and cooling on materials.

CONCLUSIONS.

From the foregoing tests the following conclusions may be drawn:

1. The insulation resistance of untreated fibrous materials, such as paper and cloth, decreases at first on being heated up, and then increases when the moisture is expelled.
2. Materials show a much higher resistance after being dried, and the resistance does not decrease so rapidly.
3. Treated materials, such as oiled paper, shellaced canvas, etc., decrease in resistance with increase in temperature, reaching even a lower value than when untreated, but do not increase again.
4. On cooling, the resistance increases rapidly because the moisture is expelled, and on reheating, it follows the curve of cooling.
5. When moisture is present, heat has a more pronounced effect, and brings the resistance down at a much lower temperature, and the rate of decrease depends upon the rate of heating, or on the rate at which moisture is expelled.
6. Insulation resistance means very little unless the physical conditions of the materials and the methods of testing are known.

* Since these experiments were completed, a further contribution to this subject was made by Messrs. Bates and Barnes in their paper on "The Effect of Heat on Insulating Materials," which was read July, 1897, before the Am. Inst. of Elec. Eng. (Trans. A. I. E. E., May '97, p. 214, discussion ib. Oct. '97, p. 429.)

APPENDIX.

The deduction of the formula used on page 30 for reducing the galvanometer deflections to insulation resistances is given below.

Using the same notation as on page 30, and putting B =battery resistance, the current corresponding to one division of the unshunted galvanometer deflection is

$$C_1 = \frac{E}{(G+r+B)d} = \frac{E_x}{(G+X+B)d_x}$$

If, now, the galvanometer be shunted, the equivalent unshunted deflection would be

$$C_2 = \frac{E}{\left(\frac{GS}{G+S} + r + B\right) \frac{G+S}{S}} \cdot d = \frac{E_x}{\left(\frac{GS_x}{G+S_x} + X + B\right) \frac{G+S_x}{S_x}} \cdot d_x$$

Let $\frac{GS}{G+S} = G^1$, $\frac{GS_x}{G+S_x} = G_x^1$, $\frac{G+S}{S} = m$, and $\frac{G+S_x}{S_x} = m_x$

then

$$\frac{E}{(G^1+r+B)md} = \frac{E_x}{(G_x^1+X+B)m_xd_x}$$

from which

$$X = \frac{E_x (G_x^1+r+B) m d}{E m_x d_x} - G_x^1 - B$$

Further, if G^1 , G_x^1 , and B are negligible in comparison with r and X ,

$$X = \frac{E_x r \cdot m \cdot d}{E \cdot m_x \cdot d_x}$$

The product $r m d$ in the numerator is called the "constant" of the galvanometer, for during the time of an ordinary test, the sensitiveness of the galvanometer is assumed constant. The readings for calculating the constant were made at the beginning of each test, but of course would vary from day to day, due to the changes in the earth's magnetic field.

An example showing how the foregoing formulas were applied to reduce deflections of the galvanometer to megohms resistance, is added for the sake of clearness.

A test of one sample of Manilla paper gave the following data :

For galvanometer constant

$$\begin{aligned} E &= 51.5 \text{ volts,} \\ S &= \text{infinity,} \\ d &= 309 \text{ m. m.} \\ r &= 4.66 \text{ megohms,} \end{aligned}$$

From which we calculate the constant

$$K = \frac{r m d}{E} = \frac{4.66 \times 1 \times 309}{51.5} = 28$$

For unknown insulation resistance:

$$\begin{aligned} E_x &= 290 \text{ volts,} \\ S_x &= 1\ 000 \text{ ohms,} \\ d_x &= 410 \text{ m. m.,} \\ m_x &= \frac{G_x + S_x}{S_x} = \frac{5\ 600 + 1\ 000}{1\ 000} = 6.6 \end{aligned}$$

$$\text{Hence: } X = K \times \frac{E_x}{m_x d_x} = \frac{28 \times 290}{6.6 \times 410} = 3.01 \text{ megohms.}$$

Calculation of Specific Resistance : —

Effective area = one surface of upper plate = 16.14 sq. in..

Thickness of sample = 7.7 mils,

Total resistance = \dot{X} = 3.01 megohms.

Hence: Resistance per sq in. per mil =

$$\frac{3.01 \times 16.14}{7.7} = 6.3 \text{ megohms.}$$



PLATE I—REAR VIEW OF BOILER HOUSE.

THE BUILDINGS OF THE ELECTRICAL AND MECHANICAL ENGINEERING LABORATORY, AND CENTRAL HEATING PLANT.

BY SETH J. TEMPLE, ASSISTANT PROFESSOR OF ARCHITECTURE.

The proper housing of the University heating and power station to give it the efficiency of a modern commercial plant, and at the same time to treat it as a laboratory for the use of students in Mechanical and Electrical Engineering, is the problem presented for consideration.

The requirements of such a station were: (1) A boiler house of sufficient size to accommodate the estimated future needs of the University for a generation; (2) a smoke stack large and high enough to furnish sufficient draft for burning a cheap grade of soft coal when the boiler house shall be used to its full capacity; (3) an engine room and a dynamo room into which may be collected all the engines and dynamos previously scattered in the different buildings, and which may form laboratories in place of the dynamo laboratory in the main building and the steam engineering laboratory in the old shops; (4) a storage battery room, tool and stock rooms, private laboratories, experiment rooms, studies, offices, and all such rooms as may be needed to properly equip both the commercial and educational functions of a plant of this kind.

The site determined upon was the lowest ground on the University land, situated north of Boneyard Branch and east of Burrill avenue.

THE ELECTRICAL AND STEAM ENGINEERING LABORATORY.—The electrical and steam engineering laboratory is two stories in height and has a frontage of one hundred feet on Burrill avenue and a depth of fifty feet, with a wing fifty feet wide which runs back one hundred feet. For a half-tone plate of the building, see the frontispiece. The main entrance consists of a flight of semi-circular steps leading to a students' door in the basement and a double flight of stone steps, guarded by wrought iron railings, leading to the entrance on the main floor.

The basement is occupied by an electrical engineering testing room, a mechanical engineering tool room, a storage battery room, a stock room, and a toilet and locker room. A broad stairway leads to the main floor and arrives with the arched entrance to the dynamo laboratory on the right, a similar entrance to the steam engineering laboratory on the left, and a window in front looking toward a marble switch-board. The dynamo laboratory occupies the entire front of this building, and has a clear floor space fifty by one hundred feet and is lighted on all sides by thirteen large windows. At the south end of this room low paneled partitions and wire railings form machinists' and students' work rooms, instrument rooms, experiment and tool rooms. See Fig. 1, page 43.

A gallery across the west end of the steam engineering laboratory overlooks the electric plant. This laboratory has the same area as the other. The upper story of this building is occupied by class rooms, photometry rooms, laboratories and offices.

The laboratory building is constructed throughout of solid brick walls upon brick footings laid in cement. The walls are faced upon the outside with a dark brown flashed brick made by the Illinois Hydraulic Press Brick Company at Collinsville, Illinois; the black brick forming the diaper pattern in the frieze were made by the same company at St. Louis. The door and window architraves and string courses are of terra cotta. The walls of the basement and first story are lined with buff Roman brick laid in white mortar. The entire basement floor is of cement. The floors above are supported upon steel girders and yellow pine beams, and consist of three-inch yellow pine tongued and grooved mill flooring and seven eighths-inch finished flooring. The beams and floors are left exposed on the under side and are finished to form the ceilings of the rooms beneath. The floors are capable of carrying a load of twenty-five hundred pounds per square foot. The entire upper story and roof is supported by six steel trusses of the Fink type. The floor and partitions are suspended by two steel rods attached to each truss. The ceiling joist are carried directly upon the horizontal lower chords. All the rooms on this floor are lathed, plastered and finished in Washington fir.

The roof of the steam engineering laboratory is supported upon eight exposed steel Fink trusses with horizontal chords.

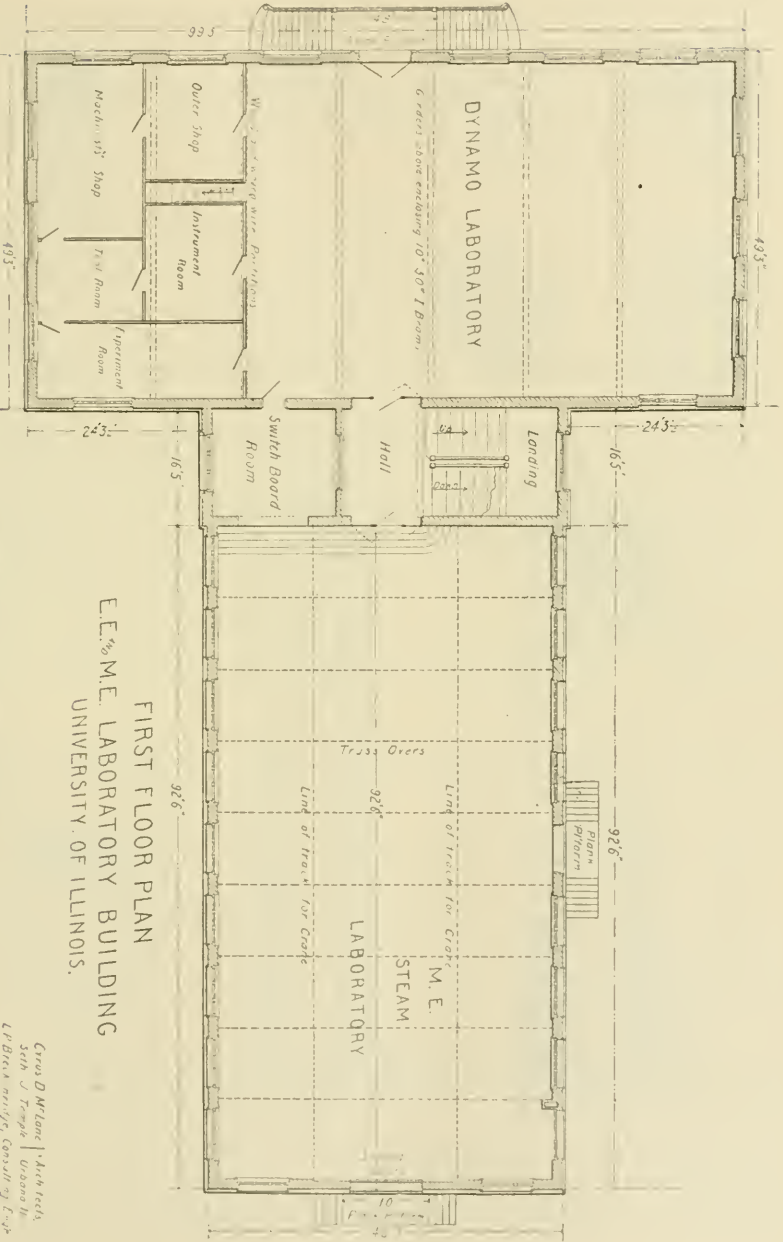


FIG. 1.—ELECTRICAL AND MECHANICAL ENGINEERING LABORATORIES.

FIRST FLOOR PLAN
 E. C. M. E. LABORATORY BUILDING
 UNIVERSITY OF ILLINOIS.

Chas. D. Wolfe, Architect,
 507 1/2 Temple & DuSable Sts.
 L. P. Brock, engrgr., University of Ill.

They carry a line shaft and the track for a four ton traveling crane. The crane is arranged to run out at the end of the building under the shed connecting the boiler house and laboratory, to facilitate handling heavy machinery. The opening left in the wall for the passage of this crane is closed by a counterbalanced flap and two sliding doors.

THE BOILER HOUSE.—The boiler house is one hundred and twenty feet long by fifty-five feet wide. The walls of the long sides are twenty-six feet high. The west wall is covered on the inside by coal bins and coal handling machinery; and the east wall has outside, along its entire length, a smoke tunnel five feet wide and twelve feet high. This connects with the chimney at the middle of the wall and with the various boilers which occupy this side of the building. The boiler house is lighted by clerestory windows on both sides. Seven light steel trusses of special design support the roof. To the south extends a pump, tool and stock room, twenty-five feet by fifty feet. This portion of the building crosses Boneyard Branch and provides an entrance to a system of tunnels which connects the various buildings. The boiler house and stack are constructed of common red Urbana brick, laid in red mortar. For photogravure of boiler house and chimney, see Plate I, opposite page 41.

The circular smoke stack is one hundred and fifty feet high and has an internal diameter of six feet. For elevations and sections, see Fig. 2, page 45. It rests upon a solid bed of Portland cement concrete six feet in thickness, which decreases in six steps from twenty-four feet and eight inches square at the base, to eighteen feet square at the top. The stack has a separate core extending to a height of ninety feet, the lower forty feet being twelve inches thick, the next thirty feet eight inches, and the upper twenty feet four inches. It is entirely free from the chimney and is never nearer to it than two inches.

The stack proper rests upon a base thirty-four feet high. The shaft itself is circular and consists of a twenty-four-inch wall to a height of fifty-four feet, where it reduces to a twenty-inch wall to a height of seventy-six feet, then to a sixteen-inch wall until ninety-eight feet is reached; a twelve-inch wall extends to one hundred and twenty-three feet, where the ornamental cap begins. The cap is twenty-seven feet high and consists of an eight-inch

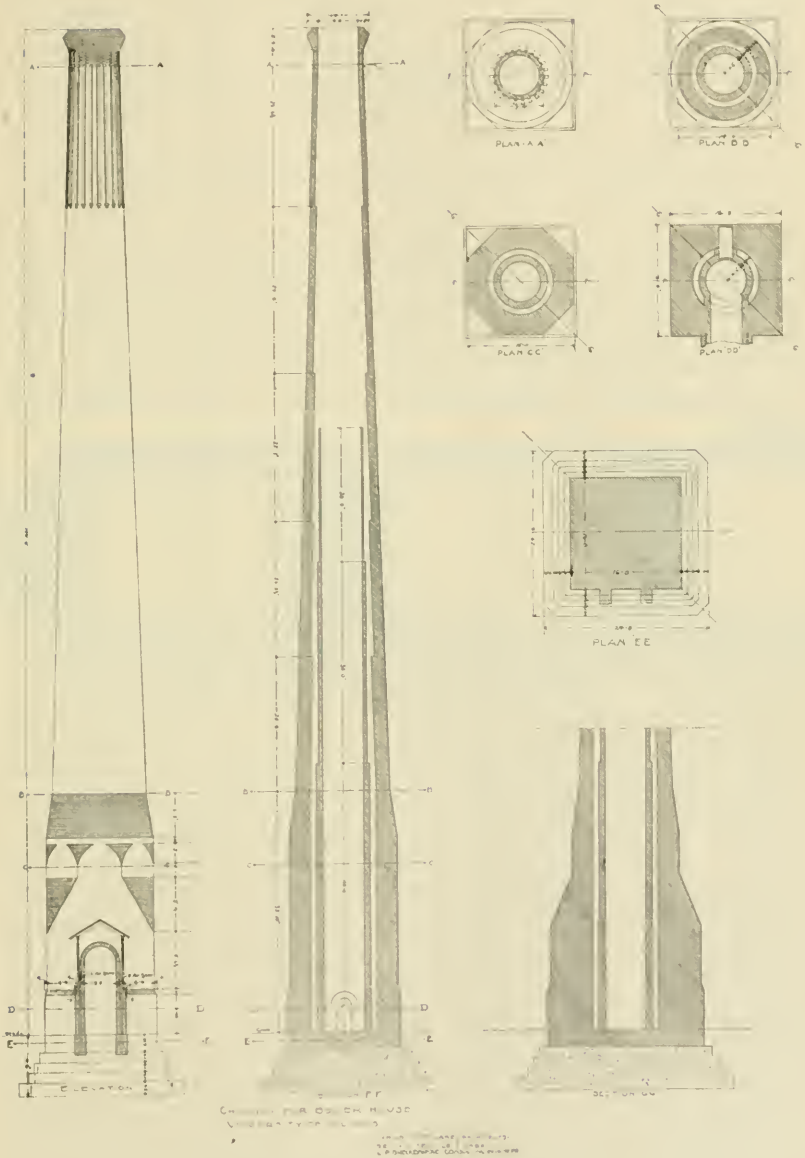


FIG. 2.—ELEVATION AND SECTIONS.

wall strengthened by two-inch ribs every eight inches. The stack is laid in cement mortar above seventy-six feet, and all the joints on the outside were raked out and pointed up after completion. There is an iron ladder running from bottom to top on the inside and a cast-iron cap protects the upper courses from disintegration.

The general contractors for both buildings and stack were M. Yeager & Son of Danville, Illinois. The iron and steel work was furnished by the La Fayette Bridge & Iron Company of La Fayette, Indiana. The contract price for the buildings was \$37 935, which can be approximately divided as follows: The chimney \$4 000, the boiler house \$9 500, laboratory building \$24 435. This building cost a trifle over seven cents a cubic foot and the boiler house a trifle under four cents a cubic foot. Less than five cents per cubic foot is the average cost of all the buildings.

ILLINOIS LICENSE LAW FOR ARCHITECTS.

Illinois is the first state to enact a law requiring every practicing architect to obtain a license from a board of examiners. The law provides that "any person who shall be engaged in the planning or supervision of the erection, enlargement or alteration of buildings for others and to be constructed by other persons than himself" shall have a license which shall be recorded with the county clerk, and he shall mark all drawings and specifications to be used in Illinois with an official stamp. A "building" is defined "to be a structure consisting of foundation, walls and roof, with or without other parts." Architects in regular practice on July 1, 1897, were entitled to license on proof of the fact. All others must pass examinations as evidence of their professional knowledge and training. About seven hundred architects have received licenses, chiefly those practicing in Chicago. This law is of interest to architectural students, since it insures that all who hereafter practice architecture in Illinois must be versed in scientific knowledge and technical training. The law will be of great benefit to the public, since it protects citizens from injury or loss by incompetent architects, fixes the responsibility for dangerous structures, and tends to raise rapidly the attainments and position of the profession. Professor Ricker, head of the Architectural Department, is a member of the board of examiners.

THE DESIGN OF ELEVATING AND CONVEYING MACHINERY.

BY J. V. E. SCHAEFER, '88, SCHOOL OF MECHANICAL ENGINEERING.

The business of the Link Belt Machinery Co., of Chicago, with whom the writer is connected, is the building of machinery for transmitting power and for elevating and conveying materials of all kinds in bulk or in package. It had its origin in the invention by Mr. W. D. Ewart of the Ewart detachable link belting illustrated in Fig. 1. Mr. Ewart was working on the construction

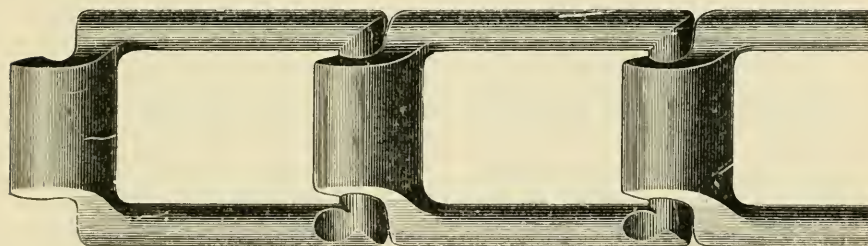


FIG. 1. EWART DETACHABLE LINK BELTING.

of a self-binding reaper and was much hampered by the slipping of belts and the imperfections of the non-detachable chains which had to some extent been applied to this use. In attempting to overcome this difficulty in the machine he was building, he devised and constructed the detachable chain illustrated in Fig. 1. The value of this invention soon became so apparent that the reaper was abandoned, and the Ewart Manufacturing Co. organized for the manufacture of malleable iron chains. The facts that the dimensions of this chain have never been changed, and that of the millions of feet of Ewart chain of many sizes now in use fully one fourth is of the original dimensions, forms a striking commentary on the sound judgment of Mr. Ewart. It soon became evident to Mr. Ewart that, entirely separate from the manufacture of the chain itself, there was needed a company whose business it would be to build complete installations of machinery using link belting. For this purpose he therefore organized the Link Belt

Machinery Co. To the Ewart Manufacturing Co. was left the manufacturing and merchandising of malleable chains; to the Link Belt Co. was opened the broader field of finding applications for the chains and installing elevators, conveyors, and power transmissions in which they were used. From this small beginning has grown the link belt business of the entire civilized world. The design of machinery of such variety soon called for a higher class of engineering skill, and at the present time the amount of business coming to the Link Belt Machinery Co. from the sale of material as called for by the judgment of the purchaser is exceeded in volume and importance by the business resulting from the submitting of problems which are solved by the engineering department of this company and executed in its workshops. The business has grown from a work-shop 60 × 100 ft. in area to four large central manufacturing plants situated in Chicago, Indianapolis, Philadelphia, and Derby, England.

In the development of the elevator and conveyor business, requirements passed beyond the strength of cast malleable chains, and special chains have, from time to time, been constructed to meet these special requirements. At the present time the designer has ready at his hand a large variety of chains each suited to a particular class of work, and from them he must select the one best suited to solve oftentimes the most curious and interesting of problems in constructive work. It may be desired to elevate the run of mine coal at the rate of 12 to 15 tons per minute. It may be desired to take loaded bank cars from the bottom of a long slope to the tippie and bring the empties back down to the bottom. It may be desired to elevate melted lead or to convey white hot cement clinker. One man wants to equip a five-story warehouse with elevators which will pick up miscellaneous freight at any floor and deliver it to any other floor. In this freight there will be, among other things, barrels of salt, oil, and cement, hogsheads of prunes and crude sugar, boxes of crackers, ingots of copper, and crates and bales of all kinds, weights, and sizes, from a foot square to five feet square and weighing from a few pounds to 1 600 pounds. Another man wants to equip a canning factory with an endless traveling platform which will move about past various workmen and carry pails, cans, or fruit. Another wants to convey and screen and elevate molding sand. Another

wants to carry molds in a foundry, bringing them in an endless succession to the cupola to be poured, and carrying them away to cool, be dumped and filled afresh. And so on in endless variety. These problems are not taken from the imagination but from the actual experience of the Link Belt Machinery Co., and they have all been successfully solved. A list of the different materials and packages that have been successfully handled by chain elevators and conveyors would be a very long one. The writer is tempted to suggest that it would be almost coextensive with a list of the articles of commerce.

There are no fixed rules which can be followed in the designing of elevating and conveying machinery. There is very little that can be learned about it in books, but there is no technical knowledge contained in books which can not at some time be used to advantage. As the requirements are scarcely ever twice alike, there is an immense amount of designing to be done, and the designer must be architect, civil engineer, electrician, chemist, and mining engineer, as well as mechanical engineer: and above all there must be the discriminating judgment of common sense plus experience.

Before undertaking the design of an elevator or conveyor, the most thorough examination must be made of the material to be handled. Is it coarse or fine; is it sticky, plastic, liquid, gritty, friable, hard, hot, cold, fibrous, slimy? Does it flow readily like wheat, or does it pack like molding sand? If in packages, are they uniform; what is the shape, size, weight, and what is the nature of the covering? Must the material or package be handled carefully, and what will be the consequence of breakage? How can it be received or discharged? Will it be shoveled, will it flow, will it be handled by hand? Perhaps it is tile, or terra cotta, or glassware that has to be automatically picked up at one point and deposited at another with sufficient care to avoid breakage. Perhaps it is quartz sand, or pulverized ore, that are so abrasive that they wear out the parts of the machinery which come in contact with them. The writer remembers the difficulties encountered in designing a long conveyor for beef pounders. They were large, heavy, slippery, easily torn, and they had to be handled so as to avoid tearing them. A material which seemed very easy to handle, but which for several years baffled the efforts

of all who tried it, is the mixture of wood planer shavings and iron oxide used in purifying illuminating gas. It would stick to the trough and scrapers and become so hard that it could be gotten off only by means of a hammer and chisel. By making the conveyor trough with a bottom of glass and sides of zinc, it was finally made possible to convey the oxide with entire success.

The nature of the material or package having been fully determined, the next thing in order is to fix upon the form of carrier best suited to the work to be accomplished.

From this point on the writer will omit consideration of carriers for packages and confine his attention to carriers for materials in bulk. It would be impossible to deal satisfactorily with package carriers within the limits of this paper without sacrificing space which should more properly be devoted to other matters.

Let us assume, then, that the material is in bulk and is to be elevated a distance within 60 feet. If it is not particularly gritty, the pieces small, the quantity within 500 bushels per hour, and a small amount of breakage not objectionable, the simplest form of elevator is that shown in Fig. 2. It consists of a malleable iron or steel bucket bolted to the face of a single Ewart malleable iron link belt. When the driving wheel at the top runs at a speed of 35 to 40 revolutions per minute, the buckets discharge their load by a combination of centrifugal and gravity forces. This does very well for grain or slack coal. For larger capacities the chains may be doubled. For very high grain elevators, rubber belt is commonly used instead of chain. The lineal speed of elevators of this type is 300 feet per minute and up.

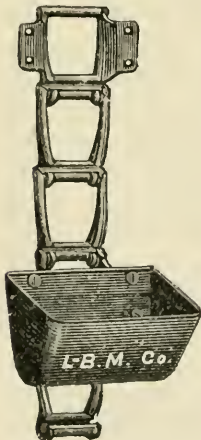


FIG. 2. ELEVATOR.

To get a more perfect discharge at a slower speed, the form of elevator shown in Fig. 3 has been designed. In this case the buckets discharge by turning up side down, dropping their load upon the discharge chute, the preceding buckets being deflected back out

of the way by the deflecting rollers shown. This elevator gives good results at a speed of 180 feet per minute.

A form of elevator used very extensively in the anthracite coal breakers of Pennsylvania, is the continuous bucket elevator, shown in Fig. 4. This elevator is run at a speed of 90 to 100 feet per minute. The back of each bucket in turn forms a chute for the load of the bucket following. The coal thus gets very little, if any, fall, and breakage is very much less than with either of the preceding two forms.

One of the most perfect of all forms of elevator is the gravity discharge elevator, shown in Fig. 5. This elevator was designed especially for the late Eckly B. Coxe, for use in his Cross Creek collieries. With this form of elevator, breakage is reduced to a minimum. At no point does the material get a fall. It slides easily from one position to another. This elevator runs well at almost any speed within limits, and can be used as a conveyor as well as

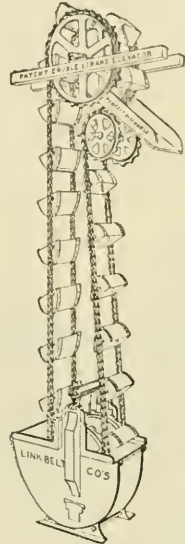


FIG. 3.
DOUBLE STAND
ELEVATOR.

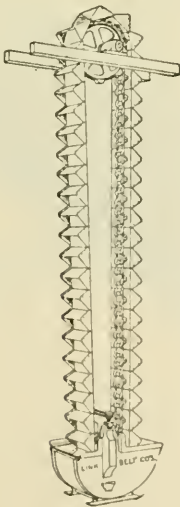


FIG. 4. CONTINUOUS BUCKET
ELEVATOR.

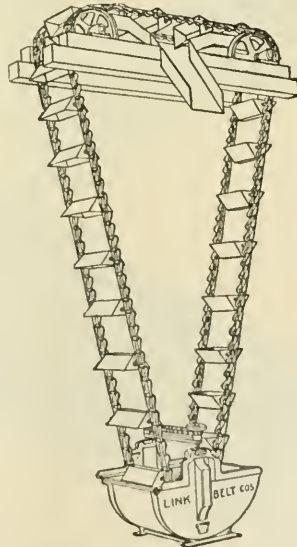


FIG. 5. GRAVITY DISCHARGE
ELEVATOR.

an elevator, thus lending itself well to situations where the requirements demand that the material be both elevated and conveyed. A very good example of this can be seen in the boiler house of the U. of I. Central Heating Plant.

Let us assume now that the material is to be carried horizontally—that is, “conveyed.” The simplest form of conveyor is a scraper bolted to a single chain, an example of which is shown in Fig. 6. The scraper or “flight” may be wood or iron, and the

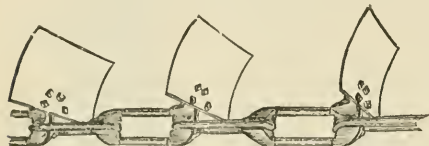


FIG. 6. DROP FLIGHT CONVEYOR.

trough in which it works may be wood or iron, or may be lined with special material, as in the case of the oxide conveyor mentioned above. A very desirable form of conveyor is that shown in Fig. 16, page 63. The flights are supported at the ends by wearing shoes. These support the weight of chain and flights, largely overcome the noise of the flights scraping on the bottom of trough, and form a wearing surface which can be easily and cheaply renewed.

For plastic, sticky, and abrasive materials a scraper conveyor is plainly not well suited. With the former the flights would get clogged up and with the latter the flights and trough would wear

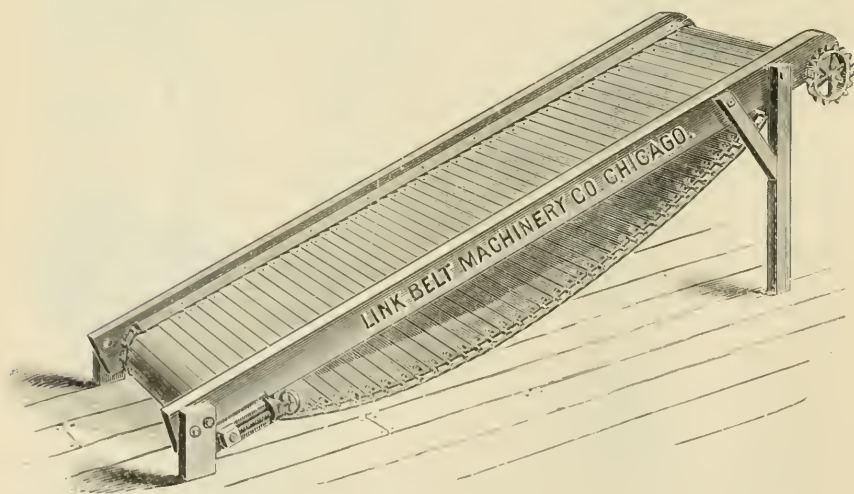


FIG. 7. CURVED SLAT CONVEYOR.

out very rapidly. For carrying soft clay from the pugmills of brick factories to the brick machines the curved slat apron conveyor shown in Fig. 7 has been used with great success. It consists of a series of curved overlapping steel slats secured to two parallel endless link belt chains. The radius of curvature of the slats is the same as the radius of the head and foot wheels, and the advancing edge of each slat is curved down to a circle struck from the center of the articulation of the chain

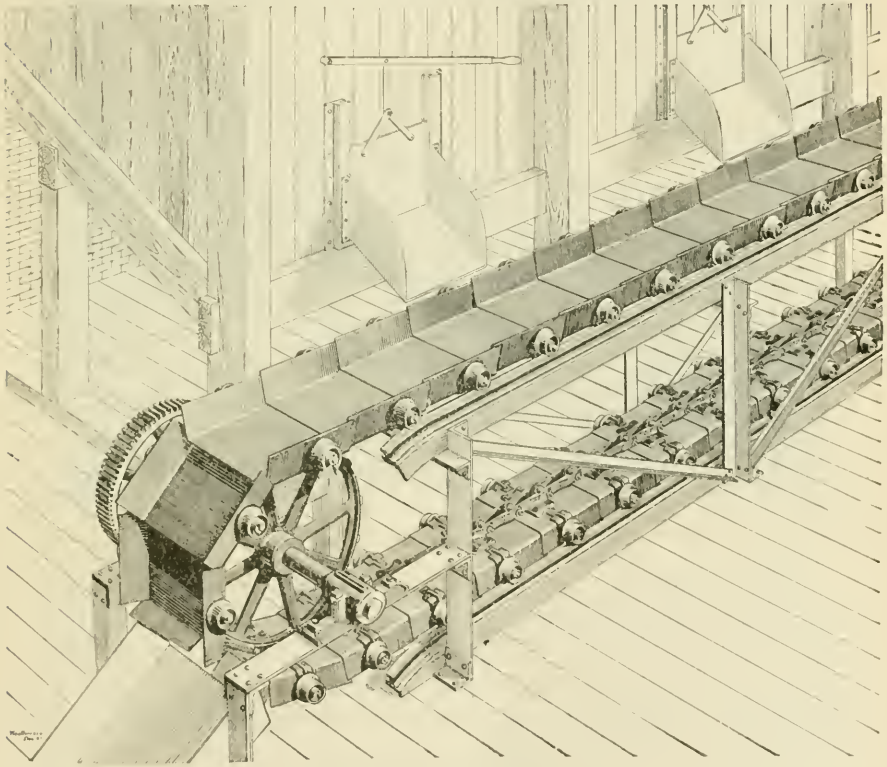


FIG. 8. PAN CONVEYOR.

links. In this way the slats form a cylindrical surface at head and foot; the joints between slats remain closed when going around wheels and a clean discharge may be insured by placing a steel scraper close to the cylindrical discharge end of the apron conveyor. For gritty material, such as coke, sand, and ore, a very satisfactory conveyor is some form of endless trough or "pan"

conveyor, such as shown in Fig. 8. This consists of a series of overlapping pans. Into this trough the gritty material falls and lies undisturbed till it drops off the end of the conveyor where the pans break away from under each other, each acting as a chute for the load of the pan following in much the same manner as the continuous bucket elevator described above.

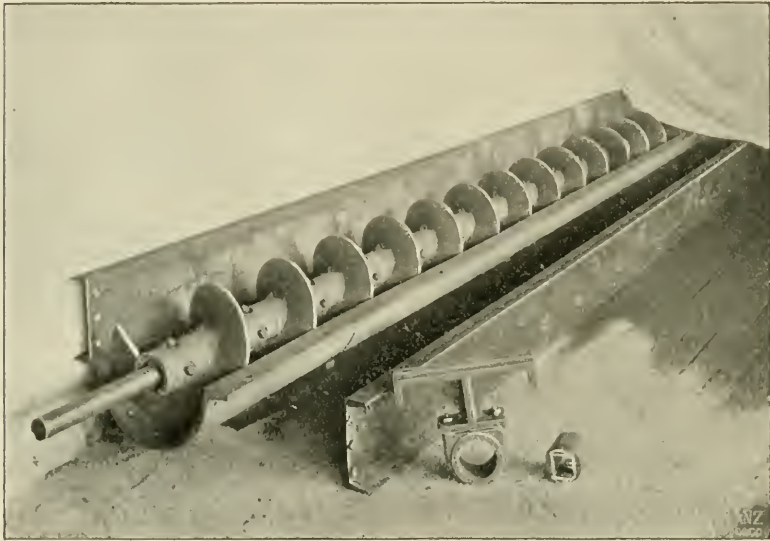


FIG. 9. CAST IRON SCREW CONVEYOR.

An objection to the pan conveyor is that it can not discharge its load at intermediate points. In this case a screw conveyor is sometimes used. The form of this made by the Link Belt Machinery Co., especially for gritty materials, is shown in Fig. 9. The screw is formed by cast-iron segments bolted together over a square shaft. The couplings are case hardened, sleeves pinned on, and the bearings chilled cast-iron; the trough also is cast-iron, made in sections. It will be readily perceived that the two objects kept in view in making this design were: first, to make all wearing parts heavy and easily renewed, and, second, to make such parts as could not be easily renewed as hard as possible. This conveyor has given most excellent satisfaction in hot cement, clinkers, and hot ashes.

The form of elevator or conductor having been settled, the next important consideration is the matter of chains. This has been a very fruitful field for invention. A large number of chains has been designed since Mr. Ewart established the link belt industry. Some have been good, some fair, and some worthless. The writer will confine himself to a few which by extensive and successful use have been proved to be good.

Within the limits of its strength and for all materials not gritty no chain has yet been made that was so good as the Ewart link belt. Its manufacture by the Ewart Manufacturing Co., at Indianapolis, has been perfected year by year until it is at present wonderfully perfect in its malleability, its accuracy, and its finish. Within the eighteen years since this company was organized by Mr. Ewart there have been made about 150 000 miles of this chain.

About ten years ago Mr. James Dodge, of Philadelphia, perceiving the need of a chain stronger than any that could be made of malleable iron, invented the Dodge chain, shown in Fig. 6, p. 52. This chain has been used in the immense anthracite coal storage plants erected by the Dodge Coal Storage Co., of Philadelphia. One of these, having a capacity of 310 000 tons, is shown in Fig. 10. The amount of coal that is annually handled by means of this chain, is probably in excess of 30 000 000 tons.

Fig. 11 is an illustration of a chain designed to be used in gritty materials. The body is of malleable iron. The articulation is formed by a hardened steel removable bushing and a turned and hardened steel pin. All the wear, both of the articulation and of the contact with the sprocket, are taken by these hardened bushings and pins. Abrasion occurs slowly, and when the bushings and pins are worn they can be readily renewed. This chain has given excellent results when used in coke, ore, and ashes.

For a number of years there was felt to be a great need of a chain for long conveyors. This chain must be light, strong, and inexpensive. The monobar chain shown in Fig. 14 comes the nearest to fulfilling these requirements of any chain yet made. It consists of a series of flexibly connected bolts. It is light because the bolts may be long and the malleable iron knuckles relatively few; strong because there are no welds in it, and the knuckles being properly proportioned, the strength of the chain is the strength of the high grade wrought iron bolts employed; inexpen-

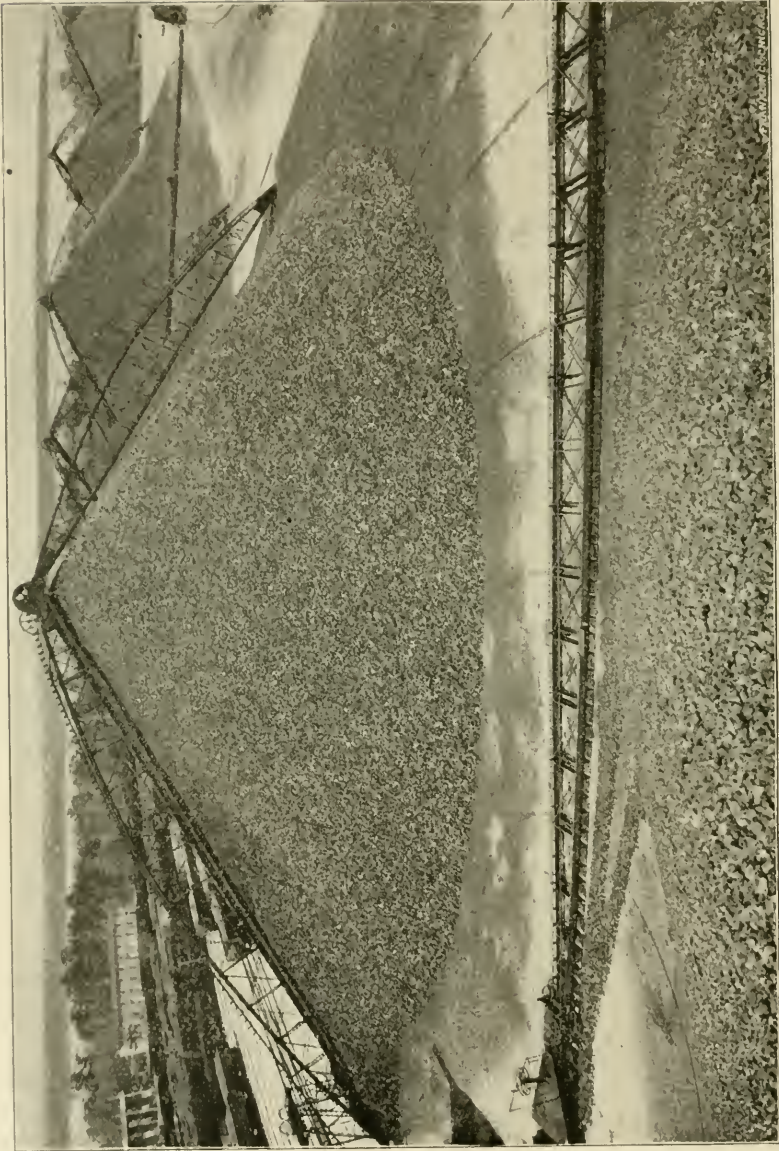


FIG. 10. DODGE COAL STORAGE PLANT.

sive because light and cheaply made, its first cost is less than that of any other chain of equivalent strength. Monobar is made in sizes from $\frac{3}{4}$ -in. diameter, weighing 4 lb. per foot and having a breaking strength of 18 200 lb., to 2-in. diameter, weighing 24 lb. per foot, and having a strength of 120 000 lb. The 45-lb. Ewart chain, with which the business began, weighs $\frac{1}{2}$ lb. per foot and has a breaking strength of 1 000 lb.

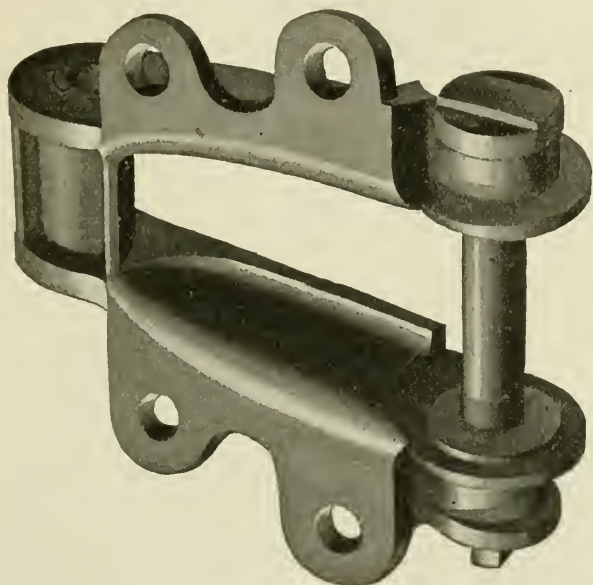


FIG. 11. LEY BUSHED CHAIN.

No paper on conveying machinery is complete without alluding to some one of the several forms of carrier that have been designed, in which the material is carried in a bucket both horizontally and vertically from its receiving point to its discharge point. One of these is the link belt carrier, illustrated on page 63, Fig. 16, which shows the feed chute, driving gear and discharging mechanism. This carrier is designed to convey friable, fibrous or gritty materials. For friable materials it is better than the gravity discharge elevator, because the material can be carried around three sides of a rectangle without leaving the buckets; and for the same reason it is well adapted to the handling of fibrous or gritty materials. The driving gear is

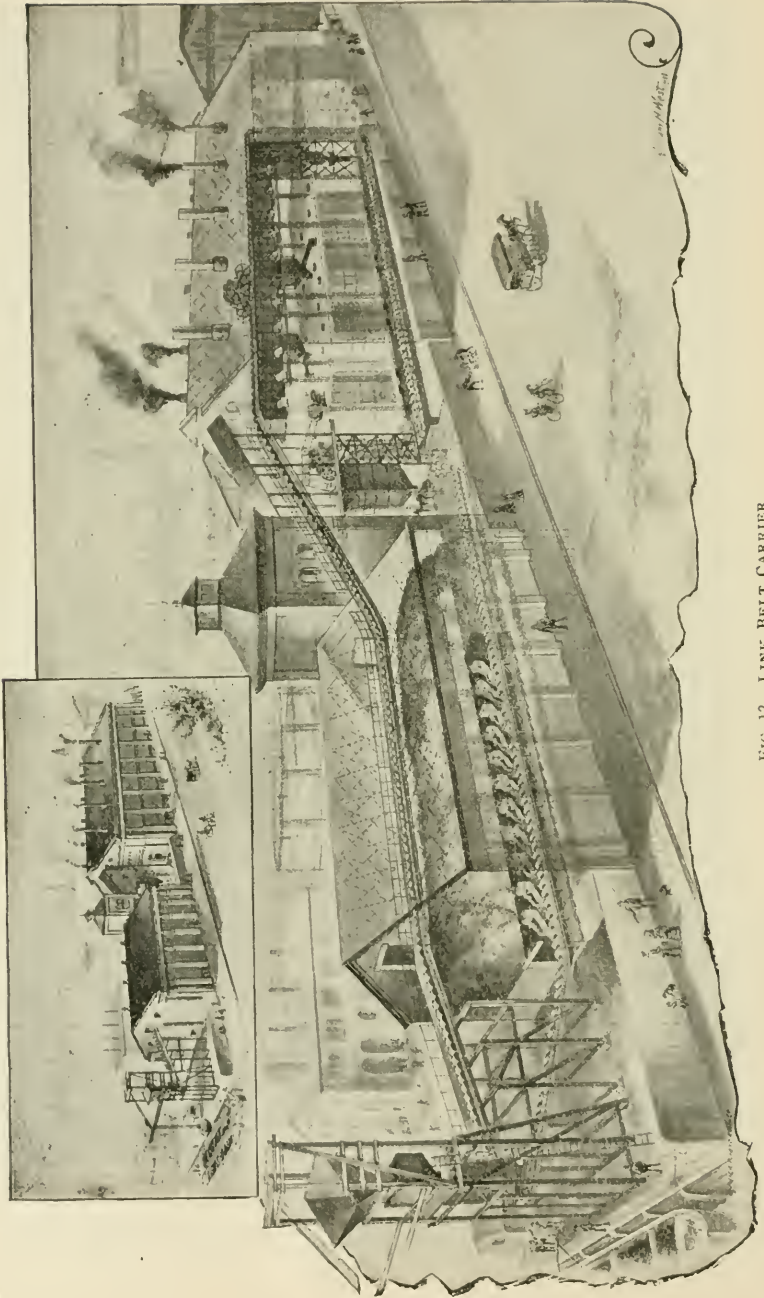


FIG. 12. LINK BELT CARRIER

worthy of special notice, being what is called an equalizing gear. If the driving shaft had a uniform angular velocity the chain would have a variable velocity due to the fact that the

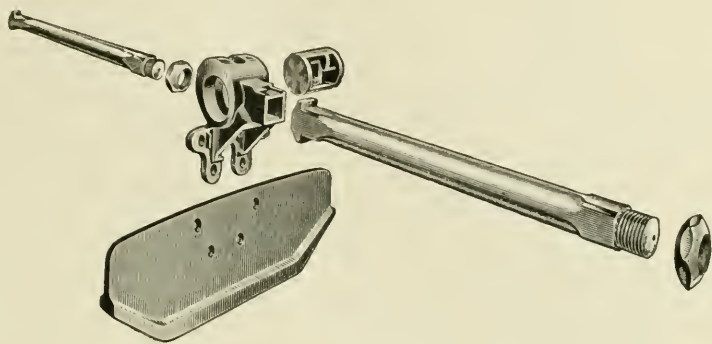


FIG. 13. MONOBAR.

teeth of the sprocket wheel where they engage the chain, being farther from the center than the centers of the links, move faster. A jerk is thus given to the chain every time a tooth

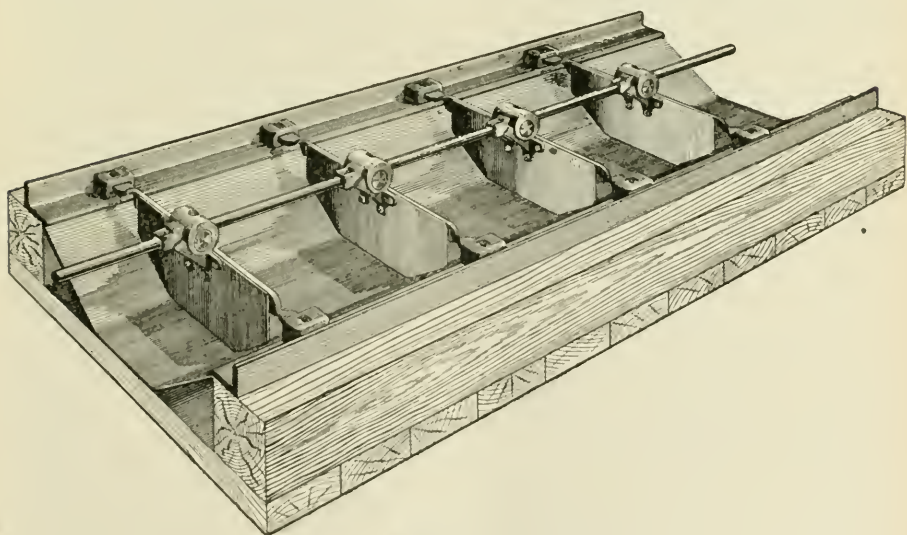


FIG. 14. MONOBAR IN TROUGH.

engages, and this pulsating motion is very noticeable in chains of long pitch. This has been overcome by making the driving gear a lobed gear. There is a high spot in the gear opposite each

sprocket wheel tooth, and the driving pinion is eccentric with a low spot opposite the high spot of the gear. By this means the main shaft has a variable angular velocity, or a pulsating motion, while the chain and the counter shaft both run with a steady motion.

Fig. 12, page 58, shows a view of this carrier as used in the works of the Equitable Gas Light Co., New York City. The length of the carrier is 728 feet, and it runs 50 feet per minute, handling coal and ashes at the same time. The coal is taken from the river and delivered to the carrier from the elevated hoppers shown at the extreme left. Passing in on the upper run of the carrier it is distributed in the storage house by means of the self moving discharger, which is quickly moved to any point desired. The coal is then taken from the storage house through the automatic feed chutes, passed around the terminal at the river end and carried through the upper part of the storage house into the generator house, shown at the right. On their return journey the buckets pass under the floor of the generator house and receive the ashes discharged from the generators. In the space between the two buildings the carrier is turned upward so that the ashes may be elevated and discharged into the steel hopper provided to receive them. The carrier then returns to its former level and completes its journey. In this link belt carrier we have the very acme of the art of handling material. Into the perfection of its design there have been brought the engineering skill and the practical experience of a decade of actual work in designing and constructing such machinery, and there are many interesting details in it which the writer would be pleased to dwell upon did space permit.

In Fig. 15, page 61, is shown a view of the link belt carrier as used in handling garbage for the city of New York at the foot of East Seventeenth street. This carrier receives both ashes and garbage from the collecting carts without the use of chutes or other feeding apparatus and delivers without transfer into the bins over head. Distribution as required is effected by the self moving discharger. The front of the pocket is provided with a series of 10 ft. \times 10 ft. doors through which, when raised, the ashes and garbage are delivered by gravity to the scows. The pocket is 100 ft. long and 45 ft. high. The carrier is com-

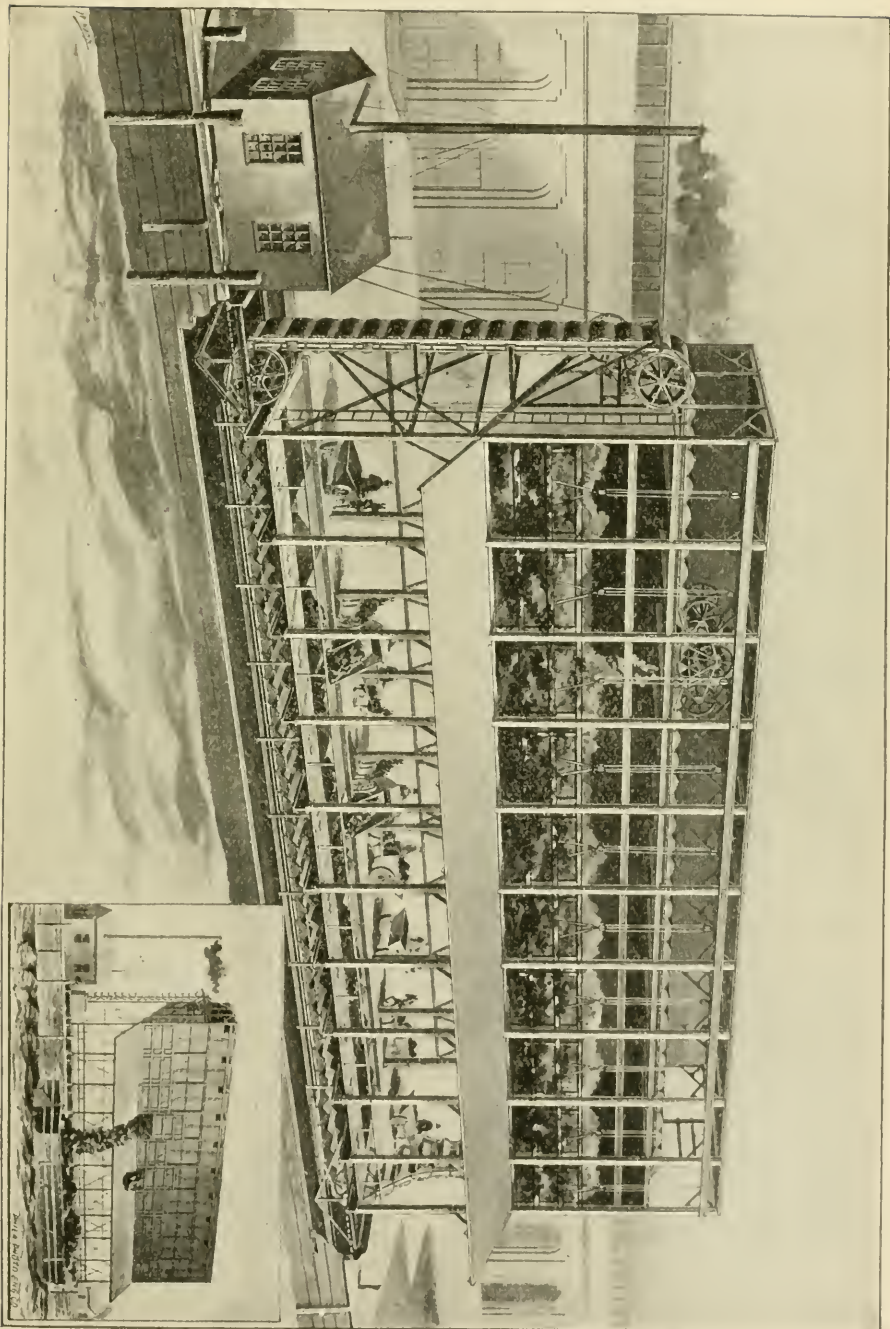


FIG. 15. LINK BELT CARRIER.

posed of 24 in. \times 36 in. buckets, is 314 ft. long, and at its present rate of speed has a capacity of two cubic yards per minute.

The writer has now attempted in a very brief manner to cover the field of material handling by means of elevators and conveyors, beginning with the simplest forms, the centrifugal discharge elevator and the scraper conveyor, handling the simplest of material, and ending with the combined elevator and conveyor, handling the most difficult of all materials viz., the garbage, and street sweepings of a great city. In this hasty review many most excellent chains and other devices have had to be omitted. A fitting close to this paper will be a description of the coal and ashes handling plant installed in the central heating plant of the University of Illinois by the Link Belt Machinery Co.

First notice that the wide difference in the nature of the materials to be handled naturally divided the problem into two distinct parts. Coal is friable, dusty, dry, and iron abrasive. Ashes are less friable, with very hard clinkers mixed in, dusty, often wet, and exceedingly abrasive. It was desired to store as much coal in the building as space would permit, and to make this coal in storage available for chuting to furnaces by mechanical handling. Thus it might be desired to take the coal direct from the wagons to the furnaces or from wagons to storage or from storage to furnaces, and avoid all manual labor except such as might be required to empty the wagons. The ashes were to be taken from the ash pits and stored in an elevated receptacle holding about a cartload, from which they could readily be discharged into carts or wagons to be hauled away. The manner in which these requirements were met will appear in the description.

FIG. 17 and 18 are plan and cross section respectively, showing in outline the entire boiler house interior. The coal bin extends along the west wall in front of the boilers, and has a false bottom dividing it into an upper and a lower part. This bottom is high enough to allow all the coal in the upper part to flow through chutes direct to the furnaces. The lower part is entirely for storage. A gravity discharge elevator and conveyor runs through under the floor of the bin up the north end, across over the top, under the roof and down again at the south end of the bin. The lower run of this conveyor under the floor is covered

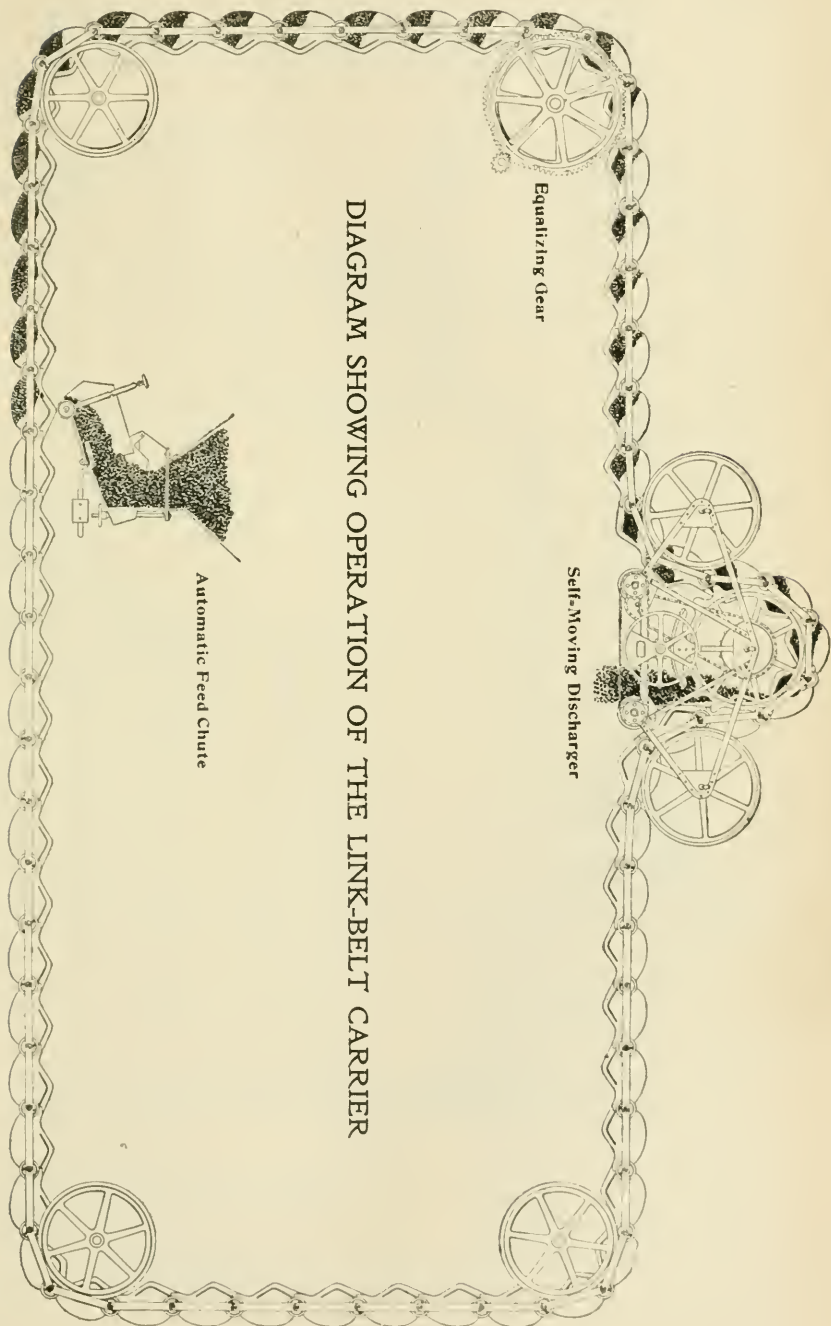


FIG. 16. LINK BELT CARRIER.

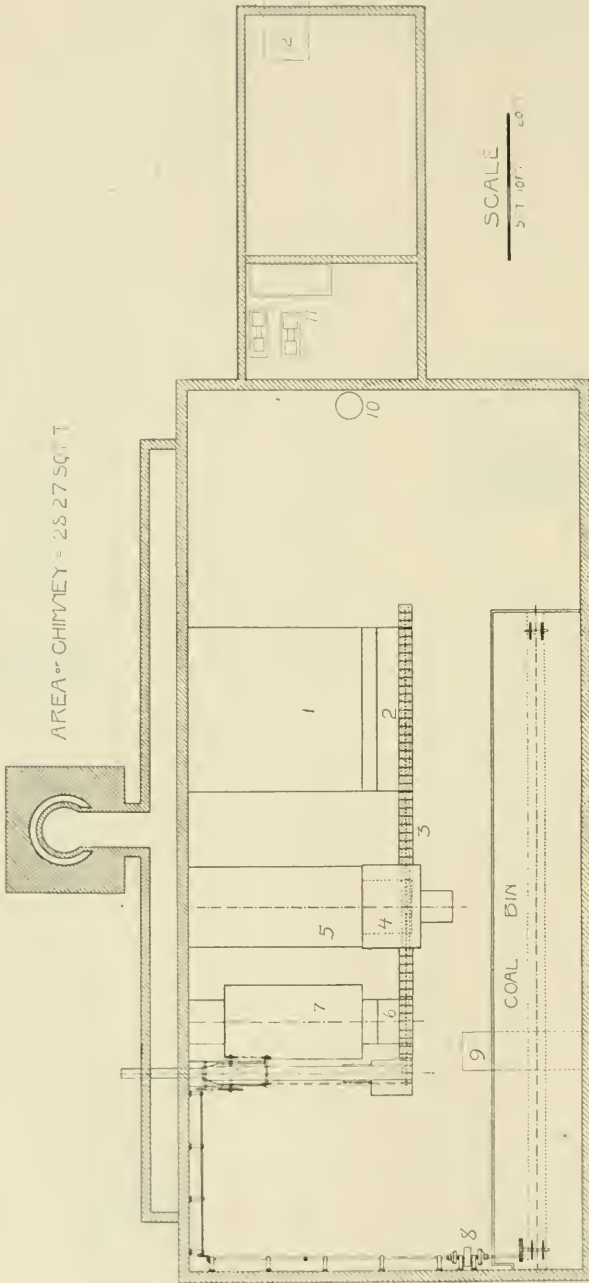


FIG. 17. PLAN OF BOILER HOUSE.

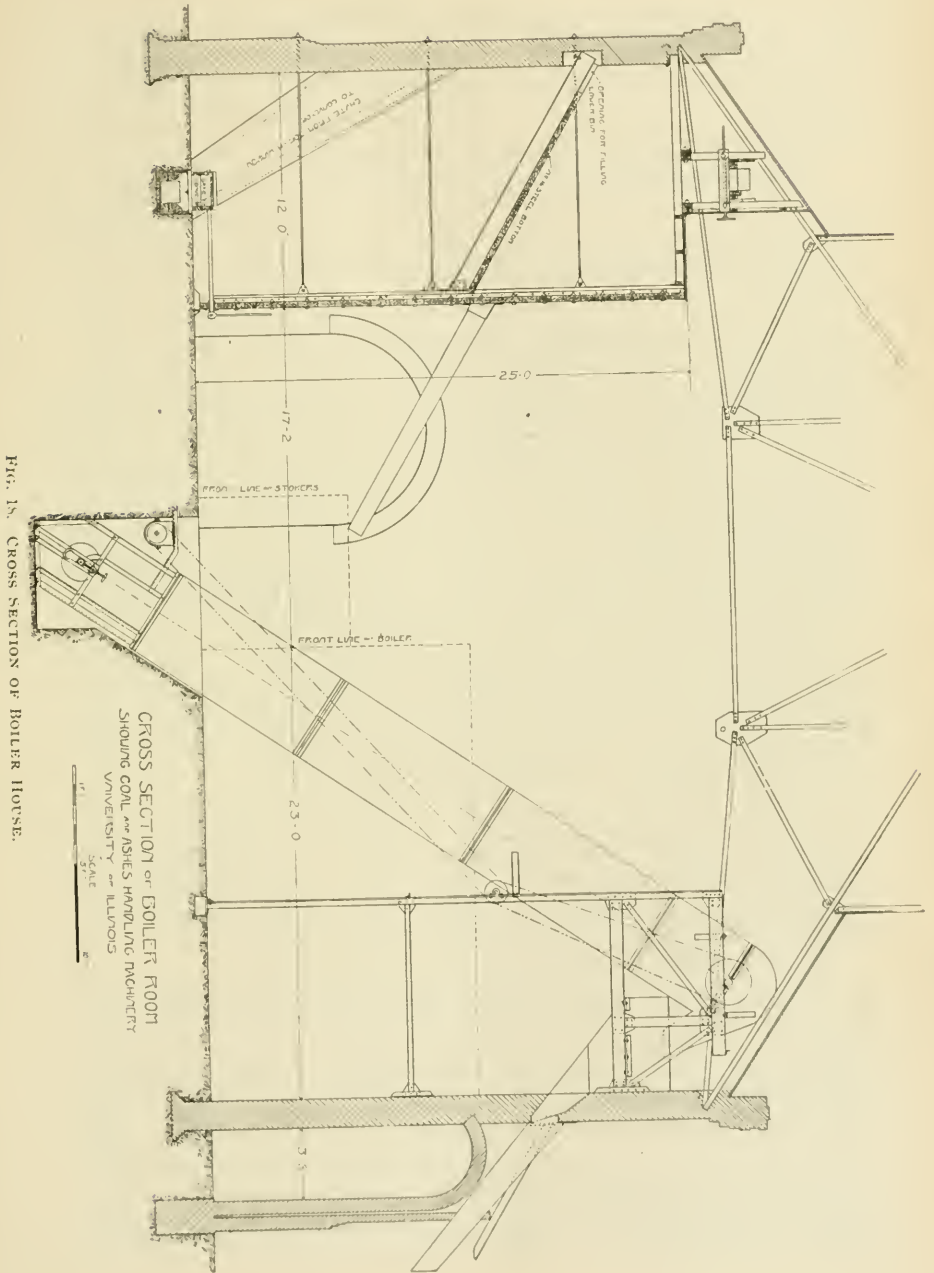


FIG. 1A. CROSS SECTION OF BOILER HORSE.

CROSS SECTION OF BOILER ROOM
SHOWING COIL AND ASHES HANDLING MACHINERY
UNIVERSITY OF ILLINOIS

by 2 in. \times 6 in. planks, every other one being loose. A piece of T iron secured longitudinally under the fixed planks, divides the openings made by lifting the loose planks, so that no large lumps can get into the conveyor. If such get into the bin they must be broken before they can be taken by the conveyor.

Let us suppose the bin is empty. Wagons are driven up to the windows on the west side and the coal is thrown into the lower part of the bin up to the level of the windows. Some of the windows are connected with the conveyor by closed chutes. The coal thrown into these goes into the conveyor, is taken up and discharged through gates in the upper conveyor into the upper part of bin. If the holes in the false bottom are open the coal falls through into the lower bin until it is full and then proceeds to fill the upper bin. In this way the entire bin may be filled to the top. Gates in the front of the upper bin permit the coal to flow out and to the furnaces by means of chutes. When the upper bin is empty the holes in the false bottom are closed and the conveyor started. By opening the gates and by lifting the loose planks above referred to, the coal in the lower bin can be transferred to the upper bin for serving the furnaces.

The writer wishes to call especial attention to the false bottom feature of this bin which allows one structure to serve the double purpose of storage and distribution. The idea is a novel one and its origin in this case is due in large measure to Professor L. P. Breckenridge, of the University of Illinois.

As coal is not very abrasive a plain riveted chain is used, which in such service will be quite durable. A roller placed in each articulation supports the buckets free from the bottom of the trough and does away in a large measure with the noise usually attendant upon the operation of such machinery.

For drawing the ashes out from under the furnaces a cast-iron screw conveyor is used for reasons given above under the description of this conveyor. This screw conveys or delivers its load into an elevator which combines the features of a pan conveyor and a continuous bucket elevator. The buckets are of steel with overlapping edges. They are supported on rollers bushed with case hardened bushings. The rollers revolve on gudgeons secured to the buckets, and fitted with case hardened thimbles. The buckets are fastened to a single strand of the Ley steel bushed chain described above.

THE EFFECT OF FREEZING CEMENT MORTAR.

BY A. C. HOBART, '97, FELLOW IN CIVIL ENGINEERING.

The great interest developed among engineers in the last few years as to the extent cement mortars are injured by freezing, and the inadequacy of the past experiments to answer such questions, led to the experiments described in this article.

As affecting the weight to be given to careful experiments, it may be stated that with one or two exceptions, the effect of freezing cement mortar has received very superficial attention. No extended series of connected tests have been made. The one important exception comprises the series of tests made by P. S. Barker and C. A. Symonds at the Thayer School of Civil Engineering, Dartmouth College, and described in the *Engineering News*, Vol. 33, p. 282. From the results obtained by these experimenters it is plainly evident that cement mortars, both Portland and natural, are injured by immediate freezing. To just what extent this is true is not so evident. In this, as in every other case where experiments upon the freezing of cements have been made, recourse was made to natural sources for such freezing, and the often violent fluctuations of the temperature from weather changes does not allow very close comparison of the results obtained. * The whole series of recorded experiments on the subject, with the exception noted above, is exceedingly meagre and unreliable.

Granting, then, that cement mortars are injured to a great extent by immediate freezing, the writer endeavored to study the effect of freezing on mortar which should have the advantage of a slight initial set. That the results might be readily compared, recourse was made to artificial freezing.

* See MICHIGAN ENGINEER'S ANNUAL, '96; T. A. S. C. E., Jan. and June, '94; *Engineering Record*, Mar. 10, '92; *Engineering News*, Mar. 2, '92; T. S. C. E., of Cornell University, '93; J. W. S. E., Vol. 1, No. 5, p. 681.

APPARATUS AND METHOD OF CONDUCTING TESTS.

After a trial of both the transverse method of testing and the common tensile tests, it was decided that with the appliances at hand the latter method was the more expeditious, while at the same time equally reliable.

Two sets of brass gang molds having a capacity of thirty briquettes each, as well as twenty-four individual brass molds, were used in making the briquettes. These molds were all of the pattern recommended by the American Society of Civil Engineers. A Richle machine having rubber-tipped grips was used in breaking the briquettes.

Great care was taken that all briquettes should be made under exactly the same conditions in order that the results might be comparable. At least two thirds of the total number of briquettes were made by the writer alone. With the remainder, very valuable assistance was rendered by E. S. Johnson. Here much care was observed that the same procedure should be gone through with in filling the molds, and a later comparison of the results given by the briquettes molded by myself and by Mr. Johnson showed that there was no appreciable difference.

In preparing mortar, the cement and sand were first thoroughly mixed dry and then the water added. The mass was then worked over with a small trowel to the consistency recommended on p. 71 of BAKER'S MASONRY CONSTRUCTION. The per cent of water necessary for the various mortars had been previously determined and was strictly adhered to throughout the series of experiments.

All briquettes were hand molded, moderate pressure of the thumbs serving to closely fill the molds and exclude all air bubbles.

The mortar was mixed upon slate tables, the molds also resting upon these tables while the cement was setting.

Through the kindness of Mr. Storer, of the Twin City Storage Co., of Champaign, Ill., a room was obtained for the freezing of the briquettes. This room served the ice company as a storage room for their artificial ice and was maintained at a temperature of about 20° F. Throughout the time during which this room was used as a freezing place for the briquettes, the temperature did not vary more than two or three degrees from 20° F. The

briquettes were stored one deep on the thin sheet-iron shelves and soon fell to the temperature of the room.

With those briquettes allowed to set but for a very short time before freezing, all work was done at the ice plant. At the expiration of the time allowed for the briquettes to set, the molds, with enclosed briquettes, were placed in the cold room until the freezing had taken place. The briquettes were then taken from the molds and placed upon the shelves before mentioned. Where the briquettes were allowed to set a longer time and the cement became hard before the expiration of this time, the briquettes were made at the Cement Laboratory of the University and there taken from the molds before being put into the freezing room. In all cases the frozen briquettes were taken from the freezing room from 18 to 20 hours before being broken. During this time they were placed in water which continued at about the same temperature as the laboratory, which was comparatively uniform and averaged 60.8° F. This allowed perfect thawing of the briquettes before they were broken.

With the briquettes of the parallel series, not frozen, equal care was taken. Here the briquettes were taken from the molds after the cement had set, and placed in pans of water as in the thawing of the frozen specimens. Also as in the case of the frozen specimens, the water of the pans averaged 60.8° F., varying from 54 to 68° F.

In the case of the briquettes destined to be frozen after quite an interval in which to set, water storage was also made. These briquettes were allowed to drain off or else were wiped off before putting them in the freezing room. Whenever briquettes were allowed to set in the molds, a damp cloth was constantly kept over them.

Each briquette was marked with steel dies to identify it after freezing. In the case of the 1 to 2 and 1 to 3 mortars, these marks were rendered legible by placing them upon a thin scale of neat cement, rubbed upon one end of the briquette.

CEMENT AND SAND.

The cement used consisted of two Portlands, viz., Dufosse and Saylor's American, and four naturals, viz., Clark's Utica,

Louisville Black Diamond, Louisville Star, and Akron. These, among others, had been in use at the laboratory for some time and were chosen as representative cements and as having given better results under test than the other brands in the laboratory. The general qualities of these cements may be seen from an inspection of Table I.

TABLE I.

RESULTS OF TESTS OF CEMENT USED IN THE FREEZING OF CEMENT MORTAR.

| BRAND. | WEIGHT PER CUBIC FT. LB. | FINENESS. | | | ACTIVITY. | |
|-------------------------------|--------------------------------------|------------------|--------|--------|---------------|--------|
| | | PER CENT PASSING | | | GILMORE TEST. | |
| | | 50 | 80 | 100 | IN. SET. | FINAL. |
| | | SIEVE. | SIEVE. | SIEVE. | | |
| Dufosseze..... | 79.9 | 99.8 | 93.6 | 84.3 | 98 | 270 |
| Saylor's American..... | 72.7 | 100.0 | 99.6 | 89.6 | 142 | 337 |
| Louisville Black Diamond..... | 52.0 | 85.1 | 78.0 | 74.0 | 23 | 65 |
| Louisville Star..... | 53.1 | 85.1 | 79.0 | 76.0 | 32 | 45 |
| Akron..... | 57.0 | 93.3 | 83.5 | 78.7 | 47 | 155 |
| Clark's Utica..... | 55.1 | 92.8 | 79.2 | 77.7 | 70 | 105 |

With the exception of the Utica and Akron, all the cements were perfectly sound. These two exceptions, however, were not bad cases, the cracks found in standard pats setting in water being small and superficial.

The Portlands were bought in the open market. The natural cements were supplied to the laboratory by the manufacturers on request.

In all tests the sand used consisted of crushed quartz of the standard size recommended by the American Society of Civil Engineers. It was sharp, clean and in every way a desirable and excellent sand for the purpose.

The water used in preparing the mortar varied in temperature from 46° to 59° F. As before stated, the per cent of water used with individual cements and the various mortars was the same during the entire time of the experiments. These proportions of water are as shown in Table II.

TABLE II.

| BRAND. | MORTAR. | PER CENT WATER. | BRAND. | MORTAR. | PER CENT WATER. |
|-----------------------------------|---------|-----------------|-------------------------|---------|-----------------|
| Dufosseze | Neat. | 20 | Saylor's American | Neat. | 22 |
| | 1-1 | 15 | | 1-1 | 15 |
| | 1-2 | 12 | | 1-2 | 12 |
| | 1-3 | 10 | | 1-3 | 10 |
| Louisville Black Diamond | Neat. | 37 | Akron..... | Neat. | 32 |
| | 1-1 | 20 | | 1-1 | 18 |
| | 1-2 | 15 | | 1-2 | 14 |
| Louisville Star | Neat. | 37 | Clark's Utica..... | Neat. | 38 |
| | 1-1 | 22 | | 1-1 | 22 |
| | 1-2 | 16 | | 1-2 | 16 |

The results of the various experiments are shown in condensed form in Table III. In all cases the briquettes were frozen six days after having been allowed to set for various intervals. They were then thawed for from 18 to 20 hours and broken. The unfrozen briquettes of the parallel series were broken at exactly the same age as the frozen specimens. It was found, however, that a difference of 1 to 24 hours in the age of the unfrozen specimens made so little difference in the strength that unfrozen briquettes between these limits were averaged for strength. Where a considerable gain in strength appeared to come from the interval between the limits of 12 and 24 hours, this strength was noted separately, those between 1 and 12 being averaged together.

STUDY OF EXPERIMENTS.

As preliminary experiments, a few briquettes of both natural and Portland cement were prepared and immediately frozen. The results obtained from these preliminary experiments practically agreed with the results obtained by Barker and Symonds. Upon one point, however, there was a slight disagreement. Natural cement briquettes frozen six days at a temperature of 20° F., showed very little evidence of surface disintegration. A slight discoloration of the outside skin, extending to a depth of a quarter of an inch only, was all the visible effect. This discolored area, while not as hard and sound as the other parts of the section, had no little strength. Portland briquettes suffered no surface change whatever, although the loss in strength was considerable.

TABLE III.

EFFECT OF FREEZING CEMENT MORTARS SIX DAYS AFTER
HAVING SET FOR VARYING LENGTHS OF TIME.

The upper line of figures for each mortar is the strength in pounds per square inch, and the lower is the ratio of the strength frozen to the strength unfrozen.

| MORTAR. | AGE IN HOURS WHEN FROZEN. | | | | | | | | | |
|--------------------------|---------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| | 1 | 2 | 3 | 6 | 12 | 24 | 48 | 72 | 168 | 336 |
| DUFOSSEZ | | | | | | | | | | |
| Neat..... | 321 | 337 | 341 | 372 | 374 | 400 | 352 | 379 | 327 | 672 |
| | 68 | 72 | 73 | 79 | 80 | 80 | 67 | 69 | 52 | 100 |
| 1-1..... | 133 | 177 | 172 | 172 | 184 | 186 | 187 | 193 | 296 | 331 |
| | 58 | 77 | 75 | 75 | 80 | 79 | 75 | 75 | 105 | 102 |
| 1-2..... | 33 | 43 | 62 | 58 | 79 | 81 | 82 | 103 | 181 | 209 |
| | 26 | 34 | 48 | 45 | 62 | 63 | 60 | 75 | 100 | 114 |
| 1-3..... | 00 | 00 | 10 | 14 | 19 | 28 | 37 | 48 | 106 | 134 |
| | 00 | 00 | 8 | 18 | 25 | 37 | 47 | 58 | 103 | 93 |
| SAYLOR'S AMERICAN | | | | | | | | | | |
| Neat..... | 285 | 238 | 234 | 268 | 284 | 248 | 240 | 300 | 590 | 671 |
| | 60 | 50 | 50 | 59 | 50 | 45 | 56 | 110 | 110 | 105 |
| 1-1..... | 144 | 176 | 173 | 175 | 179 | 255 | 260 | 271 | 303 | 391 |
| | 47 | 57 | 56 | 57 | 58 | 79 | 79 | 82 | 68 | 87 |
| 1-2..... | 61 | 81 | 96 | 102 | 129 | 143 | 138 | 146 | 161 | 226 |
| | 55 | 73 | 86 | 92 | 116 | 129 | 120 | 108 | 98 | 128 |
| 1-3..... | 18 | 26 | 15 | 33 | 48 | 54 | 69 | 74 | 87 | 124 |
| | 32 | 46 | 27 | 59 | 86 | 96 | 113 | 114 | 121 | 125 |
| CLARK'S UTICA | | | | | | | | | | |
| Neat..... | 120 | 116 | 127 | 152 | 163 | 143 | 135 | 140 | 154 | 199 |
| | 90 | 87 | 95 | 114 | 122 | 107 | 79 | 80 | 70 | 89 |
| 1-1..... | 114 | 118 | 111 | 128 | 131 | 142 | 137 | 107 | 138 | 160 |
| | 88 | 91 | 86 | 99 | 102 | 110 | 105 | 80 | 100 | 81 |
| 1-2..... | 45 | 60 | 80 | 83 | 74 | 43 | 45 | 49 | 69 | 77 |
| | 71 | 95 | 127 | 132 | 117 | 68 | 71 | 70 | 83 | 91 |
| LOUISVILLE STAR | | | | | | | | | | |
| Neat..... | 145 | 135 | 148 | 156 | 151 | 153 | 150 | 133 | 150 | 153 |
| | 109 | 102 | 111 | 117 | 117 | 115 | 93 | 81 | 81 | 79 |
| 1-1..... | 136 | 139 | 130 | 164 | 141 | 130 | 120 | 108 | 123 | 137 |
| | 132 | 135 | 126 | 159 | 137 | 126 | 114 | 97 | 100 | 92 |
| 1-2..... | 96 | 104 | 106 | 123 | 106 | 69 | 57 | 64 | 80 | 92 |
| | 133 | 144 | 147 | 171 | 144 | 96 | 98 | 88 | 107 | 93 |
| AKRON | | | | | | | | | | |
| Neat..... | 108 | 112 | 109 | 184 | 156 | 150 | 142 | 140 | 132 | 150 |
| | 83 | 86 | 84 | 142 | 120 | 114 | 103 | 105 | 93 | 97 |
| 1-1..... | 71 | 69 | 143 | 152 | 160 | 133 | 131 | 129 | 127 | 138 |
| | 79 | 76 | 159 | 167 | 176 | 148 | 146 | 137 | 130 | 115 |
| 1-2..... | 57 | 70 | 83 | 87 | 85 | 80 | 80 | 72 | 65 | 60 |
| | 168 | 206 | 244 | 256 | 250 | 235 | 222 | 189 | 108 | 82 |
| LOUISVILLE BLACK DIAMOND | | | | | | | | | | |
| Neat..... | 116 | 173 | 175 | 191 | 223 | 237 | 228 | 216 | 182 | 163 |
| | 72 | 107 | 109 | 119 | 138 | 138 | 132 | 126 | 104 | 93 |
| 1-1..... | 108 | 152 | 168 | 173 | 220 | 202 | 185 | 179 | 171 | 185 |
| | 94 | 132 | 146 | 150 | 191 | 176 | 158 | 127 | 91 | 93 |
| 1-2..... | 63 | 76 | 79 | 93 | 101 | 120 | 104 | 78 | 69 | 90 |
| | 170 | 205 | 213 | 251 | 273 | 316 | 297 | 186 | 157 | 120 |

An inspection of Table III will show results surprising in many ways. Instead of the generally accepted belief that cement mortars (and especially natural cement mortars), are injured by freezing, it is plainly evident that, given a short initial set, such freezing enormously increases the strength of natural cement mortar, and the Portland cement is most injuriously affected.

An inspection of the results for natural mortars shows that the strength rapidly increases with the time in which the briquettes are allowed to set up to a certain point. From this point the strength in some cases decreases to a second minimum and later approaches a point where the freezing has no effect either way. The maximum strength always occurs with a less initial set than twenty-four hours and generally with less than six hours. The 1 to 1 and 1 to 2 mortars attain a maximum before the neat. Where there is a second minimum, as in the case of the Clark's Utica and Louisville Star, this minimum seems to be reached at three days. The other two natural cements used in the experiment had no second minimum, but gradually decreased in strength from the maximum to the point of no effect.

The Portlands, while never increasing in strength by the freezing, appear, nevertheless, to have a maximum as in the case of the naturals. Thus the loss in strength is much less when frozen at from six to twelve hours after molding than when frozen at either twenty-four or forty-eight hours from this point. This maximum is not so well defined as in the case of the naturals, but is still plainly apparent. It also comes later than in the case of the naturals. This is to be expected. The naturals being much quicker setting than the Portlands would take a much shorter time to attain the condition at which the freezing seems to affect them most favorably.

The tabular results may be more easily studied by means of Fig. 1 to 4. Here where the ratio of frozen to unfrozen strength is taken as an ordinate, it will be clearly noted that the 1 to 1 and 1 to 2 mortars are much more favorably affected by the freezing than the neat. The height to which the 1 to 2 curve rises is surprising to say the least. Thus in the case of the Louisville Black Diamond cement it rises to 316 per cent and approaches the strength of 1 to 1 unfrozen mortar. In all the cases of natural cement mortar, the 1 to 1 frozen mortar rises to a strength equal

to the neat unfrozen mortar. This effect, if it were possible to freeze mortar cheaply at any time, would be worth taking account of in an economic sense.

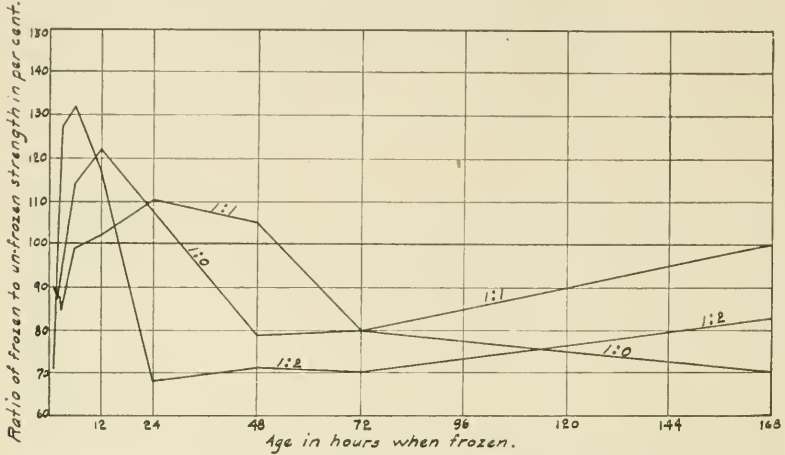


FIG. 1. EFFECT OF FREEZING CLARK'S UTICA CEMENT MORTAR SIX DAYS AFTER HAVING SET FOR VARYING LENGTHS OF TIME.

The increase of strength in the frozen natural cement briquettes noted in these experiments corresponds to the increased

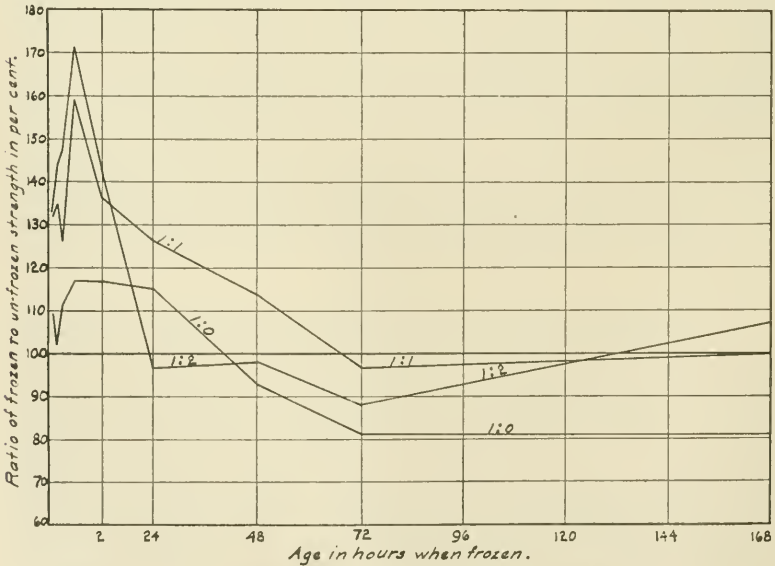


FIG. 2. EFFECT OF FREEZING LOUISVILLE STAR CEMENT MORTAR, ETC.

“internal strength” noted by Barker and Symonds. Given a short initial set, the cement attains a power to resist surface disintegra-

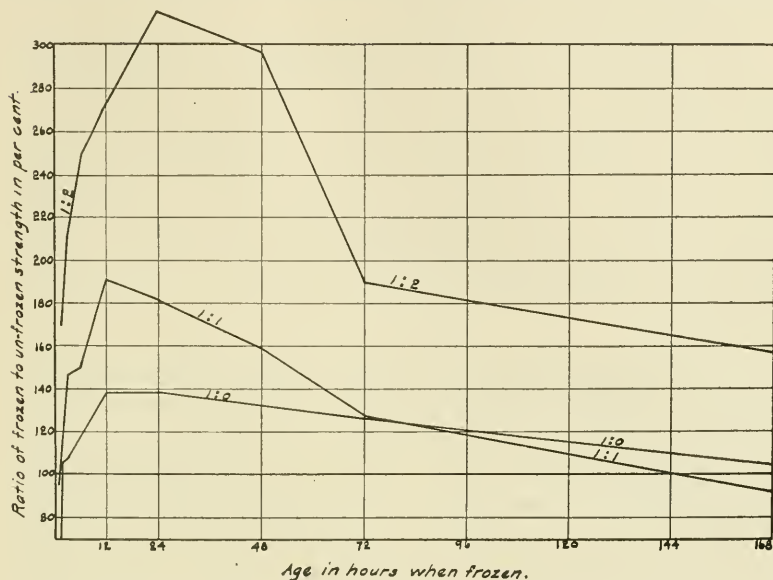


FIG. 3. EFFECT OF FREEZING LOUISVILLE BLACK DIAMOND CEMENT MORTAR, ETC.

tion, and greatly increases in strength. The broken section of the frozen briquettes showed that the surface discoloration, as evi-

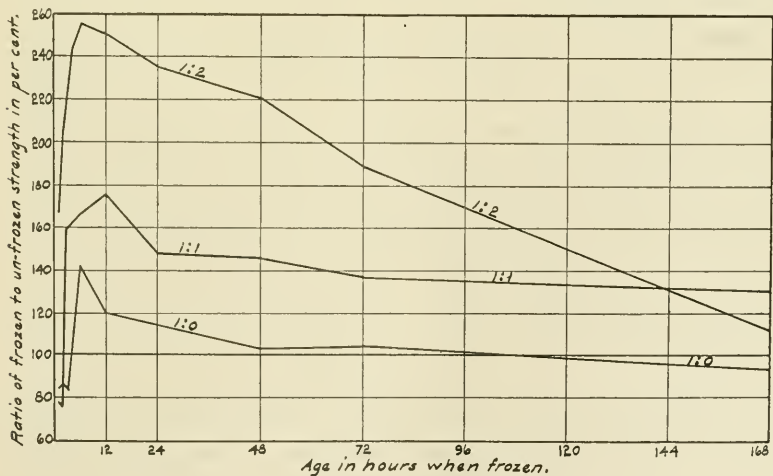


FIG. 4. EFFECT OF FREEZING AKRON CEMENT MORTAR, ETC.

dencing surface disintegration, rapidly decreased in thickness until with three or four hours initial set no difference in the color of the section could be observed.

This disintegration, it will be understood, is for such a comparatively small mass of mortar as is contained in a briquette. In no case in actual practice would the conditions be as severe, for there is no reason to expect a larger mass of mortar, such as is contained in a wall joint and surrounded as it is by protecting stone, to suffer a greater depth of surface disintegration than in the case of the briquette. With such a mass the effect of such a slight surface disintegration on the final strength would be insignificant.

In the case of the Portlands, freezing appeared simply to retard the setting, briquettes frozen six days rapidly gaining in strength on being thawed out and allowed to stand in a warm place for some time. With the natural cements the effect was entirely different in character. The rate of setting did not, however, increase under the influence of the cold; rather the reverse. While no adequate solution of the question as to how the increase of strength is gained can be given, there can be no doubt that there is such an increase; whether through more favorable conditions for the formation of the hydrate of alumina or through physical re-arrangements of the hydrate crystals, it will not be attempted to state.

Maj. Marshall, of the Corps of Engineers, U. S. A., to whom this matter was presented, has suggested an ingenious theory that, as he says, might possibly account for the unexpected results. Assuming the natural cement to be very quick setting and to have been mixed with the minimum quantity of water (as it practically was), the heat of chemical union may have been sufficient to prevent the water from freezing until it had all entered into chemical combination with the cement. The effect of the low temperature thereafter, instead of expanding uncombined water, would contract the new solid, i. e., the hydrated cement, increase its density and hence its strength. In other words, the frost acts as a tamping agent. This action would not take place with Portland cements on account of their slow rate of combination with water. As before stated, this is certainly a very ingenious theory, but it is a question whether such action by the frost would account

for so great a gain in strength of the cement. The whole question as to the setting of cements is in a very hazy condition and a great field opens before the engineer-chemist who will bring his combined knowledge to bear upon the subject.

In an attempt to explain the apparently contradictory results of the experiments in the case of the natural cement mortars, it was suggested that the time allowed the briquettes to thaw was inadequate, and that the increased strength was due to frozen material rather than the increased strength of the cement itself. This could have been satisfactorily answered, in part, by reference to the results from Portland cements. They, also, in such a case should have received an increase of strength. In order, however, that the question should be definitely settled, a briquette was prepared having a hollow interior to which access was obtained through a hole just large enough to insert a thermometer stem. This hollow was filled with mercury, a thermometer bulb inserted, and the apparatus removed to the freezing room. The briquette before removal to this room was at a temperature of 61° F. In an hour and fifteen minutes the temperature of the briquette had fallen to 32.2° F., at two hours to 29° F., and at four hours to the temperature of the room (20° F.). The briquette was then removed from the freezing room and placed in a pan of water 50.4° F. In fifteen minutes the temperature of the briquette had risen to 47° , and in forty-five minutes to the temperature of the surrounding water. This allows no question as to the perfect thawing of the briquette in the 18 to 20 hours allowed.

It had been originally intended to experiment with but two brands of natural cement. To check the general results obtained from these two, whose character caused them to be questioned, two more were selected and the subsequent results from these two amply verified the ones from the first cements.

Natural cements frozen in contact with water are almost wholly disintegrated, being reduced to mud and scales. Alternate freezing and thawing also seems to injure the strength as obtained above, but to a limited extent only. The tests on this question were limited in number on account of time and were hardly sufficient to establish the truth of the statement beyond dispute.

A few briquettes, by chance only, were frozen for six days at a temperature of about 10° F. These, in the case of the natural cement mortar, were very greatly increased in strength, much more, in fact, than occurred at the temperature of 20° F., to which most of the briquettes were exposed. This increases the incongruity of the results and adds to the difficulty of explaining them.

In moderately cold weather the disintegrating effect of the frost should not penetrate far into the mortar of a wall and with an initial set of only an hour, the neat natural cement mortar would closely approach its normal strength under the most favorable conditions. With other natural cement mortars, such an interval would even operate to greatly increase its strength.

Winter days, in all except very high latitudes, in which six or eight hours of a temperature very near, if not above, freezing can be obtained, are not uncommon and would allow the construction of first class masonry, using natural cement mortar, and a little extra care. Masonry built under such conditions would stand the frost much better than if Portland cement was used and, in fact, the added strength due to the frost would make the natural cement as strong as a Portland under normal conditions.

Many cases of masonry failures laid to the effect of frost must be attributed to other causes or a combination of unfavorable conditions. Not that the frost does not sometimes injuriously affect the strength of the mortar, but in such cases rather through the co-operation of other conditions. I have in mind the failure of a water tower (see *Eng'g News*, Vol. XXXV, p. 45) put up in freezing weather with natural cement mortar. On the thawing of the mortar by a warm rain, the tower failed. In such a case, the action of the weather, both during the construction of the tower and subsequently, when the work was sometimes covered with sleet, would seriously mitigate, if not entirely destroy, any benefit to be derived from the action of the frost. This tower, if constructed and thawed out in comparatively dry weather, would probably have shown no evidence of weakness.

CONCLUSIONS FROM THE TESTS.

(1) Portland cement mortars suffer a retardation in their setting on being frozen, the strength reducing to almost nothing in the case of mortars with a large proportion of sand. They suffer no surface disintegration, however, except in the case of

the mortars just mentioned, and from superficial examination would appear to have received no harm.

(2) Natural cement mortars with an initial set of from three to six hours are very greatly increased in strength by being frozen. This increase of strength is greater in the mortars having a large proportion of sand and in the majority of cases is as much as 50 per cent, some cements going as high as 200 per cent or more.

(3) Natural cement mortar suffers a slight surface disintegration on being frozen, this disintegration varying with the amount of initial set allowed. Natural cements frozen in water or under very damp conditions, are almost totally disintegrated.

(4) Both naturals and Portlands require an interval of at least two weeks before they are unaffected by the action of frost.

The very unusual results obtained from these experiments may cause questions as to their accuracy. This is only natural on account of the generally accepted ideas on the subject and which are almost directly opposed to the evidence offered. Yet, while the author does not feel in a position to state definitely that the conclusions drawn above from these experiments are to be taken as final in all cases, he does feel confident that the care with which the experiments have been conducted warrants their present publication in the hope that a better explanation of the unusual results than any so far presented, may be obtained.

THE CENTRAL HEATING, LIGHTING AND POWER PLANT.

BY L. P. BRECKENRIDGE, PROFESSOR OF MECHANICAL ENGINEERING.

The rapid growth and development of the University of Illinois rendered it imperative that increased facilities should be installed for the proper heating of the buildings already erected on the campus. The completion of the Library during the summer of 1897 added 3 000 square feet of hot blast radiation to the system. The boiler capacity of the old plant was not sufficient to handle any increase in radiation. This was largely on account of

insufficient chimney draft. All of the water of condensation from the Engineering Building was being turned into Boneyard Branch. The operation of two plants, one for the north end and one for the south end of the campus, was not economical and smoke was always a nuisance, whether the wind was north or south. On account of poor chimney draft, it has been necessary to burn lump coal, costing the University from \$1.75 to \$2.25 per ton. The coal consumption has for the years of '95-'96 and '96-'97 been about 3 500 tons.

In the design of the new plant it has been the aim of the writer to accomplish the following results:—

1. To concentrate at the lowest point on the campus all the heating boilers.
2. To provide increased draft, so that the cheaper grades of coal may be used for fuel.
3. To prevent smoke.
4. To provide a system of tunnels large enough to carry the heating mains, water mains, gas mains, compressed air mains, vacuum mains, as well as wiring for electric light and power purposes.
5. To concentrate all engines near the boiler house so that all exhaust steam may be used for heating purposes.
6. To provide 1 000 incandescent lights for the buildings and 20 arc lights for the campus.
7. To provide electric current for running motors for power purposes at any point on the campus.
8. To arrange the entire plant so that, as far as possible, it may be available for educational purposes.

LOCATION AND GENERAL DESCRIPTION.—The new buildings are on the east side of Burrill Ave. and on the north bank of Boneyard Branch. A description of the buildings will be found in another place in this issue. South of the branch is 1 500 feet of tunnel extending from the boiler house to the Library, passing directly under the Chemical Laboratory and University Hall. On the north side is 300 feet of tunnel, beginning at the west wall of the boiler house and ending at the north wall of the Machinery Building.

THE TUNNELS.—Fig. 1, page 81, shows a cross section of the main tunnel. The circular arch is 8 inches thick and is built of

hard burned brick laid in Utica cement mortar. The bottom is concrete made of 1 part Alpha Portland cement and 6 parts gravel, and covered with a coating of Portland cement mortar about $\frac{1}{2}$ -inch thick. The exterior of the brick work is covered with a coating of Portland cement mortar about $\frac{1}{2}$ -inch thick.

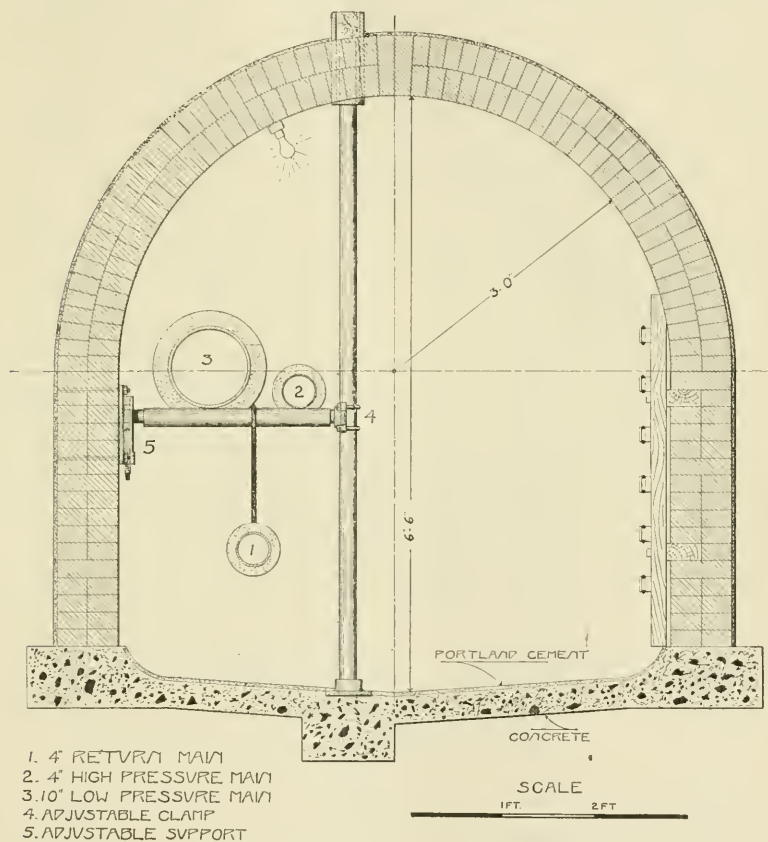


FIG. 1. CROSS SECTION OF MAIN TUNNEL.

There is a clear head room of 6 feet 6 inches, and the width is 6 feet. At every 10 feet is an adjustable pipe chair and wooden bricks are placed in the wall at the same distances, furnishing a means of fastening cleats for wires for the light and power circuits. The tunnels are lighted by incandescent lights. The location of the tunnels is shown in Fig. 2, page 82.

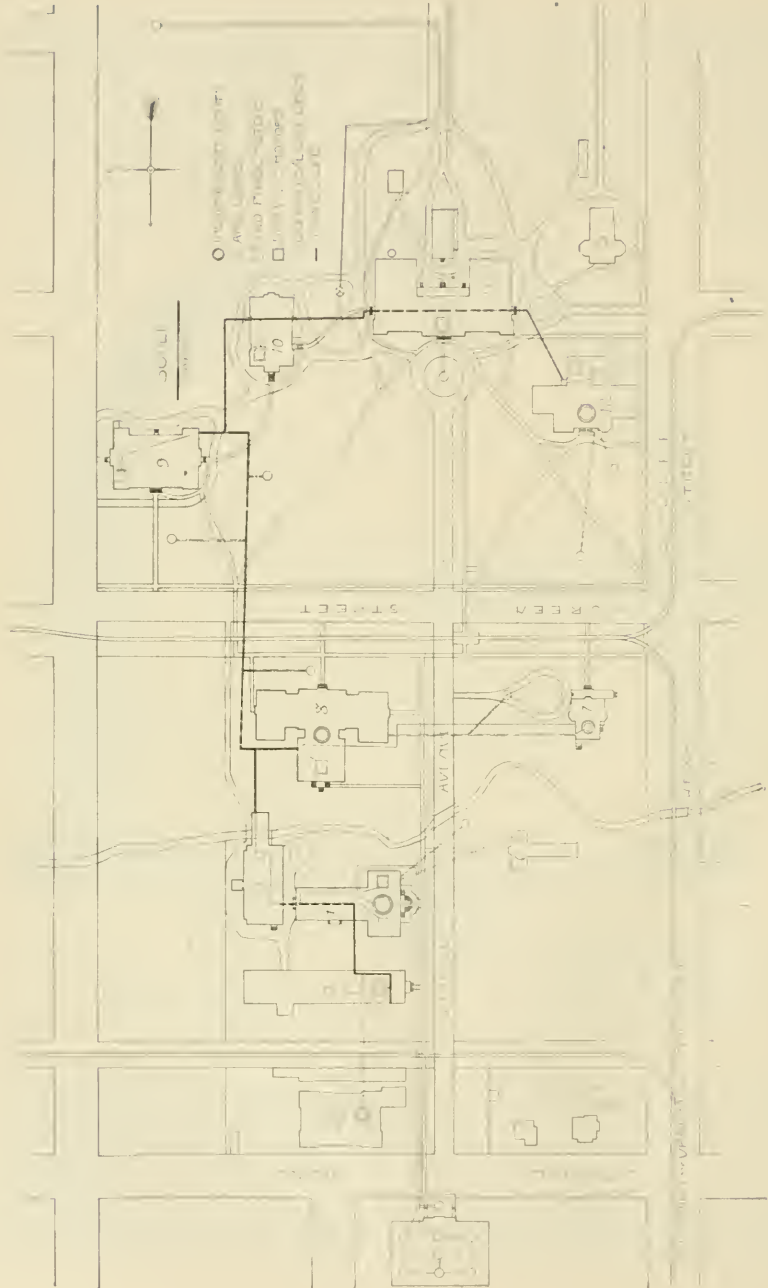


FIG. 2. LOCATION OF TUNNELS.

THE PIPING.—The 10-inch heating main extends from the boiler room, through the pump room and tool room, which occupy the extension of the boiler house that is built over the Boneyard, and enters the south tunnel on the south side. This main is carried on the pipe chairs in the tunnel and extends to the center of the Chemical Laboratory, where it is reduced to 9 inches, which runs to the center of University Hall, from which point it is 6 inches to the Library. The connections taken from this main are a 6-inch main for the Engineering Building, Natural History Building, University Hall, and Library, and a 5-inch main for the Chemical Laboratory. The return mains for the condensed water are 3-inch from the Library to the University Hall and 4-inch from there to the boiler house. No expansion joints are used, provision for change of lengths being made in double swing ells, connected by 2-inch "bleeders," the longest run in a straight line being 475 feet. This length is anchored in the middle.

The tunnel pipes are covered with magnesia sectional covering painted with one coat of red mineral paint and one coat of black asphaltum.

In the boiler house there are three steam mains:—The heating main just described; the high pressure main for the commercial lighting plant, designed for 165 lb. pressure; and the laboratory main for the experimental engines of the steam engineering laboratory, designed for 90 to 100 lb. The latter passes under the floor of the laboratory, and supplies steam to each engine through a special bent pipe. The exhaust from each engine passes to the heating main. Each engine has its own separator on the steam main and its own grease extractor on the exhaust near its entrance to the heating main.

BOILER HOUSE EQUIPMENT.—During December 250 H. P. of National Water Tube boilers were set. These boilers are equipped with a Murphy smokeless furnace and automatic stoker. Steam was turned into the heating system from these boilers on Jan. 3, 1898, and the boiler has been in use ever since. A Berryman closed feed water heater is set so that the exhaust steam from the engines may be turned through it or around it as desired.

The 500 H. P. Babcock and Wilcox boilers which will be set in the new plant some time in May, will be equipped with Roney

mechanical stokers. The 100 H. P. horizontal tubular boiler which will be moved from the old plant, will be set with a Brightman stoker. The coal and ashes are handled by machinery. The storage capacity for coal is about 600 tons.

Some of the smaller details of the boiler house equipment consist of:—A No. 6 Schaeffer & Budenberg exhaust steam injector; a Locke damper regulator; Davis back pressure valves; 8-inch Lyman exhaust head; Worthington 2-inch hot water meter; Crosby recording pressure gages; feed pumps with automatic control from return tanks; oil filter; and Austin separators.

STEAM ENGINEERING LABORATORY.—This contains all of the engines owned by the University. These may be enumerated as follows:—One Ideal compound, 100 H. P., used for running the generators for both light and power circuits; one single cylinder Ideal engine, 50 H. P.; one Westinghouse "Junior" engine, 50 H. P.; one Robinson engine, 25 H. P.; one small Robinson engine, 15 H. P.; one Ball engine, 40 H. P.; one Meyer engine, 40 H. P.; and one Sturtevant engine, 15 H. P. These engines may be run from either of two steam mains, but all exhaust into a common main connected with the heating system. During such times of the year as the external temperature does not fall below about 50° F. there will be sufficient exhaust steam for all heating purposes; at lower temperatures live steam will be supplied directly from the boilers through pressure reducing valves in the boiler house.

A large amount of new apparatus and steam appliances will be added to the equipment of this laboratory at an early date.

The University electric plant is for the purpose of furnishing current for the incandescent lamps in the building, for arc-lamps on the campus, and for power in the machine shops, in the dynamo and other laboratories, and also for the ventilating fans in the several buildings. There is a Westinghouse two-phase alternating current plant, consisting of two generators aggregating 120 K. W. normal output, a number of induction motors aggregating 100 H. P., and transformer capacity for seven hundred 16 C. P. incandescent lamps. The motors are wound for the primary voltage of 440 volts. The transformers reduce from 440 volts to 110 volts for incandescent lighting. A Wood arc-light machine supplies current for twenty-five series arc-lamps on the grounds and in Military Hall. In addition to the above the Uni-

versity has a number of 500-volt direct current motors which have been installed for a number of years. It is the intention to replace these eventually with induction motors. They are now supplied with current from a 30 K. W. Westinghouse multipolar generator. This generator also gives the Electrical Engineering Department special facilities for testing street car motors and other 500-volt direct current apparatus. The incandescent and power wiring is all in the tunnels of the heating plant. The series arc-light circuits have been designed to go underground. While the plant is first of all a commercial plant, yet it has also been designed so as to be accessible for tests.

The following table gives the capacity of the present plant:—

| | |
|------------------------------------|-----------------------|
| Coal consumption '97-'98..... | 3 500 tons. |
| Coal storage capacity..... | 700 tons. |
| Boiler capacity..... | 900 horse power. |
| Engine capacity..... | 300 horse power. |
| Number of incandescent lights..... | 1 000 |
| Number of arc-lights..... | 25 |
| Motor capacity..... | 100 horse power. |
| Length of tunnels..... | 1 800 feet. |
| Number of buildings heated..... | 12 |
| Amount of radiation..... | 50 000 square feet. |
| Amount of space heated..... | 5 000 000 cubic feet. |
| Estimated value of plant..... | \$90 000.00 |

STRENGTH OF CONCRETE OF VARIOUS PROPORTIONS.

R. B. KETCHUM, '96, ASSISTANT IN CIVIL ENGINEERING. FRED. W.
HONENS, '96, ASSISTANT U. S. ENGINEER.

The following is a summary of the results of a series of experiments made by the authors in the Cement Laboratory of the University of Illinois, to determine the variation in strength of concrete due to a difference in the proportion of the ingredients.

About 200 six-inch cubes of concrete were tested for crushing strength to study the variation in the strength of the concrete due to a variation of the proportion of the ingredients. Ten different proportions were used and six specimens were tested at three different ages, viz., seven, thirty, and ninety days, making in all thirty experiments. All details of the experiments are omitted here, except those most essential to an understanding of the results.

THE MATERIALS.

The materials used were Saylor's Portland cement, sand from a bank near Urbana, Illinois, gravel from a pit near Urbana, and broken stone from a quarry at Kankakee, Illinois. Tables I and II are self explanatory of the qualities of the materials.

TABLE I.
QUANTITATIVE ANALYSIS OF MATERIALS.

| MINERAL. | GRAVEL. | SAND. | CHEMICAL. | CEMENT. | STONE. |
|----------------------|---------|----------|--|---------|----------|
| | PER CT. | PER CENT | | PER CT. | PER CENT |
| Silica..... | 66.9 | 84.4 | Silicon dioxide, Si O ₂ | 21.58 | 2.49 |
| Clay | 2.4 | 3 0 | Ferric oxide, Fe ₂ O ₃ ... | 8 36 | ..... |
| Calcium carbonate... | 29 4 | 11 4 | Aluminum oxide, | | |
| Magnesium..... | 0.6 | 0.6 | Al ₂ O ₃ | | 1 05 |
| Iron | 0.7 | 0 7 | Calcium oxide, Ca O | 60.80 | 30.29 |
| | | | Magnesium oxide, | | |
| | | | MgO..... | 0.17 | 19.59 |
| | | | Sulphur trioxide, SO ₃ .. | 2.02 | ..... |
| | | | Carbon dioxide, CO ₂ .. | | 46.58 |
| | | | Alkalies..... | 3.70 | ..... |
| | | | Moisture..... | | 0.16 |
| Total..... | 100.0 | 100.0 | Total | 96.63 | 100 00 |

All gravel and broken stone used in these experiments passed a 2-inch ring and was caught on a No. 5 sieve, unless otherwise noted.

and water flushed to the surface. In every case only enough water was used in the concrete to cause a film of water to come to the surface after considerable tamping. The cubes were left in the molds for twenty-four hours with wet cloths over them, after which time the molds were carefully taken apart and the cubes immersed in water, where they remained six days. The thirty- and ninety-day cubes were then placed in a room with free access to the air until tested.

TABLE IV.

CRUSHING STRENGTH OF CONCRETES.

Each result is the average for six specimens.

| REF. No. | PROPORTION. | | | | AGE. | | | | | | | | | |
|-------------|-------------|-------|---------|------------------|---------|-----|---------|----------|-------|---------|----------|-----|---------|--|
| | CEMENT. | SAND. | GRAVEL. | BROKEN STONE. | 7 DAYS. | | | 30 DAYS. | | | 90 DAYS. | | | |
| | | | | | LB. | PR. | SQ. IN. | LB. | PR. | SQ. IN. | LB. | PR. | SQ. IN. | |
| 1 | 1 | 0 | 0 | 0 | 3 | 412 | | 5 | 318 | | 6 | 140 | | |
| 2 | 1 | 1 | 2 | 2½ | 1 | 430 | | 2 | 215 | | 2 | 903 | | |
| 3 | 1 | 0 | 3† | 0 | 1 | 077 | | 1 | 908 | | 2 | 517 | | |
| 4 | 1 | 2½ | 2½ | 2½ | 7 | 92 | | 1 | 482 | | 2 | 014 | | |
| 5 | 1 | 2½ | 0 | 5 | 7 | 39 | | 2 | 033 * | | 1 | 783 | | |
| 6 | 1 | 3 | 0 | 0 | 7 | 67 | | 1 | 345 | | 1 | 409 | | |
| 7 | 1 | 3 | 3 | 4 | 7 | 14 | | 1 | 028 | | 1 | 848 | | |
| 8 | 1 | 2½ | 5 | 0 | 5 | 66 | | 1 | 385 | | 1 | 609 | | |
| 9 | 1 | 2 | 3 | 4 | 6 | 40 | | 1 | 199 | | 1 | 290 | | |
| 10 | 1 | 2 | 2 | 3 | 4 | 20 | | 2 | 117 * | | 1 | 324 | | |

† Unscreened. * Rejected.

In crushing the cubes, the direction of the force applied was parallel to the tamped surface. A self-adjusting plate was used to distribute the pressure over the entire area of the cube. The rate of compression was five sixty-fourths of an inch per minute.

THE RESULTS.

Table IV gives the average crushing strength for six cubes of each proportion at the three different ages.

To aid in a further study of the results, a diagram, Fig. 1, was prepared as follows: The concretes were arranged in the order of their strengths, and numbered 1, 2, 3, etc. (see numbers at the bottom of Fig. 1); No. 1 (not shown), being the strongest,

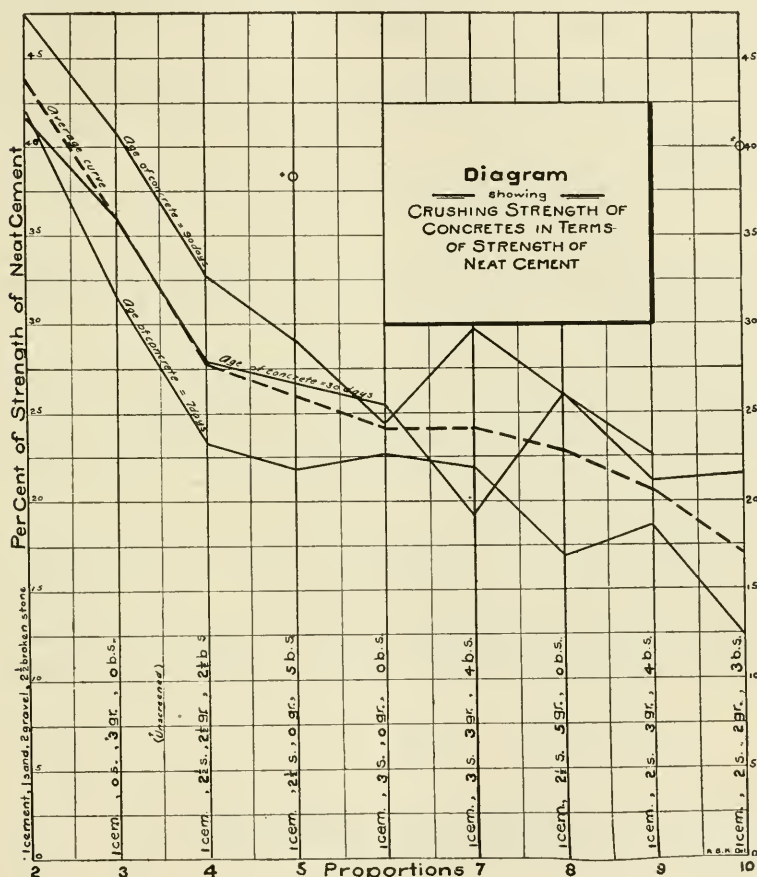


FIG. 1.

No. 2 the next in strength, and so on to No. 10, the weakest. The average crushing strength of the six cubes for each mixture, in per cents of the average crushing strengths of the neat cement cubes of the same age, is then plotted as an ordinate. In this way were plotted the three full lines for the three ages. The

broken line represents an average for these three ages. The following conclusions drawn from these experiments are interesting.

1. Although the amount of ballast in No. 3 and No. 6 is the same, No. 3 is about 50 per cent the stronger. This shows that large and small ingredients should be mixed to get the strongest concrete.

2. A comparison of No. 4, No. 5 and No. 8, which have the same amount of ballast, shows that rough angular stones are better than smooth ones.

3. No. 4 compared with No. 5 seems to show that a mixture of stone and gravel is better than either alone.

4. A comparison of No. 7 with No. 9 seems to show that a decrease in the amount of sand causes a decrease in the strength of the concrete, even though this decrease of sand makes the concrete richer.

5. The fact that No. 7 is nearly as strong as other very much richer concretes (for example, No. 6), seems to indicate that the strength of concrete depends upon the composition of the ballast. This point should therefore be carefully considered in designing concrete work.

Incidentally, the relative position of the curves shows that neat cement gains its strength more rapidly than do the concretes; and the fact that the curves for the three ages are approximately parallel, shows that the variation in the composition of the ballast, affects the strength in about the same way for all ages.

SPECIFICATION WRITING.

BY J. M. WHITE, '90, ASSOCIATE PROFESSOR OF ARCHITECTURE.

A great many attempts have been made to shorten the labor of writing specifications. Most of these efforts have been directed to the preparation of standard forms, which the general practitioners will find usually omit many essential points, and encumber the specification with much material that is irrelevant. An

architect who specializes on one class of buildings of about the same cost may find a blank form of advantage, but such a specification will not give to its author the prestige in the mind of his client that will be commanded for him by a specification written entirely and expressly for his building. A specification which is concise, clear, well arranged and carefully indexed will carry confidence with it; and it is of the utmost importance to the architect to see that he does not have a doubting client. Few owners will pretend to understand the meaning of the drawings, but they do feel confidence in their ability to criticise specifications. It therefore behooves an architect to give his best attention to this part of the work.

To write a good specification requires something more than the ability to judiciously copy paragraphs from other specifications. It requires a knowledge of all the building trades and of all the details of construction. There are aids which will be found valuable in preventing omissions; but these should be used merely to suggest points that should be included or to give better phraseology, and not to make up for the shortcomings in the author's knowledge of how it ought to be done.

The "SPECIFICATION REMINDER," a pamphlet published by the Master Builders' Association of the City of Boston, is a valuable aid and includes a very complete list of things which should be specified.

"BOWER'S SPECIFICATIONS" is a book containing an arrangement of the material commonly used in specifications. It is not a treatise on specifications, but a compilation of carefully studied paragraphs suitable for insertion in specifications.

Johnson's "ENGINEERING CONTRACTS AND SPECIFICATIONS" contains an excellent analysis of the general clauses in specifications together with some good specifications for engineering work.

Two lectures have been published which give good working synopses, one delivered by T. Roney Williamson before the architectural students of the University of Pennsylvania, which may be found in the *American Architect*, Vol. XLV, pages 79 to 92; and the other by Theodore Cooper before the students of the

Rensselaer Polytechnical Institute, which was published in the *Engineering Record*, Vol XXVII, pages 395-97.

In arranging a specification, the main divisions which represent the different trades employed should be treated in the order in which they will be executed. Each one of these divisions should begin a new page, even if the work is to be let to a general contractor, because it may be necessary through some change in plans or method of construction to re-write one division and it is then possible to do so without interfering with the remainder of the specification. There is a natural order in which the work under a general heading should be treated, as, for example, in steam heating the sequence would be boiler, mains, risers, valves, radiators, etc. An experienced writer, having the drawings hung around him so they may be readily seen and with the memorandum made during the progress of the drawings, will, by following some such classification, write a complete specification without reference to any aids. Some men have become so expert that they can dictate the entire specification in this way to a stenographer or into a graphophone. This method can be used only by an expert, for there is no method of making corrections or of changing the order of paragraphs. Writing a specification long-hand is the most satisfactory for general use, because corrections can be readily made and the manuscript can be cut to pieces and pasted up in a different order, if desired. In this way the most perfect specifications can be obtained. "BOWER'S SPECIFICATIONS" is a very valuable assistance in this case, for often entire paragraphs can be used to which the copyist may be referred, thus saving the writer much time.

A valuable scheme is to write on separate library cards the different paragraphs from a large number of specifications and then to classify them in an index case. The usual size of card is three inches by five inches, but it is more convenient to have them eight inches long so that paragraphs clipped from specifications may be pasted on them. In writing the specification the cards having clauses applicable will be selected and any new paragraphs that may have a general application will be written on similar cards for insertion in the file. These cards arranged in the proper order with suitable heading cards would make a complete specification ready for the copyist. It would not be advisa-

ble to write everything that occurs in a new specification on cards, because there are sure to be some things which pertain to that building alone and would have no future value. This scheme works best for such trades as masonry, carpentry, painting, etc., in which the ways of doing work have become fixed and where about the same clauses would apply to all work of the same kind. It would hardly be advisable to attempt to apply it to any phase of electrical work because improvements are coming so fast that it is best to go to the contractors and manufacturers for information to be sure to be up with the times. Much the same thing is true of finished hardware because of the changes in design and finish.

The usual size for specifications is 8½ inches by 14 inches, but 8 inches by 13 inches is also used. Standard contract blanks are usually of the former size. If the specification is to be printed it will be found very convenient to make it of a size that will fit readily in the pocket; 4 inches by 7 inches, bound at the end, will be found very satisfactory.

The usual methods of reproduction are the pad and stencil processes and typewriting with carbon sheets. The two chief objections to the pad processes are that the sheets are likely to stick together and the inks will fade rapidly, making them useful for reproducing matter for temporary use only. Of the stencil processes the mimeograph and electric pen are the best and give fair results with great rapidity. With ordinary care 150 to 200 copies may be made and it is more economical than printing for any number up to about one hundred copies. Twenty copies or less, double-spaced, cost about forty cents for each page duplicated. Typewriting with carbon sheets is the most economical where not more than six copies are required.

The method of paragraphing and arrangement of headings is of very great importance, because if properly done it facilitates the use of the specification besides adding materially to its appearance. The following form of heading requires more room on the page than the usual one, but is more architectural. The heading should be in capitals, and may be placed at the left hand side or in the center of the page:—

SPECIFICATION OF THE
LABOR AND MATERIAL TO BE
FURNISHED BY THE MASON IN THE
ERECTION OF A RESIDENCE
FOR JOHN J. JONES
CHICAGO, ILLINOIS.
EDWARD E. SMITH, ARCHITECT

The form of paragraphing used by the author is illustrated in the following abstract. The paragraphs are indented about eight letters to give prominence to the headings and are spaced one line apart. Single spacing is preferable because it puts the material in smaller compass, but makes it more difficult to interline corrections. Capitals are used for the main headings and small letters for subheadings. By main headings under mason work would be meant excavation, brick work, cut stone, etc.; and the subheadings under brick work would be lime, cement, sand, common brick, pressed brick, etc.:—

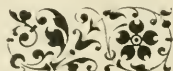
BRICK WORK.

All walls, piers, chimneys, footings, etc., where shown brickwork on the drawings, unless otherwise specified, are to be laid with sound, merchantable brick in lime mortar.

All masonry below grade, etc., etc.....

Hollow walls.

Hollow walls where shown are to have 2-inch air spaces, etc.....



THE CORROSION OF IRON.

BY S. W. PARR, PROFESSOR OF APPLIED CHEMISTRY, AND A. E. PAUL,
FELLOW IN THE COLLEGE OF SCIENCE.

The data presented herewith embodies the results of a series of experiments conducted for the purpose of determining the conditions favoring the corrosion of iron. Primarily the idea was to reproduce as nearly as possible the conditions existing inside of steam boilers. Most of the facts developed, however, are applicable to external corrosion as well.

Solutions of salts likely to be met with in natural waters were prepared, usually of one per cent strength. In one hundred cubic centimetres of the solution were placed ten grams of soft iron wire in the form of card teeth. The wire was added to the solution, which had been kept vigorously boiling for half an hour and so maintained for two hours after the iron was added. In the first experiment, however, the wire was added to the cold distilled water, having present all of the normally dissolved gases. The water was then brought to the boiling point and maintained as usual. The method of determining the amount of iron dissolved was volumetric, using a Jones reductor and potassium permanganate.

In the second column of Table I, page 96, are placed the factors which may fairly be taken to represent an absence of corrosion, any factor below 0.6 being taken as a correction factor. In two of the experiments, ten per cent solutions were used. The results are given in milligrams of iron dissolved.

These results seem to indicate that all the corrosive conditions were nullified by the presence of sodium carbonate or, in the case of pure water, by the absence of both oxygen and carbon dioxide.

TABLE I. — CORROSION OF IRON BY SALT SOLUTION.

| No. | CONDITIONS. | MILLIGRAMS IRON DISSOLVED. | |
|-----|--|-------------------------------|---------------------|
| | | CORRODING. | NON-CORROD- ING. |
| 1 | Cold distilled water, iron added and boiled for two hours..... | 3.5 | ..... |
| 2 | Boiling distilled water, boiling continued for two hours..... | | 0.6 |
| 3 | 1% boiling solution sodium chloride.... | .8 | ..... |
| 4 | 1% boiling solution sodium nitrate..... | 2.0 | ..... |
| 5 | 1% boiling solution sodium nitrate with 1 gramme sodium carbonate..... | | 0.5 |
| 6 | 1% boiling solution calcium nitrate.... | 2.9 | ..... |
| 7 | 1% boiling solution calcium nitrate with sodium carbonate..... | | 0.5 |
| 8 | 1% boiling solution calcium chloride.... | 5.1 | ..... |
| 9 | 1% boiling solution calcium chloride with sodium carbonate..... | | 0.6 |
| 10 | 1% boiling solution calcium sulphate... | 1.8 | ..... |
| 11 | 1% boiling solution calcium sulphate with sodium carbonate..... | | 0.3 |
| 12 | 1% boiling solution magnesium chloride | 3.3 | ..... |
| 13 | 1% boiling solution magnesium chloride with sodium carbonate..... | | 0.6 |
| 14 | 1% boiling solution magnesium sulphate | 2.9 | ..... |
| 15 | 1% boiling solution magnesium sulphate with sodium carbonate..... | | 0.3 |
| 16 | 1% boiling solution ammonium chloride | 9.0 | ..... |
| 17 | 1% boiling solution ammonium chloride with sodium carbonate..... | | 0.3 |
| 18 | 1% boiling solution ammonium nitrate.. | 60.2 | ..... |
| 19 | 1% boiling solution ammon. hydroxide.. | | 0.3 |
| 20 | 1% boiling solution magnesium nitrate | 1.7 | ..... |
| 21 | 1% boiling solution sodium sulphate.... | 1.0 | ..... |
| 22 | 1% boiling solution magnesium chloride and calcium carbonate..... | 4.5 | ..... |
| 23 | 1% boiling solution aluminium sulphate | 51.7 | ..... |
| 24 | 1% boiling solution calcium chloride and magnesium carbonate..... | 0.9 | ..... |
| 25 | 1% boiling solution hydrogen peroxide | 56.6 | ..... |
| 26 | 1% boiling solution calcium chloride and sodium hydroxide..... | | 0.4 |
| 27 | 10% boiling solution sodium hydroxide.. | 1.1 | ..... |
| 28 | 10% boiling solution sodium carbonate.. | | 0.3 |
| 29 | 1% boiling solution sugar..... | | 0.3 |
| 30 | 1% boiling solution tannin..... | 7.2 | ..... |
| 31 | 1% boiling solution starch..... | 1.1 | ..... |

The following would seem to indicate the order of activity of those substances, of possible occurrence in natural waters, placing the most active first :—

- Ammonium nitrate.
- Aluminium sulphate.
- Ammonium chloride.
- Calcium chloride.
- Magnesium chloride.
- Calcium nitrate.
- Sodium nitrate.
- Calcium Sulphate.
- Magnesium nitrate.

Ferrous and ferric sulphates have unfortunately been omitted ; their place, however, would undoubtedly be next to aluminium sulphate.

Some of these tests were also made in a steam digester at 90 pounds pressure, the material being placed in a porcelain beaker. The general indications being the same as when boiled in an open vessel, the use of the digester at high pressure was discontinued. However, some interesting experiments were made with this apparatus which, while needing further confirmation to give them full value, seems to warrant notice here.

The question arose as to whether the presence of oxygen or carbonic acid in the water was responsible for the corrosive effect as indicated in experiment 1, of the table. Most authorities seem to agree that it is the carbonic acid that is responsible for corrosion due to dissolved gases. *

By use of the digester it was possible to maintain under pressure a supply of oxygen or carbonic acid and by eliminating all gases in the beginning and continuing the boiling under conditions thus controlled, the data below was obtained.

The experiment was conducted as follows : Three porcelain beakers partly filled with distilled water were boiled until half evaporated, and while still briskly boiling placed inside the open digester, the iron was added and the cover quickly placed in position, fastened and the pressure kept at 90 pounds for two hours. The resulting factors in milligrams were: 0.6, 0.3 and 0.3.

The experiment was now repeated with the modification that in one of the beakers was placed some sodium carbonate and into

* *Metallic Structures, Corrosion and Fouling*, by J. Newman, 1896.

the digester outside of the beakers was dropped (just before placing on the cover) a quantity of sodium peroxide. By the decomposition of the peroxide there would be supplied free oxygen. The results were:—

- (a) Water and iron only, corrosion factor.....1.6 milligrams.
- (b) Water and iron only, corrosion factor.....1.0 milligrams.
- (c) Water, iron and sodium carbonate, corrosion.... none.

Again the above conditions were repeated, but instead of the sodium peroxide there was added outside the beakers tartaric acid and sodium carbonate, thus supplying under pressure free carbonic acid. Results were:—

- (a) Water and iron only, corrosion factor.....1.0 milligrams.
- (b) Water and iron only, corrosion factor.....0.7 milligrams.
- (c) Water, iron and sodium carbonate, corrosion.... none.

The above results are better presented for comparison in tabular form in Table II.

TABLE II.

CORROSION OF IRON BY OXYGEN AND CARBONIC DIOXIDE.

| No. | CONDITION. | MILLIGRAMS IRON DISSOLVED. | |
|-----|---|----------------------------|----------------|
| | | CORRODING. | NON-CORRODING. |
| 1 | Water and iron only; all gases expelled..... | | 0.6 |
| 2 | Water and iron only; all gases expelled..... | | 0.3 |
| 3 | Water and iron only; all gases expelled..... | | 0.3 |
| 4 | Water and iron; oxygen only present... | 1.6 | |
| 5 | Water and iron; oxygen only present... | 1.0 | |
| 6 | Water, iron and sodium carbonate; oxygen present..... | | |
| 7 | Water and iron; carbonic acid only present..... | 1.0 | |
| 8 | Water and iron; carbonic acid only present..... | 0.7 | |
| 9 | Water, iron and sodium carbonate; carbonic acid present..... | | |

SURVEY OF DEEP COAL MINE IN ILLINOIS.

BY W. H. TARRANT, '99, SCHOOL OF CIVIL ENGINEERING.

In the survey of a coal mine having a depth of more than 1 000 feet, the writer recently had occasion to adopt some rather unusual methods, which it is his purpose to describe in this paper.

A previous survey in which was employed the common method of plumbing two lines down a single shaft, did not prove altogether satisfactory. It was decided, therefore, to try the rather unusual plan of plumbing one line down the hoisting shaft and another down the air shaft, and of connecting the two points both above and below ground.

Above ground dumps and other obstructions intervened between the shafts and it was necessary to run an auxiliary line on unobstructed ground and to tie the two upper plumb points to this line by perpendiculars. This auxiliary line was established on a meridian, first approximately by needle and then precisely by observations on Polaris. Substantial hubs were established at the feet of the perpendicular tie lines. The necessary distances were very carefully measured with a steel tape, and the exact length and direction of the line between the surface plumb points was calculated.

Below ground, as the air courses were open and easy of access, a double connection was afforded for a precise azimuth traverse. The direction of the base line AB, Fig. 1, page 100, was first assumed, and a traverse run from A to I, through the east air course. Then a closing line was run through the west air course, thus checking the work. In the east portion of the traverse, AB etc., to I, the direction of the line AB was determined with reference to the line AI.

In establishing the meridian, instead of taking observations on Polaris at elongation, they were taken whenever it was most convenient at intervals of five minutes, and reductions made by the

method given in the "U. S. MANUAL OF SURVEYING INSTRUCTIONS, 1894," and also in "HODGMAN'S MANUAL OF LAND SURVEYING," page 107. The position of the star at each of the observations was marked by means of a notch cut on a board, which was placed at a distance of about 250 feet north of the air shaft. The final mean result did not vary more than an eighth of an inch from any single observation.

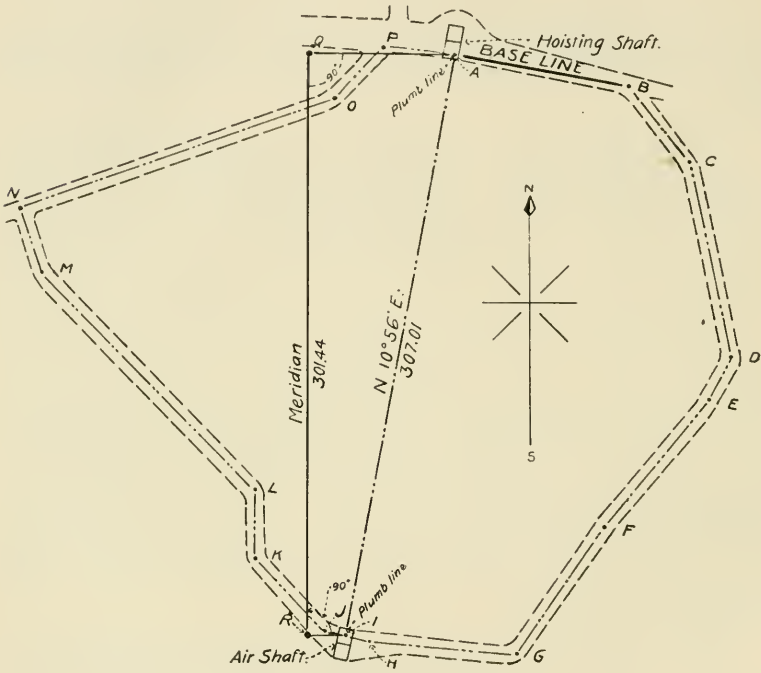


FIG. I.

The azimuth of the base line AB having been calculated, it was necessary to fix the line permanently. Holes were drilled in the bottoms of the entry to a depth of two feet and well-seasoned, hardwood plugs were driven in, after which the line was more carefully marked by means of points in the tops of the plugs. By having several plugs on the line AB and a line of plugs west of the hoisting shaft, any change in their position could be detected.

REPAIRING OF PLASTER PARIS CASTS.

BY C. R. CLARK, '98, SCHOOL OF ARCHITECTURE.

The art of handling plaster of Paris is one upon which little has been written, and especially is this true regarding the mending of broken statuary, casts and architectural ornaments. So far as I have been able to learn not a single article has been written on that subject except one running in *Architecture and Building*, by Professor Frederick of the University of Illinois.

The successful mending of casts, as well as the making of them, requires not a little skill and ingenuity. Therefore it may be of interest to know some of the ways of repairing the breaks which most commonly occur. It will be difficult to lay down any specific method of procedure, since each case will present new difficulties; but the general method is the same throughout.

Let us consider a very simple case; that of a life-size statue from which a finger had been broken. The first thing to do is to determine the original direction of the finger. The importance of this will be seen when the finger is finally put in place. If there are no missing pieces the direction will not be hard to determine. Next dig out the surfaces so that when placed together they will form a hollow disk about a quarter of an inch thick at the center. For the sake of ease in cutting it is better to moisten the cast. This will do no harm, since it should be remembered that when fresh plaster is put upon an old cast, unless the cast is first thoroughly wet the new plaster will have no strength and the pieces will not adhere.

As the finger will need some other support than the plaster, it will be necessary to arrange for putting in a wire. Copper wire should be used, as it will not rust the plaster, and it is much more easily worked. With a knife or drill make a hole in the finger about a quarter of an inch in diameter and one inch deep, with the inner end slightly enlarged. Make a similar hole in the hand that will coincide with the one in the finger. In making these

care must be taken that the outer portion of the plaster is not disturbed. Next kink the ends of a piece of wire so that it will just allow the finger to go into position when it is placed in the holes. After making sure that all will go together we may proceed to fasten the finger in place. For doing this we shall need but a small amount of good plaster. The dental plaster is satisfactory, as it is strong and allows ample time for working. It can be had at almost any drug store.

Put into a dish a sufficient quantity of water to fill the holes that were made in the finger and hand, and sift into it as much plaster as it will absorb. Then allow it to stand. While waiting on this, the finger and hand must be thoroughly soaked so that water will remain on the surface. When the plaster in the dish has stood for four or five minutes, stir it until it is of the consistency of thick cream. Care must be taken not to beat any air into it. Fill the hole in the hand with the plaster and insert the wire. As soon as it sets sufficiently to hold the wire in position, fill the hole in the finger, and the disk also, and put it in place. It now becomes evident that the position must be ascertained beforehand, since the plaster sets so rapidly that it will become hard before this can be determined. Hold the finger firmly in position for a few minutes, when the plaster will have set sufficiently to allow that which has been forced out around the fracture to be removed. This is best done with the moistened fingers.

The finger should now remain undisturbed for at least twenty-four hours, when it will be as strong as any part of the cast. If it requires still further modeling it should be allowed to dry for a week or so, when, by using very fine sand paper the plaster can be worked down to the required surface. But if a good surface is desired, it should be allowed to become so dry that it will not fill the sand paper with plaster.

Next let us consider briefly the method of replacing an arm. Owing to its great weight, it will be necessary to provide a support for the arm, until the plaster has hardened. It is impossible to describe a method for making a support, since each case is of necessity different. But this much will apply in every case. The support must hold the arm firm and be so arranged

that it can be easily removed or replaced while getting the pose. After the support has been made, the work will proceed the same as in the case of the finger, except that the hollow disk must be made thicker, and instead of the wire one must use a piece of wrought-iron, previously treated to a coat of white lead, and three or four inches long and a quarter of an inch in diameter. If there should be a number of small pieces it will be easier to omit them entirely unless they will aid in supporting the arm while the plaster sets. Where pieces are omitted it is almost always necessary to use sand paper to remove the superfluous plaster; but the greater portion of this may be cut away with a knife much more readily while damp than with sand paper or rasp, after it has thoroughly dried.

In the case of a plaque or panel the wires are not put into holes, but the pieces are laid together and grooves cut into the back in which the wires are placed, and after the pieces are stuck together the grooves are filled with plaster.

Pieces are sometimes cast without hangers, in which case if it is desired to hang them on the wall hangers must be inserted. To do this a vertical axis through the center of gravity should be determined and the hanger inserted where this line pierces the upper edge of the cast. At this point make two holes in the back or top of the cast and place in them a U-shaped wire with the ends bent to prevent pulling out. Then pour the plaster around it and allow it to stand for twenty-four hours.

Repairing with plaster of Paris, when well done, is to be preferred to all other methods. Glue is used, however, and is more convenient for most people. But it has the disadvantage, if allowed to come near the surface, of coloring the cast, and it also leaves a small crack which cannot be filled with plaster, since wetting the cast will loosen the pieces. After a time this crack will collect enough dirt to show a black line, thereby disfiguring the cast. White shellac is much used by the Italians as a cement, but it has the same objections, though to a less degree, as the glue. The shellac is put into an open vessel and set on fire. When it is of the right consistency the fire is extinguished, and the shellac is used as glue. The last two methods are used only for repairing old or dry casts.

As it is the exception to make any but the most simple casts without breaks or air bubbles, it might be well to explain how the

artist repairs them and makes his work presentable. It is frequently the case that when the mold is removed the cast is found to contain innumerable small air bubbles just on the surface. The first experience of this kind is very discouraging to the beginner. But the remedy is simple. Take dry plaster and rub the holes full. It will absorb sufficient moisture from the cast to cause it to set. This method may be used only when the holes are comparatively small. Where strength is not required, and where the holes are somewhat larger than in the previous case, killed plaster may be used. This is made by mixing the plaster as first described and then stirring it until it has set, when it will resemble putty, and may be worked like it for some time; but it never gets very hard. If the bubbles are large it is better to use live plaster. When casts are made in layers they often separate and need to be replaced or to have the parts modeled out. To prepare the plaster for this process, mix it as first described, but stir it only enough to make a homogeneous mass. Then allow it to set, and just before it finally hardens work it up with a knife, when, by keeping the hand and tools wet it can be used as clay. If parts have been broken off they may be replaced in the same manner as when the cast is dry.

Inasmuch as the dirt has to be removed from many casts before they can be mended, it will not be out of place to speak of the methods of cleaning casts. If the cast has been painted, warm water with a little soap will remove finger marks or dust. But if by some means it has not been made water proof, nothing but clear water should be applied and plenty of it, since the plaster will absorb the dirty water and leave the cast worse than before. Probably a better method would be to apply the water with a hose, as the force would loosen the dirt and carry it away. Cooked starch is also used. The thick paste is brushed over the cast, and when dry it may be peeled off, taking the dirt with it. When a cast has become dirty and can not be cleaned, it is often desirable to paint it. This may be done by applying several thin coats of white paint, mixed with turpentine.

Casts ought always to be treated with oil or wax to prevent moisture from carrying dirt into the plaster. They should be handled as little as possible and kept free from the dust by putting a cloth over them when the room is cleaned.

REPAIRS OF MASONRY ARCH.

BY A. E. HARVEY, '92, ASST. ENGINEER ILLINOIS CENTRAL R. R.

In the early days of railroading, the cost of transportation and the price of iron were high and the engineers naturally selected the material which was cheapest and most convenient for their work; consequently streams of moderate flow which would today be bridged with steel were then spanned with arches of stone. In most cases these were built of the material which lay most convenient, which was usually sandstone quarried from the upper strata and was, therefore, not of the best quality. Some of these arches have been replaced in later years by more modern structures, but many remain, which, although well constructed, are crumbling under the influence of the weather. These must be replaced when the stone has so deteriorated that pointing will not preserve them, unless their condition be such that repairs may be made similar to those described in this article. These repairs were of such a character and were such a departure from usual practice that they are a subject worthy of at least passing notice.

The Illinois Central Railroad crosses the Little Muddy river 271 miles south of Chicago upon a bridge consisting of two 40-foot semi-circular arches. The total length of the structure is 164 feet. Its width through the spandrels and arch rings is 10 feet. The arch rings are of course solid, but the spandrels and abutments consist of two walls, each $3\frac{1}{2}$ feet thick separated by a space of 3 feet. Through the spandrels at each end and between the arches are circular eyes 8 feet 4 inches in diameter. Upon the walls above the line of the top of the keystones were laid cover stones, 6 feet long and $1\frac{1}{2}$ feet thick, bridging the hollows in the spandrels. On each side and rising above these cover stones about 18 inches, parapet walls were built, between which the ballast was placed.

This bridge was built in 1853 and during its service of 44 years had become badly weather worn. The water had worked down through the ballast and cover stones and with the aid of

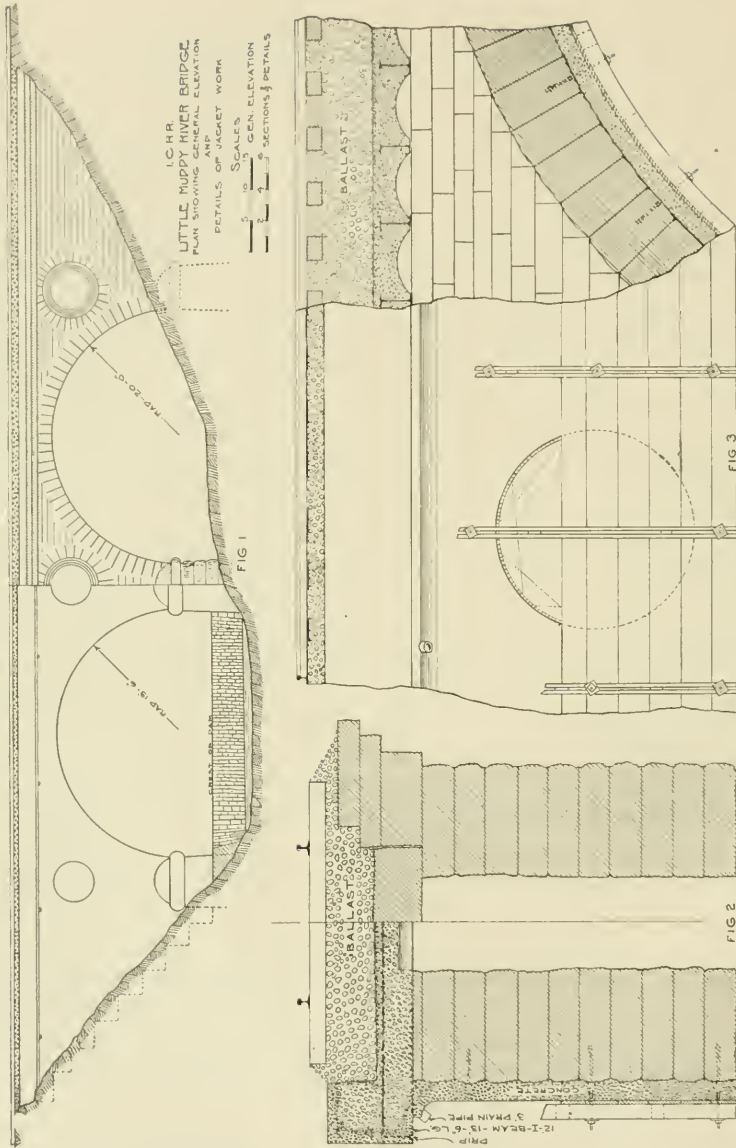


PLATE I. REPAIRS OF LITTLE MUDDY RIVER BRIDGE.

the frost had cracked and otherwise damaged many of the stones of the spandrels and parapet walls. The masonry about the eyes had become particularly weak, and was strengthened in 1891 by building a 12-inch ring of brick inside of each eye. The arch rings, however, were little damaged. The condition of the bridge was such that it would either have to be replaced at an early date or receive extensive repairs. On account of the difference between the cost of maintenance of a bridge of steel and one of masonry, it was decided to repair the old arches. These repairs consisted of building upon the top of the bridge a tight deck of concrete and I beams, upon which parapet walls were erected, and of covering all the exposed surface of the old masonry with a jacket of concrete.

FIG. 1, PLATE I, page 106, is a general elevation of the bridge. The portion to the right represents the bridge as it was in its original condition; the remaining portion is shown with repairs completed. Fig. 2 gives a section of the spandrel walls, old parapet wall, and cover stones; also a section showing the new deck, parapet wall, and jacket. Fig. 3 is a partial elevation of the finished work with a section through the arch upon the center line of the bridge.

The ballast, old parapet walls and cover stones were first removed to a level with the top of the arch ring and 12-inch I beams, $13\frac{1}{2}$ feet long, were laid transversely, $2\frac{1}{2}$ feet center to center, upon the old masonry. Between and over these beams was placed the concrete of the floor, 14 to 15 inches in depth, resting upon the walls and arching the hollows in the spandrels. Before the construction of this floor, the track was carried upon caps and stringers, but as the work progressed it was transferred to blocking resting upon the finished surface of the floor. The concrete consisted of 1 part Portland cement, 2 parts sand, and 5 parts of broken limestone. Upon this deck were built the parapet walls, 21 inches high, also of limestone concrete, but with a facing and top of the same material as the jacket below.

Inasmuch as the principal object of this deck was to keep the water away from the old masonry, every precaution was taken to make it water tight. The floor was sloped so as to drain to vitrified tile inserted in the edge of the deck at intervals of 20 feet. The floor and the inside of the parapet walls were

thoroughly coated with roofing asphalt. The deck, which projected 1 foot 8 inches beyond the face of the jacket, was provided with a drip along the under side.

The concrete jacket covering the exposed surface of the old masonry was applied by means of a mold, which is shown in place in Figs. 1 and 2, Plate I, page 106. The surface of the jacket is 8 inches from the draft line of the sides of the arches, which were rock faced, and 6 inches from the crandalled surface of the intrados of the arches. The mold was held in place by means of iron bars set in holes drilled in the stone. Each bar consisted of two parts, the expansion bolt and the extension bolt, connected by a pipe coupling. The expansion bolt was set into the stone about 6 inches and was of such length that the outer end was about 1 inch beneath the finished surface of the jacket. The inner end was split to receive a wedge. Through the coupling and the outer end of the expansion bolt a hole was drilled and a pin inserted, so as to prevent the coupling from unscrewing when the extension bolt was removed. The outer end of the extension bolt was provided with a nut and washer, which served to hold the frame of the mold in place. The extension bolt could be removed from the coupling by applying a pipe wrench, thus freeing the mold from the finished jacket.

To permit of using the extension bolts a second time, the outer end was turned down so that the pipe wrench would not destroy the thread and prevent the removal of the nut. The expansion bolt with the coupling remained imbedded in the concrete and served as an anchor or tie bolt. The hole where the outer bolt was removed was pointed up with rich mortar. The concrete of the jacket consisted of 1 part of Portland cement, 2 parts of sand and 4 parts of crushed granite.

The framing of the mold consisted of vertical posts set at intervals of about 5 feet. Each post was made of two pieces of 2×6-inch timber, spiked together with a space of 1 inch between their faces, through which the bolts were passed. By means of the nuts and washers these posts were set to the proper line and the mold boards set against their inside edge as the work progressed. The mold boards were of southern pine, 2 inches by 12 inches, dressed on one side. The concrete mixture was

shoveled into the mold and tamped in 6-inch layers and rammed into all the depressions and bad joints of the old masonry.

The jacket was put upon the under sides of the arch ring in the same manner, curved ribs being used, through which the bolts passed in the same way as they did through the posts. Upon these ribs, 2×6-inch lagging was laid parallel to the axis of the arch. The concrete was rammed in over the top of the lagging till the crown of the arch was reached, where a portion of the jacket had to be rammed from the sides. On each side of the bridge, five vertical joints were made in the jacket, and the work was carried up in each section in horizontal layers. In the sections next to the arches, the concrete against the sides was carried up at the same time and in connection with the work under the intrados of the arches. Where curves occurred about the middle pier and the abutments, special molds were made.

The method here described of holding the molds in place by means of bolts inserted in the masonry proved very efficient. It saved a large amount of labor and material in the way of bracing and framing for the mold, and obviated the necessity of building centres under the arches. The bolts were set into the stone about 6 inches and held the mold firmly in every case.

Alsen's Portland cement was used throughout the work.

The cost of the various parts of the work was as follows:—

| | |
|-------------------------------------|-------------|
| Concrete jacket, 150 cu. yds..... | \$ 1 533.75 |
| Concrete floor, 47 cu. yds..... | 1 057.75 |
| Concrete parapet, 75.4 cu. yds..... | 557.96 |
| Excavation, 227 cu. yds..... | 91.95 |
| Rubble masonry, 26.3 cu. yds..... | 98.63 |
| Force account work..... | 209 05 |
| Total | \$ 3 549.07 |

The price given for the floor included the cost of the labor of removing the ballast, old parapet walls and cover stones and the placing and maintaining of the falsework under the track, and does not include the cost of the I beams used in the floor, or the cost of the timbers used in the falsework, which were furnished by the railroad company. The force account work included the cutting off of the larger projections of the rock faced masonry so that there should not be less than 6 inches of concrete over any part of the work, and other incidentals arising in the construction.

The rubble masonry was used to level up the old work under the I beams of the floor.

The jacket will, in all probability, serve the purpose for which it was intended, that of strengthening the old masonry and preventing its further deterioration. The appearance of the structure after its completion was that of a solid concrete bridge showing no evidence of what it had been. It stands as an excellent example of what may be accomplished in similar cases, for the arches being subject to strains and vibrations during the progress of the work, which would not occur in an ordinary culvert or bridge abutment, gave rise to some fears that the concrete might be disturbed before it was properly set, but no such trouble developed.

The work was done by the J. S. Patterson Co., of Chicago, and required about 60 days, during which time there was no interference with traffic except that caused by the slow speed required over the bridge.

A PROBLEM IN METALLURGY.

BY WILLIAM H. KAVANAUGH, INSTRUCTOR IN MECHANICAL ENGINEERING.

The practical metallurgist is frequently called upon to solve problems connected with the manufacture of iron and steel. These problems comprise calculations in thermal chemistry, in calorimetry and in the testing of the efficiency of fuels and furnaces. In blast furnace working, there are calculations of the volume of blast required for the economic reduction of the ore, the size and power of the blowing engines and the determination of the composition of the charge. Similar problems involve calculations of the volume of blast, the power of blowing engines, the distribution of materials and the thermal condition of the Bessemer process. The data and requirements will vary with the problems, but the fundamental principles governing their solution are the same throughout. It is the object of this article to show

how some of these principles may be applied in the working of a certain class of problems, and it is thought this can be more clearly done by assuming a problem and giving the solution in full. The data were obtained from one of the largest steel plants in this country and represents the best American practice.

PROBLEM.—The following were the conditions of a blow in a Bessemer converter:—

| | |
|--|--------------------|
| Weight of molten metal and scrap charged..... | 22 500 lb. |
| Weight of spiegeleisen..... | 2 500 lb. |
| Loss in conversion..... | 9.37 per cent. |
| Length of blow..... | 9 min. 20 sec. |
| Average piston displacement per minute during the blow..... | 20 000 cu. ft. |
| Mean pressure of the blast..... | 27 lb. per sq. in. |
| Barometric pressure in engine room..... | 756 mm. |
| Temperature of engine room..... | 36° C. |

PERCENTAGE COMPOSITION OF CHARGE.

| ELEMENT. | MOLTEN METAL AND SCRAP. | SPIEGELEISEN. |
|----------|----------------------------|---------------|
| | PER CENT | PER CENT |
| C | 2.98 | 4.64 |
| Si | 0.94 | 0.35 |
| Mn | 1.43 | 14.90 |

PERCENTAGE COMPOSITION OF PRODUCTS.

| ELEMENT. | INGOT METAL. | SLAG. |
|--------------------------------|--------------|----------|
| | PER CENT | PER CENT |
| C | 0.45 | ..... |
| Si | 0.038 | ..... |
| Mn | 1.15 | ..... |
| Si O ₂ | ..... | 62.20 |
| Mn O | ..... | 13.72 |
| Fe O | ..... | 17.44 |
| Fe ₂ O ₃ | ..... | 2.90 |
| Al ₂ O ₃ | ..... | 2.76 |
| Ca O | ..... | 0.69 |
| Mg O | ..... | 0.29 |

ASSUMPTIONS.—The following assumptions are made:—

1. Of the 9.37 per cent lost in conversion, $142\frac{1}{2}$ lb. consist of metal shot included mechanically in the slag.
2. This metal shot has the same composition as the ingot metal produced.
3. The slag produced, exclusive of the metal shot, weighs 1 500 lb.
4. Fume to the amount of 1 290.58 lb. is produced during the blow and escapes with the gases.
5. The composition of the fume is Fe_2O_3 70.68 per cent and Mn_2O_4 29.32 per cent.
6. All the oxidized compounds of iron and manganese in slag and fume are derived from the combustion of the metal.
7. One fourth of the C that is oxidized burns to CO_2 , the remainder to CO.
8. No free oxygen escapes from the converter.
9. The blast enters the bath of metal at 100°C . and is heated to the mean temperature of the bath, or $1\ 500^\circ\text{C}$.
10. Neglect the moisture of the blast and the steam introduced during the blow.
11. All the Al_2O_3 , CaO and MgO of the slag are derived from the bottom and lining of the converter.

REQUIREMENTS.—The following items are required:—

1. The weight of blast per hundred units of the total charge, including spiegeleisen.
2. The mean volume of blast per minute at the pressure and temperature in the engine room.
3. The coefficient of useful effect in volume of the blowing engine, i. e., the ratio between the volume given in item 2 and the mean piston displacement per minute.
4. The net horse power of the blowing engine.
5. The gross horse power of the blowing engine.
6. The weight of coal required to generate steam for the blowing engine per ton of ingots produced.
7. The quantity of heat developed by the combustion of each oxidizable ingredient of the bath, per hundred units of total charge.
8. The available heat produced by the combustion of each ingredient of the bath, per hundred units of the total charge, i. e.,

the excess of heat developed by its combustion above the quantity absorbed in heating the blast required for its combustion.

9. The weight of material communicated to the slag by the bottom and lining of the converter during the blow.

I. WEIGHT OF BLAST REQUIRED.

Total charge..... = 22 500 + 2 500 = 25 000.0 lb.
 Loss in converter..... = 25 000 + 0.0937 = 2 342.5 lb.
 Ingot metal produced..... = 25 000 - 2 342.5 = 22 657.5 lb.

The spiegel formed one tenth of the total charge, while nine tenths was made up of molten metal and scrap. Therefore in the ingot metal produced there will be left of the original charge 2 265.75 lb. of spiegeleisen and 20 391.75 lb. of molten metal and scrap.

The next step is to determine the amount of C that burns to CO_2 and CO. The molten metal and scrap contained 2.98 per cent of C, and the spiegeleisen 4.64 per cent C.

Therefore the weight of C in the mol-

ten metal and scrap..... = 22 500 \times 0.0298 = 670.5 lb.
 The weight of C in the spiegeleisen.. = 2 500 \times 0.0464 = 116.0 lb.

Total C in entire charge..... = 786.5 lb.

The composition of the metal shot in the slag by assumption 2 of the problem is the same as the ingot metal. Weight of ingot metal and shot = 22 657.5 + 142.5 = 22 800 lb. This contains 0.45 per cent C, or 22 800 \times 0.0045 = 102.6 lb. This C is not oxidized. Weight of C oxidized in converter = 786.5 - 102.6 = 683.9 lb. By assumption 7 one fourth of the C burns to CO_2 , and the remainder to CO.

Therefore the weight of C, which burns

to CO_2 = $\frac{1}{4} \times 683.9 = 170.975$ lb.
 And weight of C, which burns to CO ... = $\frac{3}{4} \times 683.9 = 512.925$ lb.

Now 1 lb. C burning to CO_2 requires $\frac{8}{7}$ lb. O. Thus the total O required to burn the C to CO_2 = 170.975 \times $\frac{8}{7}$ = 455.933 lb. Again, 1 lb. C burning to CO requires $\frac{8}{7}$ lb. O. Thus the total O required to burn the C to CO = 512.925 \times $\frac{8}{7}$ = 683.9 lb.

Taking up the disposition of the silicon of the charge we have:—

Weight of silicon in metal and scrap = $22\ 500 \times 0.0094 = 211.50$ lb.
 Weight of silicon in spiegel. = $2\ 500 \times 0.0035 = 8.75$ lb.
 Total weight entire charge. = 220.25 lb.

The ingot metal and shot in the slag contain 0.038 per cent silicon or $22\ 800 \times 0.0038 = 8.664$ lb. This is not oxidized. The weight of silicon oxidized forming $\text{SiO}_2 = 220.25 - 8.664$ lb. Now 1 lb. silicon burning to SiO_2 requires $\frac{5}{8}$ lb. O. Thus the total O required to burn the silicon to $\text{SiO}_2 = 211.586 \times \frac{5}{8} = 241.812$ lb.

With regard to the disposition of the manganese we have:—

Weight of manganese in metal and
 scrap. = $22\ 500 \times .0143 = 321.75$ lb.
 Weight of manganese in spiegeleisen = $2\ 500 \times .0149 = 372.50$ lb.
 Weight of entire charge. = 694.25 lb.

The ingot metal and shot contain 1.15 per cent manganese, or $22\ 800 \times 0.0115 = 262.2$ lb. This is not oxidized. Weight of manganese oxidized = $694.25 - 262.2 = 432.05$ lb.

Part of the manganese burns to MnO and enters the slag, while the remainder burns to Mn_3O_4 and passes off in the fumes. By assumption 4 the weight of fume = 1 290.58 lb. and by assumption 5, 29.32 per cent of same is Mn_3O_4 . Thus the weight of $\text{Mn}_3\text{O}_4 = 1\ 290.58 \times .2932 = 378.398$ lb.

The molecular weight of $\text{Mn}_3\text{O}_4 = (55 \times 3) \times (16 \times 4) = 229$. Thus the weight of manganese in 378.398 lb. of $\text{Mn}_3\text{O}_4 = \frac{165}{229} \times 378.398 = 272.645$ lb. This burns to Mn_3O_4 . We previously found the amount of manganese oxidized to be 432.05 lb. The weight of manganese burning to $\text{MnO} = 432.05 - 272.645 = 159.405$ lb. To burn 1 lb. manganese to Mn_3O_4 requires $\frac{6}{11}$ lb. O. Thus the total O required to burn the manganese to $\text{Mn}_3\text{O}_4 = 272.645 \times \frac{6}{11} = 105.753$ lb. In like manner to burn 1 lb. manganese to MnO requires $\frac{1}{2}$ lb. O. Therefore the total O required to burn the manganese to $\text{MnO} = 159.405 \times \frac{1}{2} = 46.372$ lb.

The weight of fume = 1 290.58 lb., of which 378.398 lb. is Mn_3O_4 . Thus the weight of Fe_2O_3 in fume = 1 290.58 - 378.398 = 912.182 lb. Since the molecular weight of Fe_2O_3 (56×2) $\div (16 \times 3) = 160$, the weight of Fe in $Fe_2O_3 = \frac{112}{160} \times 912.182 = 638.527$ lb.

By assumption 3 the weight of slag proper is 1 500 lb. The weight of Fe_2O_3 in the slag = 1 500 \times 0.029 = 43.5 lb. Of this the Fe = $\frac{112}{160} \times 43.5 = 30.45$ lb. The weight of FeO in slag = 1 500 \times 0.1744 = 261.6 lb. Since the molecular weight of FeO = 56 + 16 = 72, the weight of Fe in FeO = $\frac{56}{72} \times 261.6 = 203.466$ lb. Now we have 638.527 + 30.45 = 668.977 lb. of Fe burning to Fe_2O_3 . To burn 1 lb. Fe to Fe_2O_3 requires $\frac{48}{112}$ lb. O. Thus the total O required to burn the Fe to $Fe_2O_3 = 668.977 \times \frac{48}{112} = 286.704$ lb.

We also have 203.466 lb. Fe burning to FeO. To burn 1 lb. Fe to FeO requires $\frac{16}{56}$ lb. O, and the total O required to burn the Fe to FeO = 203.466 \times $\frac{16}{56} = 58.133$ lb.

Summing up we have:—

| | |
|--|---------------|
| 170.974 lb. C burning to CO_2 requiring | 455.933 lb. O |
| 512.925 lb C burning to CO requiring | 683.900 lb. O |
| 211.586 lb. Si burning to SiO_2 requiring. | 241.812 lb. O |
| 272.645 lb. Mn burning to Mn_3O_4 requiring. | 105.753 lb. O |
| 159.405 lb. Mn burning to MnO requiring | 46.372 lb. O |
| 668.977 lb. Fe burning to Fe_2O_3 requiring. | 286.704 lb. O |
| 203.466 lb. Fe burning to FeO requiring | 58.133 lb. O |

Total weight O required = 1 878.607 lb.

This is to be furnished by the blast, and since by assumption 10 we neglect the moisture of the blast, it is a very simple matter to determine the weight of air necessary to furnish this amount of oxygen.

Dry air contains 23.1 per cent of O and 76.9 per cent of N by weight. Then the amount of air necessary to supply 1 878.607 lb. of O will be 1 878.607 \div 0.231 = 8 132.497 lb. Therefore 8 132.497 \div 250 = 32.53 lb. blast necessary per hundred units of total charge, *which is the answer to the first requirement.*

II. VOLUME OF THE BLAST.

1 cu. ft. dry air at 0° C and 760 mm. weighs 0.0807 lb., therefore the volume of the blast at 0° C and 760 mm. = $8\ 132.497 \div 0.0807 = 100\ 774.436$ cu. ft. This volume of air at the pressure and temperature of the engine room, *i. e.* at 36° C and 756 mm. = $100\ 774.436 \times \frac{273}{273+36} \times \frac{760}{756} = 114\ 666.882$ cu. ft. The blow lasts 9 min. 20 sec., and therefore the mean volume of blast per minute = $114\ 666.882 \div 9\frac{1}{3} = 12\ 285.737$ cu. ft., which is the answer to the second requirement.

III. EFFICIENCY OF ENGINE.

The coefficient of the useful *effect* in volume of the blowing engine = $\frac{12\ 285.737}{20\ 000.00} = 0.614$.

IV. NET POWER OF ENGINE.

Weisbach gives the following formula for the total work of the blowing engine:—

$$W_m = 3.451 p_0 v_0 \left[\left(\frac{p_1}{p_0} \right)^{0.29} - 1 \right]$$

In which W_m = work in foot pounds, p_0 = specific pressure at initial temperature and volume, v_0 = initial volume, $\frac{p_1}{p_0}$ = ratio of final pressure to original pressure. Substituting in the formula and dividing by $9\frac{1}{3} \times 33\ 000$, we have the

$$H. P. = \frac{W_m}{9\frac{1}{3} \times 33\ 000} \\ = \left\{ 3.451 \times 2\ 104.92 \times 114\ 666.82 \left[\left(\frac{27+14.618}{14.618} \right)^{0.29} - 1 \right] \right\} \\ \div (9\frac{1}{3} \times 33\ 000) = 960. +$$

V. GROSS POWER OF ENGINE.

The coefficient of useful *work* of the engine may vary from 45 per cent to 60 per cent; taking the latter value as perhaps best representing modern cases, we will have for the gross horse power of the engine $960 \times \frac{1}{2} = 1\ 600$.

VI. WEIGHT OF COAL.

The weight of ingot metal per blow = $22\,657.5 \div 2\,240 = 10.115$ tons. If the coal consumption is 5 pounds per horse power per hour, the weight of coal per ton of ingot metal produced will be $\frac{1\,600 \times 5 \times 9\frac{1}{2}}{60 \times 10.115} = 123.029$ lb.

VII. HEAT DEVELOPED.

TABLE I, gives the heat developed by the oxidation of each of the ingredients.

TABLE I.

HEAT DEVELOPED BY OXIDATION.

| OXIDATION. | NO. LBS. OXIDIZED. | CALORIES DEVELOPED PER LB. OF ELEMENT OXIDIZED. | CALORIES DEVELOPED PER 100 UNITS OF TOTAL CHARGE. |
|--|-----------------------|---|---|
| C to CO ₂ | 170 795 | 8 080.0 | 5 525.912 |
| C to CO | 512 925 | 2 382.0 | 4 887.149 |
| Si to SiO ₂ | 211.586 | 7 830.0 | 6 626.874 |
| Mn to Mn ₂ O ₄ | 272 645 | 2 300 0 | 2 508.334 |
| Mn to MnO | 159.405 | 1 700.0 | 1 083.954 |
| Fe to Fe ₂ O ₃ | 668.977 | 1 700.0 | 4 549.043 |
| Fe to FeO. | 203.466 | 1 200.0 | 976.636 |
| Total heat developed per 100 units of total charge | | | 26 157 902 |

VIII. AVAILABLE HEAT.

The blast is heated to $1\,400^{\circ}$ C. and there are blown in 32.53 lb. of air per 100 units of total charge. The specific heat of air = 0.2377, and therefore the heat necessary for the blast = $32.53 \times 1\,400 \times 0.2377 = 10\,825.333$ calories.

Total heat developed. 26 157.902 calories.
Required to heat blast. 10 825.334 calories.

Available heat. 15 332.569 calories.

IX. MATERIAL FROM LINING.

The weight of slag = 1 500 lb.

Weight of MgO in slag = $1\ 500 \times 0.0029 = 4.35$ lb.

Weight of CaO in slag = $1\ 500 \times 0.0069 = 10.35$ lb.

Weight of Al_2O_3 in slag = $1\ 500 \times 0.0276 = 41.40$ lb.

Total weight of MgO, CaO and Al_2O_3 in slag = 56.10 lb.

Weight of SiO_2 in slag = $1\ 500 \times 0.622 = 933.0$ lb. Some of this, however, comes from the charge. As found before, there were 211 586 lb. silicon oxidized, which will form $211.586 \times \frac{1}{3} = 453.398$ lb. of SiO_2 .

SiO_2 in slag = 933.000 lb.

SiO_2 from charge = 453.398 lb.

SiO_2 from bottom and lining of converter = 479.602 lb.

MgO, CaO and Al_2O_3 from bottom and lining as above = 56.100 lb.

Total material from bottom and lining = 535.702 lb.

SIMPLE STANDARD FOR THE PRECISION OF LEVEL CIRCUITS.

BY WM. D. PENCE, ASSISTANT PROFESSOR OF CIVIL ENGINEERING.

The well established principle that the errors of careful spirit leveling increase about as the square root of the distance affords a basis for the construction of diagrams to be used in gaging the precision of level circuits. The diagrams shown on Plates I and II, pages 119 and 120, are constructed upon this principle. Plate I is a compilation of the limiting errors of closure prescribed on six representative American surveys. By taking the coefficients of precision to the nearest 0.01 foot, a very simple gage or standard of precision is obtained, and the graphical representation of these values affords a simple scale for field use in leveling operations. Plate I has a range of ten miles, which is sufficient to include a majority of the cases met by the average engineer.

THE PRECISION OF LEVEL CIRCUITS.

The precision of spirit leveling is expressed by the formula

$$\text{Error of Closure} = \text{Constant} \sqrt{\text{Length of Circuit}}$$

In the following summary of practice in representative surveys of the United States, E is the maximum limit of error of closure of a level circuit having a length of K kilometers or M miles.

| NAME OF SURVEY. | MAXIMUM PERMISSIBLE ERROR OF CLOSURE. | | |
|--|--|--|--|
| | Metric Units Coefficient to nearest mm. | British Units. Coefficient to nearest 0.001 ft. 0.01 ft. | |
| Chicago Sanitary District. | $E = 3 \text{ mm} \cdot \sqrt{K} = 0.012 \text{ ft} \cdot \sqrt{M}$ | $= 0.01 \text{ ft} \cdot \sqrt{M}$ | |
| Missouri River Commission. | $E = 3 \text{ mm} \cdot \sqrt{2K} = 0.018 \text{ ft} \cdot \sqrt{M}$ | } $= 0.02 \text{ ft} \cdot \sqrt{M}$ | |
| Mississippi River Commission. (1891). | $E = 3 \text{ mm} \cdot \sqrt{2K} = 0.018 \text{ ft} \cdot \sqrt{M}$ | | |
| Mississippi River Com'n (Before 1891). | $E = 5 \text{ mm} \cdot \sqrt{K} = 0.021 \text{ ft} \cdot \sqrt{M}$ | | |
| United States Coast Survey. | $E = 5 \text{ mm} \cdot \sqrt{2K} = 0.029 \text{ ft} \cdot \sqrt{M}$ | $= 0.03 \text{ ft} \cdot \sqrt{M}$ | |
| United States Lake Survey. | $E = 10 \text{ mm} \cdot \sqrt{K} = 0.042 \text{ ft} \cdot \sqrt{M}$ | $= 0.04 \text{ ft} \cdot \sqrt{M}$ | |
| United States Geological Survey. | $E =$ | $0.050 \text{ ft} \cdot \sqrt{M} = 0.05 \text{ ft} \cdot \sqrt{M}$ | |

A simple practical test of the degree of precision attained in spirit leveling is found in the last column of the above table. This graduated scale of precision is given below graphically for distances to ten miles.

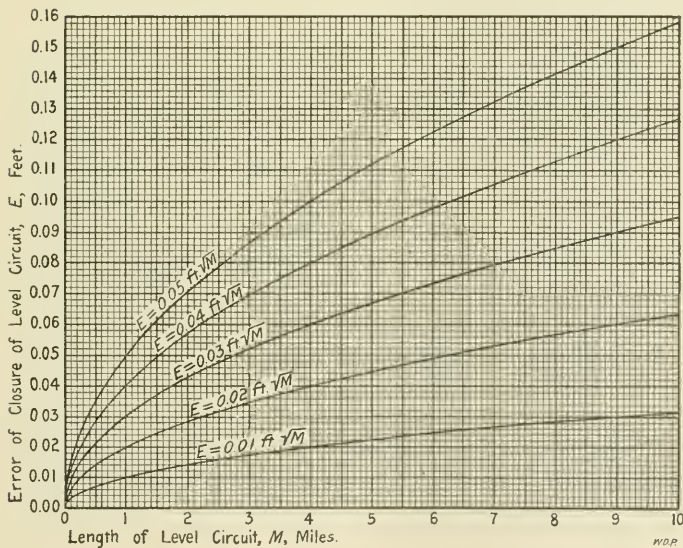


PLATE I. PRECISION OF LEVEL CIRCUITS ON REPRESENTATIVE SURVEYS.

THE PRECISION OF LEVEL CIRCUITS. (For Good Average Practice.)

When the length of the level circuit is known in 100-ft stations, or when merely the number of settings of the instrument and the approximate average distance covered per setting are known, the following modifications of the preceding text are valuable.

- Let E = maximum permissible error of closure of level circuit.
- M = length of level circuit in miles.
- L = " " " " " " 100-ft. stations.
- L' = approximate average distance covered per setting of the instrument in 100-ft. stations.
- S = number of instrumental settings in the circuit.

For good average work with the engineers' level

$$E = 0.05 \text{ ft. } \sqrt{M}$$

From which

$$E = 0.007 \text{ ft. } \sqrt{L}$$

and

$$E = 0.007 \text{ ft. } \sqrt{L'S}$$

| | |
|--|------------------------------------|
| Substituting for 400-ft average sights, $L' = 8$, | $E = 0.0195 \text{ ft. } \sqrt{S}$ |
| " 350-- " " " $L' = 7$, | $E = 0.0182 \text{ ft. } \sqrt{S}$ |
| " 300-- " " " $L' = 6$, | $E = 0.0169 \text{ ft. } \sqrt{S}$ |
| " 250-- " " " $L' = 5$, | $E = 0.0154 \text{ ft. } \sqrt{S}$ |

For a very rapid approximate check under ordinary conditions, it may be assumed that $E = 0.02 \text{ ft. } \sqrt{S}$. A graphical representation of these formulas is given below.

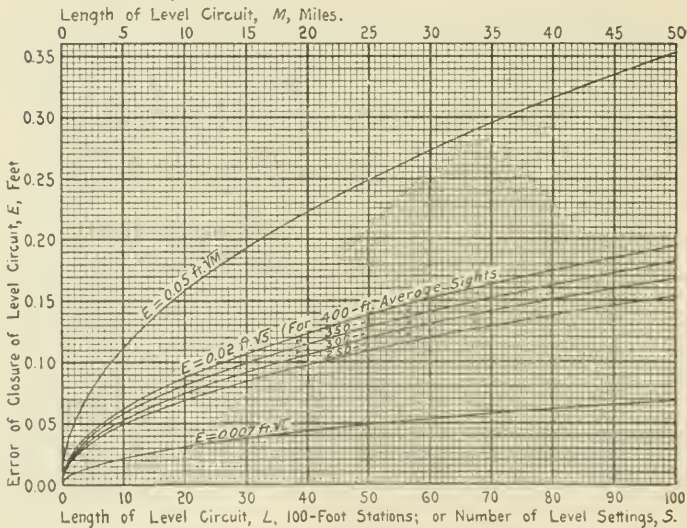


PLATE II. PRECISION OF LEVEL CIRCUITS FOR GOOD AVERAGE PRACTICE.

Plate II is merely an extension or elaboration of the upper curve of the diagram in Plate I, the degree of precision represented by this curve being about that of "good average practice." In order to cover all the conditions of actual practice, the length of circuit in Plate II is expressed in three ways: (1) in miles, (2) in 100-foot stations, and (3) in the number of instrumental settings with given average lengths of sight. The first of these is represented by the upper curve, the length of circuit being given in miles at the top of the diagram. The second is given in the lower curve, the length of circuit being stated in 100-foot stations at the bottom of the diagram. The last, for four different lengths of sight, is shown by the middle group of curves, the length of circuit being stated in instrumental settings as at the bottom of the diagram.

These diagrams may be used either to test a given result or to fix a consistent limit for the closure of a circuit of levels run under known conditions. In order to make them convenient for field use, the plates have been reproduced of a size to fit the engineers' field book. They form part of a series of practical field tests or standards provided for the use of students in surveying at the University of Illinois.

The following results from student field problems will serve to illustrate the use of the diagrams:—

1. The error of closure in a 9-mile circuit of levels was 0.058 foot. Referring to the diagram on Plate I, this result is seen to correspond to $0.02 \text{ foot} \sqrt{\text{distance in miles}}$, which is about the degree of precision required in the Mississippi and Missouri River Commissions' surveys.

2. The error of closure in a 21-mile circuit of levels run with an engineers' level under average conditions was 0.100 foot. The diagram of Plate II shows that an error of 0.23 foot would have been permissible.

3. In checking back between bench marks 16 stations apart, a difference of 0.06 foot was found. The length of circuit is 32 stations and the lower curve in the diagram of Plate II shows that the error should not have exceeded 0.04 foot.

4. A level circuit of 25 settings with 300-foot sights has a difference of 0.03 foot. The 300-foot curve in the middle group of the second diagram shows a permissible error of 0.11 foot.

IMPACT TESTS OF BEAMS.

BY D. C. WRAY, '98, SCHOOL OF CIVIL ENGINEERING.

Recently considerable interest has been manifested in the resistance of structural materials to impact, and it is quite probable that in the future more attention will be given to resilience of materials under impact. Most of the experiments which have been made are untrustworthy, either because the form of apparatus used absorbed a large part of the energy or because observations at the breaking point only were considered.

The writer has been making a series of tests in the Laboratory of Applied Mechanics, under the direction of Prof. A. N. Talbot, on the effect of impact and sudden loading on beams, which he believes is not subject to this criticism. Beams have an advantage over tension pieces for impact tests in that the deflections are many times greater than the deformations of tension pieces and the proportion of energy lost in the apparatus is much less.

The apparatus consisted of a stiff and solidly supported bed, with supporting knife edges on which the beam rested; a yoke placed over the middle point of the beam and having a heavy nut near its lower extremity; a clevis fitting over this nut and connected with a stiff tray below on which the remainder of the load was placed; and a revolving drum driven by the line shaft of the Laboratory on which a pencil held by an arm fastened to the middle of the beam recorded the deflection of the beam to a natural scale. The clevis and load were suspended from the bed of the machine and then, when suddenly tripped, fell until the clevis struck the nut of the yoke. This nut allowed adjustment from a zero drop to five inches. Space does not permit a description of the several devices for securing the ends and sides of the beams and of obtaining a direct blow. The low center of gravity of the load gave a straight pull upon the apparatus, and it is believed that the machine combined the elements of stability, minimum friction and lost energy, direct impact, and a good recording device.

Fig. 1 gives specimen records of the tests; four diagrams of the Pine Beam No. 16 ($1\frac{3}{8} \times 1\frac{3}{4} \times 54$ -in.) with loads of 50, 75,

and 100 pounds and with zero drop (suddenly applied load) and with a drop of $\frac{1}{4}$ inch; two records of Steel Beam No. 1 ($1 \times 1 \times 72$ -in., mild steel of 60 000-lb. tensile strength) with a load of 100 lb. and drops of 0 and $4\frac{1}{2}$ inches. The pencil moved from the line of zero load to the full deflection, and then vibrated back and forth until it finally came to rest on the line of static deflection due to the load. The vertical scale is shown by the distance marked "1 inch," and the horizontal, or time scale by that marked "1 second of time."

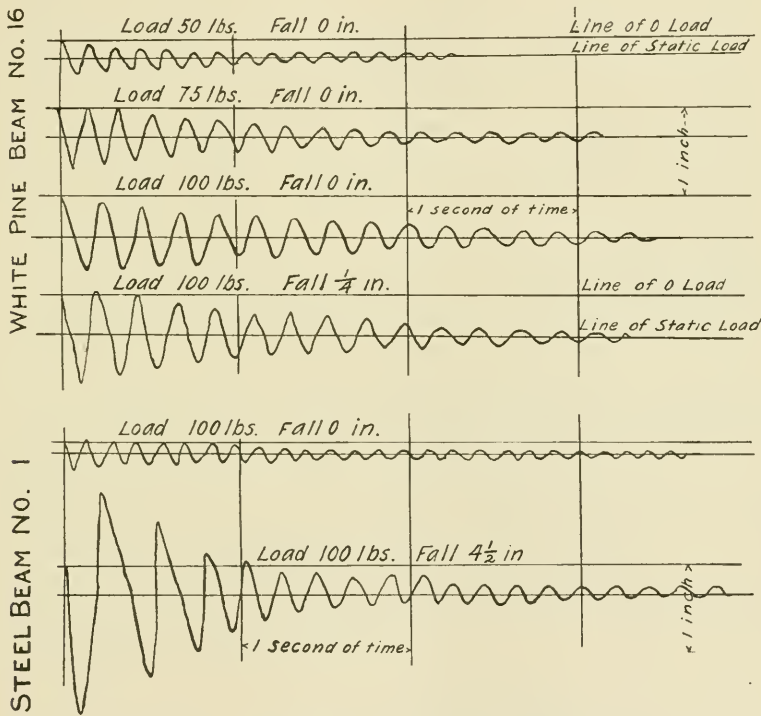


FIG. 1. CHARACTERISTIC RECORDS OF DEFLECTIONS.

The deflections were computed by a formula modified from the form given on page 253 of MERRIMAN'S "MECHANICS OF MATERIALS" to allow for the weight of the yoke and beam, the value of the static deflections in the calculations being determined from the average of a number of observations on gradually applied loads. Fig. 2 shows the theoretical curve for steel beam No. 1 up to a stress of 63 230 lb. per sq. in., and also the observed deflec-

tions, for a load of 100 lb. and the drop or fall as shown. The right hand diagrams are the results of similar calculations and ob-

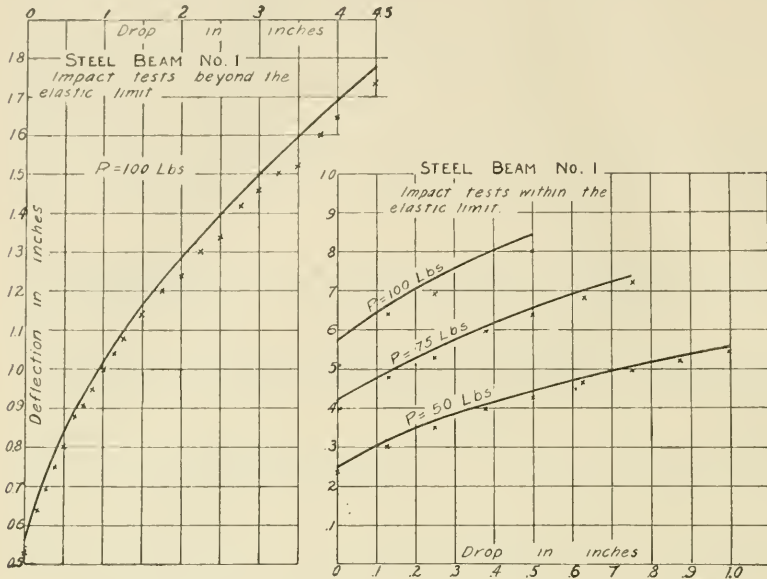


FIG. 2. THEORETICAL AND OBSERVED DEFLECTIONS.

servations, all within the elastic limit of the material. The experiments on wooden beams gave results quite similar to these.

The observed deflections under impact agreed quite closely with the calculated values, falling under the latter about 4 per cent for the steel beams, and 7 to 9 per cent for the wooden beams. This deficiency is readily explained by the presence of some friction, by the possible movement of the knife edges, and by slight spring in the apparatus. In fact, since the formula referred to in MERRIMAN'S MECHANICS assumes that all the energy of compression of two bodies colliding is lost and since the coefficient of restitution may be 0.6 or 0.7, it is possible that the computed curve should be 3 or 4 per cent higher than the formula gives.

These experiments, then, tend to verify the theoretical laws of resistance of elastic beams to impact, including the one that a suddenly applied load produces twice as great a stress as one gradually applied, and show that the coefficient of elasticity within the elastic limit has the same value for impact as for gradually applied loading.

No direct determination could be made in reference to the elastic limit, since there was no marked divergence of the observed deflections from the calculated curve. However, a comparison of the apparent elastic limit was made by observing first the load which produced the first permanent set or distortion by static loading of wooden beams, and second the same condition in other wooden beams by impact loading. The resulting value of the stress in two beams with static loading was 5 770 and 5 580 lb. per sq. in.; and that in a beam under impact was 5 750 lb. per sq. in. Similarly the results of two steel beams were 48 600 lb. per sq. in. for static loading, and 52 000 lb. per sq. in. for impact loading. The high value for this apparent elastic limit of these beams is evidently due to the rectangular form of the beam, as only a small portion of the section is strained beyond the elastic limit. These results tend to refute the claim sometimes made that the elastic limit for impact is much less than for static loading.

The modulus of rupture of white pine beams under impact was found to be practically the same as that for static loading, but both elastic resilience and ultimate resilience were much greater for impact than for static loading. For steel beams the elastic resilience was likewise much greater for the impact tests.

It is interesting to note that the number of vibrations of the beams per second as recorded on the diagrams for deflections less than one inch is independent of the fall of the load and that it varies inversely as the square root of the load. This accords with Newton's law concerning the time of vibrations.

The writer intends to embody the results of his investigations in a thesis entitled "An Investigation of the Effects upon Beams of Impact and Sudden Loading."

DATA ON ELECTRIC CAR HEATERS.

BY WILLIAM ESTY, ASSISTANT PROFESSOR OF ELECTRICAL ENGINEERING.

An extended series of comparative tests on five prominent makes of electric car heaters was conducted two years ago in the Electric Laboratory of the University by Messrs. Adams, '96, and Campbell, '96, under the direction of the writer. As considerable interest has been shown in the results obtained, a brief summary is given in Table I, page 126.

TABLE I.

DATA ON ELECTRIC CAR HEATERS.

| ITEMS. | DESIGNATION OF HEATERS* | | | | |
|---|--------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| | A | B | C | D | E |
| NO. OF HEATERS PER CAR. | 4 | 4 | 4 | 6 | 6 |
| NUMBER IN SERIES. | 2 | 2 | 2 | 3 | 3 |
| CONDUCTOR MATERIAL. | KRUPP METAL. | IRON. | GERMAN SILVER. | IRON. | GERMAN SILVER. |
| Size, B. & S. gauge No. . . . | 20. | 18. | 22. | 20. | 19. |
| Diameter, in. | .032 | .0403 | .0253 | .032 | .0359 |
| Cross section in circ. mils. . . | 1 024 | 1 624. | 640.1 | 1 024. | 1 289. |
| Length of wire per heater, in feet | 372. | 181.5 | 128. | 339. | 163. |
| Length of wire per car, in feet | 744. | 726. | 512. | 2 034. | 978. |
| Resistance per 1 000 feet at 22.5C | 28.2 | 46.83 | 196 | 91. | 232. |
| Resistance per car (as connected) at 22.5 C | 105. | 34. | 100.4 | 92.7 | 113.7 |
| Diameter of resistance coils, in in. | $\frac{3}{8}$ | $\frac{7}{8}$ | $1\frac{3}{8}$ | $\frac{3}{8}$ | not coiled |
| Pitch of resistance coils in turns per in. . . . . | ..... | 3. | 6. | 9. | ..... |
| Radiating surface of wire, in sq. in. | 6.2 | 7.6 | 3.44 | 16.9 | 9.2 |
| Radiating surface of cases, in sq. ft. | 32.4 | 9. | 8.66 | 12.5 | 13. |
| Area of upper air ducts, in sq. in. . . . . | ..... | 84. | 197.4 | 164. | 300. |
| Area of lower air ducts, in sq. in. . . . . | ..... | 84 | 69. | 164. | 187.5 |
| Volume of cases, in cu. ft. . . . . | ..... | 2.52 | 1.33 | 3.15 | 2.15 |
| Watts radiated, per hour per sq. ft. of wire surface. . . | 546. | 468. | 587. | 173.6 | 350. |
| Weight of set, in lb. | 238. | 168. | 90. | 231. | 129. |
| Watts per hour, per lb. . . . | 14.2 | 21.1 | 22.4 | 12.7 | 25. |
| Max. tem. of conductor, in degs. C | 69. | 147. | 130. | 137. | 136. |
| Av. Watts absorbed | (1 776.) (one heater) | (1 826.) (1 in series) | (1 037.) (2 in series) | (1 637.) (3 in series) | (1 607.) (3 in series) |

* Heater A, was made by the Whittingham Co.
 Heater B, was made by the Interior Conduit & Insulation Co
 Heater C, was made by the Ohio Brass Co.
 Heater D, was made by the Consolidated Car Heating Co.
 Heater E, was made by the American Electric Co.

THE SHEARING STRENGTH OF RIVET STEEL.

BY ARTHUR N. TALBOT, PROFESSOR OF MUNICIPAL AND SANITARY
ENGINEERING.

Five years ago the use of steel for rivets in high-grade boilers, stand-pipes, and structures was considered doubtful practice by many engineers, and wrought iron rivets were used long after wrought iron plates had been displaced by steel. Steel rivet material of that day was unreliable and lacked the toughness and uniformity which is essential for standing the abuse of ordinary riveting operations. Improvements in manufacture have produced a steel rivet bar, which for toughness, uniformity, and reliability, in fact for everything except the range of temperature allowable in riveting, is the equal of the best iron rivet.

Present practice in designing joints uses values of the shearing strength of steel based upon experiments made several years ago. The data frequently quoted are from experiments made in England by Professor A. B. W. Kennedy in 1885. The shearing strength of these steels varied from 67 to 83 per cent of the tensile strength. From these and other tests on the earlier structural steels, the ratio of the shearing strength of rivet steel to its tensile strength has been assumed to be 80 per cent, and the ratio of this shearing strength to the tensile strength of the plate used in the joint, 75 to 83 per cent.

As a contribution to the knowledge of this subject, the results of a series of tests made in the Laboratory of Applied Mechanics of the University of Illinois are presented. The tests first described were made by the different class divisions as regular laboratory work, and the later tests directly by Mr. C. V. Seastone, assistant in the Laboratory of Applied Mechanics. Three sizes of four varieties of rivet material were used, and tests were made both for single shear and double shear.

Four varieties of material were tested: 1. The Victor boiler rivet steel, manufactured by the Champion Rivet Co. of Cleveland, Ohio; 2. Best Boiler rivet steel, manufactured by Sternbergh & Son, Reading, Pa.; 3. Structural rivet steel (said to be Bessemer

steel), manufactured by Sternbergh & Son; and 4. Best rivet iron, manufactured by Sternbergh & Son. Three sizes of each of these makes were used,— $\frac{1}{2}$ - $\frac{3}{4}$ - and 1-inch diameter. The rivet rod fitted the holes in the apparatus so accurately that it was not found necessary to turn the rods down.

The determination of the phosphorous and sulphur of the rivet material made by Prof. S. W. Parr resulted as follows:

Victor steel: phosphorus .015 per cent, sulphur .050 per cent.

Best boiler steel: phosphorus .011 per cent, sulphur .033 per cent.

Structural rivet steel: phosphorus .014 per cent, sulphur .052 per cent.

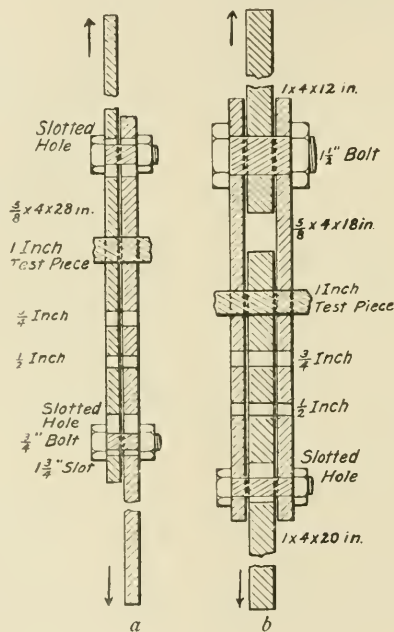


FIG. 1. SHEARING APPARATUS.

Fig. 1 shows sections of the apparatus used for making the shearing tests. The apparatus for single shear, shown at *a*, consisted of two bars with accurately drilled holes through which the test pieces passed. A bolt through the slotted holes above the test piece and one through the holes below it, held the bars firmly so that the shearing planes remained together. Tests showed that

the friction between these plates was small. The length of the bars (28 inches) reduced the eccentricity of the pull to a very small amount.

The apparatus for double shear, shown at *b*, consisted of two middle bars $\frac{5}{8}$ -inch thick and an upper and a lower bar each 1-inch thick. The upper bar was fastened to the two middle bars with a $1\frac{1}{2}$ -inch bolt, and the test pieces passed through ac-

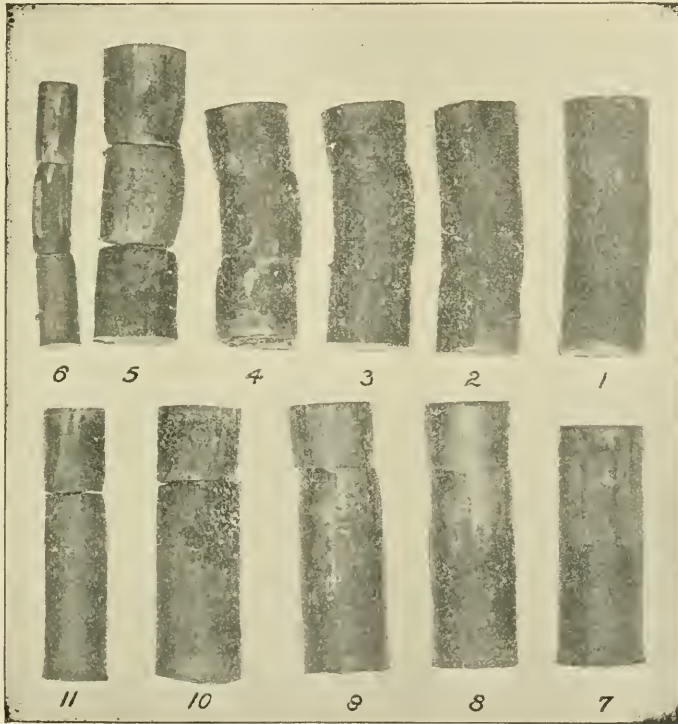


FIG. 2. VIEWS AT SUCCESSIVE STAGES.

curately drilled holes in the middle and lower bars. A bolt through a slotted hole in the middle and lower bars held them firmly together. The bolts and the stiffness of the middle bars prevented any bulging or buckling of the bars during the process of shearing.

The bars were tool steel of 80 000 lb. tensile strength. The upper and lower bars were placed in the grips of the 200 000 lb.

Olsen testing machine and tension applied. Little perceptible distortion took place in the test holes of the apparatus. The usual tension tests of the rivet material were also made. The steel rods were bent cold flat on themselves without showing flaws, and a 1-inch Victor steel rod was tied in a close knot by cold bending.

Fig. 2, page 129, is a view of test pieces of the Best Boiler steel in various stages of the test. Nos. 1 to 5 are 1-inch pieces tested in double shear with the following stresses per sq. in.: 1, 20 000; 2, 22 500; 3, 26 500; 4, 31 700; 5, 36 200 (sheared). Nos. 7-10 are 1-inch pieces in single shear at the following stresses per sq. in.: 7, 18 600; 8, 26 500; 9, 33 150; 10, 36 100 (sheared). No. 6 shows a $\frac{1}{2}$ -inch piece broken in double shear and No. 11 a $\frac{3}{4}$ -inch piece in single shear.

TABLE I.

COMPARISON OF SHEARING AND TENSILE STRENGTHS OF RIVET MATERIAL.

| MATERIAL. | TENSION. | | | | | SINGLE SHEAR | | | DOUBLE SHEAR | | |
|-----------------------------------|-------------------|-------------------|--------------------|--------------------|--------------------|-------------------|--------------------|--------------------------------|-------------------|--------------------|--------------------------------|
| | No. of Tests..... | Ultimate Strength | Elastic Limit..... | Elongation in 8-in | Reduction of Area. | No. of Tests..... | Ultimate Strength. | Ratio of Shear to Tension..... | No. of Tests..... | Ultimate Strength. | Ratio of Shear to Tension..... |
| VICTOR BOILER RIVET STEEL. | | | | | | | | | | | |
| $\frac{1}{2}$ -in. | 1 | 48 100 | 31 000 | 33 | 76 | 2 | 38 400 | 80.0 | 2 | 37 700 | 78.4 |
| $\frac{3}{4}$ -in. | 2 | 49 930 | 31 000 | 34 | 55 | 3 | 37 900 | 75.7 | 2 | 37 550 | 75.3 |
| 1-in. | 2 | 47 350 | 31 150 | 37 | 65 | 2 | 34 500 | 73.3 | 2 | 34 700 | 73.3 |
| BEST BOILER RIVET STEEL. | | | | | | | | | | | |
| $\frac{1}{2}$ -in. | 2 | 48 700 | 35 300 | 33 | 62 | 2 | 38 550 | 79.1 | 2 | 39 250 | 80.6 |
| $\frac{3}{4}$ -in. | 2 | 47 600 | 28 650 | 36 | 68 | 2 | 36 200 | 77.0 | 5 | 36 300 | 77.2 |
| 1-in. | 1 | 49 330 | 30 600 | 32 | 70 | 3 | 36 100 | 73.2 | 3 | 36 200 | 73.4 |
| STRUCTURAL RIVET STEEL. | | | | | | | | | | | |
| $\frac{1}{2}$ -in. | 3 | 55 400 | 37 700 | 26 | 70 | 3 | 43 400 | 78.3 | 3 | 42 100 | 76.0 |
| $\frac{3}{4}$ -in. | 2 | 55 900 | 37 350 | 29 | 64 | 2 | 41 700 | 74.6 | 2 | 41 900 | 74.9 |
| 1-in. | 2 | 53 600 | 35 500 | 29 | 71 | 2 | 38 000 | 70.9 | 3 | 38 600 | 72.0 |
| WROUGHT IRON. | | | | | | | | | | | |
| $\frac{1}{2}$ -in. | 1 | 49 600 | 37 750 | 25 | 46 | 3 | 40 200 | 81.5 | 2 | 38 200 | 79.5 |
| $\frac{3}{4}$ -in. | 2 | 50 200 | 31 200 | 38 | 48 | 4 | 38 600 | 77.0 | 2 | 39 100 | 79.8 |
| 1-in. | 2 | 48 400 | 32 000 | 33 | 52 | 2 | 35 200 | 72.8 | 2 | 36 400 | 75.2 |

Ultimate strength and elastic limit are given in lb. per sq. in. and elongation and reduction of area in per cent of original length and area.

The sheared pieces are especially noticeable for the indentation which takes place after the elastic limit is reached. The shoulder or indentation was as much as 10 per cent of the diameter, and increased with the diameter of the test piece. The bending action was slight and was scarcely noticeable on the compressed side. An examination of the pieces during and after the tests showed that this method of testing largely eliminates the flexural effect upon the rivet and hence is not subject to the criticism sometimes made upon shearing tests.

The average of the results of the tests are given in Table I, page 130. Averaging the ratios for the different sizes gives the values shown in Table II.

TABLE II.

AVERAGES OF RATIOS OF SHEARING STRENGTH TO TENSILE STRENGTH.

| SIZE OF RIVET. | SINGLE SHEAR. | DOUBLE SHEAR. |
|------------------------------|---------------|---------------|
| $\frac{1}{2}$ -inch diameter | 79.7 | 78.6 |
| $\frac{3}{4}$ -inch diameter | 76.1 | 76.8 |
| 1-inch diameter | 72.5 | 73.5 |
| Average of all tests | 76.1 | 76.3 |

It would be interesting to know why the ratios for the small rivets are higher than those for the large. If bending entered into the results, the smaller rivets would have the smaller ratios. The table shows that the tensile strengths of the several sizes average almost exactly the same. To find whether the variation was caused by softer material in the large rivets, 4 test pieces of the larger sizes were turned down to $\frac{1}{2}$ inch and tested for double shear. The results gave ratios within 1 per cent of the ratios in Table I for $\frac{1}{2}$ -inch rivets of the same material. It seemed probable that the increased bearing stresses in the larger size—the thickness of plate remaining the same—might be the cause, and the larger indentation in the larger test pieces corroborated this view. The bearing stresses brought upon the rivets with this apparatus are equal to the shearing stresses multiplied by the following ratios,—single shear: $\frac{1}{2}$ -in. rivet, .63; $\frac{3}{4}$ -in., .94; 1-in., 1.26; double shear: $\frac{1}{2}$ -in. rivet, .79; $\frac{3}{4}$ -in., 1.18; 1-in., 1.57. As the as-

sumed ratio in practice ranges from $1\frac{1}{2}$ to 2, it will be seen that the bearing stresses are comparatively low, and those of the $\frac{1}{2}$ -in. rivet are especially low.

To determine the effect upon the shearing strength of increasing the bearing stress, an apparatus for single shear was then constructed having the shearing bars of $\frac{3}{8}$ -inch tool steel. This size made the comparative bearing stresses one and two-thirds times the former ones. The results are shown in Table III. It will be seen that the shearing ratio of the $\frac{1}{2}$ -inch rivets has been decreased nearly 4 per cent and the 1-inch $1\frac{1}{4}$ per cent. As even with this apparatus, the $\frac{1}{2}$ -inch rivet has not reached the usual bearing stress, it is quite probable that the shearing ratio would be still smaller for the usual conditions of joints, and would reach a value for all sizes as low as that given in Table II for 1-inch rivets. These results tend to show that the amount of the bearing stresses affects shearing strength, the latter decreasing with an increase in the former. They, at least partially, explain the higher ratios for the smaller rivets in Table I.

TABLE III.

EFFECT OF DECREASED BEARING SURFACE.
Single shear tests with $\frac{3}{8}$ -inch hard steel bars.

| MATERIAL. | No. OF TESTS. | ULTIMATE SHEARING STRENGTH. | RATIO OF SHEAR TO TENSION. | DECREASE IN RATIO. |
|--|---------------|-----------------------------|----------------------------|--------------------|
| Victor rivet steel, $\frac{1}{2}$ in | 2 | 37 200 | 77.4 | 2.6 |
| Structural rivet steel, $\frac{1}{2}$ in | 3 | 40 600 | 73.3 | 5.0 |
| Structural rivet steel, 1-in. | 1 | 37 500 | 70.0 | 0.9 |
| Wrought iron, 1-in. | 1 | 34 500 | 71.3 | 1.5 |

To determine the effect of the hardness of the shearing plate upon the shearing strength of the rivet material, an apparatus for single shear was constructed with 56 000-lb. mild steel bars. With this apparatus not more than one or two rivets could be tested in a single hole, for the distortion of the plate became quite marked. The results are given in Table IV. It will be seen that the shearing ratios have been increased about 4.6 per cent over the corresponding values in Table I. This increase in the ratios more than neutralizes the decrease found by reducing the bearing areas to

the values used in practice as discussed in the preceding paragraph, and would make the final effect not far from the values given in Table II.

TABLE IV.

EFFECT OF SOFT SHEARING PLATES.

Single shear tests with $\frac{5}{8}$ -inch mild steel bars.

| MATERIAL. | NO. OF TESTS. | ULTIMATE SHEARING STRENGTH. | RATIO OF SHEAR TO TENSION. | INCREASE IN RATIO. |
|--|---------------|-----------------------------|----------------------------|--------------------|
| Victor rivet steel, $\frac{1}{2}$ -in. . . . | 1 | 41 500 | 86.3 | 6.3 |
| Wrought iron, $\frac{1}{2}$ -in. | 1 | 41 600 | 83.9 | 2.4 |
| Structural rivet steel, $\frac{1}{2}$ -in. | 1 | 46 200 | 83.4 | 5.1 |
| Victor rivet steel, $\frac{3}{4}$ -in. . . . | 2 | 41 000 | 82.1 | 6.4 |
| Wrought iron, $\frac{3}{4}$ -in. | 2 | 40 400 | 80.5 | 3.5 |
| Wrought iron, 1-in. | 1 | 37 000 | 76.4 | 3.6 |
| Best boiler rivet steel, 1-in. | 1 | 38 550 | 78.2 | 5.0 |

It may be considered, then, that for the usual bearing stresses, with mild steel plate and soft steel rivet metal, the ratio of shearing strength of the rivet to its tensile strength is less than that generally quoted, .80, and that .75 is a more probable value. It seems to be shown, also, that an increase in the bearing area of the rivet will give increased shearing strength to the rivet. The use of hard steel plates with soft steel rivets likewise decreases the shearing strength of the rivets.

In all the preceding discussion, comparison of the shearing strength of the rivet has been made with that of the tensile strength of the rivet itself. The ratio of the shearing strength of the rivet metal to the tensile strength of the plate will be lower yet. For 48 000-lb. tensile strength rivet metal and 56 000-lb. steel plate, the ratio is .65; and for 55 000-lb. rivet metal and 62 000-lb. steel plate, it is .68. These results indicate that the ratios commonly used in designing joints (the shearing strength of the rivets equal to three-fourths or five-sixths of the tensile strength of the plate) are too high and hence that rivet spacing should be made closer. While these conclusions are based upon results found beyond the elastic limit, it does not seem possible to obtain comparative data within that limit.

The writer does not accept the statement sometimes made that the shearing strength of rivets has little influence upon the strength of the joint on the ground that the friction of the plates will hold the tensile stress well up to the elastic limit of the plate; for he does not think that it has yet been conclusively proved that the friction is so great. Tests made in the Laboratory of Applied Mechanics on riveted joints show that slipping occurs at or below the usual working stresses. The average of 22 double-riveted lap joints, hand riveted, gave 4 900 lb. per sq. in., the maximum being 9 500 and the minimum 3 000. The average of 16 double-riveted butt joints, machine riveted, gave 9 000 lb. per sq. in., the maximum being 13 000 and the minimum 5 500. Tests made elsewhere indicate that slip occurs at or below the usual working stresses, although some show much higher results. At any rate, it is not safe to assume that friction between the plates will prevent shearing stresses in the rivets, and with this view the shearing strength of rivet material becomes an important matter.

A GOVERNOR INDICATOR.

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The rapidity with which steam engine governors act under sudden and great variations of load and their stability under the same conditions, is of considerable importance in all work requiring a constant speed as in electric lighting. Fig. 1, page 135, shows an instrument designed by the writer for determining the above qualities. It consists of four wooden rollers A, B, C, D, mounted on standards as shown. A is a roller on which is wound a roll of paper. This roll has at one end a cone bearing, and at the other a pivot bearing, the screwing up of which gives the amount of friction necessary to keep the paper taut. B is the drum on which the record is made while the paper passes over it. (The paper is shown by the dot and dash line.) C is a rubber-covered roller which is connected to the engine shaft by means of a worm and worm-wheel, and which makes one turn to every one hundred revolutions of the engine. D is a smaller roller in a frame pivoted to the base of the instrument, the roller D is

pressed against the roller C by a rubber band (shown in the end view just below the rollers) and thus produces the necessary pressure on the paper so that it will be moved along by the rotation of C. The recording pencil I is attached to a slide E, which moves parallel to the axis of the drum B along the bar J. The slide E is attached to the valve-stem of the engine by means of the link F, the large end clamping the valve-stem and the small slot in the other end fitting over the pin on E. If the valve-travel is not sufficient, or if a greater length of line is desired, a pantagraph may be used in place of this link.

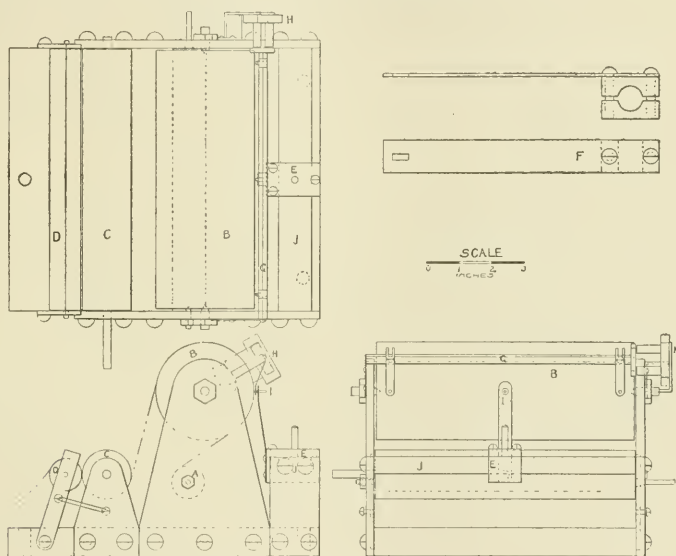


FIG. 1. GOVERNOR INDICATOR

The time-recording mechanism consists of an electro-magnet H (core only shown in cut) which is connected in circuit with a seconds pendulum having a platinum point in the lower end which passes through a mercury cup thus closing the circuit every second. The armature of this electro-magnet H is fastened to a bar G, which is itself connected to the larger standards by means of a strip of spring brass at each end. These springs serve to draw the armature away from the magnet when the circuit is broken. To this bar G are attached the two pencils shown in line with the recording pencil I. It will be seen that this mechanism will make a record similar to that of a chronograph.

It is seen that this instrument makes a continuous record of the movement of the valve of the engine, making a line for each half revolution, and a V-shaped figure for each complete revolution. For the same load and steam pressure, the lines will always be of the same length. The lines can be made any convenient distance apart, by simply increasing the velocity ratio of the roller C, i. e., by putting a larger pulley on the end of the engine shaft. From the diagrams can be read directly the number of revolutions of the engine per minute, the time the governor required to change from one position to the other and the number of revolutions made by the engine during this time. By blocking out the weights and finding the corresponding valve-travel, and then measuring the distance of the weights from the center of rotation, the path of the weights during the change of position may be determined.

Experiments were made with the instrument on an 8×10 Ball Engine built at the University about ten years ago. The governor on this engine is a shaft governor of the centrifugal type, whose weights are so situated as to have more or less inertia effect in harmony with the centrifugal force. The governor has an oil dash-pot with a spring connection to give it the necessary stability. The variation of load was obtained by means of a friction brake (rope and lever). In each case indicator diagrams were taken at the instant of taking the governor diagrams. The diagrams were taken with ordinary lead pencil and were inked for reproduction, and therefore the lines are somewhat straighter than they were in the original. The seconds are shown by the dot and dash lines across the governor diagrams. On the indicator cards from the steam cylinder, are given the speed, horse power, etc., for the correspondingly numbered governor diagram. An indicator was used on each end of the cylinder, and hence the two diagrams were not taken on the same card. The horse power given on each card is for the diagram from the corresponding end of the cylinder only, and of course the total horse power exerted by the engine is the sum of that given by the corresponding head and crank-end diagrams.

Indicator diagram No. 2, Fig. 2, page 137, and governor diagram No. 2, Fig. 3, page 138, show the greatest variation in load, viz.: from 8.02 H. P. to 33.38 H. P., the corresponding valve travels

being 1.64 and 2.80 inches. At *c*, Fig. 3, the load was suddenly thrown on, and we see that it required less than one revolution of the engine (about 0.19 seconds) for the governor to move to the position of equilibrium. At *d*, Fig. 3, the load was thrown off suddenly, and it required two and one-half revolutions (about 0.4 seconds) for the governor to get into the proper position. The speed at the smaller load was 320 R. P. M., and that for the larger load was 300, the variation being about 6 per cent.

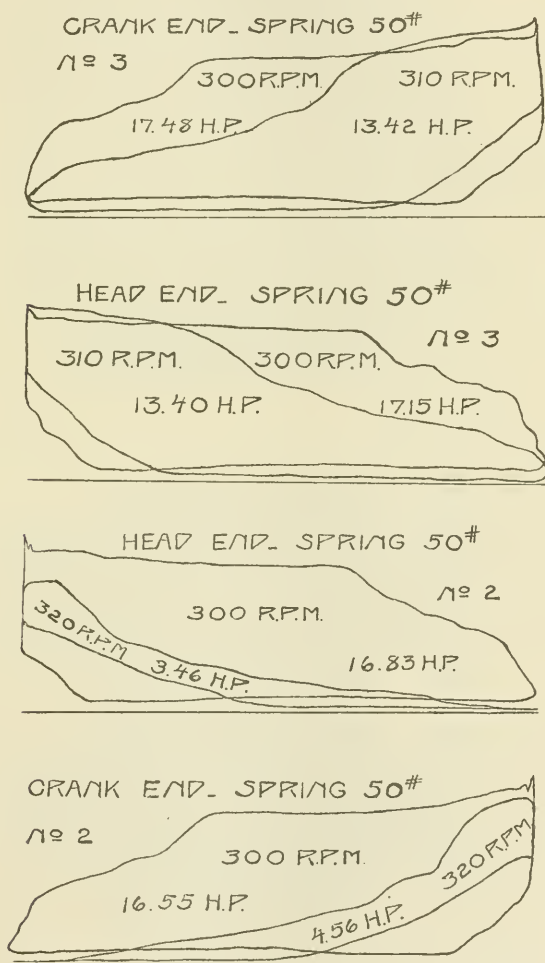


FIG. 2. INDICATOR DIAGRAMS.

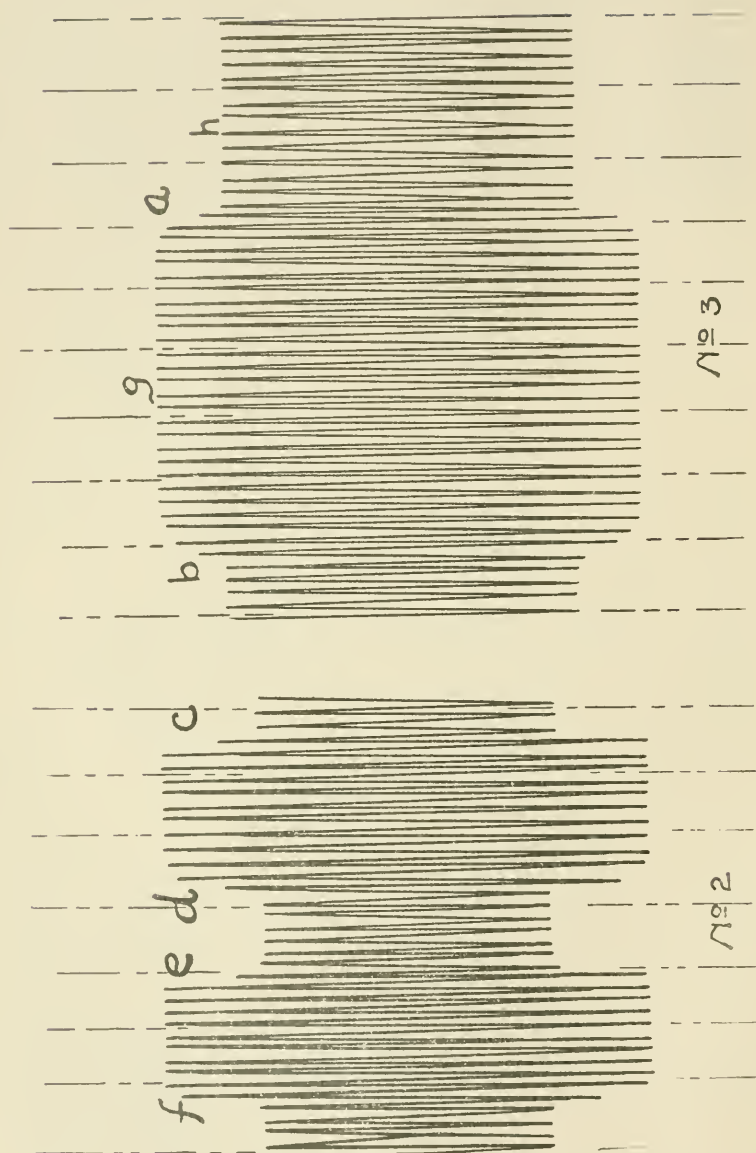


FIG. 3. GOVERNOR DIAGRAMS.

In diagram No. 3, Fig. 3, we have a change of load from 26.82 H. P. to 34.63 H. P. The corresponding travel of the valve was 2.08 and 2.84 inches respectively. At *a*, Fig. 3, the load, about 8 H. P., was thrown on suddenly, and it required three revolutions (about 0.57 seconds) for the governor to get into position. At *b*, Fig. 3, the same load was thrown off, and it required a little more than three revolutions (about 0.6 seconds), for the governor to get into position. The difference in R. P. M. was about ten, or about 3 per cent.

The results of these experiments show that the governor acts remarkably quickly, but that the engine does not maintain the same rate of speed at all loads. The governor is also very stable (due to the spring connected oil dash-pot), and does not pass the proper position at any time, but takes the proper position at once and remains there until the load is changed.

A SHORT METHOD FOR RAILROAD CROSSING COMPUTATIONS.

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The computations connected with the solution of a single or double curved crossing by any of the ordinary methods is a laborious task. Various solutions of this problem have been used, but all that have come to our notice are based upon the long process of solving triangles, and some of the methods are for some cases too inaccurate to be practical, even though they are founded upon rigid mathematical deductions. The inaccuracy here referred to will be discussed later.

A short practical solution of this problem has been in use for several years by the Ajax Forge Company, Chicago, and also by the Western Indiana Railway Company, and although it has great advantages over other methods, it seems to be little known among engineers. While this solution is approximate, its use is far more consistent than the use of more complex methods which involve no approximations. We therefore propose to give in detail this solution with a discussion of the approximation involved. A few remarks by way of comparison of this with other methods are also added.

There are three general cases to be considered: First, the crossing of two tangents; second, the crossing of one tangent and one curve; and, third, the crossing of two curves.

The complete solution of any crossing consists in finding the frog angles, f_1, f_2, f_3 and f_4 (see Fig. 1, 2 and 3), and the chord lengths,

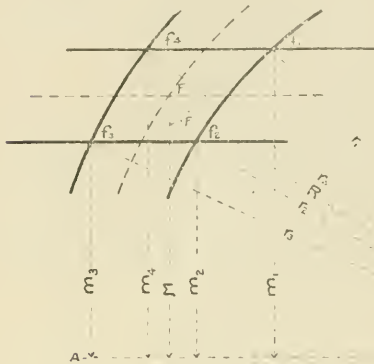


FIG. 2.

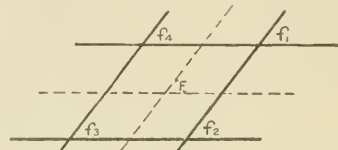


FIG. 1.

$f_1 f_2, f_2 f_3, f_3 f_4$ and $f_4 f_1$, having given the angle of intersection of the center lines of the two tracks and the degree of curvature or radius of each.* The basis for the advantages claimed for this method is embodied in the following statement:—

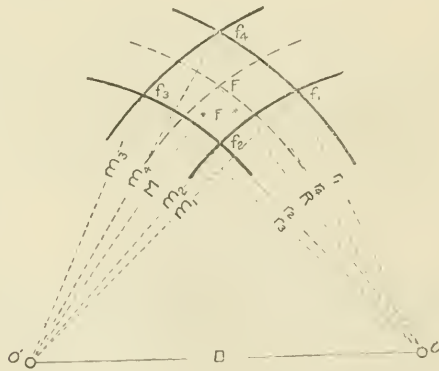


FIG. 3.

Any chord length equals the product of the gage and the cosecant of the mean of the adjacent frog angle.

* For complete enumeration of data taken in the field, see THE TECHNOGRAPH No. 10, article on R. R. Crossing Frogs, by Prof. Wm. D. Pence.

Or, algebraically, chord = $g \csc \frac{A+A^1}{2} \dots\dots\dots (1)$

where g = gage, and A and A^1 are the frog angles adjacent to the chord. This equation is rigidly true for all chords of Case 1, and chords $f_1 f_2$ and $f_3 f_4$ of Case 2, but it is approximate for the other chords of Case 2 and for all the chords of Case 3.

CASE I. CROSSING OF TWO TANGENTS.

For the frog angles we have $F = f_1 = f_2 = f_3 = f_4$. For the "chord" lengths, we have $f_1 f_2 = g \csc F$; or, for sake of analogy to equation (1), $f_1 f_2 = g \csc \frac{f_1+f_2}{2}$. Similarly for the other three chords.

CASE II. CROSSING OF ONE TANGENT WITH ONE CURVE.

For the frog angles we have, noting that $M = R \cos F$ and m_1, m_2, m_3 and $m_4 = M = \frac{1}{2} g$:—

$\cos f_1 = \frac{m_1}{r_1} \dots\dots\dots (2)$ $\cos f_2 = \frac{m_2}{r_2} \dots\dots\dots (3)$

$\cos f_3 = \frac{m_3}{r_3} \dots\dots\dots (4)$ $\cos f_4 = \frac{m_4}{r_4} \dots\dots\dots (5)$

For the chord lengths we have from equation (1), $f_1 f_2 = g \csc \frac{f_1+f_2}{2}$, and similarly for the other three chords.

CASE III. CROSSING OF TWO CURVES.

Frog angles. After solving triangle OO^1F for $OO^1 (= D)$, we have from triangle OO^1f_1 ,

$\tan \frac{f_1}{2} = \frac{1}{S_1 - D} \sqrt{\frac{(S_1 - D) (S_1 - r_1) (S_1 - m_1)}{S_1}} \dots (6)$

from triangle $OO^1 f_2$,

$\tan \frac{f_2}{2} = \frac{1}{S_2 - D} \sqrt{\frac{(S_2 - D) (S_2 - r_2) (S_2 - m_2)}{S_2}} \dots (7)$

from triangle $OO^1 f_3$,

$\tan \frac{f_3}{2} = \frac{1}{S_3 - D} \sqrt{\frac{(S_3 - D) (S_3 - r_3) (S_3 - m_3)}{S_3}} \dots (8)$

from triangle $OO^1 f_4$,

$\tan \frac{f_4}{2} = \frac{1}{S_4 - D} \sqrt{\frac{(S_4 - D) (S_4 - r_4) (S_4 - m_4)}{S_4}} \dots (9)$

where D , r and m are the known sides, and S the half sum of the sides of the triangle corresponding to the frog angle in question.

For chord length, we have from equation (1), $f_1 f_2 = g \csc \frac{f_1 + f_2}{2}$ and similarly for the other three chords.

The degree of accuracy of this method and the limitation of the application of equation (1), is shown in the following discussion.

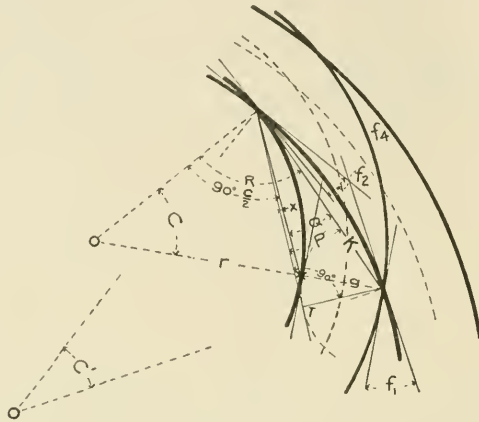


FIG. 4.

Fig. 4 is an exaggerated case, drawn to show the error of the approximation. We constructed the figure by drawing the center lines, the gage lines, the radii of the two curves, the tangents at the frogs f_1 and f_2 , and the chords subtended by the angles C and C'

By geometry, $Q = f_1 - \frac{c}{2} + \frac{c^1}{2}$, and $Q = f_2 + \frac{c}{2} - \frac{c^1}{2}$;

$$\text{hence } Q = \frac{f_1 + f_2}{2}$$

The right angled triangle $f_1 f_2 T$ is constructed with gage as one side and the chord K^1 as the other and

hence $K^1 = g \csc P = \text{exact value of the chord length}$

but $K = g \csc \frac{f_1 + f_2}{2} = \text{approximate value of the chord by equation (1)}$

Then $P - Q = x$ is the angle causing the approximation in equation (1). In other words, $g \csc \frac{A + A^1}{2} - g \csc \left(\frac{A + A^1}{2} + x \right)$

= the approximate chord length minus the exact chord length. We first obtained x in terms of c , r and g as follows:—

$$\begin{aligned} \text{From Fig. 3. } x &= P - Q = P - \left[R - \left(90^\circ - \frac{c}{2} \right) \right] \\ &= P - R + 90^\circ - \frac{c}{2} \dots\dots\dots(12) \end{aligned}$$

$$\text{From trigonometry, } R - S = 2 \tan^{-1} \left(\frac{g}{2r+g} \cot \frac{c}{2} \right) \dots\dots(13)$$

$$R + S = 180^\circ - c \dots\dots\dots(14)$$

$$\text{whence } R = \tan^{-1} \left(\frac{g}{2r+g} \cot \frac{c}{2} \right) + 90^\circ - \frac{c}{2} \dots(15)$$

$$Q = R - \left(90^\circ - \frac{c}{2} \right) \dots\dots\dots(16)$$

$$\text{From (15) and (16), } Q = \tan^{-1} \left(\frac{g}{2r+g} \cot \frac{c}{2} \right) \dots\dots\dots(17)$$

$$\text{Then by trigonometry, } K^1 = (2r+g) \frac{\sin \frac{c}{2}}{\cos \frac{R-S}{2}} \dots\dots\dots(18)$$

substituting for $(R-S)$ its value in equation (13) we get

$$K^1 = (2r+g) \frac{\sin \frac{c}{2}}{\cos \left[\tan^{-1} \left(\frac{g}{2r+g} \cot \frac{c}{2} \right) \right]}$$

but $\sin P = g \div K^1 =$ (after reducing)

$$\csc \frac{c}{2} \cdot \frac{g}{2r+g} \cos \left[\tan^{-1} \left(\frac{g}{2r+g} \cot \frac{c}{2} \right) \right] \dots\dots\dots(19)$$

$$\begin{aligned} \text{Finally } x &= \sin^{-1} \left\{ \csc \frac{c}{2} \cdot \frac{g}{2r+g} \left[\tan^{-1} \left(\frac{g}{2r+g} \cot \frac{c}{2} \right) \right] \right\} \\ &\quad - \tan^{-1} \left(\frac{g}{2r+g} \cot \frac{c}{2} \right) \dots\dots\dots(20) \end{aligned}$$

TABLE I gives values of x , computed from equation (20), to be added to $\frac{A+A^1}{2}$. Since x is nearly proportional to the central angle, corrections may be interpolated between two given limits. For any given case, c needs to be known only approximately in order to apply the correction given in the table; c may be found from Table II for any given radius and for any value of

$\frac{A+A^1}{2}$. The tabulated values of $\frac{c}{2}$ were obtained as follows:—

$$\text{since } g \cot \frac{A+A^1}{2} = 2r \sin \frac{c}{2} \dots\dots\dots (21)$$

$$\text{then } \frac{c}{2} = \sin^{-1} \left(\frac{g \cot \frac{A+A^1}{2}}{2r} \right) \dots\dots\dots (22)$$

TABLE I.
VALUES OF x FOR DIFFERENT VALUES OF r AND c .

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---------------|---------|---------|---------|---------|---------|---------|---------|---------|----------|
| $\frac{c}{2}$ | $r=100$ | $r=200$ | $r=300$ | $r=400$ | $r=500$ | $r=600$ | $r=700$ | $r=800$ | $r=1000$ |
| 30' | 0' 22" | 0' 10" | 0' 07" | 0' 04" | ..... | ..... | ..... | ..... | ..... |
| 1° | 0' 40" | 0' 23" | 0' 16" | 0' 12" | 0' 08" | 0' 06" | ..... | ..... | ..... |
| 2½° | 1' 43" | 0' 52" | 0' 35" | 0' 27" | 0' 20" | 0' 16" | 0' 14" | 0' 12" | 0' 08" |
| 5° | 2' 27" | 1' 45" | 1' 10" | 0' 52" | 0' 41" | 0' 36" | 0' 31" | 0' 27" | 0' 22" |

By a study of Tables I and II, we notice that the greatest value of $\frac{c}{2}$ in Table II is about ^{see next page} 2° 48' for radius of 700 feet. In Table I notice that the value of x corresponding to radius of 700 feet and $\frac{c}{2} = 2^\circ 48'$ is 14 " + 2 " = 16 ". In column 3, Table II, the allowable angular discrepancy for $\frac{A+A^1}{2} = 4^\circ$ is 16 ". Since the value of x decreases as the central angle decreases, and since the above assumed value for $\frac{c}{2}$ is its greatest possible value when 4° is taken as a minimum for $\frac{A+A^1}{2}$, we conclude that *equation (1) is practically correct in all cases where either or both curves have radii greater than 700 feet.* By a similar line of reasoning we have determined that the error due to the approximation in equation (1) is inappreciable under the following limits:—

For radius of 600 feet or greater, when $\frac{A+A^1}{2}$ is greater than 5°

For radius of 500 feet or greater, when $\frac{A+A^1}{2}$ is greater than 6°

For radius of 400 feet or greater, when $\frac{A+A^1}{2}$ is greater than $7\frac{1}{3}^\circ$

For radius of 300 feet or greater, when $\frac{A+A^1}{2}$ is greater than 10°

For radius of 260 feet or greater, when $\frac{A+A^1}{2}$ is greater than 12°

From the preceding, it is readily seen that equation (1) is practically universal in its application to general railroad work. However, in order that no one may be misled in the use of our solution, we have shown above the limiting conditions under which equation (1) may be used without applying a correction; and Tables I and II are given to show that the method may also be used for even the most extreme cases, by applying a correction. In computing the values given in Tables I and II, the gage

TABLE II.

VALUES OF $\frac{c}{2}$ FOR DIFFERENT VALUES OF $\frac{A+A^1}{2}$.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|-------------------|--------------------------|--|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| $\frac{A+A^1}{2}$ | $g \cot \frac{A+A^1}{2}$ | Allowable Variation in $\frac{A+A^1}{2}$ | r=100 | r=200 | r=300 | r=400 | r=500 | r=600 | r=700 | r=800 | r=1000 |
| Degrees. | Feet. | Seconds. | Deg. Min. | Deg. Min. | Deg. Min. | Deg. Min. | Deg. Min. | Deg. Min. | Deg. Min. | Deg. Min. | Deg. Min. |
| 4 | 67 | 16 | 19 34 | 0 39 | 6 25 | 4 48 | 3 51 | 3 12 | 2 45 | 2 24 | 1 55 |
| 5 | 54 | 20 | 15 40 | 7 49 | 5 10 | 3 52 | 3 06 | 2 35 | 2 12 | 1 56 | 1 40 |
| 6 | 45 | 24 | 13 00 | 6 28 | 4 18 | 3 13 | 2 35 | 2 09 | 1 50 | 1 40 | 1 17 |
| 7 | 38 | 28 | 10 57 | 5 28 | 3 38 | 2 43 | 2 11 | 1 49 | 1 33 | 1 22 | 1 05 |
| 8 | 33 | 32 | 9 30 | 4 44 | 3 09 | 2 22 | 1 54 | 1 34 | 1 21 | 1 11 | 0 57 |
| 9 | 30 | 36 | 8 37 | 4 18 | 2 52 | 2 09 | 1 43 | 1 26 | 1 14 | 1 05 | 0 52 |
| 10 | 27 | 40 | 7 46 | 3 52 | 2 35 | 1 56 | 1 32 | 1 17 | 1 06 | 0 59 | 0 47 |
| 11 | 24 | 45 | 6 54 | 3 27 | 2 17 | 1 43 | 1 22 | 1 09 | 0 59 | 0 51 | 0 41 |
| 12 | 22 | 50 | 6 19 | 3 09 | 2 06 | 1 34 | 1 16 | 1 03 | 0 54 | 0 47 | 1 38 |
| 13 | 20 | 55 | 5 44 | 2 05 | 1 54 | 1 26 | 1 09 | 0 57 | 0 49 | 0 43 | 0 34 |

Column 2 in Table II gives values of the chord subtended by c for different values of $\frac{A+A^1}{2}$. Column 3 gives values of allowable discrepancy in value of $\frac{A+A^1}{2}$ corresponding to a variation of $\frac{1}{16}$ -inch in gage. In establishing limits for the use of equation (1), $\frac{1}{16}$ -inch has been considered the maximum allowable variation in width of gage.

is taken as 4.708 feet, but a slight variation in gage does not cause an appreciable effect in the value of x . However, equation (20) is perfectly general and values of x could easily be computed for other values of gage and for limits of r and c beyond those given in Table I.

To illustrate the use of our tables where a correction is necessary, take for example a case in which $r=250$ feet and $\frac{A+A^1}{2} 7^\circ 43' 20''$. Column 6 of Table II shows $\frac{c}{2} = 5^\circ 28' - 0^\circ 30' = 4^\circ 58'$ approximately. By interpolation in Table I, column 4, we get $x = 1' 17''$. This is *always added* to $\frac{A+A^1}{2}$, giving $7^\circ 44' 37''$ as the angle to be used, instead of $\frac{A+A^1}{2}$ in equation (1). By studying the construction of Fig. 4, it will be seen that the value of x is always positive. This is the same as saying that the value of the chord length obtained from equation (1) is always in excess of the true value.

To illustrate the inaccuracy of other methods in which the triangles are solved in the usual way to obtain the chord length, take a crossing, one track of which is a one-degree curve. Since the central angle subtending the chord on the one-degree curve can never be much more than one degree, it is evident that an error of one second in the angle will cause an error in the chord length of $0.00005 \times 5730 =$ about $\frac{3}{8}$ of an inch. Since this error may enter in crossings of any angle, it is evident that such a method of computation is not practical. The impracticability of such a method is seen perhaps more clearly when we remember that crossings made up of curves of slight curvature are very frequently met in general railroad work. The method given in Prof. Nagle's new "FIELD MANUAL FOR ENGINEERS," is open to the above criticism, as is also the method given by Prof. W. D. Pence in THE TECHNOGRAPH No. 9. The method used on the Michigan Central R. R., as given by Tratman in his "RAILWAY TRACK AND TRACK WORK," is an ingenious one and is free from the inaccuracies mentioned above; it is very laborious in its application to double curved crossings. A solution of this problem was published in *Engineering News*, April 21, '98, which is essentially the same as that given by Profs. Nagle and Pence, and is therefore open to the same criticism.

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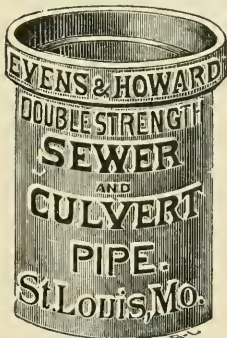
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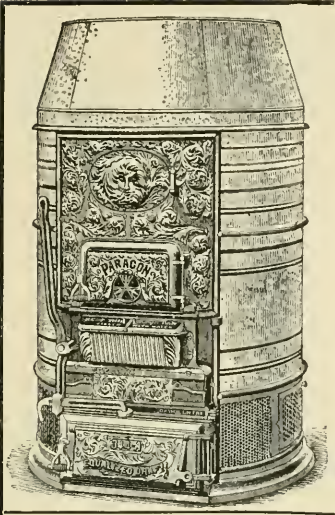
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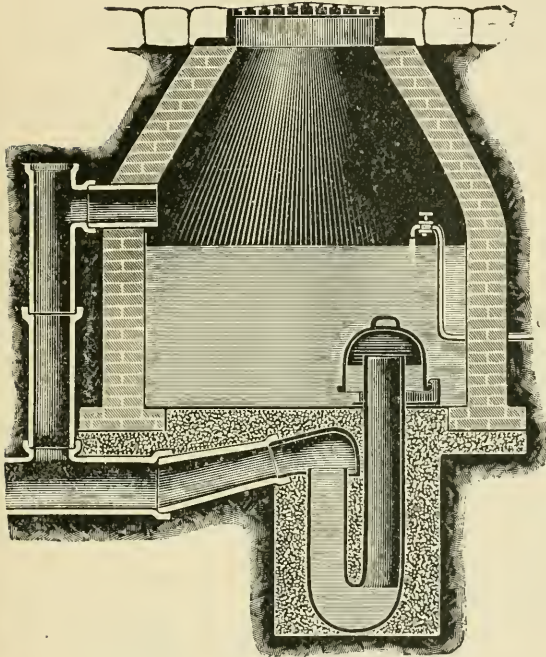
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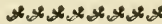
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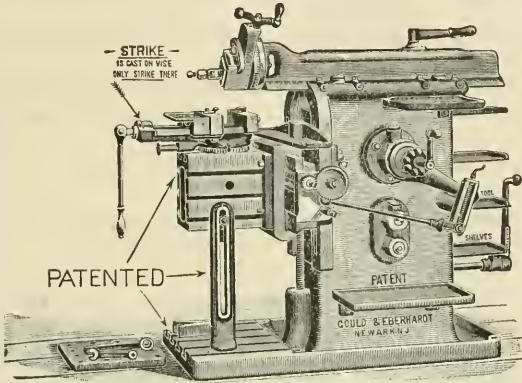
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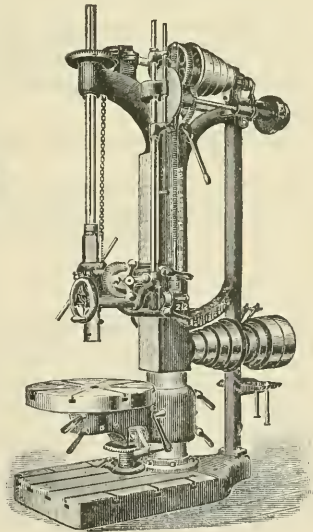
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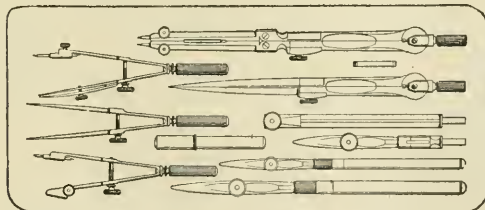
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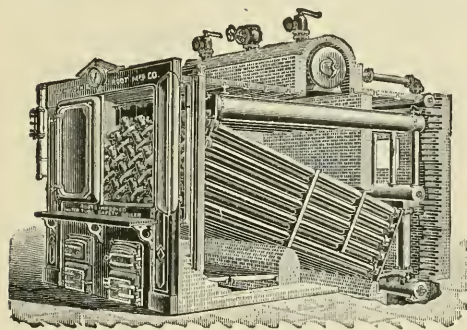


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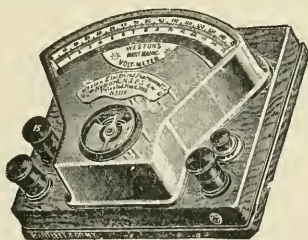
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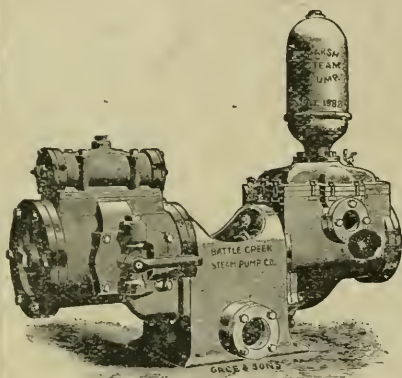
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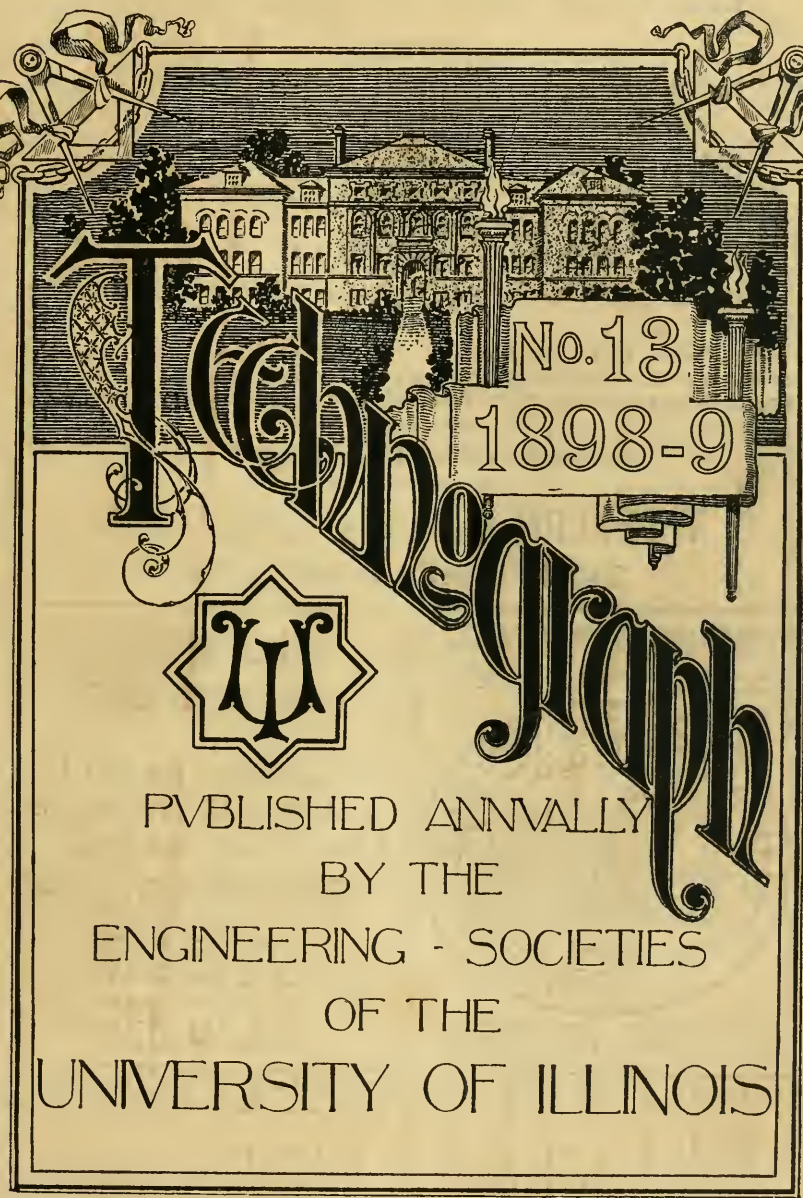
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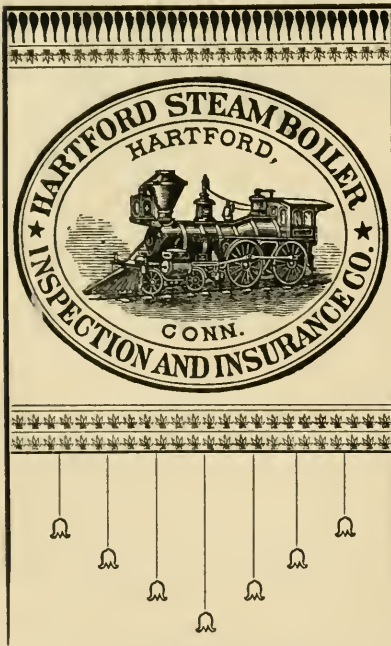
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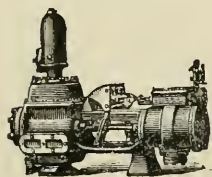
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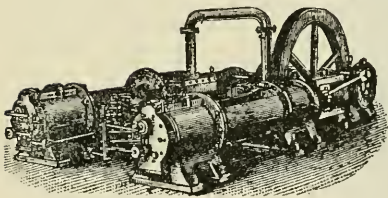


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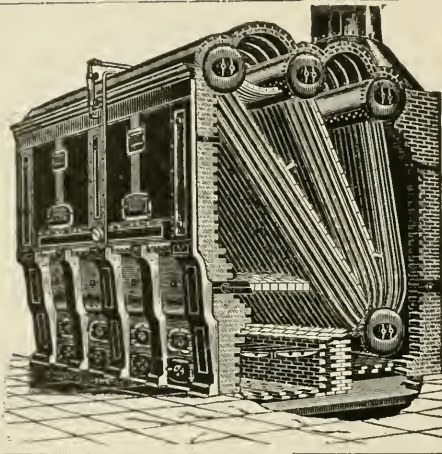
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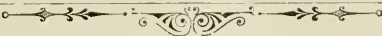
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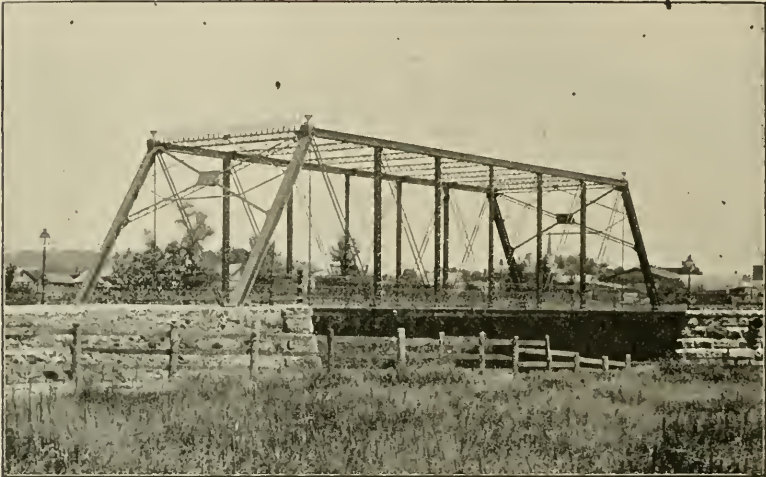
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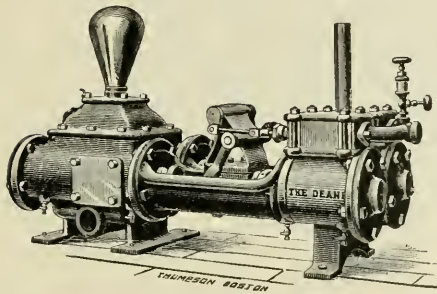
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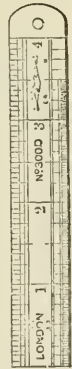
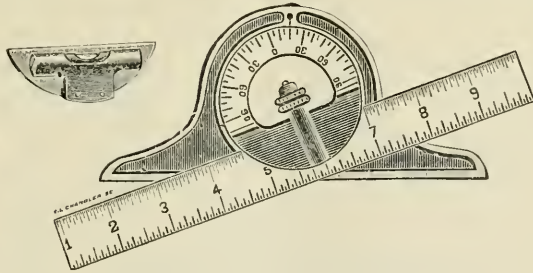
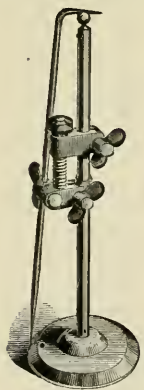
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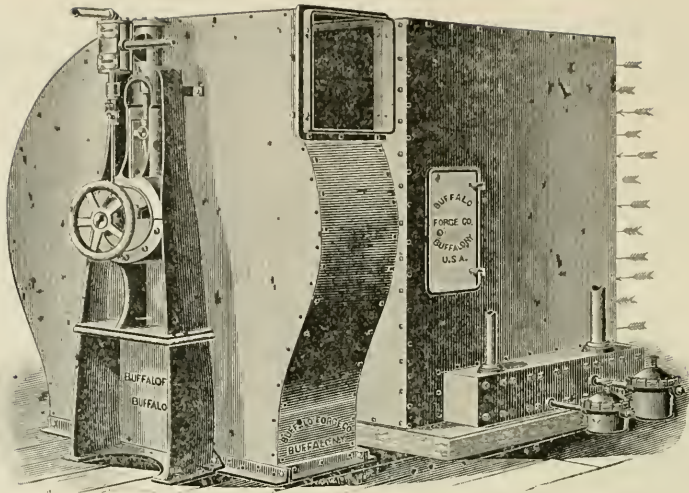
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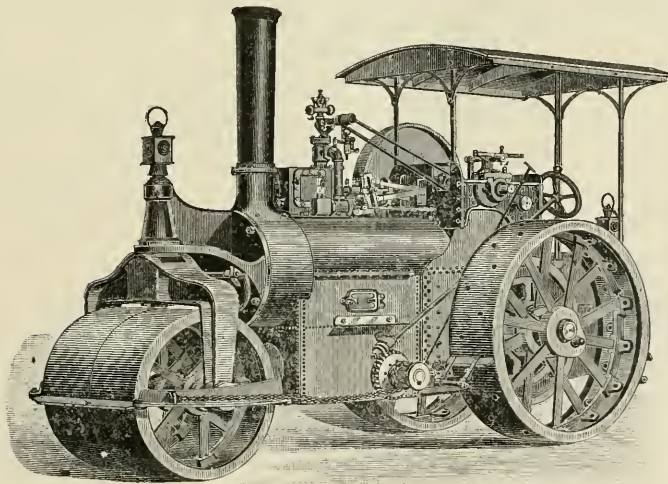
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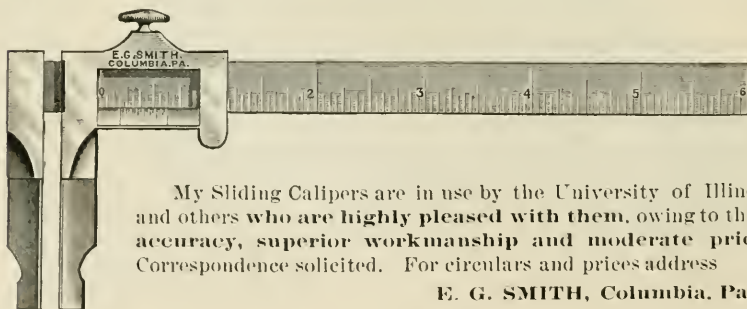
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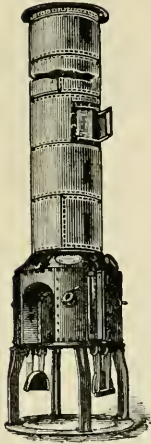
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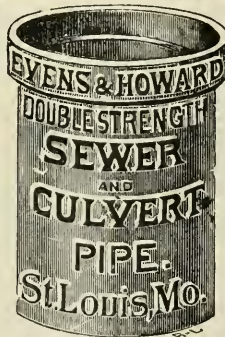
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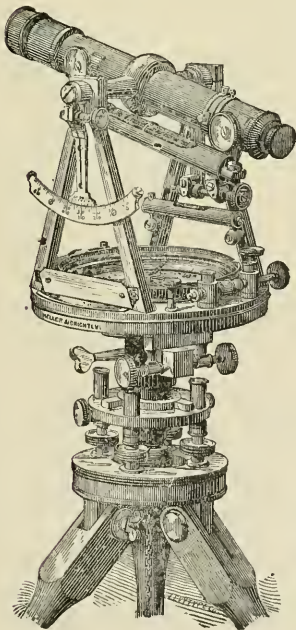
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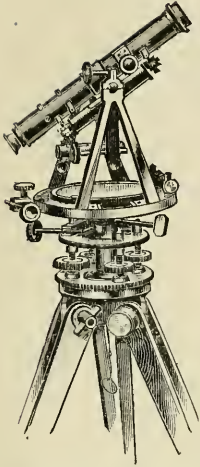
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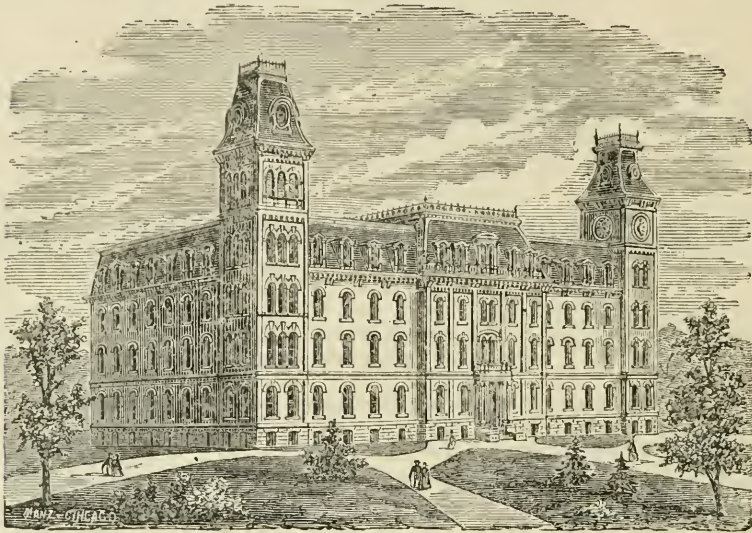
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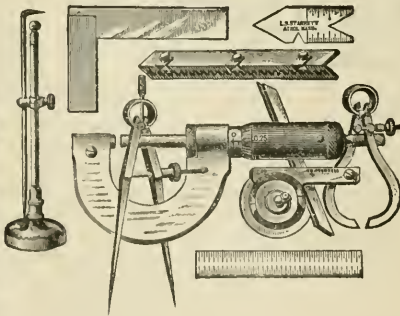
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PUBLISHED ANNUALLY

BY THE

ASSOCIATION OF ENGINEERING SOCIETIES

OF THE

UNIVERSITY OF ILLINOIS

VOL. XIII

1898-9

UNIVERSITY OF ILLINOIS
CHAMPAIGN OR URBANA

1899

“That man who best understands nature and can best turn nature to the benefit of man, will be accounted the most successful engineer.”

—*A. E. Phillips.*

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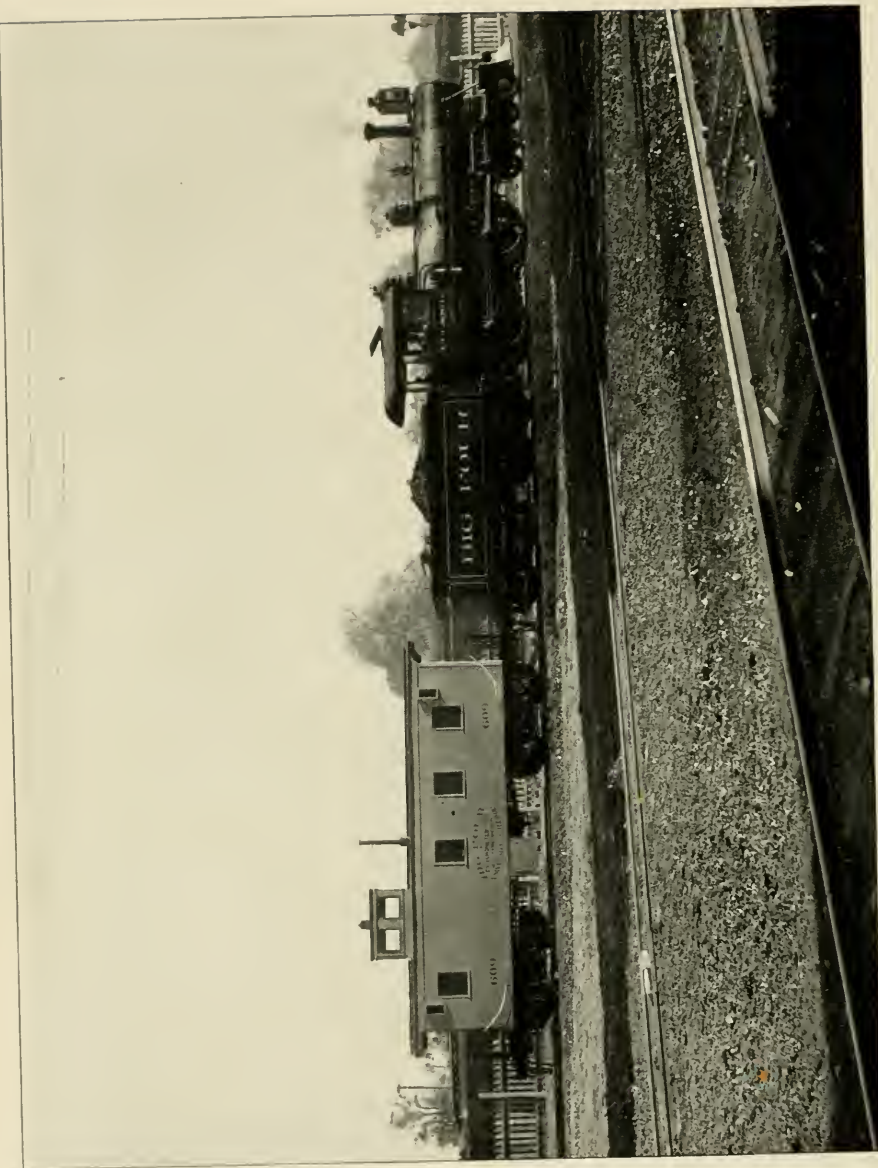
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THE TECHNOGRAPH.

No. 13

UNIVERSITY OF ILLINOIS.

1898-99.

PARKS AND BOULEVARDS.

—

BY A. C. SCHRADER, '85, CHIEF ENGINEER FOR WEST CHICAGO PARK
COMMISSIONERS.

—

The proper construction and correct maintenance of a park or boulevard system undoubtedly does much towards creating civic pride, as well as public spirit and interest in the welfare of a city or municipality. A stranger visiting a city frequently wishes to see the parks and boulevards, as well as the public buildings, and these improvements often serve as a fair index of the public spirit of its citizens, modified perhaps by the city's commercial prosperity and importance. No further arguments will here be made in favor of the construction of parks and boulevards as they are too numerous and well known to require mention. Their existence in many of our cities is proof of their desirability, but their extent and effectiveness are too frequently limited by lack of foresight or funds.

In order to avoid an extravagant outlay, the proposed land should be secured as early as possible, but since a city's growth and importance cannot always be predetermined, the selection of grounds is frequently delayed. The final location and adoption of park grounds is therefore not infrequently determined by other considerations than that of adaptability, and is usually incident to, and dependent upon, the growth and commercial importance of the city.

The work of making a park of the lands selected usually devolves upon the engineer and the landscape gardener, working in harmony and with the same end in view, namely, to emphasize and render more attractive any desirable existing features of the chosen grounds, and to obliterate the undesirable; to prepare a well-matured plan for the improvement of the whole park as a unit, and after its adoption to adhere to the lines laid down, and discourage as far as possible the frequent attempts of succeeding boards of control to materially change the plan. The importance of following a complete and well-matured plan cannot be over-estimated, and especially is this true when the controlling board is subject to changes in its personnel, and therefore a change of ideas as to desired improvements. As the construction or final completion of a park system is often extended over a number of years, the work of each year should be in close conformity with the adopted plan, and thus avoid the confusion and often the needless additional expenditure caused by a change of plans.

The working plans should accurately show the grade lines of all roadways, walks, and the conformation of ground or topography proposed, as well as the location and description of all water, sewer and electric light service, buildings, lakes and bridges. The planting plans should be drawn to the same scale as the grading plan, and should show the correct grouping of trees and shrubbery and the numerous view lines to be preserved, and should be studied with reference to the grading plan to secure the proper landscape effects of trees, lawns, lakes, buildings, etc. An index to the planting plan should be prepared, which will closely define the kind and number of trees or shrubs, or both, in any group indicated in the plan, and the work of preparing this properly belongs to the landscape gardener, and is important. The complete construction, however, of all the work, the preparation of all detailed plans and specifications come more particularly under the direction of the engineer of the park and boulevard system.

The duties of a park engineer, as some of our systems are managed today, are numerous, and he deserves not a little credit if his training and experience are sufficiently broad to enable him without the assistance of specialists, to economically and comprehensively solve all problems presented. The broader his knowl-

edge of civil, mechanical and electrical engineering, architecture and landscape work, the greater the ease with which he may discharge his many duties, and the less the demand for the opinion or assistance of outside specialists. He is wise if he knows his limitations in this respect and leaves to specialists the particular parts of which he may have only a general knowledge.

The designing of park buildings should be made under the direction of able architects, and be in harmony with the surroundings. As a rule the structures are not carried more than fifty to sixty feet in height, tall buildings being undesirable, as they may overtop the foliage line. Refectories are usually placed in the larger parks for the convenience and comfort of the public. Greenhouse construction should be carefully considered with reference to durability of framework, roof outline and economical and effective heating apparatus. On account of the moisture in greenhouses, wood decays rapidly and therefore iron or steel, if kept well painted, is preferable. It is not desirable that work rooms or heated basements be placed under exhibit rooms, as this tends to make the air too dry in the exhibit rooms, unless an unusually heavy water-tight floor intervenes. All park buildings should be constructed with a view of having every side presentable, and sanitary regulations should be observed.

The impression which a visitor receives in viewing the parks, buildings, etc., should be one of restfulness and comfort rather than obtrusiveness, healthful recreation rather than an array of monumental buildings. The placing of monuments commemorative of historical persons in parks is evidently considered desirable by many park boards. The total absence of such monuments in some of our principal park systems may evidence a contrary opinion. The public squares frequently afford an advantageous location for such work, as may also prominent points along the main boulevards. The placing of such monuments, however, is usually an after thought, and is seldom considered in the original plan.

A drinking fountain for horses, suitably designed and placed at an accessible point in the park roadway, usually forms an attractive feature, if the water supply and pressure are adequate. Drinking fountains for persons should be supplied at various points in the parks.

The original plan should contemplate a complete water and drainage service. For the purpose of watering the lawns, trees and floral displays economically and quickly it is desirable that the distributing pipe and lawn hydrants be so placed that all desired areas can be reached with about one hundred feet of hose, and so that a considerable number of sprayers may be in operation at the same time. In this manner one attendant can readily tend from twenty-five to thirty-five sprayers. The shorter length of hose also reduces the friction head losses and insures a greater discharge.

The drainage should adequately care for the rainfall on all roadways, walks, and such lawns as are apt to remain saturated for a considerable period of time after a heavy rainfall or during the summer months. For lawn drainage, farm tiling 3 to 6 inches in diameter is commonly used when a heavy clay subsoil exists. For the proper maintenance of the park roads, catch basins should be placed about 250 to 275 feet apart, depending upon the grades, and they should be placed so as to prevent the scouring action of heavy rainfall upon the roadway pavement.

The park roadways may vary considerably in width, depending somewhat on the size of the park. For the more probable lines of heavy travel, those most frequented, a width from 45 to 55 feet is ample in a large park, and from 35 to 40 feet in a smaller park. It is desirable that the width of lawns in a smaller park be not too much dwarfed by the introduction of wide drives and walks, thus creating a disproportion of lawn and pavement area. The principal entrance to the park, however, should be much wider, as a rule, than the other roadways, and these are frequently from 100 to 150 feet in width. Except in formal work they are laid out in curved lines, and their location should command the best view of the park. Crushed limestone, as well as bank gravel and crushed gravel are most commonly used in the construction of park roads, and when heavy clay subsoil exists cinders or slag may be used to good advantage as a subdrain, greatly facilitating the work on wet grounds. With the crushed limestone drive considerable dust is always present, unless well sprinkled, and the white glare in the sun is not pleasant to the eye, therefore a neutral tint is more desirable. Both defects can be partially remedied by using crushed granite and gravel for roadway finish, but at an advance in cost.

Paved gutters are not desirable, except where the roadway grades are steep, and it is desired that erosion, due to heavy rainfall, be checked thereby.

The walks and paths in a park may vary considerably in width, say from 6 to 16 feet, and their construction and maintenance should receive as much care as the roadways; ample drainage should also be provided. The surface should be smooth and unyielding, and should not become muddy or sticky, nor should the pebbles, if gravel is used, be so large as to be disagreeable to walk on. A fairly good walk may be laid on clay subsoil by using as a base from 9 to 12 inches of cinders, on which are placed from $1\frac{1}{2}$ to 2 inches of screened binding gravel, and surfaced with a clean lake shore or river gravel, screened through a $\frac{3}{8}$ inch mesh; it is desirable that the finishing gravel consist mainly of flat pebbles, rather than round ones. It is understood that rolling is necessary to compact the several layers of material.

The permanent improvement and easy maintenance of lawns is best secured by the liberal use of black soil, from 8 to 12 inches in thickness, depending upon the character of the soil. The same is true of tree planting, the depth of black soil required being from $2\frac{1}{2}$ to $3\frac{1}{2}$ feet, and of ample area to provide for the growth of the roots.

For the larger and more important roadway bridges the stone arch naturally suggests and admits of appropriate designing. Whether in heavy woodland or formal plantation, the particular locality and surroundings will indicate the use either of rough granite boulder facing or the carefully dressed stone facing and railing when the space is within the limits of the stone arch. For the longer spans, if iron must be used, the trusses should form the arch outline, and no portion thereof should extend above the floor line; the structural iron work should be masked as far as practicable. For the minor bridges for paths, etc., the rustic type of wood-work frequently gives pleasing variety, but constant repairs are necessary. In general, it is deemed desirable that a bridge site be at least partially hidden by suitable tree and shrubbery planting.

The desirability of introducing speeding tracks for horses and for bicycle riders into parks, as park improvements, is ques-

tionable, and depends largely upon the manner in which they are conducted. While they are not particularly conducive to park embellishment, or to the landscape effects, they probably furnish a recreation ground to a considerable number of citizens, and then, too, all fast speeding may thus be removed from the boulevards and limited to these tracks only. A public bath is an attractive feature to the small boy. With him, however, cleanliness is not his primary object; it is perhaps more the sport of swimming in water, which is kept at a comfortable temperature. If the baths are free, their popularity is unquestioned, but stringent rules and first-class management are necessary; otherwise every privilege will be abused. Although something may be said in favor of public speeding tracks and public baths or natoriums, yet in general, if grounds can be secured adjacent to the main parks or boulevards for this purpose, they could be considered as an adjunct to the system, rather than a central feature of a park.

In every park of suitable size, it is desirable that some portion of it be so laid out, as to accommodate the large numbers that usually attend the free concerts given during the summer months. The music grounds may, or may not have a band stand, but the ground should easily accommodate a great number of vehicles, as well as pedestrians and those who reach the parks on street cars. Temporary seating should be provided.

The flickering gas and gasoline lamps of a few years ago have largely been replaced by the more brilliant electric arc lights, to mark roadways and paths at night, and to brilliantly illuminate the boulevards. During the summer months, much of the driving, as well as bicycle riding, is done in the early evening hours, and good illumination of all roadways is a much appreciated improvement. If the cost of operating 2000 C. P. electric arc lights can be kept down to two cents per lamp per hour no serious complaint of the cost need be made, and if the number of lamps out does not exceed 2 per cent the maintenance is good. The electric light cables should be placed underground in permanent conduits, and suitable manholes should be provided for drawing in the cables. Socket sewer pipe is very often used for these conduits with success; they should be well reamed, however, so that there may not be too severe abrasion of the lead

sheath of the cables in drawing them in. The lamp should be of neat design, and none of the cables or wires should be exposed to view. The post should be of appropriate design with a substantial base.

If the circuits will permit of it, a desirable plan is to have the lights on the boulevard on two circuits, thus enabling one-half of the lights to be shut down at midnight, and one-half to continue all night, if desired; also in case of accident to either circuit or dynamo, one-half of the lights can be kept in service.

Desirable as are the large outlying parks of a city, the smaller parks and squares are also of great importance. They should be distributed throughout the densely populated districts, wherever the local conditions will permit, or land can be secured, for they serve as breathing places and as play-grounds for children.

The boulevard system is no less important to the welfare of a city's growth than is its park system, and its construction and maintenance forms a considerable part of the park engineer's duties.

For a single-drive boulevard the width should not be less than 100 feet, to provide for a drive of proper width as well as lawn spaces and sidewalks, although many city streets are reconstructed as boulevards whose width is only 66 to 80 feet. For a double-drive boulevard 200 to 250 feet in width allows an ample lawn space in the center for trees, shrubbery, or floral display if desired. A typical boulevard of this kind in Chicago is Drexel Boulevard, extending from Fifty-first street to Oakwood Boulevard. With a width of 200 to 250 feet, a three-drive boulevard may also be constructed by way of variation, but the lawn spaces must be considerably reduced, leaving them somewhat narrow for planting, other than line shade trees. This style of boulevard is illustrated by Grand Boulevard on the south side and Humboldt Boulevard on the west side, both of Chicago.

All telegraph and telephone poles and wires should be strictly excluded from the boulevards, and even at the street crossings they should cross the boulevard in conduits in preference to the network of wires overhead.

It is impossible within the scope of this paper to enter into the subject of pavements, concretes, and cements in detail. Volumes have been written on these subjects, and specifications

clearly set forth what must be done and what must not be done, and a study of existing pavements shows the defects or limitations of each kind.

When heavy traffic wagons are not permitted on the boulevards, the maintenance is rendered easier thereby, except at the intersecting cross streets.

The prime requisites of a boulevard drive are smoothness, cleanliness, noiselessness, safety, durability, moderate first cost as well as low cost of maintenance, and ease of repair.

The writer is inclined to the opinion that but two class of pavements for boulevards need consideration, and these are granite macadam and asphalt, although wooden blocks and limestone macadam are also used. The ordinary wooden blocks will show their weakness, whether they are used much or at not all, and their life is very limited, which is not true of a macadam drive, as this will last for years, especially with light travel, and repairs are easily made.

A good granite macadam roadway has the advantage of low first cost, noiselessness, ease of repair, and does not deteriorate with time alone, as does asphalt or blocks, and is not slippery. It, however, becomes muddy during an open winter and wet spring or fall months, and is dusty in summer unless kept well sprinkled, and its renewal is dependent largely on the amount of travel. It is not kept clean as easily as asphalt, nor will it stand heavy travel.

Asphalt pavements have the advantage in smoothness and cleanliness, as the street may be easily washed down with sprinkling carts, and will fairly well resist heavy travel. It is more noisy, however, than macadam or wooden blocks. It is frequently very slippery and should not be laid on grades steeper than about four per cent; repairs must usually be made by an asphalt company. The deterioration of the pavement due to time alone, aside from the consideration of travel is important, and the higher cost of replacing the top or wearing surface, as well as the higher first cost of the pavement, which is about two to two and one-half times the first cost of a granite macadam drive, must also be considered.

A granite macadam roadway may be constructed as follows: Upon a firm clay or sand soil, which has been properly shaped

and rolled, from 10 to 12 inches of two-inch crushed limestone is compacted, and the upper surface is bonded with $1\frac{1}{2}$ to 2 inches of bank gravel or limestone screenings. Upon this about 3 inches of one-inch crushed granite is placed and thoroughly bonded with the least amount of good bonding gravel, which will secure the smooth, hard, resisting surface desired; usually $1\frac{1}{2}$ inches in thickness is required. A thin coating of granite screenings is usually placed on top. Every layer of material should be well rolled with a heavy steam roller. One must look carefully to the quality of the bonding gravel; in order to secure good results it should not be too clayey, nor too sandy or stony, and when well wet it should form a hard surface after the steam roller has compacted it with the crushed granite. The frequent loosening of the crushed granite is a painful evidence of poor gravel, and spoils a roadway for bicyclists.

Asphalt pavements are usually laid on a concrete foundation 4 to 8 inches thick, but where a good, firm macadam roadway has been in service, asphalt may be laid directly on such a base, and only as much concrete used as may be required for leveling up, to secure good form. When a natural cement is used, specifications frequently require 8 inches of concrete and seldom less than 6 inches. When Portland cement is used 6 inches are commonly specified and seldom less than 4 inches in thickness are used, except as noted above. The mixture frequently used for natural cement is 1 part of cement, 2 parts of sand, 4 parts of crushed limestone; and for Portland cement, 1 part of cement, 3 parts of sand, 7 parts of crushed limestone, but these proportions are varied by different engineers and according to the particular material specified. After the concrete has set well, and when it will bear a heavy steam roller without breaking the bond, the binder course $1\frac{1}{2}$ inches in thickness is usually laid, consisting of limestone coated with asphaltic cement, and upon this the wearing surface of asphalt, 2 inches in thickness, is laid. Extremely cold weather causes perhaps the most rapid deterioration of asphalt surface. Numerous fine cracks first appear during severely cold weather, and when dirt once finds its way into these the fracture does not cement itself again. Along the gutter lines the asphalt disintegrates more rapidly than elsewhere, unless they are kept very clean and are well drained. In many places a combined curb and gutter

of granite concrete is used in connection with the pavement, and in some cities stone or vitrified paving blocks are laid for a width of from 3 to 4 feet for a gutter. For the sake of appearance it is preferable to have the asphalt pavement extend from curb line to curb line, and if funds will permit to have granite stone curbs for permanence. The laying of asphalt in the latitude of Chicago should be confined to the months included between May first and the following November first. Work is occasionally undertaken at other times, but the chances of obtaining a permanent pavement are decidedly reduced. Engineers are extending the period of guarantee on asphalt pavements to ten years.

For the construction of sidewalks and curbings on the boulevards the granite concretes have come into general use. The cheapness and general adaptability of concrete for these purposes is undeniable, and with good material and workmanship the work is enduring. Much poor and defective work of this class is scattered about, no doubt due to indifferent inspection of material and workmanship, or to faulty foundation. The use of combined curb and gutter is being largely replaced by the straight curb. This is particularly desirable on macadam drives, as moderate wear of the macadam soon drops the surface below the outer edge of the concrete gutter, and perfect drainage is not secured.

The correct and economical maintenance of a park and boulevard system requires vigilance, and prompt and efficient service. It also means that for every dollar once expended in improvements, a certain percentage of that cost must each year be expended in care taking. In a growing system this is a point occasionally overlooked, and with a fixed income new improvements may be hastened beyond the ability to properly maintain them.

NOTES ON LANDSCAPE GARDENING AS APPLIED TO
PUBLIC PARKS AND BOULEVARDS.

BY JAMES JENSEN.

The Landscape Gardener should be a careful student of the aesthetics of Nature and must be versed in history of architecture. Nature offers such a variety, that in following her teaching promiscuously imitation must be avoided, and it is necessary to choose carefully the effects most suitable for the environments they are to ornament. The maintaining of public gardens is quite different from that of private grounds, and however beautiful a wild border, "where the spade does not dig nor the scythe does not cut," may look in a private garden, it would soon become an unsightly spot where the public are at liberty to tramp without restraint.

A park is made picturesque by pastoral meadows, terminating in thickly wooded rising borders; mirror lakes, with marshy and hilly shores; rivulets and waterfalls, beautified by numerous aquatic and semi-aquatic plants; valleys, with wavy lines of trees and shrubs of varied foliage; water lily ponds, with a gorgeous array of flowers; the perennial garden, and the formal flower garden.

In natural plantations a judicious thinning out will in most instances be found necessary to admit light and air for the full development of the trees. In plantings of a wild character an undergrowth of shrubs and herbaceous perennials should be encouraged, the last named bordering the path or roadway. The old adage, "plant thick and thin quick," should rule supreme. This is the only way to obtain immediate effect, then, too, the trees will shade and protect one another, and through proper cultivation for the first few years, a quicker growth will be obtained; at the same time such a planting would become a nursery. But do not be afraid to remove trees that become overcrowded, either through the agency of the ax or by transplanting; otherwise, the whole plantation will be fit only for the woodpile.

Distinct lines between lawn and woodland should be maintained, if tameness in the landscape feature is to be avoided. Trees that are noted for their beautiful fall coloring, as for instance several varieties of the oak, sugar maple and swamp maple, should be planted on the border of the woodlands, and by adding clumps of shrubs and dwarf trees, noted for their flower and foliage effect, at the margin of these plantations, each group of planting will help to form a picturesque whole. For these margins we have wild plum, wild crab, the various thorns, sumacs, choke-berry, June-berry, wayfaring tree, button-bush, cornel, Indian current, and a host of others.

Scattered in pairs or singly, in close proximity to the woodland, specimen trees of various kinds will help to enliven the landscape. Here may be used advantageously the honey locust with its feathery foliage; the Norway maple and its varieties; the pin oak, changing in the fall into a brilliant red; several varieties of the elms, birches, thorns (especially the cockspur thorn), catalpas, and the, for this section, not over-hardy sweet gum (*Liquidambar styraciflua*), besides numerous others. On very large lawns or meadows, massing of shrubs in conformity with the woodland plantings will produce more picturesque outlines. Climbers, such as wild grape, bittersweet, woodbine, Dutchman's pipe, etc., running over tree stumps or climbing up the trunk of a tree will add wildness to the surroundings of ravines, rivulets and waterfalls. Their introduction into woodland plantations, forming natural arches over walks and driveways, is also desirable.

Bordering on the lake there is nothing grander than weeping willows, while on the marshy shore lines may be planted such varieties of the great willow family as through their bark coloring give attractiveness to the winter landscape, and mingled with tamarisks and red osier dogwood are in perfect harmony with cat tails, rushes and other aquatics at the water's edge. Quite a number of other trees are useful for shore planting, especially those kinds that love a moist situation, as the ash, alder, birch, sycamore and others. The aborescent species of our native thorns are likewise very valuable for shore planting.

On hilly grounds or as a background for long vistas nothing is more effective than evergreens, but unfortunately they do not thrive in all situations, especially where smoke and soot

poisons the air of the park, and then the planting of more vigorous varieties is advisable. Those that take most kindly to city life are the Scotch pine, white pine, white spruce, balsam spruce and blue spruce.

As to the park fence, a shrubbery belt, mixed with trees, and of undulating outlines will be beautiful as well as servicable, and equally attractive both from the park drive and the outside street.

For educational purposes, as well as for every lover of horticulture, a piece of land may be set aside for the cultivation of trees and shrubs, arranged botanically, and properly labeled with the common and scientific names. In connection with this a nursery and small experimental garden should be maintained.

Of late years the aquatic garden has become a new feature in park gardening, and it is quite surprising that this was left unnoticed by the earlier landscape gardeners. The aquatic garden proper, while not so much of a landscape feature in a broader sense, can become, by proper designing and planting, one of the most interesting and beautiful parts of the park. Three minor ponds, connected with one another, will be necessary if all kinds of aquatics are to be cultivated; one, which must be supplied with heat, for tropical waterlilies; and one for the lotuses, these last named being strong believers in the survival of the fittest. Among the lilies for the tropical lily pond are the *Victoria regia* and its varieties, *Nymphaea dentata*, *N. Devonieusis*, *N. rubra*, *N. Zauze barieusis*; of these a number of pretty hybrids have been introduced the last few years, there being the *N. gigantia*, *N. coerulea*, *N. Mexicana*, *N. gracilis* and others. In the hardy lily pond we have our native species, the *Nymphaea tuberosa* and *odorata*, which have produced numerous hybrids which in most instances are better than the types; but far more free blooming is the European waterlily, *Nympha alba*, and its varieties, to which belong the Marliacea strain, the product of the great aquatist, Mr. Marliac of France, and without question the most beautiful of the hardy kinds. Of the dwarf class *Nymphaea Laydeckerii* ranks first; other forms, like *N. pygmea*, are better adapted for shallow nooks or the rivulet where they are better seen. Of lotuses we have our native *Nelumbium luttia* and the Japanese and Egyptian varieties. To produce a natural aspect the shore lines of the lily ponds should be irregular and should be made the

home of semi-aquatic and aquatic vegetation, such as cat tails, bulrushes, spike rushes, arrowheads, mallows, irises and other inhabitants of our swamps and sloughs. Picturesqueness is added by having part of the shores (especially the northern) bordered by wood plantings, provided with strong undergrowth, and here and there a wild grape sending from the tree tops its long vines to the water's edge, its beautiful green foliage, in harmony with asters, flea bane, golden rod, shrubby cinquefoil and stately grasses, adding charm and color to the landscape. Subtropical plants, such as canna, caladiums, castor beans, pawpaws, banana trees, pampas grass and others would add splendor and character to the tropical pond.

At one end of the lily pond might be formed a meadow, with a rivulet flowing through it, which would be an ideal place for buttercups, wake robins, phloxes, lobelias, etc., while at the edge of the woodland, following the course of the rivulet, a home could be provided for native azaleas, rhododendrons, andromedas, kalmios, also cyripeds, orchis, sarracenias and other plants belonging to the bog garden.

Herbaceous perennials, which to a large extent formed the garden of our grandmothers' time, have again come into recognition, not because they are fashionable, but rather for their usefulness, which in their ignorance the gardeners for some time left unnoticed. They are just as necessary in park or garden making as a tree or shrub, and a landscape without them can be compared to a picture, on which the last touches of the artist had been left undone.

In public parks herbaceous perennials, with the exception of a few varieties, are more easily taken care of and will give better satisfaction in prepared beds, placed along the margins of woodland plantations. In these borders shrubs may be planted at intervals. Great discretion must be exercised in selecting and planting the herbaceous border, and a proper knowledge as to time of flowering, color of flowers and height of plants, is necessary to produce artistic effect. Monotony must be avoided and undulation in ground as well as sky lines is obtained by permitting plants of tall growth to be planted at intervals in the full width of the border, using smaller ones in intervening places. Plants of a bold nature and beautiful growth should always be

given a position where they can be seen to their full advantage. Bulbous plants, such as lilies, crocuses, narcissuses, snow drops, tulips, etc., have their home in the perennial border. Starting with snow drops in early spring, and finishing with the feathery plumes of the *Eulalia* and *Ravenna* grasses in late fall, the herbaceous garden should give a gorgeous array of flowers during the entire season.

Floriculture in our public parks, desirable as it may be, should not be attempted until the park has been finished and enough funds are on hand to carry it out successfully. Greenhouses as a rule have no architectural beauty, and their place in the landscape is out of question. For the convenience of the public, especially in the winter time, it is important that their location, if possible, should be in the neighborhood of a main car line, and for the welfare of the plants grown in them it is equally important and necessary to give them a place where there are no obstructions of any kind to the full passage of air and light. One often sees the dominating palm houses in the best situation, while the propagating houses, on the supply of which the flower garden depends, is given a secondary position, receiving only such light as their big neighbor graciously will permit. To avoid the formation of icicles the curvilinear designs for greenhouse construction have been found the best.

For the sake of convenience the flower garden should be located near the greenhouses. The proper place would be in front of the palmhouse, which, by judicious planting of trees, has been partly hidden from the main view of the garden. Symmetry in the design of the garden is necessary, and such ornaments as fountains and statuary of minor size are desirable, also the introduction of pyramidal and globular shaped trees and shrubs. Let us once for all plant the flowers of the greenhouses, the product of skilled floriculturists, where they properly belong and not destroy the beautiful natural park scenery by monstrosities of so-called flower designs. Such designs are to be tolerated only in the garden, in which the beauty of different colored flowers, or the harmonious combinations of colors in foliage are employed. Fantastic designs are in bad taste, and defeat artistic effect. Suitable terraces may be encouraged, providing a better view of the whole garden, and permitting the palm house to be raised to a higher, and for heating purposes, a more favorable situation.

Broad promenades, lined by low-growing trees and furnished with settees should, if space is available, border the two sides of the garden, back of which at a proper distance and at the margin of tree plantations, could be located perennials, out-door fernery and rockery with Alpine plants.

A special feature of the flower garden should be the rose garden, but on account of the short flowering season of many roses, it would be desirable to locate it in a separate place, surrounded by such plantings as would permit plenty of sunlight. Beds of narrow design are necessary, in order to allow the viewing of roses at short range. The climbing varieties may be used for hedges and arbors or trained into pyramids, or other not too fantastic shapes. Dwarf forms, such as the new introductions from Japan, form pretty borders along the walks.

Boulevard planting will vary according to the amount of lawn space provided for, and here the landscape gardener or arboriculturist meets with problems of the most serious character. This is especially so in large cities or manufacturing towns where the air is polluted with poisonous gases, and where a narrow lawn space, often of objectionable soil, must provide nourishment for the trees, besides which an asphalt street pavement and cement sidewalks make natural watering almost impossible. To this must be added the deadly attacks of numerous insects that are encouraged in their work of destruction by the weakness of the only half-fed trees. Plenty of good soil, sufficient water and the selection of robust and vigorous trees is the only remedy.

On account of its robustness, quick growth and stately form, the American elm (*Ulmus Americana*) has been largely used for street planting, but in crowded streets and manufacturing districts its usefulness is out of question, and here the cottonwood (*Populus deltoidu*, Marsh) under the name of Carolina poplar, has been used of late years. No doubt it answers the purpose, and if provision is made to plant new trees every fifteen or twenty years, and only the male species is selected, it is by no means a bad looking tree. Nevertheless if permitted to remain until old it is as bad as the willow (*salix alba*). The Norway maple is a pretty and healthy tree, surviving under very unfavorable circumstances, but of rather too slow growth to satisfy this rapid age. The tree of heaven (*ailanthus glandulosus*) will stand the worst kind of treatment but suckers badly, and the female species becomes

obnoxious on account of its ill-smelling flowers. In small cities or on boulevards skirting the city, sycamores and lindens will make grand stout trees, and a little further south than Chicago the maidenhair tree (*Ginkgo biloba*) and the tulip tree (*Leriodendron tulipifera*) will be useful for this purpose.

On broad boulevards, where plenty of lawn space has been provided, the introduction of shrubbery and in some instances flower beds outside of the straight lines of shade trees, may add considerable to the beautifying of these boulevards, and for long stretches of boulevards interspersed by paths it is desirable to change the character of each part as much as possible. Thus one part may be lined with shade trees only, and if there is more than one drive, a selection of different trees in harmony with one another would be effective. Shrubs in irregular groups, especially at the intersections of streets, and of different varieties, with an occasional weeping tree at intervals may be introduced in the next section; and again, irregular planting of trees and shrubs with winding walks, if space is sufficiently large, may be used. Flower beds, although not entirely out of place in boulevard planting, will add considerable to the maintaining expense, and if planted at all should only be used as an addition to the whole.

Small squares are often designed in connection with the boulevard system, and especially when a boulevard turns in another direction. Here shrubbery planting, symmetrical flower beds, fountains and monuments should dominate, and would thus furnish a pleasant change to the otherwise rather monotonous boulevard design.

The same kind of planting should be used in small city parks or squares, and there are undoubtedly the proper places for monuments and ornamental fountains, surrounded by flowers, shrubs and trees, in perfect harmony with the architectural design of the buildings adjacent to the park.

In the poorer districts playgrounds for children, under shady trees, should be provided, but some part of the square and especially that part bordering the surrounding streets must be kept in the best of order and planted with shrubs and flowers for the enlightenment and joy of those who visit these parks, teaching them a lesson whose influences can not be overestimated, for it is truly said that those who love flowers can never be wholly bad.

LANDSCAPE GARDENING—PAST AND PRESENT.

BY JOSEPH CULLEN BLAIR, ASSISTANT PROFESSOR OF HORTICULTURE.

“Landscape gardening” is a term no older than the 18th century, at which time it was coined in an effort to show the struggling away from *formal* toward *naturelike* effects in gardening. This striving after naturalistic effects is still the trend of the landscape art, and in many instances the picture has been so skillfully painted with nature’s own materials that the human artist agency is forgotten or overlooked. There is surely no other art in which nature works hand in hand with the artist, helping him where he is powerless, yielding to him where he is master. Nature gives the material, man furnishes the conception of the picture, and nature again comes in to give the finishing touches in velvety greensward, luxuriant foliage, and brilliant bloom. And this work of art has been planned and executed—why? To render the exterior surroundings as pleasing and harmonious as the interior of the house; to make of the public park a place which will be no less attractive to wealthy frequenters than their own grounds; better still, to give to the poor their only opportunity to revel in delights like those of the rural scenes which they can never visit; and not least of all, to make of “God’s acre” a restful, reposeful picture such as is the Graceland Cemetery of Chicago.

We are apt to think of ornamental gardening as of no earlier date than that which witnessed the geometric formalities surrounding the Italian villas of the Cæsars. We read of the fairy-like beauty of the pond of Agrippa surrounded by its groups of palms, its lotus groves and bowers of roses, its fountains flowing with perfumed water, its statues of gods and goddesses, and its silver cages filled with brilliant birds. Yet centuries before this garden had reached its voluptuous perfection, centuries before Nero had lighted his own garden with human torches made of Christian martyrs, Persian monarchs were revelling in their parks and Chinese mandarins wandered through pleasure grounds as

beautiful as the English landscape gardens. From centuries back comes the advice of a Chinese writer, Lieu Tschieu, which we of today may well heed. He says: "The art of laying out gardens consists in combining cheerfulness of prospect, luxuriance of growth, shade, retirement and repose. Variety, which is one chief merit in the natural landscape, must be sought by the choice of ground, with alternation of hill and dale, flowing streams and lakes covered with aquatic plants. Symmetry is wearisome, and a garden where everything betrays constraint and art becomes tedious and distasteful." What better criticism could we find of the Continental ideal, what more appreciative praise of the English system?

The Italian gardens, which, ever since their creation, have served as models of formalism in ornamental gardening, came into existence during the 15th century. In the days of the Renaissance the architect of the house also planned the gardens, and there is a resultant architectural stiffness, as well as a greater harmony between the house and grounds that would otherwise probably have been wanting. The gardens, terraces and groves were designed as were the apartments of the house. Unfortunately nearly all the gardens are now desolated or too much altered by later styles to be easily traced as they originally were, but there are a few in comparative preservation, the best being the Villa Lante at Bagnia. This garden covers an acre of ground, but by far the greater part is occupied by a most ornate fountain consisting of a group of bronze figures surrounded by four large basins which catch the falling water. This garden is partially enclosed by a high hedge and the orangerie, but the southern side lies exposed and looks out over the broad campagna. The paths through the parterre are outlined by low hedges, and orange trees in pots mark the corners. Stone staircases connect the garden with the terraces leading to the house; and surmounting all lies the grove, in which are hidden the reservoir and two beautiful pavilions.

The largest villa in Rome is the Borghese, but little remains of the original design, although in its prime it was aglow with flowers. In some of the other villas, too numerous to mention, and after all only empty names to one who has not wandered through them, the architecture, the cold design itself, is too much

in evidence because of the scanty planting. Some one has said that they look like flower gardens with the flowers left out. In gardens sunken as were those of Italy, close planting is necessary, or too much of the skeleton can be seen by the observer. None of the gardens contained the varieties it would be possible to grow there now. Their trees were all of one character—the box and kindred types—and but few plants decorated the formally designed beds, although roses and violets were in high favor in all the gardens. As the Italians of the Renaissance used many of the ideas of the ancient Romans, so the gardeners of France copied the splendors of the fifteenth century Italian, until their efforts resulted in the glories of the Tuilleries and the Luxembourg and the milder beauties of the Elizabethan gardens of England. But the Italian gardens are responsible for something besides the magnificent reproductions which were made of them, for it is hard to imitate without exaggerating. In the garden of Marshal de Biron at Paris, which contained only fourteen acres, every walk was buttoned by flower pots, there being not less than 9000. More deplorable still, travelers have returned from there to erect on their own estates, stone jack-rabbits and various other representations of the animal kingdom, hideous rustic summer houses and huge plaster of Paris vases, with nothing in them unless it be perchance a sickly geranium or an abnormally clinging vine. Such monstrosities as these are responsible for the fleeing of sane minds towards the freedom of the modern English landscape garden.

“The Italian gardens, however splendid,” says Downing, “fall as far below the English gardens in interesting the imagination as a level plain does below the finest mountain valley in Switzerland.” An English garden is nature refined by art; the continental or Italian garden is art itself scarcely animated by life and nature. The English garden is nature idealized; the continental garden is art realized, symmetry and geometric designs casting a lifeless chill over the whole. Humboldt accounts for this distinction in gardening tastes in the fact that northern nations are more aglow with a love of nature than are southern peoples, and that although the Greeks and Romans were endowed with artistic tendencies, yet they had not a great appreciation of the beauties of nature.

It has been but a short time since landscape gardening has been granted its rightful place among the arts, and indeed it has only seemed worthy of that distinction since the days when it forsook its idols of formalism. Even now it is in its infancy as compared with sculpture and painting, both of which have had the advantage of several centuries the start of landscape gardening, which is scarcely more than a centenarian.

The era of landscape painting which was ushered in by the Reformation, was destined to be probably the first counter-influence against formal gardening. Yet of these first landscape painters, Ruskin says: "They had neither love of nature nor feeling of her beauty; they looked for her coldest and most commonplace effects, because they were the easiest to imitate; and for her most vulgar forms because they were the most easily to be recognized by the untaught eyes of those whom alone they could hope to please." They lacked that love for nature which would have taught them the secret of her charms and how to copy them. Yet they served their purpose, for poets, seeing their work, were turned natureward with more potent effect, and we find Addison and Pope putting in a plea for nature and a more natural style of gardening.

In 1718 Alexander Pope leased a house surrounded by five acres of ground on the banks of the Thames. He spent much time, thought and money on the improvement of this little estate, which was doubtless the inspiration of his ideas on the adornment of a garden. Somewhere he expresses his opinion of the then prevalent practice of formal gardening in these words: "We seem to make it our study to recede from nature, not only in the various tonsure of greens into the most regular and formal shapes, but even in monstrous attempts beyond the reach of art itself, and are better pleased to have our trees in the most awkward figure of men and animals than in the most regular of their own." In most sarcastic vein he goes on to describe the probably exaggerated case of a gardener so skilled that he could carve in trees "whole family groups of men, women and children. Women may have their own effigies in myrtle, or their husbands in hornbeam." He then quotes from this man's catalogue: "Adam and Eve in yew, Adam a little shattered by the fall of the tree of knowledge in a great storm, Eve and the serpent very flourishing." "St.

George in box; his arms scarce long enough, but will be in condition to stick the dragon by next April. A green dragon of the same, with a tail of ground ivy for the present."

Some years before this Joseph Addison had said in the "Spectator": "Our British gardeners, instead of humoring nature, love to deviate from it as much as possible. Our trees rise in cones, globes and pyramids. We see the mark of the scissors upon every plant and bush. I do not know whether I am singular in my opinion, but, for my own part, I would rather look upon a tree in all its luxuriance and diffusion of boughs and branches, than when it is thus cut and trimmed into a mathematical figure; and cannot but fancy that an orchard in flower looks infinitely more delightful, than all the little labyrinths of the most finished parterre."

There may of course be instances where the formal style, if carried out in sufficient proportions, reaches a certain sublimity. For example, a formal garden covering 200 acres and filled with the bold designs of Andre Le Notre, who lived 1614-1700, and designed the French gardens at Versailles and the Tuilleries, could easily become magnificent and might even attain a landscape effect, when characterized by avenues of trees radiating from the centre and crossed by terraces and canals. It will be readily seen then that the formal style is not adapted to small estates, such as are found in America, unless the surroundings are of such severe architectural lines that the natural style would seem incongruous and out of harmony.

America has not been blessed with many landscape gardeners of first rank, but there are several names which will live long in the memories of her citizens. Perhaps the earliest of note whom it is worth while to consider in a paper which makes no pretense to fullness, is A. J. Downing, who combined a poet's eye with a philosopher's mind; and who before his twentieth year had formulated theories of art in landscape gardening. He was born in 1815 and died in 1852, so that the years of his usefulness to the world were few. His earliest years were spent as the junior partner in his brother's nursery. When twenty-three he dissolved this relation in order to devote himself more fully to his favorite art of landscape gardening. In 1841 he published "A Treatise on the Theory and Practice of Landscape Gardening Adapted to

North America." This book became popular at once because it told thousands how to beautify their homes, and told them in a manner that betrayed the exquisite polish of the author's mind. The following year he published a volume on "Cottage Residences." Europe, as well as his home land, honored him, and well might both countries do so, for under his gentle but potent influence there came a gradual improvement of national rural taste. In 1851 he was invited by the President of the United States to design the public grounds about the capitol, White House and Smithsonian Institute. The design for this and part of the work was all that was completed before his untimely and tragic death by drowning in the Hudson. By his influence both on the public and private grounds of the States, he paved the way for his successors, of whom Fredrick Lant Olmsted is probably the best known, although Professor L. H. Bailey, of Cornell University, has done much by his writings and lectures to further the cause of garden making, and to aid those owners of private grounds who cannot employ a landscape artist and yet desire to improve their estates.

Not many landscape gardeners are given the opportunity to achieve results on so large a scale as Olmsted. By his skill and that of Calvert Vaux, Central Park in New York City was created out of material which would have been the despair of a man less sanguine of success than he. Never doubting that he would succeed, he went to work on his designs, and out of the rocky tongue of land, stretched out from Fifty-ninth to One Hundred and Tenth street, were constructed the magnificent drives, wooded bluffs and stretches of velvety lawn. Begun in 1857, and gradually improved from year to year, it is now the garden spot of the continent. Yet this artist-gardener's greatest work was yet to be done, and when the gates of the Columbian Exposition were thrown open the public realized that at last Olmsted had beaten his own record. The landscape effect of the Chicago World's Fair grounds will last long in the memory of her visitors before it will be effaced by another scene excelling or even equaling it. Only he could realize the vastness of the undertaking who had seen the desolate acres before their transformation. Lagoons were created out of mud holes, a wooded island in the midst of what may have been a frog pond, while terraced avenues everywhere took the place of dismal swamps.

To triumph over such natural obstacles as these is not often permitted to even the greatest of landscape gardeners, but results of a like character are always possible to him with the soul of an artist and a mind capable of executing that soul's demands. The landscape garden of today should be a picture in which the attention is directed to a central object, as, for instance, the house, and not to meaningless individual plants, bold statuary or formal flowerbeds, which should have no place in the scheme. It is this care for and attention to the effect that the planting shall produce both individually and in combination with its surroundings, which makes of landscape gardening the art of all arts, where nature takes the artist's hand and teaches him where to find her treasured beauty, and then gives him somewhere the material with which to create a picture as fair as her own, and yet original with himself.

THE MACHINERY OF AN OFFICE BUILDING.

BY FRED. J. THIELBAR, FORMERLY WITH CLASS OF '93.

In discussing, within the limits of a short magazine article, a subject involving such a variety of detail and such a multitude of mechanical devices as does "The Machinery of an Office Building," the object will be to give information which may be of interest to the architect who for the first time is confronted with the problem of designing an office or commercial building, and to give details only of items about which little information has been published. The purposes for which machinery is required are in general as follows: Heating and ventilating; elevator service; electric lighting; hot and cold water supply; surface water and basement sewage disposal.

The system of piping for heating is what is known as the overhead system; a main steam riser is carried directly to the top of the building and distributing mains run from that point; risers are returned through the building, the radiating surface being supplied by the down-flowing current of steam, and the condensation is returned by a system of mains in the basement. Exhaust

steam is always utilized for heating, supplemented by live steam reduced by passing through a reducing valve. In some of the recent smaller buildings, the boilers are used for heating only, electric machinery being used throughout, and the power is supplied from the street electric main.

But little has been attempted in the line of special ventilation. The *Engineering Record* of September 3, 1898, gives a description of a method of indirect heating and ventilation recently installed in a New York building, which is an adaptation of a system used somewhat in Chicago but on a smaller scale, for restaurants and saloons, where a fan driven by an electric motor, is used for exhausting the air. The objection to any special ventilating system in an office building is that tenants are continually moving in and out, and each new tenant requires changes in partitions to suit his own particular needs. To make the changes in a ventilating system to conform to such changes in layouts, would be a complicated matter and a source of expense beyond the actual benefits to be derived. In most buildings, ventilators are provided over the elevator hatchways which act as flues, creating a constant draft of air from the offices through the corridors, and in buildings planned in this manner for general office purposes there is little if any complaint of impure air.

Various forms of hydraulic, electric and steam elevators are in common use, but in the better class of office buildings hydraulic machines are used exclusively. The old type known as the "gravity elevator," which consisted of a cylinder, either vertical or horizontal, a pump and discharge tank in the basement, and an open tank on the roof, has almost disappeared. The water pressure applied to the piston caused it to travel through the length of the cylinder, drawing on the cables which raise the car; to make the down trip, the weight of the car instead of the water pressure caused the piston to travel back to its original position, the height of the cylinder depending on the height of the building and the gearing. The system in use at present is essentially the same except that a closed tank containing air is substituted for the open tank, the operating pressure being on an average 125 pounds per square inch, although in what is known as high-pressure machines, a 750 pound pressure is used. Recently the so-called plunger machine has been used to some extent, the

height of the cylinder being half the rise of the building, and consequently the gear is two to one; in this machine the load is lifted by the weight of the plunger and the water pressure lifts the plunger as the load descends. Electric elevators are used in the smaller office buildings and in commercial and apartment buildings, and have an advantage over all others in their economy of power. The amount of power consumed by a hydraulic or steam machine for each trip of the car remains constant, irrespective of the load raised, whereas in an electric machine the amount of power consumed is proportional to the load. Another strong point is that where the current can be supplied by a central plant, it is not necessary to have a power plant in the building, and in some instances this feature is a decided advantage. There is a constantly increasing demand for this style of elevator, and it is being gradually improved but it has not reached the state of perfection of the hydraulic machine in points of service, speed, smoothness of running qualities, and control.

In most instances light is furnished by a lighting company, for as a rule agents think that it is a source of more annoyance than profit to furnish electric light directly to tenants, so it eventually resolves itself into the owner furnishing light free of cost. Lighting plants are more common in commercial buildings, especially where one tenant or small number of tenants occupy the building, and here items of economy enter which vary with individual cases.

A duplex pump, controlled automatically, supplies a house tank on the roof from which water supply lines are taken to the different plumbing stacks; one line is taken directly to the basement to supply the hot water tank, which may be either an ordinary tank suspended from the ceiling or supported from the floor, with brass heating coils inside, or a feed water heater of the Berryman type, the latter being the more satisfactory under all conditions. A heat regulating device is also essential. In buildings supplied with electric power, electric pumps are used, usually of the rotary or triplex type.

It usually happens that the city sewer is above the level of the basement floor, consequently an ejector must be provided to dispose of surface water and basement sewage. The Shone ejector is used extensively, and centrifugal pumps are also applied for

this purpose. Sometimes the basement toilet rooms can all be arranged under the sidewalk, the floor level being perhaps a foot above the general floor level; if possible this arrangement is preferable, as it simplifies matters and eliminates one source of care and expense. In this case surface water only needs to be disposed of, and for this purpose a steam syphon, a special pump known as a bilge pump or an electric pump, may be used, the latter in buildings where electricity is the only power. Fig. 1 shows "the

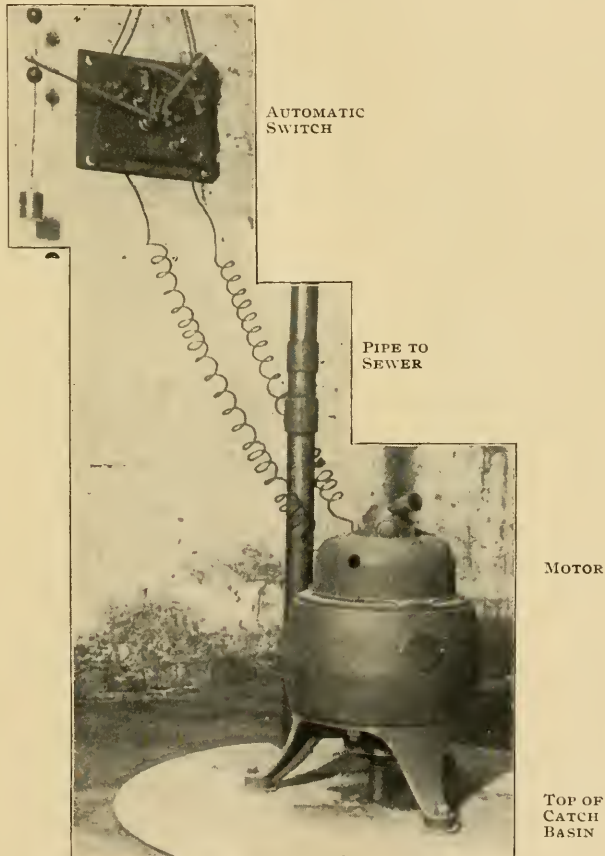


FIG. 1.

Ideal" electric centrifugal pump, the first one having been constructed from the specifications of the writer. It is controlled

automatically, and has the advantage of possessing no valves or mechanical parts to get out of order. Another device employed for this purpose and constructed on the principle of the Shone ejector, is constructed as follows: A closed tank, six feet in depth by four feet in diameter, capable of withstanding pressure, is placed in a basin below the floor level and is provided near its top with inlets from the drainage system and blow-off basins; the inlets are provided with back pressure valves. To another opening is connected a discharge to the overhead sewer. A float in the tank is connected to an air pump, and when the water in the tank raises the float to a certain level, the pump starts automatically and the pressure forces the contents of the tank through the discharge into the sewer. Many engineers prefer to use the ordinary steam syphon. The architect on beginning the layout for the engine room usually finds, in his endeavor to keep as much space for renting purposes as possible, that he has an exceedingly small space left into which he is obliged to arrange the different parts. Structural conditions and facilities for handling coal will fix the exact location of the boilers. Nine feet is the ordinary basement height, and the height necessary for the setting of the furnaces and boilers with the necessary connections is not less than eleven feet. In order to overcome this difficulty the space between two lines of footings is selected, which is excavated to a sufficient depth for the furnace setting and the pit in front of the boilers. The boiler fronts are placed so as to be convenient to the coal room, the coal room if possible being located underneath the alley. The pit should be wide enough so that the fireman can handle coal and cinders without difficulty. Care must be taken to provide an adequate drainage system, as surface water is always a source of annoyance to the fireman. Ventilation is an important item to consider in boiler room design, a sufficient air supply being essential for satisfactory results from the furnaces. Figure 2 shows the method of admitting air through bulkheads at the floor line overhead. It is preferable to have the coal room cut off from the boiler room so that the coal dust can be confined. Cinders are disposed of in numerous ways; if a freight lift is conveniently situated, they are taken up from the basement in an iron car by this route; a special hydraulic, steam, or electric lift may be used, and in some instances a revol-

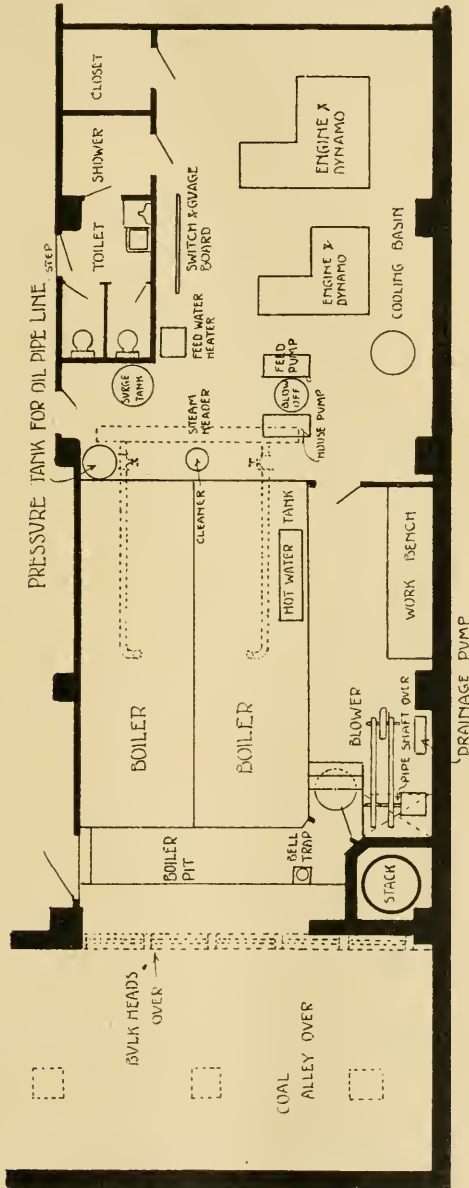


FIG. 2.

ing arrangement similar to a grain elevator is employed. The smoke stack is located where it interferes as little as possible with the general floor arrangement. In Figure 2, it happens to be close to the boilers, but in some instances it is a considerable distance away, in which case if possible, it is best to run the breeching underneath the floor in order to keep the ceiling clear. The air space around the stack can be utilized for ventilating purposes. Figure 2, selected as a typical rather than an ideal example, shows the arrangement of the layout of a commercial building recently completed; the piping is omitted in order to avoid confusion. The elevators, which are operated by steam, are not shown. The plant consists of two horizontal tubular boilers sixty inches in diameter and eighteen feet long; Gadey smokeless furnace setting; blower with number four steam engine; two 6×4×6-in. brass fitted Worthington duplex pumps, one for house service and one for boiler feed, both cross-connected so that either may be used at pleasure for either purpose; one 250 horse power Webster heater and receiving tank; one 24-in.×24-in. surge tank; one 60-gallon oil pressure tank with pipe lines taken from its top to the lubricators, city water pressure being connected to the bottom; one hot water tank eight feet long and twenty-four inches in diameter; one 1200 gallon house tank on roof; two horizontal automatic cut-off center crank high speed engines, Ide manufacture, one with 12-in.×12-in. cylinders and one with 8-in.×10-in. cylinders.

The pipe shaft indicated is continuous from top to bottom and has but one opening in its whole height, and this is at the ceiling of the middle story. A pipe shaft acts as a flue and should be designed to confine a fire in order to prevent its spread. The following pipes are provided for: One 8-in. exhaust; one 3-in. vapor pipe; one 9-in. steam riser; one 2-in. pump discharge to house tank; one 6-in. soil pipe; one 4-in. vent pipe; one 2-in. safe waste; one 1½-in. hot water riser, and one 1-in. circulation pipe; one 1-in. cold water supply; one 1-in. supply to hot water tank; two 2-in. gas risers. Electric cables should not be placed in the pipe shaft. It is best to provide a separate shaft for this purpose with the floor space filled in closely around the wires at all floors, and a closet for meters and cutouts at each floor, located in the public corridor.

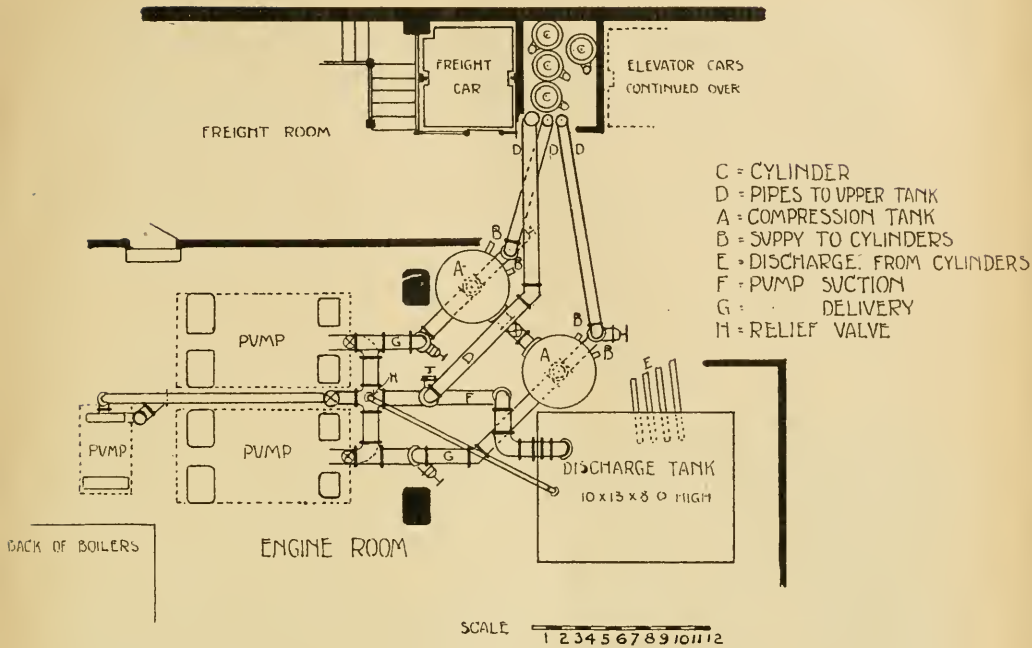


FIG. 3

The elevator layout shown in Fig. 3 is a typical one and illustrates what can be done in a small space; the elevator discharge and elevator supply pipes are broken off in the illustration in order to avoid confusion. The piping is run either close to the ceiling or underneath the floor, in which case brick troughing with movable cast iron covering is provided. In addition to the parts shown, two pressure tanks each six feet in diameter and eighteen feet long are placed in the attic. The plant operates four cars, and the piping is so arranged that any or all three pumps may be used directly, or so that any one cylinder or either one of the two sections may be cut off and in addition the small pump may be cut off and the pressure applied directly to the freight elevator cylinder. The compression tanks from which the supplies to the cylinder are taken and which contain air, serve as cushions to prevent jarring in the pipes and also to promote distribution. * The pumping plant consists of two compound pumps each 16 x 24 x 14 x 18-in., and one duplex

16×8½×10-in. of Blake manufacture. Two Westinghouse air pumps are provided for pumping against 150 pounds water pressure. Pressure regulating devices maintain a definite level of water in the upper tank at all times and maintain a definite pressure. Each car has a lifting capacity of 3 000 pounds with 125 pounds pressure in the basement, and a speed of 400 feet per minute with a load of 1 500 pounds and 100 feet per minute with a maximum load. Although this system was constructed in 1894 it probably can be improved only in minor details. High duty pumps would operate more economically.

The elevator car must be designed with the idea of reducing jostling and crowding to a minimum, "A," Fig. 4, should be avoided, the depth being large in proportion to the width makes it necessary for a passenger in the rear to force his way through a number of passengers in front of him who are unable to get out of his way, "B" is an improvement and "C" is an additional step in advance as it provides crowding space near the door without

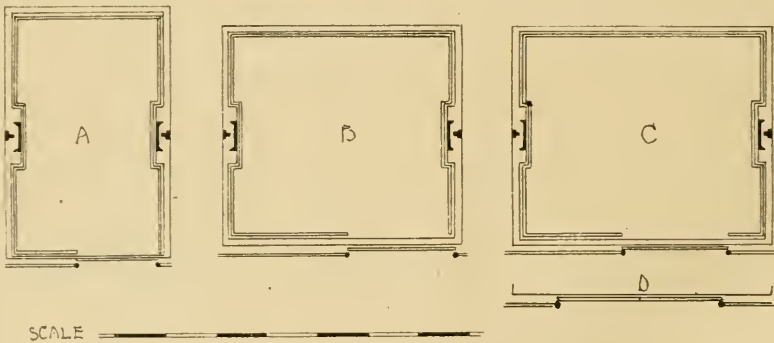


FIG. 4

interfering with the operator; the operator is also out of the way of the crowding. In "D" the doors are operated by compressed air, it being only necessary for the man in charge of the car to push a button in the floor of the car when it reaches the corridor floor level. The advantage of this scheme is that the entire front can be opened up. No definite rules can be given for determining the number of cars as so much depends on the location of the building and the particular profession* or business for which it may be intended, and it is to a great extent a matter of judgment.

In preparing layouts for buildings in which electric power is supplied from the street mains the same general rules apply. The piping for steam heating is similar except that the condensation is returned directly to the boilers. The electric elevators necessarily are placed underneath the hatchways. Instead of using an ordinary tank for heating water for the hot water supply, it is best to provide a heater of the Berryman type as it is more satisfactory with low pressure steam, especially if large quantities of water are consumed. It is also necessary to connect to this tank a heater of the Wilks or Tabasco type for use when there is no steam on the boilers. The electric pumps, one for house service and one for drainage, should be placed in a room free

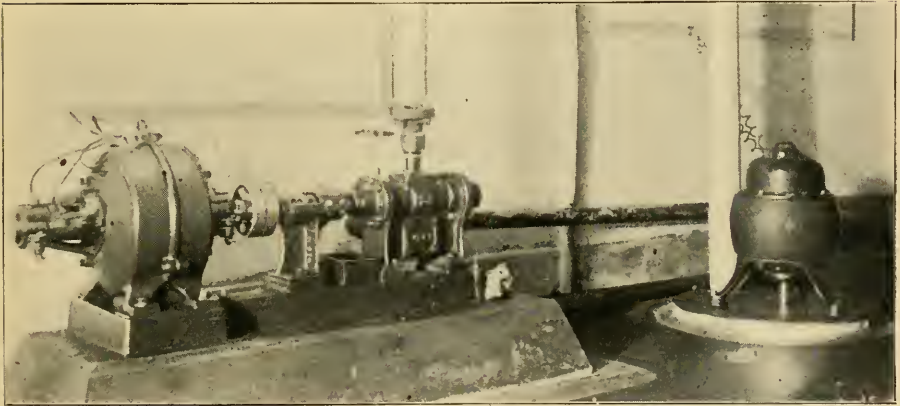


FIG. 5

from dust and in a location convenient for the engineer. Figure 5 shows the pumping plant of the Williams building, a recently completed commercial building of Chicago, consisting of a Quimby screw pump with a two horse power motor and a capacity of 1 200 gallons per hour for a height of 150 feet, and an "Ideal" sewer pump with a one horse power motor and a capacity of sixty gallons per minute. The Quimby pump has suction from a 3-ft. \times 3-ft. surge tank and discharges through a 2-in. pipe which runs up exposed through the center of the building and is connected to the bottom of the house tank, which has a capacity of

2 000 gallons. On each floor there is a hose connection on the pump discharge, controlled by a valve, and fifty feet of hose on a reel. As the building is thoroughly fire proof this arrangement can be made effective in an incipient fire.

In preparing the specifications, service, cost of maintenance and simplicity are the tests to apply to everything. The best plant is the one which gives the best service with the least expenditure for fuel, repairs and attention; if the same results can be obtained without the use of a particular device it had better be dispensed with. As a rule it is best to beware of materials or appliances which have not demonstrated their superiority by practical tests, no matter how feasible a scheme may appear from a model or drawing. Enthusiastic inventors and eloquent representatives never fail in an argument, but the man who permits the other fellow to do the experimenting will enjoy the most peace of mind and better please his client.

HOLDING POWER OF ANCHOR BOLTS.

BY M. M. WILLCOX, CIVIL ENGINEERING, '99.

In connection with thesis work, experiments were made upon the holding power of bolts fastened with cement, lead and sulphur. Holes $1\frac{1}{4}$ to $1\frac{5}{8}$ inches in diameter were drilled in hard limestone blocks about 6 inches thick. About one half the rods were 1 inch, and one half $\frac{3}{4}$ -inch in diameter. Smooth, threaded and notched rods were used. The threaded rods had either eight or ten threads to the inch, the two giving in all cases substantially the same results. The indentations in the notched rods were made by pressing the rod against the rounded corner of an emery wheel. The notches were two to three sixteenths of an inch deep and about five eighths of an inch in diameter.

The smooth and notched rods always drew out of the cement-

ing material. The threaded bolts sometimes pulled out of the lead, and sometimes pulled the lead out of the hole; and always pulled out of the cement and sulphur.

A good Portland cement was mixed to a thick grout or plastic mortar and rammed around the rods. The amount of water varied from 25 to 38 per cent and apparently the resistance was independent of the amount of water in the grout. After standing seven days the mean of twelve experiments with smooth rods was 106 pounds per square inch of surface of contact of the rod. Three experiments with notched rods gave a mean result after seven days of 336 pounds per square inch. Two threaded rods gave 585 pounds per square inch at seven days; and two gave 832 pounds per square inch at the end of 14 days.

With lead, four smooth rods gave 167 pounds per square inch, one notched rod 460, and six threaded rods 903 pounds.

The sulphur with threaded rods gave a resistance of 1502 pounds per square inch—a mean of seven experiments. One notched rod gave 328, and one smooth rod 200 pounds per square inch.

The above experiments differ considerably from other experiments. For example, two experiments by Mr. Robert Moore* with a smooth bolt and a threaded bolt in Harris Portland cement, after 10 days gave over 900 pounds per square inch for the smooth rod. The threaded one held a trifle less. In both cases the stones broke before the rods drew out. The writer could get only 106 pounds per square inch. It was thought that this difference was due to the fact that possibly the cement used by Mr. Moore expanded in setting. Several cements were tested in an attempt to find one that would expand in setting, but none were found which did not contract when stiff grout was rammed into a test tube.

In a series of experiments Mr. C. F. Miner† found a resistance with sulphur and threaded bolts of only about 900 pounds per square inch—about 60 per cent of those obtained by the writer—and substantially the same results with lead as obtained by the writer.

An experimenter, signing himself A. A. S.,‡ with cement at two weeks found a resistance of between 400 and 500 pounds per

**Engineering Record*, Vol. xxiii, p. 209.

†*Engineering Record*, Vol. xxvi, p. 43.

‡*Engineering News*, Vol. xxiv, p. 53.

square inch—with but little difference between threaded and smooth bolts. These results are, for smooth bolts, about five times as much as those obtained by the writer, and for threaded not quite as great.

In a very extensive series of experiments at the St. Mary's Fall Canal, under the direction of Mr. E. S. Wheeler,* rods set one month in a mortar composed of one part Portland cement and two parts limestone screenings gave about 500 pounds per square inch. Smooth rods set one month in neat cement mortar gave a resistance of about 300 pounds per square inch. The time these rods set is so much greater than that used by the writer that no comparison can fairly be made.

The writer made these experiments as carefully as he could, and submits the results as indicating the results that may possibly occur with equal care. He greatly regrets that time does not permit him to repeat and extend the experiments.

DYNAMOMETER CAR.

BY W. W. WEBSTER, '99 AND H. M. ELY, '99.

The Mechanical Department of the University of Illinois recently equipped a dynamometer car, built for the purpose by the Peoria and Eastern division of the C., C., C. & St. L. R. R. at their shop at Urbana, Ill. The equipment was designed and installed under the direction of Professor Breckenridge and Assistant Professor Van Dervoort.

This car was designed with the following objects in view: 1, To secure greater convenience in making locomotive road tests; 2, To provide an automatic apparatus for recording the pull at the draw-bar of the tender; 3, To permit the inspection of track for gage, alinement, surface, joints and elevation of curves; 4, To

*REPORT OF CHIEF OF ENGINEERS, U. S. A., 1895. D. 2917-2940.

determine train resistance; 5, To test the operation of air brakes in service; 6, To test stationary plants. For this purpose a caboose was rebuilt, being mounted on four-wheeled passenger-car trucks, equipped with M. C. B. couplers and Westinghouse air

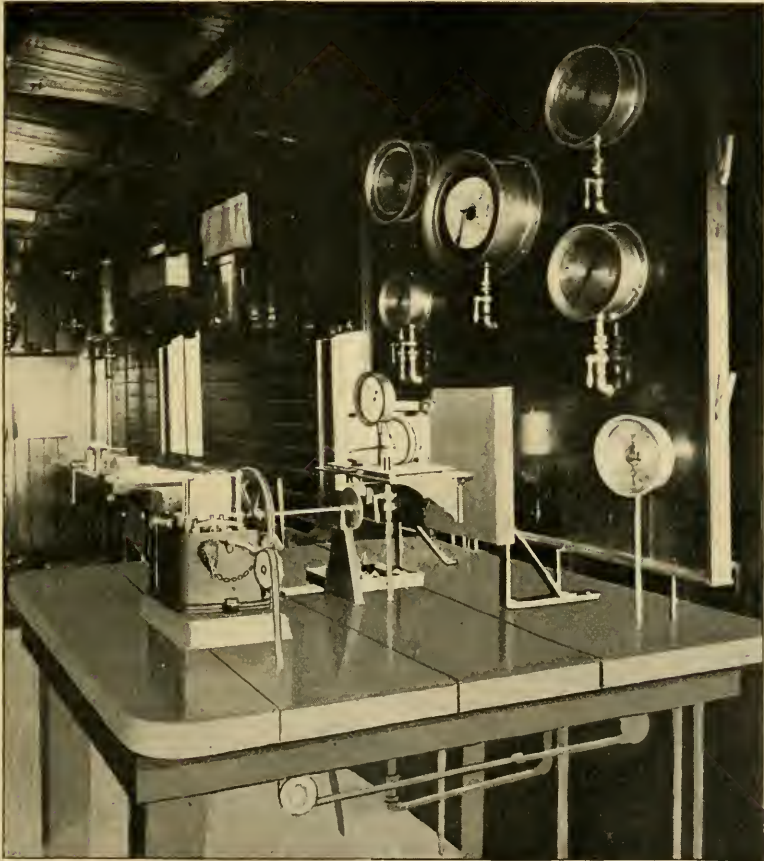


FIG. 1. INTERIOR VIEW OF CAR.

brakes. The car is thirty-six feet long and weighs about thirty-six thousand pounds.

The speed of the train during a test is recorded by a Boyer speed recorder, driven from the car axle by a wire belt.

The recording device shown on the table, Fig. 1, page 41, and

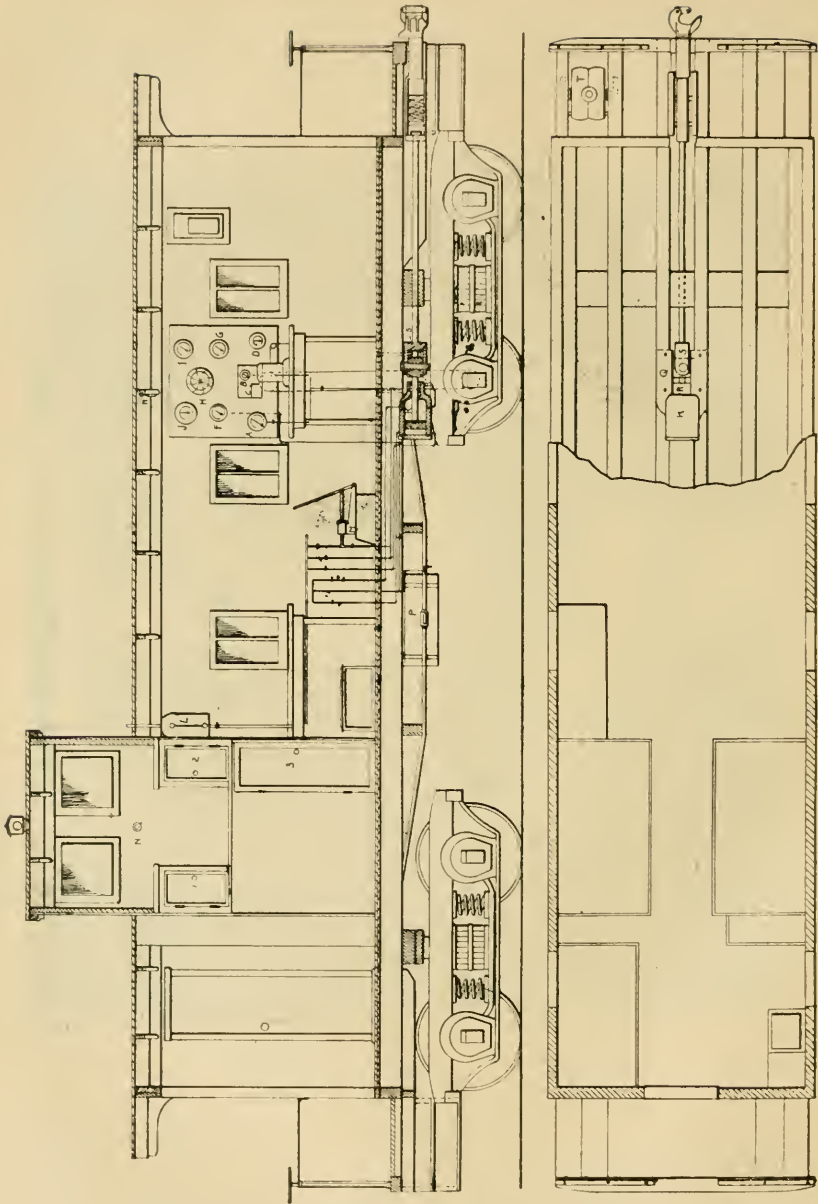


FIG. 2. SECTIONAL VIEW OF CAR.

the indicating gage at lower right hand corner of the vertical board, each give the speed in miles per hour.

The Metropolitan recording gage at "A," Fig. 2, page 42, reading to one thousand pounds per square inch, records the pull

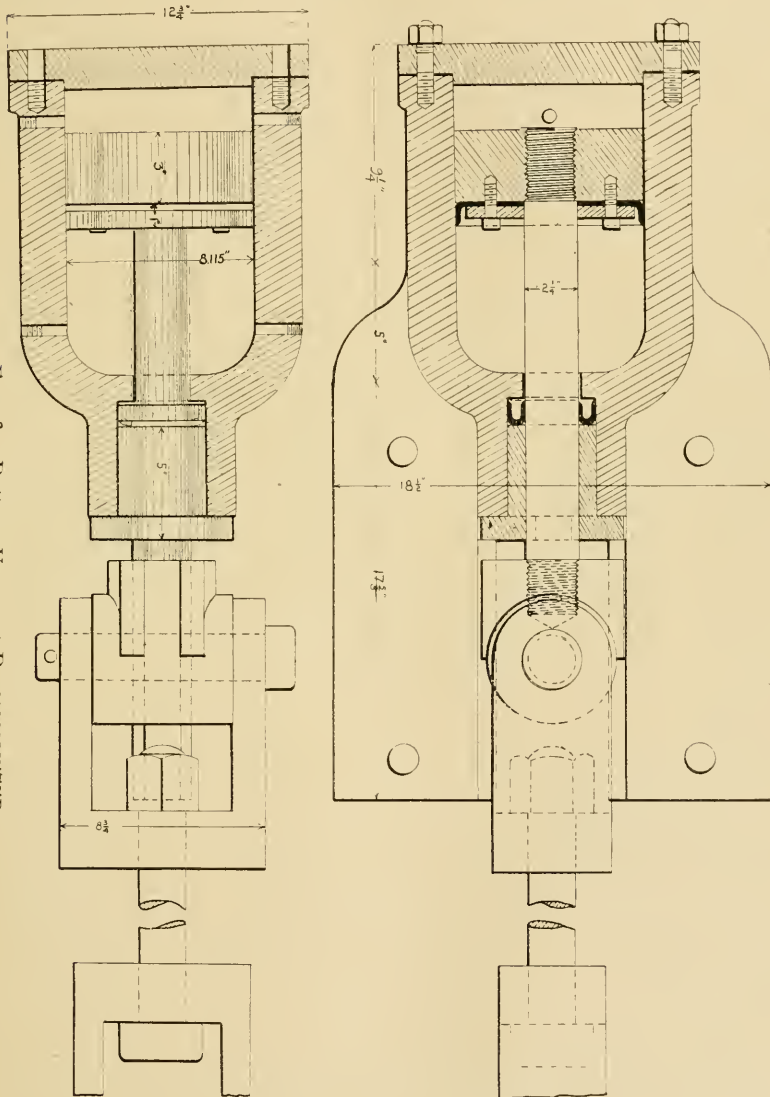


FIG. 3. DETAIL VIEW OF DYNAMOMETER.

on the draw bar. The drum upon which the continuous diagram is obtained is driven from the Boyer shaft, the clockwork having been removed and reducing gear substituted. The gearing can be so changed as to rotate the drum at different speeds. The one in use gives a chart of four and one half inches per mile. A continuous record of the pull is obtained by the paper being drawn by the drum from one roll and wound on another by suitable mechanism. A hydrostatic gage, reading total-tons-pull on the draw bar, is also connected to the dynamometer cylinder. The following records are also recorded: boiler pressure, steam chest and air pressure, revolutions of drive wheels, amount of water furnished to boiler (by meter), position of reversing lever, time of passing mile post, time of taking indicator cards, etc.

The dynamometer cylinder, shown in Fig. 3, page 43, is securely bolted to the center sills of the car and the piston rod is attached to the draw bar through a cross-head yoke and connecting rod in such a way that when the cylinder is filled with oil none of the load is carried by the buffer springs, but when the oil is discharged the pull is taken by the springs in the usual manner, the piston moving up nearer the front of the cylinder. Under no circumstances can the piston strike either cylinder head. The piston is eight inches in diameter, packed with a cup, and the piston rod is two and one fourth inches in diameter, packed with U leathers. The cylinder in front of the piston is filled with light coach oil, so that the pull on the draw bar is taken by the oil and the pressure per square inch recorded by the gages described above.

When not in use the oil is stored in a tank, from which it can be forced into the cylinder of the dynamometer by means of the hand pump, Fig 4, page 45, and it can be raised again to the tank by allowing air from the auxiliary reservoir to enter the top of cylinder by the pipes shown. Any oil leaking past the piston may also be raised into the tank in the same way. This is accomplished by the arrangement of piping and valves. The two air-vent cocks near the globe valves in the air pipe are allowed to remain open when testing, as it is assumed that the air pressure will not act on either side of the piston.

When pulling the dynamometer car alone, a record is made on the chart showing that the dynamometer is sufficiently sensitive for all purposes.

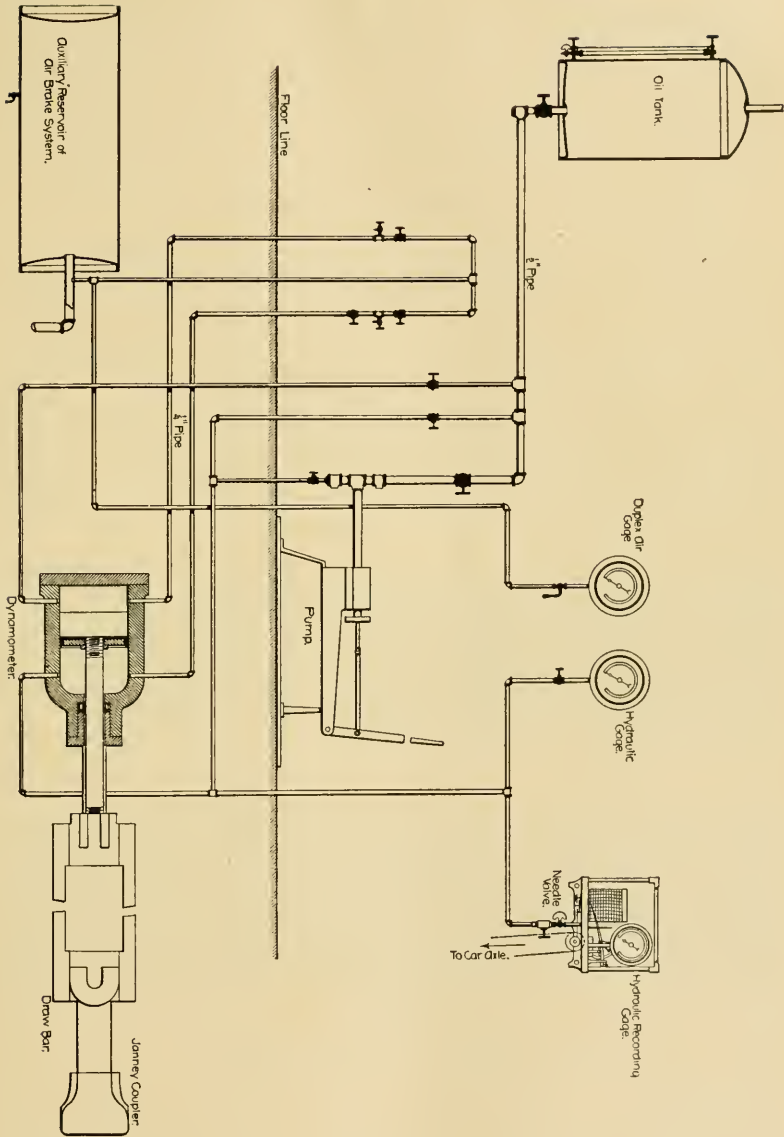
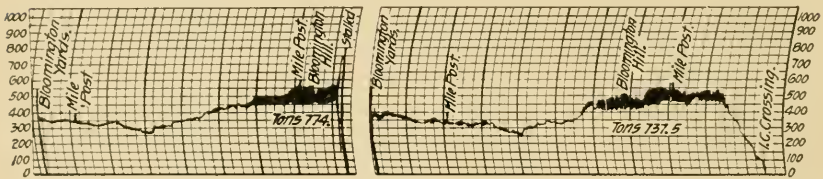


FIG. 4. DIAGRAM SHOWING ARRANGEMENT OF HYDRAULIC DYNAMOMETER AND FITTINGS.

During November, 1898, a series of pulling tests were made with this car on the P. & E. Division of the Big Four Railroad from Pekin, Illinois, to Springfield, Ohio, to determine the maximum number of tons that could be hauled in each direction up the ruling grades. These trials were made with special test trains and the types of freight locomotives used on the P. & E. Division, namely, "Consolidated" and "Ten wheeler." Seven different locomotives were tested both singly and as double headers.

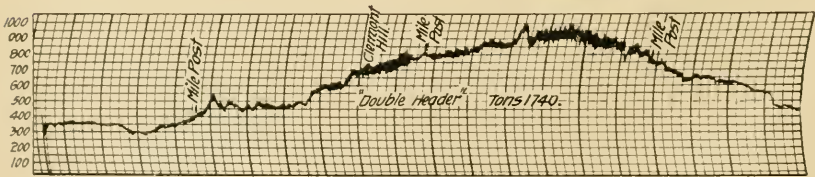
The method of making a pulling test was as follows:

If, in ascending a grade, the engine stalled under full steam pressure, the trial was repeated with fewer cars until the engine was able to haul the train over the hill. If, on the other hand, the train passed over the hill at a speed greater than four or five miles per hour, another trial was made with more cars. During the trials the following observations were made: Draw bar pull, speed, boiler pressure, total tonnage of train, number of cars in train, name of grade, time of passing mile posts, temperature, wind, weather and date.



DIAG. A.

DIAG. B.



DIAG. C.

FIG. 5. DIAGRAM OF DRAW BAR PULL.

Diagrams "A" and "B," Fig. 5, page 46, show two trials going east with a consolidated locomotive on a 1.3 per cent grade out of Bloomington, Illinois. Diagram "A" is one obtained from a train of twenty-one cars, weighing seven hundred and seventy-four

tons, the speed at the foot of the grade being nine miles per hour, boiler pressure one hundred and thirty-five pounds and one hundred and forty-five pounds near the top where the engine stalled nine hundred feet beyond mile post No. 305, exerting a maximum draw bar pull of twelve tons. Diagram "B" shows a record of the pull of a train of twenty cars, weighing seven hundred and thirty-eight tons, on the same grade. The speed and boiler pressure were the same at the foot of the hill as in the first trial, and the top was passed at a speed of less than one mile per hour, the boiler pressure at that point being one hundred and forty pounds per square inch and the maximum draw bar pull eleven and seven tenths tons.

Diagram "C," Fig. 5, shows a trial with a double header, a "consolidated" and a "ten-wheel" locomotive, about six miles west of Indianapolis, up Clermont hill, which has a one per cent rise for about three miles. This train consisted of fifty cars, weighing one thousand, seven hundred and forty tons. The speed at the foot of hill was twenty-three miles per hour and when going over top, about two miles per hour. The maximum draw bar pull being twenty-one and nine tenths tons. The boiler pressure was one hundred and seventy pounds for the "ten-wheeler" and one hundred and forty-three pounds for the "consolidated," which pressures remained the same throughout the test.

From the results of these tests a tonnage rating was made out, showing the number of tons that could be hauled between certain stations where the ruling grades were found. From this a through rating was established, which was the same as the rating for the heaviest grade.

These tests covering a period of three weeks were conducted by Professor Breckenridge and Assistant Professor Van Dervoort, assisted by the Senior Mechanical Engineering Class, the road being represented by some of its officials.

THE TECHNOGRAPH is indebted to the *Railroad Gazette* for the use of the cuts for Fig. 4 and 5.

STRENGTH OF COKE CONCRETE.

BY WM. H. VANCE, CIVIL ENGINEERING, '99.

It is sometimes desirable to use a concrete lighter than that made of broken stone, as, for example, for the foundation of a pavement on a viaduct or bridge. Apparently no experiments have been made on this subject and as this field promised some practical conclusions, the writer undertook as his thesis work the determination of the strength and weight of concrete made by using coke instead of broken stone. The following is a summary of the results.

The experiments consisted of testing sixty 6-inch cubes, which were broken at 30, 60, and 90 days. Two brands of cement were used, Milwaukee natural and Commercial Portland. As far as could be seen by the tests of these cements they are fairly representative. The sand was ordinary building sand having the following fineness: 5^{21} , 20^{16} , 30^{31} , 50^{32} , the larger figures representing the number of the sieve and the smaller figure representing the per cent retained on the sieve next following. The sand contained 39 per cent of voids when loose. The coke was broken by hand to pass a $1\frac{3}{4}$ -inch ring, and substantially all was caught on a No. 5 sieve. It contained 50 per cent of voids. All ingredients were measured by volumes, loose,

Six preliminary tests were made to determine the difference between gas-retort coke and coke-oven coke, but the results did not differ materially; and hence gas coke was employed as it was believed to be cheaper, more generally available and ordinarily in a form more easily used.

A preliminary test was made with six cubes to determine the effect of wetting the coke before mixing with the mortar. The result seemed to show that dry coke was about 30 per cent stronger than wet or damp coke. This result is very astonishing, for it is well known that laying a dry soft brick on cement mortar

practically kills the mortar. The writer is unable to explain the cause of the anomalous result of his experiments, nor is he willing to accept the conclusion as being generally true. Certainly the dry cubes were stronger proportionally than other cubes tested subsequently.

TABLE I.
CRUSHING STRENGTH DRY GAS COKE CONCRETE—POUNDS PER SQUARE INCH.

| REF. NO. | COMPOSITION. | | | AGE WHEN BROKEN. | | | | | |
|----------|-----------------|-------|-------|------------------|------------------|----------|------------------|----------|------------------|
| | CEMENT. | SAND. | COKE. | 30 DAYS. | | 60 DAYS. | | 90 DAYS. | |
| | PORTLAND CEMENT | | | No. | Lbs. per sq. in. | No. | Lbs. per sq. in. | No. | Lbs. per sq. in. |
| 1 | 1 | 3 | 5 | 9 | 646. | 4 | 638. | 6 | 771. |
| 2 | 1 | 3 | 6 | 3 | 635. | 3 | 676. | 2 | 749. |
| 3 | 1 | 3 | 8 | ..... | ..... | 3 | 620. | 3 | 720. |
| | NATURAL CEMENT | | | | | | | | |
| 4 | 1 | 3 | 5 | ..... | ..... | 3 | 263. | 3 | 356. |
| 5 | 1 | 3 | 6 | ..... | ..... | 3 | 341. | 3 | 307. |

TABLE II.
COMPARISON OF COKE AND BROKEN STONE CONCRETES.

| PROPORTIONS. | STRENGTH OF PORTLAND CEMENT CONCRETE. | | | | RATIO. | WEIGHT. | | |
|--------------|---------------------------------------|------------------|---------------|------------------|--------|------------------|---------------|--------|
| | COKE. | | BROKEN STONE. | | | LBS. PER CU. FT. | | |
| | No. | Lbs. per sq. in. | No. | Lbs. per sq. in. | | COKE. | BROKEN STONE. | RATIO. |
| 1:3:5 | 12 | 610. | 3 | 1351. | 1:2:2 | 92. | 139. | 1:1:5 |
| 1:3:6 | 3 | 635. | 3 | 877. | 1:1:4 | 81. | 137. | 1:1:7 |

Table I shows the strength of coke concrete at different ages and of different proportions, with both Portland and natural cement. It is interesting to note that the average strength of the

1:3:6 mixture is about 1 per cent more than that of the 1:3:5 mixture.

Table II is a comparison between coke and broken stone concrete made with Portland cement. Taking the averages for both the two proportions of concrete, we see that coke concrete is only 60 per cent as heavy as that made of broken stone, and only 55 per cent as strong.

Incidentally the conclusion may be drawn that the Portland cement was eight times as strong at 7 days as the natural cement, while the concrete made with Portland was only 2.3 times as strong as that made with natural cement.

CEMENT AND SAND REQUIRED FOR A YARD OF MORTAR.

BY F. GRIM, CIVIL ENGINEERING, '99.

It is important to know the quantities of hydraulic cement and sand required to produce a given quantity of mortar. Such data is useful in making estimates of cost and also in determining the quantities required for any particular job. Apparently but few experiments have been made in this field, and therefore the writer determined to investigate this subject for a thesis. The following is a summary of the results.

Table I gives the yield of neat paste for four brands of cements. The data in this table is of special use in subsequent steps of the investigation. Each result is the mean of ten experiments. The data in the first four columns was determined directly, and the remainder arithmetically from these. The weight of a cubic foot of cement measured loose was found by allowing the cement to drop three feet through a sieve into a box holding one-tenth of a cubic foot. The table shows that there was no practical difference between the two Portland cements or between the two natural cements.

TABLE I.
YIELD OF NEAT CEMENT PASTE.

| NAME OF CEMENT | CEMENT MEASURED BY WEIGHT | | | | CEMENT MEASURED BY VOLUMES PACKED | | | | CEMENT MEASURED BY VOLUMES LOOSE | | | | |
|-----------------------|------------------------------|------|------------|----------------|--------------------------------------|---------|------|----------------|-------------------------------------|---------|---------|----------------|-------|
| | Cement | | Water | Paste Loose | Cement | Water | | Paste Loose | Cement | Water | | Paste Loose | |
| | lbs. | lbs. | Per ct. | Cu. ft. | | Barrels | lbs. | Gal. | | Cu. ft. | Cu. ft. | lbs. | Gals. | Cu. ft. |
| Portland— | | | | | | | | | | | | | |
| Commercial } Amer. | 100 | 35 | 35 | 1.102 | 1 (380 lbs.) | 133 | 16.1 | 4.19 | 1 | 28 | 3.4 | 0.88 | |
| Buckeye | 100 | 35 | 35 | 1.092 | 1 (380 lbs.) | 133 | 16.1 | 4.15 | 1 | 26 | 3.1 | 0.81 | |
| Natural— | | | | | | | | | | | | | |
| Akron..... | 100 | 47 | 47 | 1.287 | 1 (265 lbs.) | 117 | 14.1 | 3.22 | 1 | 28 | 3.4 | 0.77 | |
| Louisville } Star | 100 | 47 | 47 | 1.303 | 1 (265 lbs.) | 117 | 14.1 | 3.26 | 1 | 24.6 | 2.9 | 0.68 | |

Table II shows the amount of cement and sand required to produce a cubic yard of rammed mortar. In making the experiments the proportions were determined by weight. Each result is the mean of three tests. Both Portland and natural cements

TABLE II.
CEMENT AND SAND REQUIRED FOR ONE CUBIC YARD OF RAMMED MORTAR.

| PARTS OF SAND TO ONE PART OF CEMENT | PORTLAND CEMENT | | | | NATURAL CEMENT | | | | |
|---|-----------------|-------------------|------------------------------------|--------------------------|----------------|----------|----------|------------------------------------|--------------------------|
| | Am't of Cement | | Am't of Sand Voids=35.4 per ct. | | Am't of Cement | | | Am't of Sand Voids=35.4 per ct. | |
| | Weight lbs. | Bbls. 380 lbs. | Weight lbs. | Vol. Loose Cu.yds. | Weight lbs. | Barrels | | Weight lbs. | Vol. Loose Cu.yds. |
| | | | | | | 265 lbs. | 300 lbs. | | |
| 0. | 2 460. | 6.47 | 0.0 | 0.0 | 2 085. | 7.87 | 6.95 | 0.0 | 0.0 |
| 1. | 1 534. | 4.03 | 1 534. | .556 | 1 459. | 5.51 | 4.86 | 1 459. | .529 |
| 2. | 1 050. | 2.76 | 2 097. | .761 | 1 045. | 3.94 | 3.48 | 2 089. | .758 |
| 3. | 812. | 2.13 | 2 435. | .884 | 799. | 3.01 | 2.66 | 2 397. | .87 |
| 4. | 648. | 1.70 | 2 673. | .97 | 645. | 2.43 | 2.15 | 2 580. | .962 |
| 5. | 543. | 1.43 | 2 716. | .99 | 541. | 2.04 | 1.80 | 2 704. | .99 |
| 6. | 463. | 1.22 | 2 778. | 1.01 | ..... | ..... | ..... | ..... | ..... |

were used. The sand was dry and weighed 102 pounds per cubic foot, loose, and had the following fineness, the larger numerals being the number of the sieve, and the smaller numbers preceding a large number represent the per cent retained on that sieve, and the small number succeeding the last sieve number represents the per cent passing that sieve: "5⁴ 20¹⁴ 30¹⁹ 50³⁸ 80⁵. The voids were determined by allowing the sand to fall through water and ramming it into place as it fell. This method of determining the voids was chosen as securing a maximum value for the voids, since less air is imprisoned than by any other process known.

Perhaps the most elaborate tests ever made to determine the quantities of sand and cement required for a yard of mortar were those made in connection with the construction of the Poe lock of the St. Mary's Falls Canal,* by Mr. L. C. Sabin, assistant to Mr. E. S. Wheeler, U. S. Assistant Engineer. Mr. Sabin measured the mortar in a loose state, while the writer determined the volume after it had been rammed. For some purposes the difference between these methods is not important; but in some cases the difference is important, as, for example, when the mortar is used in making concrete which is to be rammed into place. For the first half of Table II, Mr. Sabin's results are slightly the greater, and for the last half, smaller. The difference is easily within the limits of errors in making the tests.

It is very common for engineers to attempt to determine by computations the volume resulting from mixing given quantities of sand and cement paste. The writer mixed sand and enough cement paste to fill the voids of the loose sand, and found the resulting volume of rammed mortar was 103.5 per cent of the original volume of the loose sand, which shows that the particles of cement got between the sand grains and thus increased the volume somewhat. When the cement paste was equal to the voids in the rammed sand, the resulting volume of rammed mortar was 101.5 per cent of the original rammed sand.

The facts stated in the preceding paragraph led the writer to determine the volume produced by mixing cement mortar and

* Report of the Chief of Engineers, 1894, pp. 23-26. Note that in the Chief of Engineers Report for 1893, p. 3018, Mr. Sabin gave some results which he afterwards stated to be erroneous. These latter results have frequently been quoted.

broken stone. The stone passed a one-inch ring and was retained by a No. 5 sieve. It contained 37 per cent voids when rammed. The mortar was one part cement to two parts of the sand described above, both measured loose. Mixing broken stone with mortar equal to 100 per cent of the voids in the stone when rammed, gave a volume of rammed concrete equal to 108 per cent of the broken stone. In other words, the mortar surrounding the fragments of the stone increased the volume eight per cent; and, consequently, the voids were not filled with mortar. With mortar equal to 110 per cent of the voids, the increase of volume was 8.5 per cent; with 120 per cent of mortar, 11.0; and with 130 per cent of mortar, 12.8 per cent. The mixing was very thoroughly done. The writer regrets that the time available after the discovery of this relation did not permit him to make further experiments with proportions of mortar insufficient to fill the voids.

Incidental to the investigation referred to in the preceding paragraph, the writer deduced Table III, which shows the quantity of mortar and broken stone required to produce a yard of rammed concrete.

TABLE III.

MORTAR AND BROKEN STONE REQUIRED FOR ONE CUBIC YARD OF
RAMMED CONCRETE.

| Mortar in terms of the Voids in the Broken Stone when Rammed | Broken Stone having 37.2 per cent Voids. Cubic Yards | Per cent of Voids in the Concrete |
|--|--|--------------------------------------|
| 100 per cent. | 0.92 | 8.0 |
| 110 per cent. | 0.91 | 4.8 |
| 120 per cent. | 0.90 | 3.6 |
| 130 per cent. | 0.89 | 1.6 |

REQUIREMENTS FOR ELECTRIC ELEVATORS.

BY MELVILLE C. CHATTEN, '96, WITH OTIS ELEVATOR CO., QUINCY, ILL.

The elevator has become such an important feature in modern business buildings that its requirements demand a more careful study than is often given, in order that a suitable place may be provided for it. The fact that the subject is not always given sufficient study is made apparent by observing the number of elevators that are put off in some dark corner of a building, chiefly for the reason that the space can be utilized for no other purpose.

The electric elevator of today is very compact, simple in construction, and easily operated, but, like any other machine, requires attention, and should be placed in a light, dry place, free from dirt. If the machine is crowded into some dark corner difficult of access, it is almost certain to be neglected, the commutator will become dirty and spark, the worm, from lack of oil, will wear unevenly and cause an unpleasant vibration in the movement of the car, and the whole service will soon become unsatisfactory. The machine can be placed on any floor of a building, wherever most convenient, and in some cases it is supported directly over the hatchway on the roof. If the roof beams are strong enough to support the machine safely, there are some points of advantage in placing it overhead. A large room can be provided for it on the roof, which will be free from dampness and dirt, and the elevator will not then be taking up valuable space that can be used for other purposes. With the machine in this position the hoisting cables will run from the car directly to the drum, which saves the friction that would result from overhead sheaves. The important points for an architect to bear in mind when planning for an elevator are: 1. To see that the hatchway is large enough for a platform of the requisite size, with room at the sides for the counterbalance weights and controller; 2. That there are no piers, pipes, walls or other obstruction to interfere with the placing of the machine; 3. That the elevator is so placed

in the building as to be convenient of access from all parts; 4. That suitable supports are provided for the overhead sheave beams.

It is difficult to give any measurements for hatchways, counterbalance weights, etc., that would be of service in planning for an elevator, since there are scarcely ever two cases where the conditions are the same, but an average case will illustrate some of the points that must be considered. Let us take for example a passenger elevator with a speed of 250 feet per minute, 2000 pounds capacity, and a 4 foot by 5 foot steel platform. The platform would weigh about 1000 pounds, and the cab 600 pounds. The hatchway should be from twelve to fourteen inches larger than the platform postwise, and two or three inches larger from front to back. If it is necessary, for any reason, to place the counterbalance weights at the back, there should be a clear space of at least five inches between the platform and the line of the hatchway. It is good practice to counterbalance the platform to within 300 pounds of its weight, and to make the drum counterbalance equal to about one-half the capacity of the machine, plus the remaining 300 pounds of the platform weight. With an elevator running at 250 feet per minute there should be a clear height of fourteen feet from the top floor to the under side of the sheave beams, to allow room for the cross beams of the platform, with a three-foot clearance. When the height of the top story is not sufficient for this amount of clearance, it is necessary to build a cupola on the roof to receive the overhead sheaves and beams. This should be about one foot larger than the hatchway on all sides.

It is often difficult for a client to decide upon what is the best speed and capacity for an elevator in his particular line of business. As a general rule, more work can be accomplished with high speed elevators carrying light loads, than with less speed and greater capacity. Very often the mistake is made of buying a machine of much greater capacity than is needed, for the sake of additional safety. The word capacity, as used by elevator builders, refers to the mechanical power of the machinery which enables the elevator to raise a given load at a certain number of feet per minute, and not to the strength of the materials from which the machine is made.

The size of the platform should be determined from the desired capacity of the machine, and if made large enough to carry double the average load it will be ample for most cases. If the average load for a passenger elevator is to be 1 000 pounds, then the capacity would usually be taken at 2 000 pounds, and allowing 100 pounds per square foot of floor area, a 4 foot by 5 foot platform would be sufficient.

The speed of elevators should be governed by the height of the building and the class of work for which they are to be used, but, generally speaking, it is sufficient to run freight elevators from seventy feet to eighty feet per minute, and passenger elevators from 150 feet to 200 feet, in buildings of from three to five stories in height, while for buildings of much greater height it is better practice for freight elevators to have a speed of 100 feet to 125 feet, and for passenger elevators from 250 feet to 300 feet.

THE SUPERINTENDENT'S POINT OF VIEW.

BY EDWIN B. CLARKE, '91, SCHOOL OF ARCHITECTURE.

The art of superintending is not only the art of fault finding, but the art of fault remedying and fault preventing. If building operations were not attended by mistakes, misinterpretations and disagreements, it is evident there would be no need for the genus superintendent, hence, it is with the difficulties that beset him, and their remedies, that this article will chiefly concern itself.

The faulty plan is the first source of annoyance. Frequently a set of drawings is so hastily finished that omissions and inaccuracies are almost unavoidable. Contradictions and discrepancies occur between the general drawings, scale and full size details, and the specifications, resulting not only in annoyance and controversy, but also in no little expense and delay if not discovered before the ordering of material, or the performance of that part of the work affected by them.

It should be the superintendent's first care to make a thor-

ough examination of all plans and details, comparing them with the specifications, and with each other, in order that all errors may be discovered and eliminated before the work is begun.

This examination will also aid in fixing in the mind the peculiarities which differentiate the new work from others with which he has previously been connected.

The plans furnished the contractors should be complete. By this I mean the drawings should be provided in sufficient number to thoroughly cover the work, and show plainly *how* it is to be done, so nothing will be left to the imagination of the builder. I strongly favor numerous sectional drawings, which shall clearly show any unusual or special features or finish, and a sufficiency of dimensions to permit the execution of the work with the fewest possible arithmetical calculations by the workmen at the building.

Draftsmen are usually reluctant to "bind" themselves by figures on a drawing, but unless the workmen are mind readers—and few of them are—it is hardly to be expected they will properly carry out the artist's idea when he himself declines to define it. In figuring dimensions, it is of advantage to give, where possible, a string of distances between *centers* of main features, with subordinate lines of dimension for the separate parts of those features, and also to note on each plan the bays or dormers which are to center with some other feature of the building, above or below them. This method will materially decrease the liability of the builder to make mistakes in laying out his work, and an error, when made, may be quickly found and easily rectified without affecting more than a single feature.

It will also be found useful to adopt a "building" line (usually the line of the first story wall above the water table) as a base line from which to figure dimensions, as well on the basement and foundation plans as on the first floor plan. This building line may be shown by a red or black dotted line on the drawings.

The value of explanatory notes on drawings should not be underestimated, and the more of them there are, even though they are repetitions of items covered by the specifications, the better. The plans may be called common property, since they are used by all the craftsmen alike, while the specifications, if ac-

cessible, are usually so divided that each foreman refers only to the particular section covering his special work, and is ignorant of its relation to that of the other trades. In such cases it is evident that proper co-operation is improbable, if not impossible.

The repetition of the common lines of height on all elevations and vertical sections is to be recommended. It is quite a convenience to the superintendent, and saves mistakes arising from the builder's inclination to trust to memory rather than to turn to the plan on which the heights occur.

It may be said that the contractor should be made to suffer for his own negligence, but it must be remembered that the drawings are really implements or tools, as necessary for the prosecution of the work as the trowel, saw or hammer, and it is the duty of the architect to furnish them to the builder in as perfect a state as possible, if the final results are to be satisfactory.

Any improvements tending to convenience in handling will amply repay any extra time consumed in preparing them in the draughting room, and a day or two, or in unusual cases even a week, devoted to figuring and checking up dimensions on the working plans, will avoid expensive mistakes and time wasting delays, with the resulting disputes and controversies, and at the same time will give the plans a definiteness that will enable the estimator to make a closer proposal for the work before the contract is awarded. For the same reason it is desirable to fully indicate, by framing plans or diagrams, the kind and size of materials to be used, and the methods to be employed.

It is a decided advantage to the superintendent if he has been employed in the production of the plans whose execution he is to supervise. His familiarity with the drawings will enable him to see more readily the effect that a change at one point will have on other parts of the work, and will be especially valuable to him when it is necessary to give an order without a chance for study or leisurely consideration.

The superintendent should secure a complete set of *all* drawings to be used in the work, including general plan, scale and full size details and diagrams, outside of the sets furnished the contractors. He should also have his own copy of the specifications, and all agreements and contracts, to which to refer in case of dispute between contractors concerning the scope of their respective

contracts. The above applies only to the superintendent in charge of large work not in the same city with the architect, who cannot, therefore, have access to the office sets.

The first duty of the superintendent on the ground is to check up the dimensions and "laying out" of the building. For this a steel tape should preferably be used, and, for a long series of measurements, the ring end held at a single point while the different required dimensions are marked off in order along the length of the tape from a memorandum slip previously prepared. This prevents accumulative errors, which, with the average mason, reaches four or five inches in the hundred feet before it is considered "worth noticing." In order to keep the work in hand, the superintendent should require that he shall have approved all work laid out before building is proceeded with. To measure the width of footing trenches, a stick cut to the width of the footing, with a notch for the building line, will be found convenient. A plumb line dropped from the building line stretched above, will pass the notch, and show at once if the trench is properly located, and of the required size. With several different widths of footings, and for places where no line can be stretched in the excavation itself, this method should save much time and many mistakes.

If the plans show no "chases" or slots for soil and waste pipes, or gas, water and electric mains, the superintendent should arrange with the mason to build them in the proper places as the walls go up. Neglect to consider this frequently leads to unsightly results, such as a group of pipes cutting through a handsome cornice, or spoiling the appearance of an otherwise attractive room. The location of the horizontal pipes should also be considered; whether in the floor, that is, between the joists or cut in over them; under the floor, hung to the ceiling below and exposed to sight; or under a raised floor; also, whether the marble or other wainscoting back of toilet room fixtures can set flat against the wall or must be moved far enough forward to allow the waste, supply and vent pipes to run behind it.

The note book should be the superintendent's constant companion, not only for jotting down ordinary items to jog the memory for the daily details of the work, but to be used as well to preserve a record of orders to, and agreements with contractors,

instructions to foremen, and alterations or changes sanctioned in plans or specifications. In fact, the entries should include everything relating to the building which may possibly be needed for future reference. Especially should dates of orders, and delivery of plans and details (if no record is kept in the office) be noted down, in case it becomes necessary to refer to them in settlement of claims for enforced delay in completing a "time" contract.

The superintendent should notice, from time to time, if all the workmen who can be advantageously employed are on the different branches of the work. He should inquire concerning the ordering of material, and the progress of the work of the sub-contractors, in order that no delay be caused by their failure to "come to time." More time is thus lost than from all other causes together, in my experience.

The superintendent should see that application is made for detail drawings in such season that they will be on hand before needed for use.

It is a good plan to occasionally visit the mills, foundry, pattern and modeling shops, to inspect the work in progress, and explain to the workmen points that are vague or misunderstood, before it is too late.

One should not be above accepting advice from contractor or workman, for fear of loss of prestige, since frequently their experience suggests methods or facts, either of merit in themselves, or expedient under existing circumstances. Neither should one be so complaisant as to adopt these suggestions without careful consideration. If they are rejected, it should be done so as to leave no doubt about it in the mind of the workman, nor as to the method actually to be employed. Frequently it is necessary to say to the builder: "Your way *may* be just as good, but the specifications prescribe a method which I *know* will give results satisfactory to the architect, and as I am answerable to him after your responsibility in connection with the work ceases, I must require you to follow the specified directions." Material or work condemned should be ordered removed *at once*. It is a common trick among foremen to agree to "see to that later," with the expectation that the matter will slip the superintendent's mind until the defective material or work can be hidden or covered up.

Structural iron is usually required to have several coats of paint after delivery. In order to insure its receiving the required number of coats, and proper care in their application, and also to prevent a delay for painting and drying when the material is wanted for use, it is well to insist that this work be done as soon as the metal is on the ground.

The superintendent himself should cultivate the following characteristics: Tact, force, decision and gentlemanliness. He will be called upon to listen to endless complaints of interference by one contractor's men with the work of the others, and is expected to arbitrate them. He will be referred to as a walking specification by foremen who find it more convenient to question him than to take the trouble to look up requirements themselves. This he should be encouraged to do. Some foremen ignore the specifications entirely, depending on the superintendent to assume responsibility for anything opposed to them, which he has failed to discover, but "which it is *his duty* to find out," as I was once informed by a foreman. The same brilliant fellow was one day very much "put out" with me, because I had not called his attention to a note on one of the plans. He had shored up a seventeen inch brick wall, and cut an opening in it in the first story, before he discovered that it should have been torn out above also, to make way for a stud partition to take its place. Of course the single I beam, which the note called for, while ample to support a stud partition, would hardly do the same service for a seventeen inch brick wall. As I had not been present when he put up his columns and needles, and tore out his opening, I informed him that, though I was inclined to be accommodating, he could hardly expect me to correct his mistakes before he made them. Another nuisance is the man who always knows a better way to do everything than the way he is called on to do it (simply for the sake of change), and who is positively unhappy if his suggestions are unheeded. Of course, the superintendent ought never to lose his temper. He may lose his patience, and express his opinions, but he should let the other fellow put himself at a disadvantage by getting "mad." As a general rule, however, flattery builds quicker than friction, and the greater the superintendent's skill in overcoming difficulties, expediting work and settling differences, the better superintendent he is.

DUTY TRIAL OF THE AURORA HIGH DUTY PUMPING ENGINE.

L. P. BRECKENRIDGE, PROFESSOR OF MECHANICAL ENGINEERING.

The following is a record of the results of a duty trial made by the writer May 26 and 27, 1898, at Aurora, Ill., and constituted the official trial of the pumps for the city.

The makers guaranteed to deliver 6 000 000 gallons of water into the mains against 200 feet hydraulic head every twenty-four hours, at a piston speed of 250 feet per minute. They also agreed to perform 130 000 000 foot pounds of work with 1 000 pounds of steam evaporated from the temperature of the hot well into steam of 125 pounds boiler pressure.

The pumping engine is a horizontal, triple expansion Corliss engine, having three steam cylinders abreast. The piston rods extend through each steam cylinder, driving a three-throw crank shaft with two fly wheels on one side, and coupled directly to the pump plunger rods on the other. The steam cylinders are 16, 28 and 36 inches in diameter, respectively, and the pump plungers are 12 inches in diameter, all having a stroke of 36 inches. The plungers are externally packed, and all steam cylinders are steam jacketed both sides and heads. Reheaters are placed between the cylinders.

The writer was assisted by J. H. McKee and six students from the Mechanical Engineering Department of the University of Illinois, and the Nordberg Company was represented by Mr. Nordberg and Mr. Lenz. Care was taken to have all apparatus in perfect condition. The scales on which the feed water and coal were weighed were tested just before the start of the test, by the "sealer of weights and measures," of the City of Aurora, and found to be correct. Although not required under the specifications, the boiler furnishing steam for the engine, was also tested.

During the test all connections to the boiler, for both steam and water, except those supplying steam to the engine, and feed water from tank to boiler, were disconnected. The steam for running the boiler feed pump used during the test was taken from another boiler. The main boiler feed pump, driven from a connection to the connecting rod of the low pressure cylinder, discharged into the weighing tank or through an overflow pipe as required.

The water condensed in the jackets, as well as in each reheater, is usually pumped back to the boilers at boiler pressure, but during the test this water was trapped separately, cooled and weighed. The water condensed in the steam main taken from the separator was also cooled, trapped and weighed.

Six indicators were used on the steam cylinders and six on the water cylinders. During the trial the cards were not usually taken simultaneously, but on several occasions cards were thus taken, and from these cards the mechanical efficiency was deduced.

The plungers being externally packed all leakage past them could be seen, and during the trial all of this leakage was caught and weighed to several known lengths of time. At the close of the test the stand-pipe pressure was admitted on the discharge and suction valves and they were practically tight. The principal results are recorded in the following table:

RESULTS OF TRIAL.

Owners of Plant, Aurora Water Company, Aurora, Illinois.

1. Date of trial..... May 26-27, 1898
2. Duration of boiler trial..... 25.2 hours

PRINCIPAL DIMENSIONS OF BOILERS.

3. Type of boilers Marine
4. Outside diameter of shell..... 96 inches
5. Length of shell..... 13 feet
6. Number of horizontal tubes..... 132
7. Outside diameter of tubes 3 inches
8. Length of tubes..... 13 feet
9. Diameter of steam dome..... 30 inches
10. Length of each furnace..... 6 feet
11. Width of each furnace..... 2.5 feet

| | | |
|-----|--|---------------|
| 12. | Grate surface..... | 30 sq. ft. |
| 13. | Heating surface..... | 1 600 sq. ft. |
| 14. | Ratio of grate to heating surface..... | 1 to 53.5 |
| 15. | Ratio of heating surface to grate..... | 1 to .01876 |

DIMENSIONS OF NORDBERG CORLISS PUMPING ENGINE

| | | |
|-----|---|-----------------------|
| 16. | Diameter of high pressure cylinder..... | 16 inches |
| 17. | Diameter of intermediate cylinder..... | 28 inches |
| 18. | Diameter of low pressure cylinder..... | 39 inches |
| 19. | Diameter of high pressure piston rod..... | $2\frac{1}{8}$ inches |
| 20. | Diameter of intermediate piston rod..... | $2\frac{1}{8}$ inches |
| 21. | Diameter of low pressure piston rod..... | $2\frac{1}{8}$ inches |
| 22. | Diameter of pump plunger..... | 12 inches |
| 23. | Diameter of pump plunger rods..... | 3 inches |
| 24. | Stroke..... | 36 inches |

DATA FOR BOILER TEST.

| | | |
|-----|--|------------------------|
| 25. | Steam pressure in boiler by gauge..... | 132 lbs. per sq. in. |
| 26. | Absolute pressure in boiler..... | 146.7 lbs. per sq. in. |
| 27. | Force of draft in inches of water..... | .34 inches |
| 28. | Temperature of external air..... | 64° |
| 29. | Temperature of feed water..... | 84.9° |
| 30. | Temperature of steam..... | 365.5° |

DATA CONCERNING FUEL.—(Jackson Hill Lump Coal)

| | | |
|-----|------------------------------------|-------------|
| 31. | Moist coal consumed..... | 11 855 lbs. |
| 32. | Total dry refuse..... | 443 lbs. |
| 33. | Total combustible..... | 11 412 lbs. |
| 34. | Dry coal consumed per hour..... | 470.4 lbs. |
| 35. | Combustible consumed per hour..... | 452.8 lbs. |

QUALITY OF STEAM.

| | | |
|-----|--|---------------|
| 36. | Quality of steam..... | 97 pr. ct. |
| | Factor of evaporation..... | 1.176 pr. ct. |
| 37. | Total weight of water fed to boiler..... | 92 629 lbs. |
| 38. | Water actually evaporated corrected for quality of steam..... | 89 842 lbs. |

| | | |
|-----|---|--------------|
| 39. | Equivalent water evaporated from and at 212° F..... | 105 654 lbs. |
| 40. | Equivalent water evaporated from and at 212° F. per hour..... | 4 192 lbs. |
| 41. | Water actually evaporated per lb of coal..... | 7.579 lbs. |
| 42. | Equivalent water from and at 212° per lb. of coal | 8.912 lbs. |
| 43. | Water actually evaporated per lb. of combustible. | 7.872 lbs. |
| 44. | Equivalent water from and at 212° F. per lb. of combustible..... | 9.258 lbs. |

RATE OF COMBUSTION AND EVAPORATION.

| | | |
|-----|---|-------------|
| 45. | Coal burned per hour per square foot of grate surface..... | 15.68 lbs. |
| 46. | Water evaporated per hour from and at 212° per square foot of grate surface..... | 139.73 lbs. |
| 47. | Water evaporated per hour from and at 212° per square foot of heating surface..... | 2.62 lbs. |

COMMERCIAL HORSE POWER.

| | | |
|-----|---|-------------|
| 48. | On basis of 34.5 lbs. of water from and at 212° F. per hour..... | 121.5 H. P. |
| 49. | H. P. builders rating at 15 square feet per H. P. | 107 H. P. |
| 50. | Per cent developed above rating..... | 13.5 |

DATA FOR ENGINE TRIAL (24 hours).

| | | |
|-----|---|---------------|
| 51. | Average steam pressure in engine room (gauge). | 129.99 lbs. |
| 52. | Average steam pressure in 1st receiver (gauge).. | 34.78 lbs. |
| 53. | Average steam pressure in 2nd receiver..... | .851 lbs. |
| 54. | Average reading of water force main gauge..... | 77.93 lbs. |
| 55. | Average vacuum in condenser for low pressure cylinder..... | 25.32 in. Hg. |
| 56. | Average suction vacuum of pump..... | 8.09 in. Hg. |
| 57. | Average temp. of hot well discharge..... | 91.16° F |
| 58. | Average temp. of water discharged from jackets. | 327.84° F |
| 59. | Average temperature of water discharged from receiver..... | 281.01° F |
| 60. | Total number of revolutions of pumping engine dur- ing trial (24 hours)..... | 62 190 |

| | | |
|-----|--|-------------------------|
| 61. | Revolutions per minute..... | 43.19 |
| 62. | Total number of gallons pumped during trial (24 hours) calculated from plunger displacement | 6 548 103.25 |
| 63. | Total number of pounds pumped during trial. | 54 649 462.5 |
| 64. | Leakage .4204 per cent..... | 229 746.3 |
| 65. | Actual number of pounds pumped to stand pipe. | 54 419 716.2 |
| 66. | Head against which water was pumped, equivalent reading of force main gauge (180.07 feet), plus suction lift, plus frictional resistance through pump (2.31 feet)..... | 193.4 ft. |
| 67. | Total amount of work done in raising water by pumping engine during trial (24 hours) | 10 524 773 113 ft. lbs. |

HEAT UNITS SUPPLIED TO ENGINE.

| | | |
|-----|---|-------------------|
| 68. | Total feed water supplied to boiler at temp. of hot well (91.16 F) in 24 hours..... | 88 255 lbs. |
| 69. | Water trapped from separator in steam pipe in 24 hours | 2 808 lbs. |
| 70. | Moisture in steam (3.05 per cent.)..... | 2 692 lbs. |
| 71. | Dry steam actually supplied to engine in 24 hours. | 82 755 lbs. |
| 72. | Total heat above 0° F in a pound of dry steam at 129.99 pounds gauge or 144.69 pounds absolute | 1 222.21 B. T. U. |
| 73. | Total heat above 0° F in 1 pound of water at temp. 91.16° F..... | 91.21 B. T. U. |
| 74. | Steam supplied engine in each pound of steam | 1 131.10 B. T. U. |
| 75. | Total B. T. U. supplied engine in 24 hours, 82 755 × 1 131.10..... | 93 594 180 |
| 76. | B. T. U. in jacket water above temp. of hot well returned to boiler in 24 hours, 9 044 × (330—91.21)..... | 2 159 769 |
| 77. | Same for receiver water 5815 × (283—91.21)..... | 1 115 334 |
| 78. | Actual B. T. U. given to engine..... | 90 319 077 |

DUTY CALCULATED ACCORDING TO MEASURED HEAD.

Allowing 1 lb. loss of pressure through pump.

79. Duty per 1 000 000 B. T. U.

$$= \frac{10\,524\,773\,113 \times 1\,000\,000}{90\,319\,077} = 116\,528\,000$$

80. Duty per 1 000 pounds of steam..... 131 804 820 ft. lb.

DUTY AS CALCULATED FROM AVERAGE MEAN.

81. Average M. E. P. of pump cards..... 87.731 lbs.
 82. Equivalent head..... 202.66 ft.
 83. Work (54 419 716.2 \times 202.66)..... 11 028 699 645 ft lbs.
 84. Duty per million heat units..... 123 215 400 ft. lbs.
 85. Duty per 1 000 pounds of steam..... 139 368 938 ft. lbs.

THE AMERICAN SOCIETIES OF ENGINEERS.

HORATIO W. BAKER, '01, SCHOOL OF CIVIL ENGINEERING.

There are two great agencies which help to advance the engineer in his profession—the technical college and the engineering society. The object of this article is to interest the students, about to leave the former, in the members and methods of the latter.

The work of the engineering societies is accomplished by affording its members personal acquaintanceship, by the reading papers and by publications. The latter are of such importance as to be sought with the greatest eagerness by all the great public and other libraries, and by the practitioner, as furnishing the best possible accounts of current and standard engineering practice throughout the country.

The four leading societies of engineers in the United States have made the fact manifest that engineering has come to be a profession, and, more than that, a learned profession, demanding more of its novices, and compelling a more rigid and exacting course of preparatory study from those seeking to enter its higher fields than any other profession. Their lists of honorary and active members contain the names of not only all the prominent and successful engineers of the day, but also many foreign engineers of distinction.

The American Society of Civil Engineers, the oldest, and probably the most prominent of the above-mentioned societies, was organized in 1852, being the first engineering society formed in the United States. It now has 2 124 members, representing every State in the Union, three Territories and twenty-six foreign countries.

The requirements for membership are high and are rigidly enforced. The constitution requires that "a Member shall be a Civil, Military, Naval, Mining, Mechanical, Electrical, or other professional Engineer, an Architect or a Marine Architect. He shall be at the time of admission to membership, not less than thirty years of age, and shall have been in active practice of his profession for ten years; he shall have had responsible charge of work for at least five years, and shall be qualified to design as well as to direct engineering works. Graduation from a school of engineering of recognized reputation shall be considered as equivalent to two years active practice." Membership is carefully guarded, an applicant for membership being required to make a concise detailed statement of his training and experience, which shall be vouched for by at least five members to whom he is personally known. After receipt of this statement the Board of Direction writes to each of the references as to his personal knowledge of the applicant, and his professional work. No further step is taken until at least five communications have been received from the references. If the applicant is approved by the Board of Direction a statement of his qualifications is sent to each member of the Society with a request that members transmit any information in their possession which may affect the disposition of the application. Later a secret letter ballot is issued to the entire membership, and seven negative votes exclude from membership.

Associate and Junior Members have requirements slightly less rigorous than Members.

“An Associate Member shall be a professional Engineer or Architect, not less than twenty-five years of age, who shall have been in active practice of his profession for at least six years, and who shall have had responsible charge of work as principal or assistant for at least one year. Graduation from a school of engineering of recognized reputation shall be considered equivalent to two years active practice.

“A Junior shall not be less than eighteen years of age, and his connection with the Society shall cease when he becomes thirty years of age, unless he be previously transferred to another grade. He shall have had active practice in some branch of engineering for at least two years, or he shall have graduated from a school of engineering of recognized standing.”

The initiation fee for Members is \$30, and for Associates and Juniors \$25 and \$10 respectively. The annual dues are for residents within fifty miles of New York City, \$25 for Members and \$20 for others; and for residents more than fifty miles from New York, \$15 for all Members and \$10 for Juniors.

The headquarters of the Society are at 220 West Fifty-seventh St., New York, in a house owned by the Society. The house contains reception room, offices of the Society, conversation room, auditorium, library, reading room, and kitchen. A Secretary and five clerks are in constant attendance.

Regular meetings are held twice a month at the Society house, except during July and August. One of the above meetings is called the annual meeting, at which all business of the Society is transacted. The Annual Convention is held at different places from year to year.

The papers before being presented at the meeting are printed and sent to members to allow of preparation of written or oral discussion thereof. At the reading of the paper the written discussions are read, after which the papers are open for oral discussion. A volume of transactions is issued monthly, containing papers and discussions thereof. These transactions are of the very highest professional interest to members and others.

The American Society of Mechanical Engineers was established in 1881 and is modeled much after the same plan as the American Society of Civil Engineers. The requirements for mem-

bership are as follows: "All persons connected with engineering may be eligible for admission into the Society. To be eligible as a Member, the candidate must not be less than thirty years of age, and must have been so connected with engineering as to be competent as a designer or as a constructor, or to take responsible charge of work in his department, or he must have served as a teacher of engineering for more than five years.

"To be eligible as an Associate, the candidate must not be less than twenty-six years of age, and must have the other qualifications of a Member; or he shall have been so connected with engineering as to be competent to take charge of work, and to co-operate with engineers.

"To be eligible as a Junior, the candidate must have had such engineering experience as will enable him to fill a responsible position, or he must be a graduate of an engineering school."

The manner of making application for membership, the number of the references, manner of voting and the number of negative votes necessary to debar from membership are the same as in the American Society of Civil Engineers.

The initiation fee of Members and Associates is \$25, and the annual dues are \$15. The initiation fee for a Junior is \$15 and the annual dues \$10. Any Member or Associate may become a Life Member in the same grade by the payment of \$200 and shall not be liable thereafter to annual dues.

The American Institute of Electrical Engineers is of later origin, having been organized in 1884. The requirements for membership are not as rigid as in the other societies. The following in regard to membership is taken from the rules of the Society.

"The Institute shall consist of Members, Honorary Members and Associates. Members shall be Electrical Experts, Electricians or Electrical Engineers possessing such knowledge of the principles of electrical science and such familiarity with the practical application of electricity in its several branches as those branches imply.

"Associate Members shall be such persons as are or have been connected with the utilization of electricity, or who by means of study or experimental investigation are qualifying themselves to become identified with electrical science and such others to whose admission no objection shall be made by any member

of the Council. Proposals for admission shall be indorsed by at least three Members or Associates, and referred to the Council, which shall have power to elect to Associate Membership only.

“All Members and Associates shall be equally entitled to the privileges of membership. Transfers from associate membership to membership may be made by the Council upon application, subject to the approval of a Board of Examiners.

“The entrance fee shall be \$5 for each person. The dues of Members and Associates shall be \$10 per annum. Any Member or Associate may become, by the payment of \$100 at any time, a life Member or Associate and shall not be liable thereafter to annual dues.”

The American Institute of Architects was organized in New York in the year 1857 and at present has about 500 members. The membership of the Institute consists of Fellows, Associates, Corresponding and Honorary Members. Local organizations known as Chapters are maintained by the Institute. Fellows are resident architects of the United States or may be architects engaged in professional education. Fellows are only chosen from the ranks of Associate Members, except in special cases, and election to the rank of Fellow is for professional merit only. Any architect in the United States is eligible to Associate Membership if able to submit the required proofs of his professional capacity and honorable personal and professional standing. When an application for the rank of Fellow is received, signed by three Fellows of the Chapter of the applicant, if the candidate is considered eligible to election, a letter ballot is issued and five negative ballots debar from membership. The manner of electing Associates is identical with that of electing Fellows. Only Fellows and Associates may hold office.

The annual dues of Associates are \$5, and of Fellows, \$10. The initiation fee is \$5 and no fee is paid by an Associate passing to the rank of Fellow.

STRENGTH OF CONCRETE AS AFFECTED BY THE PROPORTION OF MORTAR.

BY G. F. BECKERLEG, CIVIL ENGINEERING, '99.

As a thesis investigation, the writer sought to determine the crushing strength of concrete with different proportions of the voids in the aggregate filled with mortar. As far as known no other experiments have ever been made along this line. The tests consisted of crushing 6-inch cubes when 30, 90 and 180 days old; but at the present writing only the first two have been completed. The following article is an abstract of the thesis.

The materials were measured by volumes, all uncompacted except by shaking. The cement was Saylor's Portland. The sand was a natural silica sand having a fineness as follows, the larger figures representing the number of the sieve, and the smaller number preceding the sieve number being the per cent caught on that sieve, and the small number after the sieve number being the per cent passing that sieve and caught on the next one: 5^{21} 15^9 20^{13} 30^{24} 50^{31} . The voids in the dry sand were 33 per cent when well shaken down. The aggregates consisted of broken limestone screened to practically an uniform size, limestone unscreened except to remove particles that would pass a No. 5 sieve, broken flint and gravel. The per cent of voids in the aggregates were: Screened limestone 40, unscreened limestone 40, flint 50, gravel 20. Three sets of cubes were molded, viz.: (1) those in which the volume of the loose mortar was equal to 100 per cent. of the voids in the aggregate, (2) mortar equal to 75 per cent, and (3) mortar equal to 50 per cent of voids.

As before stated the tests are not yet completed, but the results of the tests of fifty-seven cubes are as follows: Considering as unity the mean for all the cubes having the mortar equal to the voids, the strength with mortar equal to 75 per cent of

the voids is 0.69, and with mortar equal to 50 per cent of the voids is 0.36. In other words, the strength of the concrete decreases more rapidly than the proportion of mortar omitted. Of course the experiments are too few to make such a conclusion absolutely conclusive; and, besides, the variations of the experiments among themselves is such as to cast a doubt over the conclusion. The later experiments are awaited with anxiety. The author feels that the question is worth a more thorough investigation than his other duties permitted him to make.

THE RAILWAY TRANSITION SPIRAL.

BY ARTHUR N. TALBOT, PROFESSOR OF MUNICIPAL AND SANITARY
ENGINEERING.

[This article was originally published in *THE TECHNOGRAPH* No. 5, 1890-91. Principally because of demands for this article, that number of *THE TECHNOGRAPH* is now out of print, and as the method here described has been adopted on many railroads and has been commended by engineers, it is republished with modifications and extensions.

To the engineer not mathematically inclined, it may be well to add that a knowledge of the demonstrations of the formulas is not essential to an understanding of the principles, and that the methods used in laying out the spiral are found to be readily mastered by instrument men.]

A transition curve, or easement curve, as it is sometimes called, is a curve of varying radius used to connect circular curves with tangents for the purpose of avoiding the shock and disagreeable lurch of trains, due to the instant change of direction and also to the sudden change from level to inclined track. The primary object of the transition curve, then, is to effect smooth riding when the train is entering or leaving a curve.

The generally accepted requirement for a proper transition curve is that the degree-of-curve shall increase gradually and uni-

formly from the point of tangent until the degree of the main curve is reached, and that the super-elevation shall increase uniformly from zero at the tangent to the full amount at the connection with the main curve and yet have at any point the appropriate super-elevation for the curvature. In addition to this, an acceptable transition curve must be so simple that the field work may be easily and rapidly done, and should be so flexible that it may be adjusted to meet the varied requirements of problems in location and construction.

Without attempting to show the necessity or the utility of transition curves, this paper will consider the principles and some of the applications of one of the best of these curves, the railway transition spiral.*

The Transition Spiral is a curve whose degree-of-curve, increases directly as the distance along the curve from the point of spiral.

Thus, if the spiral is to change at the rate of 10° per 100 feet, at 10 feet from the beginning of the spiral the curvature will be the same as that of a 1° curve; at 25 feet, as of a $2^\circ 30'$ curve; at 60 feet, as of a 6° curve. Likewise, at 60 feet, the spiral may be compounded with a 6° curve; at 80 feet, with an 8° curve, etc.

This curve fulfills the requirements for a transition curve. Its curvature increases as the distance measured around the curve. The formulas for its use are comparatively simple and easy. The field work and the computations necessary in laying it out and in connecting it with circular curves are neither long nor complicated, and are similar to those for simple circular curves. The curve is extremely flexible, and may easily be adapted to the requirements of varied problems. The rate of change of degree-of-curve may be made any desirable amount according to the maximum curve used, the maximum speed of trains or the requirements of the ground.

As the derivation of the formulas is somewhat long, their demonstration will be given first. The explanation and application of these formulas to the field work and to the computations will be given separately, a knowledge of the demonstration not being essential to the application.

*The author desires to express his obligation to Mr. J. K. Barker, '92, for valuable aid in the preparation of drawings, the calculation of tables, and the checking of formulas, and to Messrs. Alfred Kuehn, C. L. Eddy and others of the class of 1900 for assistance on the revision

NOMENCLATURE.

In Fig. 1, DLH is the circular curve and AP the prolongation of the initial tangent which are to be connected by the transition spiral. D is the point where the completed circular curve gives a tangent DN parallel to the tangent AP, and will be called the P.C. of the circular curve. AEL is the transition spiral connecting the initial tangent AP with the main or circular curve LH. A is the beginning of the spiral and will be known as P. S., point of spiral. L is the beginning of the circular curve LH, and will be called P.C.C., point of circular curve. AP will be used as the axis of X, and A as the origin of co-ordinates. BD is the offset between the tangent AB of a circular curve and spiral, and the parallel tangent DN of an unspiraled curve.

The degree-of-curve of the spiral at any point is the same as the degree of a simple curve having the same radius of curvature as the spiral has as that point. The radius of the spiral changes from infinity at the P.S. to that of the main curve at the P.C.C. The spiral and a simple curve of the same degree will be tangent to each other at any given point; *i. e.*, they will have a common tangent.

The following notation will be used:

P.S.=Point of spiral.

P.C.C.=point where spiral compounds with circular curve.

P.C =beginning of offsetted circular curve, as D Fig. 1.

R=radius of curvature of the spiral at any point.

D =degree-of-curve of the spiral at any point; called D_1 at the end of spiral. Generally D_1 is made the same as D_0 , the degree of the main curve.

a =rate of change of the degree-of-curve of the spiral per 100-ft. of length. It is the degree-of-curve of the spiral at 100 ft. from the P.S.

s =length in feet from the P.S. along the curve to any point on the spiral.

L =number of 100-ft stations from the P.S. along the curve to any point on the spiral; in other words the distance to any point measured in units (or stations) of 100 ft. For the whole spiral (to P.C.C.) it is called L_1 .

I =total central angle of the whole curve (intersection angle), or twice BCH of Fig. 1, H being the middle of the circular arc.

J =angle showing the change of direction of the spiral at any point, and is the angle between the initial tangent and the tangent to the spiral at the given point. For the whole spiral it is equal to PTL and may be called J_1 . The latter is also equal to DCL.

θ =deflection angle at the P.S., from the initial tangent to any point on the spiral. For the point L, it is BAL.

ϕ =deflection angle at any point on the spiral, between the tangent at that point and a chord to any other point. At L, for the point A, ϕ is TLA.

x =abscissa of any point on the spiral, referred to the P.S. as the origin and the initial tangent as the axis of X. For the point L, $x=AM$.

y =ordinate of the same point, measured at right angles to the above axis. For the point L, $y=ML$.

t =abscissa of the P.C. of the main curve produced backward; *i. e.*, of a simple curve without the spiral. For P.C. at D, $t=AB$.

o =offset between the initial tangent and the parallel tangent from the main curve produced backward, or it is the ordinate of the P.C. of the produced main curve. If D is the P.C., BD is o . It is also the radial distance between the concentric circles LH and BK.

T =tangent-distance for spiral and main curve=distance from A to the intersection of tangents.

E =external-distance for spiral and main curve.

C =long chord AL of the transition spiral.

The length of the spiral is to be measured along chords around the curve in the same way that simple curves are usually measured, using any length of chord up to a limit which depends upon the degree-of-curve of the spiral. The best railroad practice, in the writer's opinion, considers circular curves up to a 7° curve as measured with 100-ft. chords, from 7° to 14° as measured with 50-ft. chords, and from 14° upwards as measured with 25-ft. chords; that is to say, a 7° curve is one in which two 50-ft. chords together subtend 7° of central angle, a 14° curve one in which four 25-ft. chords together subtend 14° of central angle. The advantages of this method are two-fold,—the length of the curve as measured along the chords more nearly approximates the actual length of the curve, and the radius of the curve is almost exactly inversely proportional to the degree-of-curve. The latter con-

sideration is an important one, simplifying many formulas. With this definition of degree-of-curve, the formula $R = \frac{5730}{D}$ will give no error greater than 1 in 2 500. For a 10° curve the error in the radius is .15 feet, and for a 16° curve .06 feet. This approximate value of R will give a resulting error in the length of the spiral, for the ordinary limits of spirals, of less than $\frac{1}{6000}$ of the length, and will not reach 0.1-ft. The resulting error in alignment is $\frac{1}{6000} y$, and will not reach 0.01-ft. The difference between the length of the curve and that of these chords is less than 1 in 7 000. For spirals measured with lengths of chords as here specified, or shorter, the error either in alignment or distance will be well within the limits of accuracy of the field work, and hence the relation $R = \frac{5730}{D}$ will be considered true.

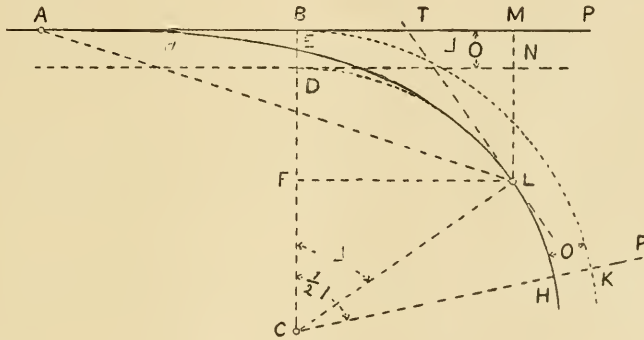


FIG. 1.

THEORY.

From the definition of the transition spiral, we have, remembering that the value of a as defined above requires the length of curve to be measured in 100-ft. units (*stations*) instead of feet,

$$D = a L = \frac{a s}{100} \dots \dots \dots (1)$$

For the P.C.C. this becomes $D_1 = a L_1$.

From the calculus the radius of curvature

$$R = \frac{ds}{d\Delta}$$

Substituting the expression $R = \frac{5730}{D}$ and solving,

$$d\Delta = \frac{a s ds}{573000}$$

$$\text{Integrating, } J = \frac{a s^2}{1146000} = \frac{a L^2}{114.6}$$

Changing J from circular measure to degrees,

$$J = \frac{1}{2} a L^2, \dots \dots \dots (2)$$

which is the intrinsic equation of the Transition Spiral.

For the P.C.C. this becomes $J_1 = \frac{1}{2} a L_1^2$.

Since from (1) $a = \frac{D}{L}$, we also have

$$J = \frac{1}{2} D L = \frac{1}{2} \frac{D^2}{a} \dots \dots \dots (3)$$

From these equations it will be seen that

(a) the change of direction of the spiral varies *as the square of the length* instead of as the first power of the length as in the simple circular curve, and

(b) that the transition spiral for any angle J will be twice as long as a simple circular curve.

To find the co-ordinates, x and y , of any point on the spiral, we have by the calculus $dy = ds \sin J$ and $dx = ds \cos J$. Expanding the sine and cosine into an infinite series, substituting for ds its value in terms of dJ , and integrating, we have

$$y = \frac{1070.5}{(a)^{1/2}} \left\{ \frac{1}{3} J^3 - \frac{1}{42} J^5 + \frac{1}{1320} J^{7/2} - \text{etc.} \right\} \dots \dots \dots (4)$$

$$x = \frac{1070.5}{(a)^{1/2}} \left\{ J^2 - \frac{1}{10} J^4 + \frac{1}{216} J^6 - \text{etc.} \right\} \dots \dots \dots (5)$$

As J here is measured in circular measure and is only $\frac{1}{2}$ when the angle is $28.^\circ 65$, these series are rapidly converging, especially for smaller angles.

Changing the angle J from circular measure to degrees, substituting for J , and dropping the small terms,

$$y = .291 a L^3 - .00000158 a^3 L^7 \dots \dots \dots (6)$$

For values of J less than 15° the last term may be dropped, and up to 25° the term will be small. $D L^2$ may also be written in place of $a L^3$. Also

$$x = 100L - .000762 a^2 L^5 + .0000000027 a^4 L^9 \dots \dots \dots (7)$$

$$\text{Or } x = 100L - .000762 D^2 L^3 \dots \dots \dots (8)$$

The second term in eq. (7) or (8) may be used as a correction to be subtracted from the length of the curve in feet. The third term in eq. (7) can generally be omitted.

To find the deflection angle θ for any point on the spiral, as BAL for the point L, divide equation (4) by equation (5).

$\tan \theta = \frac{1}{3}J + \frac{1}{105}J^3 + \frac{2}{1575}J^5$, etc. But from the tangent series for $\frac{1}{3}J$,

$\tan \frac{1}{3}J = \frac{1}{3}J + \frac{1}{81}J^3 + \frac{2}{3645}J^5$, etc. Subtracting one from the other, we get a series which is rapidly decreasing when J is less than 40° . Investigating this difference, remembering that J is in circular measure, it is found that the error of calling the two equations equal is less than $1'$ for $J = 25^\circ$ and decreases rapidly below this. As J will rarely reach 25° and as the resultant error of direction will be corrected at the P.C.C when $J - \theta$ is turned off, we may write

$$\theta = \frac{1}{3}J = \frac{1}{6}a L^2 = \frac{1}{6} \frac{D^2}{a} \dots \dots \dots (9)$$

Between 20° and 40° , .000053 J^3 (where J is in degrees) will give the numbers of minutes correction to be subtracted from $\frac{1}{3}J$ to give θ . This deduction for the larger values of θ is as follows: $\theta = 4^\circ, 0'.1$; $5^\circ, 0'.2$; $6^\circ, 0'.3$; $7^\circ, 0'.5$; $8^\circ, 0'.7$; $9^\circ, 1'.0$; $10^\circ, 1'.4$; $11^\circ, 1'.9$; $12^\circ, 2'.4$. As stated above for J less than 25° this correction may ordinarily be omitted on the spiral, using the J and θ for that point.

For the terminal point of the spiral, P.C.C., this becomes $J_1 - \theta_1$ which is generally expressed with sufficient precision by $\frac{2}{3}J_1$.

To find the tangent at any point of the spiral, L, lay off a deflection angle from LA equal to $J - \theta$. When J is not over 20° , $\frac{2}{3}J$, or 2θ may be used. This since $FLT = PTL = J$, and $FLA = PAL = \theta$. This is true for any point.

At any point on the spiral to find the deflection angle for a second point. In Fig. 2, let L' be the distance from the P.S. to R, and L the distance from the P.S. to any other point on the spiral, as K. Let FRN be the tangent at R, and $RFM = J'$ its angle with the initial tangent, and θ' the corresponding spiral deflection angle. Let $KTM = J$ be angle of tangent at K with initial tangent, equal to total change of direction of the spiral up to that point. θ' and θ are the deflection angles at the P.S. for R and K respectively. $KRN = \psi =$ required deflection angle. Then

$$\tan (\psi + J') = \frac{UK}{RU} = \frac{y - y_1}{x - x_1}$$

Substituting for the co-ordinates their values from equations (4) and (5), and also developing $\tan \frac{1}{3} \frac{J^3 - J'^3}{J^{\frac{1}{2}} - J'^{\frac{1}{2}}}$ into a series, and subtracting the latter from the former, an expression for the difference will be found, which amounts to but a small fraction of a minute for any value of J up to 35° . Hence we may write

$\phi + J' = \frac{1}{3}(J' + J'^{\frac{1}{2}} J^{\frac{1}{2}} + J)$; whence by substitution and reduction

$$\phi = \frac{1}{2} a L' (L - L') \pm \frac{1}{6} a (L - L')^2 \dots \dots \dots (10)$$

$$J' - \theta' \pm \phi = \theta + \frac{1}{6} D' L \dots \dots \dots (11)$$

$$J' \pm \phi = \theta' + \theta + \frac{1}{6} D' L \dots \dots \dots (12)$$

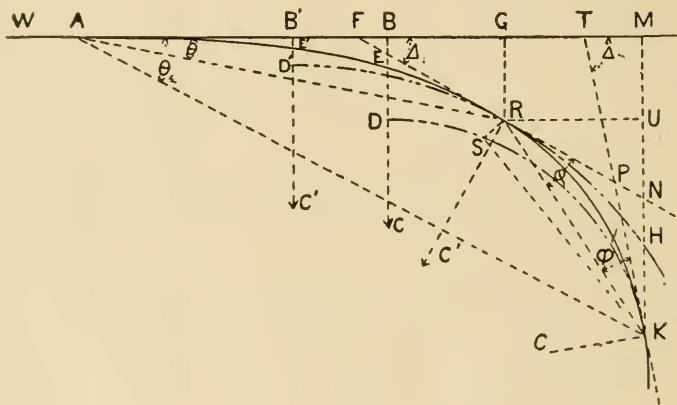


FIG. 2.

It will be noticed that the first term of equation (10) is the deflection angle for a simple curve of the same degree as the spiral at the point R (called the osculating circle), and of length equal to the distance between the two points; while the second is the deflection angle at the P.S. from the initial tangent for an equal length of spiral. If the second point had been chosen on the side nearer the P.S., the second term would have an opposite sign from the first. Equation (10) may then be written with the plus and minus sign.

The spiral then deflects from a circle of the same degree-of-curve at the same rate that it deflects from the initial tangent. D'RH, in Fig. 2, represents the circular curve tangent to spiral

at R, the two having the same radius at that point and both being tangent to FRN. The deflection angles between points on the spiral and on the circle RH, and also between the spiral and RD' are the same as for the same length of spiral from A. In the same way at K, RKT=SKT—SKR, the latter angle being equal to the deflection from initial tangent at A for a length of spiral equal to KR.

Equation (11) shows that the angle at any point between the chord joining this point with the P.S. and a chord to any other point (the angle, Fig. 2, between AR and RK if the point K is to be located from R) is equal to the spiral deflection angle at the P.S., θ , for the point to be located (KAM) plus one third of the deflection angle of a circular curve of the same degree as that of the spiral at the vertex of the angle, R, and of the length of the spiral from P.S. to the point K. This is true whether the point to be located is nearer the P.S., or farther, than the point used as the vertex of the angle.

It may also be readily shown from (2) that the difference in direction of the two tangents, $J—J'$, is the central angle for this simple curve plus the spiral angle, both for a length equal to the distance between the two points.

Ordinates from osculating circle. It may also be shown that the distance between a point on the spiral and one on the osculating circle is the same as the ordinate y from the initial tangent at a point the same distance from the P.S. as the former point is from the point of osculation. These ordinates may be measured in a direction normal to the circular curve.

To find the offset o . From Fig. 1, $BD = BF - DF = BF - CD$ vers DCL. But $o = BD, BF = y$ for end of spiral, $DCL = J$ for whole spiral, and $CD = R$. Hence, $o = y - R$ vers J . Substituting for y, R , and J their values in terms of the length of the whole spiral, and reducing, we have for o in feet

$$o = .0727 a L_1^3 = .0727 D_1 L_1^2 \dots \dots \dots (13)$$

where D_1 and L_1 refer to the whole length of the spiral. The other terms of the series are so small that they may be dropped when J is less than 30° . The next term is $-.0000002 a^3 L_1^3$. It will be seen that o is approximately one fourth of the ordinate of the P.C.C., which, of course, should be true if E, the middle point of the spiral, is opposite D, the P. C.

To find t , or A B. From Fig. 1, $AB = AM - BM = x - FL = x - R \sin J$. Expanding and reducing,

or $t = 50 L_1 - .000127 a^2 L_1^5 \}$
 $t = 50 L_1 - .000127 D_1^2 L_1^3 \}$ (14)

A comparison of t with the abscissa found by substituting $\frac{1}{2} L_1$ in equation (8) shows that BD cuts the spiral at a point only .0001 $a^2 L^5$ feet from the middle point of the spiral. This is $\frac{1}{3}$ of the correction used in equation (14) for finding t from $\frac{1}{2} L_1$. For our purpose we may say that BD bisects the spiral. It also follows that the spiral bisects the line BD, since $BE = \frac{1}{8} J$. This is subject to slight error for large angles.

The length of the spiral from the P.S. to BD, therefore, exceeds t by one fifth of the t correction, and the remainder of the spiral exceeds the length of the circular curve from the P.C. to the P.C.C. by four fifths of the t correction. The entire length of the spiral exceeds the distance measured on t (AB, Fig. 1) plus the distance measured around the circular curve (DL, Fig. 1) by the t correction given in equation (14).

If the offset is given. From (11) and (3) we have

$L = 3.7141 \frac{o}{D}$ (15)

$J = 1.8571 \sqrt{\frac{o}{D}}$ (16)

$a = .2691 \frac{D^3}{o}$ (17)

$3\frac{5}{7}$, $1\frac{6}{7}$ and $\frac{7}{36}$ may be used for these co-efficients with advantage.

To find the tangent-distance T , consider in Fig. 1 that AB intersects CH, H being the middle of the circular curve, at some point P outside the diagram. Then $T = AP = AB + BP$. $BP = BC \tan BCH$.

Hence $T = t + (R + o) \tan \frac{1}{2} I$ (18)

t and $o \tan \frac{1}{2} I$ may be computed separately and added to the T found from an ordinary table of tangent-distances.

(18) gives T for the same transition spirals at each end of the main curve. It may be desirable to make one spiral different from the other. To find an expression for the tangent-distances for this case proceed as follows: In Fig. 3, let $RS = HD = o_2$, $BD = o_1$, $AB = t_1$, $RT = t_2$, $AE = T_1$, $TE = T_2$, R = radius of main curve DLKS, $R + o_2$ = radius of HR, and I = angle PER.

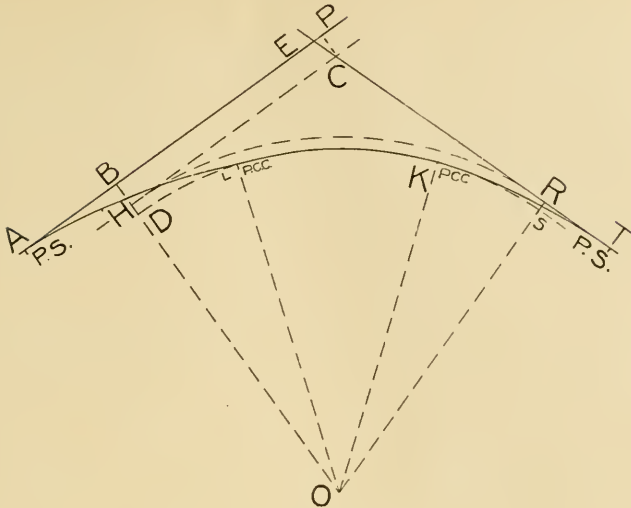


FIG. 3.

Then $T_1 = t_1 + HC - PE$, and

$$T_1 = t_1 + (R + o_2) \tan \frac{1}{2} I - (o_1 - o_2) \cot I \dots \dots \dots (19)$$

Similarly, $T_2 = t_2 + (R + o_2) \tan \frac{1}{2} I + (o_1 - o_2) \operatorname{cosec} I$.

When I is more than 90° , the last term of (19) becomes essentially positive.

To find the external-distance, $E = HP$. In Fig. 1, $HP = KP + HK$. Hence

$$E = (R + o) \operatorname{exsec} \frac{1}{2} I + o \dots \dots \dots (20)$$

To find the long chord, $C = AL$. In Fig. 1, $ML = AL \sin MAL$,

or $C = \frac{y}{\sin \theta}$. Putting this in terms of the length of the curve,

$$C = 100L - (.0004 a^2 L^5 \text{ or } .0004 D^2 L^3) \dots \dots \dots (21)$$

in which C is in feet and L in stations. It will be seen that the last or correction term is $\frac{1}{125}$ of the correction for x as given in equation (7).

The middle ordinate for any arc of the spiral is equal to the middle ordinate for an equal length of circular curve of the same degree-of-curve as the spiral at the middle point of the arc considered. This degree-of-curve is the average of the D 's, at the

end of the given arc. This is an approximate formula which is true whether one end of the chord is at the P.S. or not.

The ordinate from any other point along the chord may be found as follows: Since the spiral diverges from the osculating circle at the middle point of the arc at the same rate as from the initial tangent, the amount of this divergence may be calculated by the method given on page 81 and added to or subtracted from the ordinate for the osculating circular curve.

SUMMARY OF PRINCIPLES.

For convenience of reference the principal formulas will be repeated here.

$$\left. \begin{aligned} D &= aL \text{ and } L = \frac{D}{a} \dots\dots\dots (1) \\ D_1 &= a L_1 \text{ for whole spiral } \dots\dots\dots \end{aligned} \right\}$$

$$\left. \begin{aligned} J &= \frac{1}{2} a L^2 = \frac{1}{2} D L = \frac{D^2}{2a} \dots\dots\dots (2) \\ J_1 &= \frac{1}{2} a L_1^2 = \frac{1}{2} D_1 L_1 \text{ for whole spiral } \dots\dots\dots \end{aligned} \right\}$$

$$j = .291 a L^3 - \text{etc.} \dots\dots\dots (6)$$

$$j_1 = 100L - .000762 a^2 L^5 + \text{etc.} \dots\dots\dots (7)$$

$$\left. \begin{aligned} \theta &= \frac{1}{3} J = \frac{1}{6} a L^2 = \frac{1}{6} D L = \frac{D^2}{6a} \dots\dots\dots (9) \\ \theta_1 &= \frac{1}{3} J_1 = \frac{1}{6} a L_1^2 \dots\dots\dots \end{aligned} \right\}$$

$$\phi = \frac{1}{2} a L' (L - L') \pm \frac{1}{6} a (L - L')^2 \dots\dots\dots (10)$$

$$J' = \theta' \pm \phi = \theta + \frac{1}{6} D' L \dots\dots\dots (11)$$

$$J' \pm \phi = \theta + \theta' + \frac{1}{6} D' L \dots\dots\dots (12)$$

$$o = .0727 a L_1^3 = .0727 D_1 L_1^2 \dots\dots\dots (13)$$

$$t = 50 L_1 = .000127 a^2 L_1^5 \dots\dots\dots (14)$$

$$L_1 = 3.7141 \frac{o}{D_1} \dots\dots\dots (15)$$

$$J_1 = 1.8571 \frac{o}{D_1} \dots\dots\dots (16)$$

$$a = .2691 \frac{D_1^3}{o} \dots\dots\dots (17)$$

$$T = t + (R + o) \tan \frac{1}{2} I \dots\dots\dots (18)$$

$$E = (R + o) \operatorname{exsec} \frac{1}{2} I + o \dots\dots\dots (20)$$

$$C = 100L = .0004 a^2 L^5 \dots\dots\dots (21)$$

An inspection of the formulas and demonstrations will show the following properties of the transition spiral:

1. The degree-of-curve at any point on the spiral equals the degree at 100 feet from the P.S. multiplied by the distance along the spiral from the P.S. to the point (Eq. 1). This distance must be expressed in units of 100 feet (stations). Thus, if $a=2$, at 100 feet from the P.S. the spiral will be a 2° curve; at 25 feet, a $0^\circ 30''$ curve; at 450 feet, a 9° curve. $\frac{100}{a}$ is the number of feet in which D changes one degree. At the terminal point, P.C.C., D becomes D_1 , which should generally equal the degree of the circular curve D_0 . The total length of the spiral will be $\frac{D_1}{a}$. If $a=2$, a 6° curve would require a spiral 3 stations (300 feet) long.

2. The angle J between the initial tangent and the tangent at any point on the spiral (the change of direction corresponding to central angle of circular curves) in degrees equals:

(a) One half of a times the square of the distance in 100-ft. stations from the P.S. to the point; thus if $a=2$, for 300 ft. from P.S., $J = \frac{1}{2} \times 2 \times 3^2 = 9^\circ$. Or

(b) One-half of the product of this distance by the degree-of-curve of the spiral at the given point; thus at 300 ft. with $a=2$, $D=6^\circ$ and $J = \frac{1}{2} \times 3 \times 6 = 9^\circ$. Or

(c) One-half of the square of degree-of-curve at the point divided by a ; thus at 300 ft. with $a=2$, $J = \frac{1}{2} \times \frac{6^2}{2} = 9^\circ$.

For the same angle, then, the spiral is twice as long as a circular curve.

3. The spiral deflection angle θ at the P.S. from the initial tangent to any point on the spiral, as PAL in Fig. 1, is $\frac{1}{3}J$, or $\frac{1}{6}aL^2$. Thus, for a point 300 ft. from the P.S., if $a=2$, $\theta = \frac{1}{6} \times 2 \times 3^2 = 3^\circ$. It is also one third of the deflection angle for a simple curve of the same degree as the spiral at the given point. Thus, as above, the deflection angle for 300 ft. of 6° curve is 9° and $\theta = \frac{1}{3} \times 9 = 3^\circ$.

These values are subject to slight corrections in large angles as explained in the derivation of the formula.

4. The deflection angle at any point on the spiral between the tangent at this point and the chord to the P.S. (TLA in Fig. 1) is $J - \theta$. This enables the tangent to be found.

5. For deflection angles from a point on the spiral to other points on the spiral, the principle that the spiral diverges from the osculating circle (circular curve of same degree) at the same rate that the spiral deflects from the initial tangent is of service. The angles may be treated in three ways.

Angles from Tangent. By equation (10) the deflection angle between the tangent at a transit point on the spiral and the chord to any other point on the spiral (as CBH, Fig. 4) is the sum or difference of two angles: (1) the deflection angle for a circular curve of the same degree as the spiral at the transit point for a length equal to the distance between the two points, and (2) the spiral deflection angle θ for a length of spiral equal to the distance between the two points. The latter angle is *plus* if the desired point is further from the P. S., and *minus* if nearer than the point from which the deflections are made.

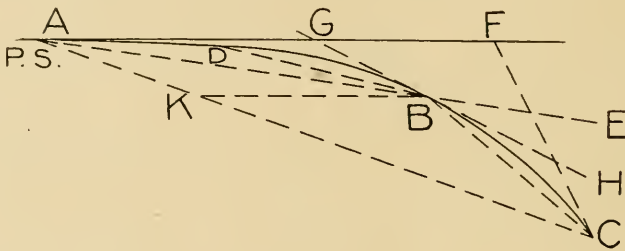


FIG. 4.

Thus, if $a=2$ and the transit be at B (Fig. 4), 250 ft. from the P.S., the degree-of-curve at the transit point will be 5° , and the deflection angle CBH to set a point 150 ft. ahead will be $3^\circ 45'$, ($\frac{1}{2}$ of 150 ft. of 5° curve) $+ 45'$, (spiral deflection angle for 150 feet, $10 \times 2 \times \frac{150^2}{10000}$) or $4^\circ 30'$. For D, 150 ft. back, it would be $3^\circ 45' - 45' = 3^\circ 0'$.

Angles from chord. Likewise by equation (11) the angle CBE, Fig. 4 (deflection angle from chord to P.S.) may be calculated by adding the spiral deflection angle θ for the point C (GAC) to $\frac{1}{6}$ the product of the degree of curve at B by the number of stations from the P.S. to C. For $a=2$ and the transit at B, 250 ft. from the P.S., the degree of curve at the transit point is 5° , and the angle CBE to locate the point C 150 ft. ahead and 400 ft. from

the P. S., will be $(\frac{1}{6} \times 2 \times 4^2 = 5^\circ 20')$ $+$ $(\frac{1}{6} \times 5 \times 4 = 3^\circ 20')$ $= 8^\circ 40'$. For the point D 100 ft. from the P.S., the angle DBA will be $(\frac{1}{6} \times 2 \times 1^2 = 20')$ $+$ $(\frac{1}{6} \times 5 \times 1 = 50')$ $= 1^\circ 10'$. This method is applicable whether the point to be located is nearer to, or farther from, the P.S. than the transit point. It permits the calculation of the spiral deflection angles at P.S. for the whole spiral and the determination of the angles between the chords in question by adding to these spiral deflection angles the angles $\frac{1}{6} D' L$, where D' is the degree-of-curve at the transit point and L is the distance to the point to be located.

Angles with Initial Tangent. If θ' is added to these values, the resulting angle (equation (12)) will give the angle with the direction of the initial tangent.

6. The spiral diverges from its osculating circle (circular curve of same degree) at any point at the same rate that the spiral deflects from the initial tangent, and the distance between the circle and spiral is the same as the y for an equal length of spiral.

This enables the spiral to be located by offsets measured from the circular curve. By this method half of the spiral may be located from the initial tangent and half from the produced circular curve, the offsets for the two being the same for the same distances from the P.S. and the P.C.C. respectively. See Fig. 5.

7. The offset o , between the initial tangent and the parallel tangent from the main curve produced backward, in feet equals .0725 times the product of a , by the cube of the length of the whole spiral in stations, or .0725 times the square of the length of spiral and the degree of main curve. This ordinate is approximately one fourth of the ordinate y of the end of the spiral. The spiral bisects the offset at a point half-way between the P.S., and the P.C.C. (Eq. 11.) $BE = ED$. $AE = EL$. (Fig. 1.) The slight error in this is discussed in the derivation of the formulas.

8. The distance t from the P.S. to this offset is found by subtracting the correction $.000127 a^2 L_1^5$ from the half length of the curve in feet. (Eq. 14.)

9. The long chord is found by subtracting the correction, $.0004 a^2 L^5$ from the length of the curve in feet. (Eq. 21.)

10. Other properties may be found by ordinary trigonometric operations.

THE TABLES.

The computations may be shortened by the use of the tables.

Tables I-VIII give the values of the principal parts of the transition spiral for the following values of a ,—1, $1\frac{1}{4}$, $1\frac{2}{3}$, 2, $2\frac{1}{2}$, $3\frac{1}{3}$, 5 and 10. The column headed "Length" is the distance in feet along the spiral from the P.S. to any point on the spiral, and is equal to 100 times the L of the formulas. The column headed " x COR." gives the correction to be subtracted from this distance in feet along the spiral to obtain x , and that headed " t COR." gives the correction to be subtracted from the half length of the spiral in feet to obtain t . Both t COR. and o are to be taken from the line for the full length of the spiral. For example, by Table I, with $a=1$, to connect with a 5° curve, the length of spiral is 500 ft. and $L=5$; the change of direction Δ_1 is $12^\circ 30'$; the offset o to P.C. of circular curve is 9.07 ft; t is $250-.4=249.6$ ft; x is $500-2.37=497.63$ ft; and the values of D , Δ , θ , y and x COR. for points 200, 210, 220 ft., etc., distant from the P.S. are found in the line with 200, 210, etc. To find the long chord to P.S., subtract $\frac{1}{5}$ of x COR. from the length of the curve in feet.

To find values intermediate between the distances given in the tables, interpolate by multiplying one tenth of the difference between consecutive values by the number of additional units. Thus Table I gives Δ for 400 ft. as $8^\circ 00'$; for 410 ft., $8^\circ 24'.3$. One tenth of the difference between these is $2'.4$. For 406.8 ft., add $6.8 \times 2.4 = 16'.3$ to $8^\circ 00'$, giving $8^\circ 16'$. For y , add $6.8 \times .143 = .97$ to 18.59, giving 19.56 ft.

In general this interpolation gives accurate results. For Δ the error in interpolation with values of a greater than 5 may need to be taken into account. To find exact values of Δ , deduct from the interpolated values a times the following quantities: For a length in feet ending with 1, .027'; 2, .048'; 3, .063'; 4, .072'; 5, .075'; 6, .072'; 7, .063'; 8, .048'; 9, .027'. It can easily be determined whether this correction need be considered. The difference arises from the fact that the square of numbers does not increase uniformly. For the other columns the errors of interpolation are very slight and may be neglected.

Table I has been carried to several decimal places to permit its use for any value of a . To calculate values for another a , multiply the tabular value of D , Δ , θ , o , or y in Table I for the distance from the P.S. to the point on the spiral by the a of the spiral, and the x COR. and t COR. by the square of the a of the spiral. Thus if $a=2.2$ and $L=3.1$, multiply the D , Δ , θ , o and y opposite 310 by 2.2, and the x COR. and t COR. by the square of 2.2. The values of y , o and x COR. obtained in this way are subject to slight errors for large values of a if Δ is more than 18° , but fortunately y for a distance greater than half of the length of the spiral is seldom needed, and as the error of this and the errors in o and x COR. are ordinarily small the correction may generally be neglected. The amount of this error may be found by the method given in a succeeding paragraph.

To use Table I for another a , it may be desirable first to determine the length of the spiral by dividing the D_1 of the required spiral by a or determine it from o . Thus, for $a=1.5$, to connect with a 6° curve, divide 6 by 1.5, which gives $L_1=4$; that is, the whole spiral will be 400 ft. long, and the properties for the spiral may be computed by multiplying those in the line with the required distance by 1.5. In other words it must be borne in mind that the distances in the column of lengths remain unchanged with new values of a , and the quantities in all the other columns will be changed for a other than 1.

For the calculation of tables and other work requiring the recognition of a further term in the equations, the value of the second term of the o series ($.0000002 a^3 L^1$, eq. (13)) and of the second term of the y series ($.00000158 a^3 L^1$, eq. (6)) may be obtained by multiplying the quantities in the table on page 90 by a^3 , and the third term of the x series ($.0000000268 a^4 L^9$, eq. (7)) by a^4 . These terms for o and y are negative, and the term for x is to be subtracted from the x COR.

For making corrections on results obtained from Table I for a other than 1, subtract from the product of the multiplication $a(a^2-1)$ times the value from the above table in obtaining o and y , and $a(a^3-1)$ times the value from the table in obtaining x COR.

| L | o | y | x |
|------|-------|-------|-------|
| 2.50 | ..... | .0010 | ..... |
| 3.00 | .0004 | .0035 | ..... |
| 3.50 | .0013 | .010 | ..... |
| 4.00 | .0032 | .026 | .0007 |
| 4.50 | .0074 | .059 | .002 |
| 5.00 | .015 | .124 | .005 |
| 5.50 | .030 | .241 | .012 |
| 6.00 | .055 | .442 | .027 |
| 6.50 | .097 | .775 | .055 |
| 7.00 | .163 | 1.301 | .108 |

By Table IX the ordinate from the tangent or from the circular curve at a decimal part of the half length of the spiral may be obtained by the multiplication of o of the spiral by the factor given in the table. See method by co-ordinates and Fig. 5.

Table X gives values of o and L for various values of a . Within reasonable limits it will bear interpolation, but for intermediate values of a and D and to determine a for intermediate values of o . It is of service in location problems.

CHOICE OF a AND LENGTH OF SPIRAL.

The selection of a and with it the length of spiral requires consideration. The value of a to be used is dependent upon the speed of trains, the maximum degree-of-curve, the length of tangents, the permissible offset of the line for the topographical conditions in question, the distance in which the superelevation of the outer rail may be attained, etc., and hence is subject to a wide range. It may, however, aid the engineer's judgment to discuss these conditions briefly.

For the same rolling stock and for the same comfort in riding, it would seem that a given amount of superelevation must be attained in the same length of time; and hence it is probable that a should vary nearly inversely as the cube of the speed of train. This conclusion also emphasizes the desirability of spiraling curves used under high speeds. Considering that $a=1$ is a proper value for speeds of 50 miles per hour, this principle would suggest the following maximum values of a : 60 miles per hour, $\frac{1}{2}$; 50 miles per hour, 1; 40 miles per hour, 2; 30 miles per hour, $3\frac{1}{3}$; 25 miles per hour, 5; 20 miles per hour, 10. While for the very high speeds this may seem to require unnecessarily long

spirals and for low speeds short spirals, yet $a=1$ has given satisfactory results at speeds of 50 to 60 miles an hour, and $a=2$ at 40 to 50 miles an hour, and for 60 miles an hour, $a=\frac{1}{2}$ is not too small. Of course, in any case, longer spirals and smaller values of a will give smoother riding curves.

The speed of trains may be limited by the maximum superelevation allowable on the sharper curves. Under usual practice the requirement of maximum superelevation would limit the maximum degree-of-curve for speeds of 60 miles an hour to 3° , for 50 miles to 4° , for 40 miles to 6° , for 30 miles to 12° , etc. Where the track is not used for slow trains and a superelevation of more than 7 or 8 inches is allowable, somewhat higher speeds on such curves may be used. The maximum speed of train, however, will be the governing consideration in the choice of a rather than the maximum degree-of-curve.

The rate of attaining the superelevation is sometimes given as the governing consideration, but this rate must be governed by the speed. To illustrate: The distance in which the outer rail attains an elevation of 1 inch should not be the same for a speed of 60 miles an hour as for one of 40 miles. The schedule of maximum values of a for various speeds as given above involves, approximately, attaining 1 inch of elevation in the following distances: 60 miles, 80 feet; 50 miles, 53 feet; 40 miles, 44 feet; 25 miles, 40 feet.

For a given value of a there may be a question as to how flat a curve may profitably be spiraled. In general it would seem that for the lighter curves a value of θ less than 1 foot and for the sharper curves of less than 0.6 foot would be the limit of effective service, and that the efficiency is largely increased with higher values of θ . For $a=\frac{1}{2}$, curves of $1^\circ 30'$ and sharper would fill this condition; for $a=1$, $2^\circ 30'$; for $a=2$, $3^\circ 30'$; for $a=3\frac{1}{2}$, 5° ; for $a=5$, 6° ; for $a=10$, 9° . With these values of a , spirals on curves lighter than those named are not very efficient; and in any case decreasing the value of a and thus increasing the length of the spiral will increase the efficiency of the spiral and better the riding qualities of the curve.

The selection of a , then, must be a matter to be left to the judgment of the engineer. As a guide the following table containing values of a which have given satisfactory results at the

speeds noted is given. Lower values of a are of course advantageous; as, for example, at a speed of 40 miles an hour $a=1\frac{1}{3}$ or even 1 will make a more efficient easement than the one given. Higher values of a —shorter spirals—may be necessary in many cases, but it must be understood that they will not be so satisfactory. The column headed "Minimum curve spiraled" is the lightest curve which it is considered desirable to spiral with the value of a given opposite. The speeds are given in miles per hour and the elevations in inches.

MINIMUM SPIRAL FOR MAXIMUM SPEED.

| Maximum Speed. | a | Maximum Curve. | Min. Curve Spiraled. | Length per Degree. | Elev. per Degree. |
|----------------|----------------|----------------|----------------------|--------------------|-------------------|
| 60 | $\frac{1}{2}$ | 3' | 1° 30' | 200 | $2\frac{1}{2}$ |
| 50 | 1 | 4' | 2° 30' | 100 | $1\frac{7}{8}$ |
| 40 | 2 | 7° | 3° 30' | 50 | $1\frac{1}{8}$ |
| 30 | $3\frac{1}{3}$ | 11° | 5° | 30 | $\frac{5}{8}$ |
| 25 | 5 | 14° | 6° | 20 | $\frac{1}{2}$ |
| 20 | 10 | 25° | 9° | 10 | $\frac{2}{100}$ |

For shorter spirals, the following values of a are consistent with each other: 60 miles per hour, 1; 50 miles per hour, $1\frac{2}{3}$; 40 miles per hour, $3\frac{1}{3}$; 30 miles per hour, $6\frac{2}{3}$; 25 miles per hour, 10.

LOCATION OF P.S., P.C.C. AND P.C.

LOCATION FROM INTERSECTION OF TANGENTS. When the tangents have been run to an intersection, the P.S. (A Fig. 1) may be located by measuring back on the tangent from the point of intersection a distance equal to the tangential distance T (equation 18). This distance may also be computed by adding $t + \theta \tan \frac{1}{2} I$ to the tangential distance of the circular curve as ordinarily calculated. The P. C. (D Fig. 1) may be located by calculating θ and offsetting this amount at a point on the tangent distant t from the P.S. The P.C.C. may then be located by running the spiral from the P.S., or by locating the circular curve from the P.C. for a distance $\frac{1}{2} L_1$.

LOCATION FROM P.C. OF A CURVE WITHOUT SPIRAL. In case a simple curve has been run without a spiral and without offsets, the distance of the P.S. back of the P.C. of the simple curve is $t + \theta \tan \frac{1}{2} I$. The new curve will come inside the old but will not be exactly parallel to it.

LOCATION FROM P.C. OF OFFSETTED CURVE. If a simple curve has been run, as DLH in Fig. 1, o may be computed, the offset measured to B and the distance t measured to locate the P.S. (A). The length $\frac{1}{2} L_1$ measured from the P.C. on the circular curve will locate the P.C.C. (L). Similarly if the tangent is fixed the curve may be located by first making the offset from the tangent to the P.C.

If both P.C. and tangent are fixed with an offset $o=BD$ between them, a may be found from $a=.2691\sqrt{\frac{D^3}{o}}$; or a and L may be found from Table X. After finding t , the P.S. may be located in the usual manner. This method is a great convenience where it is desired on account of the ground to throw the curve in or out without changing the tangent, or where a similar change in the tangent is desired without a change in the curve, the connection to be made by means of a suitable spiral.

LAYING OUT THE SPIRAL BY CO-ORDINATES.

With the initial tangent as axis of X and the P.S. as the origin of co-ordinates, it is not difficult to locate points on the spiral by means of co-ordinates. These may be calculated from equations (6) and (7), or they may be taken from the tables. Beyond B of Fig. 1, the ordinates become large and the x correction may be considerable. For long spirals, the second term of the y series, may need to be considered. The property that the spiral diverges from the circular curve at the same rate as from the initial tangent is of service. Between E and the P.C.C.(L) measure the ordinate or offset from the circular curve, using for this offset at a point a given distance from the P.C.C. the ordinate y of the spiral from the tangent at the same distance from the P.S. Thus, for $a=1$, by Table I, for a point 200 ft. from the P.S., $y=2.33$ ft. To locate a point on the spiral 200 ft. from the P.C.C., offset from the circular curve this same distance, 2.33 ft.

Knowing the y for any point on the curve, the y for any other point within ordinary limits may be found by multiplying the former by the cube of the ratio of the distances from the P.S. to the respective points; thus, if for a point 250 ft. from the P.S., $y=2.33$ ft., y at 300 ft. equals $(\frac{3}{2})^3 \times 2.33 = 7.85$ ft. Simi-

larly points may be located by offsets from the circular curve, the distance being measured from the P.C.C.

If the length of the half spiral be divided into an integral number of parts (See Fig. 5), any ordinate from the tangent or from the circular curve may be easily calculated from σ , by multiplying σ by one half the cube of the ratio of the number of parts this point is from the P.S. to the whole number of parts.

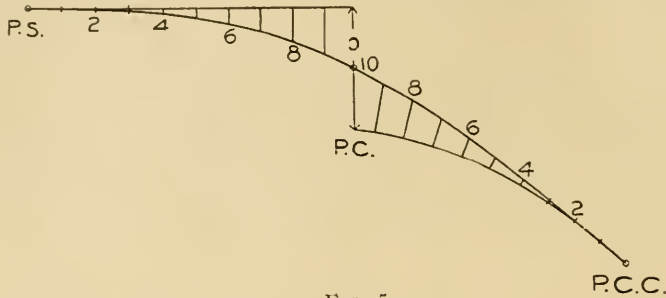


FIG. 5.

The following table gives the factor by which the σ of the spiral may be multiplied to determine the y of the point when the length of the half spiral is divided into 10 parts.

TABLE OF FACTORS FOR ORDINATES.

To find y , multiply σ by the factor.

| Ratio to half length. | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 |
|-----------------------|-------|------|------|------|------|------|------|------|------|------|
| Factor. | .0005 | .004 | .014 | .032 | .063 | .108 | .172 | .256 | .365 | .500 |

As an example, with $a=1$, σ for a 5° curve (spiral 500 feet long) is 9.07 ft. The half length of the spiral is 250 ft. and one-tenth of this distance is 25 ft. y at 100 ft. (.4 of the half length) is $.032 \times 9.07 = 2.9$ ft. Similarly, 2.9 ft. will be the offset from the circular curve at a point 100 ft. from the P.C.C.

To divide the half-length of spiral into 5 parts and the whole spiral into 10 parts, use the even numbered tenths of the above table.

For intermediate values, interpolation in the above table will give reasonably accurate results. This enables interpolation for quarter points, and other fractional parts; thus, for .67 of half length the factor is .153.

The results by the above table are subject to error in the hundredths place, but for usual cases are within .02 ft.

Many engineers prefer the co-ordinate method. The circular curve is run from the P.C. established by making the offset from the initial tangent, and the spiral is then located by setting off ordinates from the simple curve between P.C. and P.C.C. and by ordinates from the initial tangent back to the P.S., or for the latter portion by laying off $o-y$ from a tangent at the P.C. parallel to the initial tangent, the ordinates being calculated by one of the preceding methods. This is particularly applicable to location work and to short spirals, though under many conditions it may readily be applied to setting track centers.

LAYING OUT THE SPIRAL BY TRANSIT AND DEFLECTION ANGLES.

The spiral may be run in with the transit by turning off deflection angles and making measurements along chords in much the same manner as circular curves. The deflection angles are easily calculated, and the field work is not more difficult than for circular curves. The ordinary transit-man will find no difficulty in understanding the work. Since it is not necessary to keep succeeding chords the same length as the first, the stationing may be kept up, and the even stations, +50's, and other points put in as usual. Herein is an advantage over methods requiring a regular length of chord to be used.

TRANSIT AT P.S. With the transit at the P.S., the deflection angle θ (BAL, Fig. 1) will locate points on the spiral. θ may be taken from the tables, or it may be calculated from Eq. (9), $\theta = \frac{1}{3} \sqrt{\frac{1}{6}} a L^2$. For this calculation, if desired, the square of L may be taken from a table of squares, the lower decimals dropped, and the multiplication by the simple factors remaining may be made easily and rapidly. Thus, when $a=2$, to determine θ for a point 234 ft. (2.34 stations) from the P.S., find the square of 234 (54756), change the decimal point so that it will become the square of 2.34 (5.48), and $\theta = \frac{1}{6} a L^2 = \frac{1}{6} \times 2 \times 5.48 = 1^\circ 49'$. If the result is wanted in minutes, since $\frac{1}{6} \times 60 = 10$, use 10 instead of $\frac{1}{6}$.

If it is not desired that the even stations be located, the spiral may be located by 50-ft. chords, or chords of other length,

directly from the P.S. and the labor of calculation will be reduced.

TRANSIT ON SPIRAL.—For deflection angles from an intermediate transit point on ordinary circular curves, three methods are in use among engineers:

(a) The measurement and record of the angle between the tangent to the curve at the transit point and the chord to the point to be located.

(b) The use of the angle between the chord connecting the transit point to the P.C., and the chord to the point to be located.

(c) The use of the angle between a line through the transit point parallel to the initial tangent and the chord to the point to be located. These three methods may be used with the spiral and will be treated separately.

(a) *Angles from Tangent.* By equation (10), the angle between the tangent at the transit point and any chord (as CBH, Fig. 4) is $\phi = \frac{1}{2} a L' (L-L') \pm \frac{1}{6} a (L-L')^2$. This method then involves the following steps. With transit at B (Fig. 4) set vernier at $\Delta' - \theta'$ (these being the angles for transit at the P.S. for the point B), and back-sight on the P.S. so that the zero reading will give the tangent BH. To locate any point C find the sum of (1) one half of the product of the degree-of-curve at the transit point B by the distance in stations from the transit point to C and (2) the spiral deflection angle θ for the same distance. For D, find the difference of these quantities. Thus, for $a=1$, with the transit 300 ft. from the P.S., D' the degree-of-curve at B is 3° . For C 100 ft. from B, add $\frac{1}{2} \times 3 \times 1 = 1^\circ 30'$ and $\frac{1}{6} \times 1 \times 1^2 = 10'$, giving $1^\circ 40'$ for CBH. For D 100 ft. from B, $DBG = 1^\circ 30' - 10' = 1^\circ 20'$.

(b) *Angles from Chord to the P.S.* This is the method generally to be recommended. By equation (11) the angle between the chord from transit point to P.S. and any chord (as CBE, Fig. 4) is $\theta + \frac{1}{6} D' L$, D' being the degree-of-curve at the transit point. This method involves the following steps: With transit at B and vernier reading zero, back-sight on the P.S. To locate C turn off an angle equal to the sum of (1) the spiral deflection angle θ for a distance equal to the distance from C to the P.S. and (2) one sixth of the product of the degree-of-curve at the transit point and L for the point C. Thus for $a=1$, with the transit 300

ft. from the P.S., D' at B is 3° . For C 100 ft. from B and 400 ft. from the P.C., add $\frac{1}{6} \times 1 \times 4^2 = 2^\circ 40'$ and $\frac{1}{6} \times 3 \times 4 = 2^\circ$, giving $4^\circ 40'$ for CBE. For D 100 ft. from B, $DBA = 40' + 1^\circ = 1^\circ 40'$.

To facilitate the calculation the transit point may be chosen at a point where the spiral has an even degree-of-curve, as in the above example, but this is not essential. It may be seen that $\frac{1}{10} D'$ gives the minutes per foot in $\frac{1}{6} D' L$.

(c) *Angles with Initial Tangent.* The use of angles with the line parallel to the initial tangent (BK, Fig. 4) is the same as (b) except that θ' , the spiral deflection angle to the transit point, must be added to all angles. Otherwise the method is the same as (b). Use Equation (12).

TRANSIT AT P.C.C. With the transit at the P.C.C., the tangent to the curve may be found by turning off from the chord to the P.S. an angle $\angle_1 - \theta_1$. Within ordinary limits this equals $2\theta_1$. The main circular curve may be run as usual.

In case the P.S. can not be seen from the P.C.C., the chord to the P.S. may be located by turning off from the chord to an intermediate point on the spiral an angle $\angle_1 - \theta_1 - \psi$ (ACB, Fig. 4.) where ψ is the angle between this chord and the tangent at P.C.C.

To locate the chord from P.C.C. to P.C. (not shown in any diagram), deflect from the chord to the P.S. the angle $\frac{1}{2} \angle_1 - \theta_1$. To locate chord to P.C. from a chord to an intermediate point on spiral, deflect from chord to the intermediate point the angle $\frac{1}{2} \angle_1 - \psi$. With the data already at hand, it may be easier to calculate this angle as $\theta + \frac{1}{6} D' L - \frac{1}{2} \angle_1 + \theta_1$, remembering that θ and L refer to the intermediate point and D' , \angle_1 and θ_1 to the P.C.C.

Some engineers prefer to measure the deflection angles at the P.C.C. for the circular curve from the tangent at the P.C.C., and others prefer to measure from the chord to the P.C. and thus maintain the same notes as though the spiral had not been used. By the use of the angles discussed in the preceding paragraphs, either method may be used.

To run from the P.C.C. toward the P.S.

(a) When the distances \bar{L} are measured from the P.C.C., deflect from the tangent to the curve an angle equal to the difference of (1) one-half the product of D_1 (degree-of-curve at P.C.C.) and distance L to point (which is the same as the deflection angle

for D_1^2 circular curve) and (2) spiral deflection angle θ for distance L , ($\frac{1}{6}aL^2$). This is the same as method (a) of "Transit on Spiral." The method depends upon the principle that the spiral deflects from the osculating curve at the P.C.C. at the same rate that it deflects from the initial tangent at P.S.

(b) When the distances L are measured from the P.S., deflect from the chord to the P.S. an angle equal to the sum of (1) the spiral deflection angle θ for distance L from the P.S. ($\frac{1}{6}aL^2$) and (2) one sixth of the product of D_1 (degree-of-curve at the P.C.C.) and L ($\frac{1}{6}D_1L$). This is the same as (b) of "Transit on Spiral." Either method is easily used.

TRANSIT NOTES. For a spiral with $a=2$ connecting with an 8° curve, $L=4$, and if the P.S. has been found to be at 16+29, the notes may be made as follows, using method (b) for the transit on the spiral. At Sta. 19 the deflection angle from the chord to the P.S. as a back-sight is the sum of those given in third and fourth columns, and it is here inclosed in brackets.

| STA. | POINTS | θ | $\frac{1}{6}D_1L$ | |
|-----------|---------------------|---------------|--|---|
| +29 0 | P.C.C. 8° | $5^\circ 20'$ | $3^\circ 37'$ | Set Vernier at $0^\circ - 4^\circ 56'$, back-sight on 19, and 0° reading gives tangent. |
| 20 | | $4^\circ 35'$ | $[8^\circ 57']$ | |
| +50 | | $3^\circ 26'$ | $3^\circ 21'$ $[7^\circ 56']$ $2^\circ 54'$ $[6^\circ 20']$ | |
| 19 | \odot $D' = 5.42$ | $2^\circ 27'$ | | Set Vernier at 0° , back-sight on P.S. and turn off angle in brackets |
| +50 | | $1^\circ 37'$ | | |
| 18 | | $0^\circ 58'$ | | |
| 17 | | $0^\circ 10'$ | | Curve to Right |
| 16 + 29 0 | P.S. | $0^\circ 0'$ | | $a=2, L=4, \Delta_1=16^\circ$. |

FIELD NOTES

APPLICATION TO EXISTING CURVES.

When a road has been constructed without transition curves, the ordinary application of the preceding principles will require a new line to be built inside the old curve, and the cost of construction may be considerable. To retain as far as possible the old roadbed, two methods are applicable:

(a) To replace the old curve by a new and sharper curve located so as not to vary far from the old alignment; and

(b) To replace a part of the existing curve with a curve of slightly smaller radius, compounding with the old curve.

(a) TO REPLACE THE ENTIRE CURVE. In Fig. 6, the line TNH is the old curve. It is desired to throw the line out at H the middle point of the curve, a distance $HK=p$, in order to put in a spiral by throwing the line in at the P.C. P is the intersec-

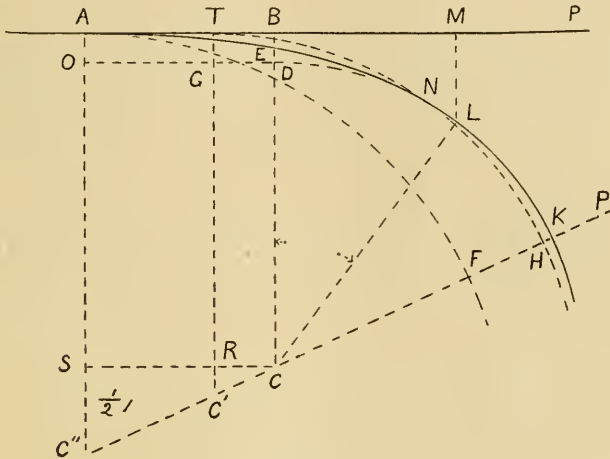


FIG. 6.

tion of tangents, which comes outside the diagram. Let R_1 be the radius of the old curve and R of the new, $HP-KP=p$, or $R_1 \text{ exsec } \frac{1}{2} I - (R+o) \text{ exsec } \frac{1}{2} I - o = p$. Hence

$$R_1 - R = o + \frac{o+p}{\text{exsec } \frac{1}{2} I} = \frac{o+p}{\text{vers } \frac{1}{2} I} = p \dots \dots \dots (22)$$

$$p = \frac{(R_1 - R) \text{vers } \frac{1}{2} I - o}{\cos \frac{1}{2} I} = (R_1 - R - o) \text{exsec } \frac{1}{2} I - o \dots \dots \dots (23)$$

$$\begin{aligned} \text{Also } AT = AP - TP = t - (R_1 - R - o) \tan \frac{1}{2} I \\ = t - (o+p) \cot \frac{1}{4} I \dots \dots \dots (24) \end{aligned}$$

by which the P.S. may be located; or if T is not known, the tangent distance AP may be calculated and A located.

Values of p from 0 to $\frac{1}{2} o$ may be used. If the new curve comes inside the old at the center, p must be used as negative and its sign in the formula must be changed. It must be borne in mind that the o used in the above formula must be the o of the new curve. As this will not be known, use the value of o for the

required to locate D and the P. S. and P. C. C. so that a selected curve, D_1 , will give a calculated or assumed distance EF as o .

Let R_0 be the radius of the D_0 curve and R_1 that of the D_1 curve, and I_1 the angle to be replaced.

$$o = EF = FH - EH = (R_0 - R_1) \text{vers } I_1.$$

$$\text{vers } I_1 = \frac{o}{R_0 - R_1} \dots \dots \dots (25)$$

Having I_1 , back up on the curve to D, run the D_1 curve to G, the P. C. C. of spiral, and locate the spiral. The P. S. may be located from B by

$$AB = t - (R_0 - R_1 - o) \tan I_1 = t - (R_0 - R_1) \sin I_1 \dots \dots \dots (26)$$

Thus consider that a part of a 4° curve is to be replaced with $4^\circ 30'$ curve, and that $a=1, o=6.62$. By (25), $I_1=16^\circ 35'$. Take out $BD=414.6$ ft. of a 4° curve and locate D. $16^\circ 35'$ of $4^\circ 30'$ curve requires 368.5 ft. The half length of the spiral is 225 ft. The P. C. C. is then found by running from D $368.5 - 225 = 143.5$ ft. of $4^\circ 30'$ curve to the P. C. C., G. Likewise by (26) $AB = 224.8 - 45.4 = 179.4$ ft.

The limiting values of D_1 will be on the one hand $\frac{2}{3}D_0$ and on the other a value which will make BD one-half the length of the original curve. Ordinarily, D_1 should not be one fifth more than D_0 ; better less than one tenth more on sharp curves.

SECOND METHOD. When the middle portion of the curve is in fair alignment, and it is desired not to disturb it, a method by taking up points on the old track and not running the tangents to an intersection, may be used. See Fig. 8. Select M, N, and O on the curve on the portion not to be disturbed. Set transit at M, measure the distances MN and NO, and by the usual methods for circular curves determine the degree-of-curve, D_0 , which will fit this middle portion. The selection of points in this way will probably not give a curve whose tangent coincides with the track tangent. Consider, that when this curve is run back until parallel to A H at B, the distance from the track tangent is m . From M, intersect with tangent at H and measure I . Determine m by running out MDB, or by calculation from $m = HG \sin I$ and $HG = HM - GM$, remembering that GM is the tangent distance for I° of D_0 curve. Let ED be the new D_1 curve which must be run in from D that EF shall be the o for the D_1 curve. Call the radius of the

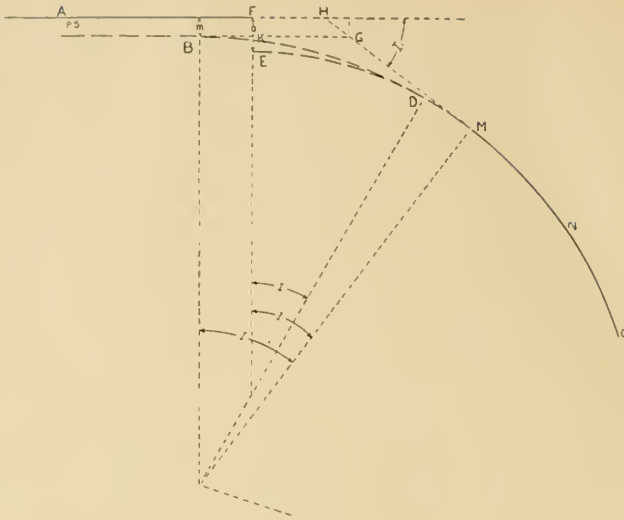


FIG. 8

D_0 curve R_0 and that of the D_1 curve R_1 . The D_1 curve will have I_1 of central angle. Then

$$EK = o - m = (R_0 - R_1) \text{ vers } I_1$$

$$\text{vers } I_1 = \frac{o - m}{R_0 - R_1} \dots \dots \dots (27)$$

If o is less than m , then R_1 must be greater than R_0 . If K comes outside of AH , m must be added to o . Care must be taken that M is far enough back on the curve.

To locate the curves, run $I-I_1$ of D_0 curve from M to D . Run DE to locate the P.C., or run such part of this D_1 curve as will give the P.C.C. for the spiral.

The P.S. (A) may be located as follows:

$$AH = t + BG - BK - HG \cos I \dots \dots \dots (28)$$

$BG = GM$, the tangent distance for P' of D_0 curve, $BK = (R_0 - R_1) \sin I_1$, and $HG \cos I$ is also $m \cot I$.

For example, if D_0 has been found to be 4° and I at H 20° and m 1.2 ft., select $D_1 = 4^\circ 30'$ and $a = 1$. Then $o = 6.62$. From equation (27) $I_1 = 15^\circ$. Then as MB is 500 ft. and DB 375 ft., $MD = 125$ ft., $DE = 333.3$ ft. The P.C.C. for spiral is $333.3 - 225 = 108.3$ ft. from D . AH is $224.8 + 253.6 - 41.1 - 3.3 = 434.0$ ft. The spiral may be run in by usual methods.

When the new D_1 curve is so much sharper that it is desired to connect it with the old by a spiral, the following method is applicable. Call a_1 the offset to tangent, and a_0 the offset between the two curves, the latter to be found as for compound curves. Then by a method similar to the foregoing,

$$\text{vers } I_1 = \frac{a_1 - a_0 - m}{R_0 - R_1 - a_0} \dots\dots\dots (29)$$

METHODS OF TRACK MEN. When curves are left without transition curves, many track men “ease” the curve by throwing the P.C. inward a short distance and gradually approaching the tangent a few rail lengths away, while the main curve is reached finally by sharpening the curve for a short distance.

Another simple method for track which is aligned to a circular curve, consists in utilizing one of the properties of the transition spiral. In Fig. 1, let ABK be the original track line, B being the P.C. Select a length of spiral and calculate a , or select a and calculate the length, by a preceding method. At a distance from B equal to half the length of spiral (point on the curve opposite L) throw the track inward to L a distance equal to a . At B, the old P.C., throw the track to E, a distance half as great. Measure back from B half the length of the spiral to A for the beginning of the easement. Between A and L, line the track by eye, or calculate offsets from Table IX. The remainder of the main curve must then be thrown in the same distance as at L.

On long curves the latter work would be objectionable. It may be avoided by using a spiral running up to a curve whose degree-of-curve is one third greater than that of the main curve and compounding directly with the main curve. To do this, first select length of spiral for a curve one third sharper than the circular curve which call L . See Fig. 9. Call the circular curve D_0 and the curvature of the end of the spiral D_1 . Measure back from the old P.C. on tangent a distance $\frac{1}{3} L$, which will locate the P.S. Measure forward on the curve from the P.C. a distance $\frac{1}{6} L$ to locate the middle of the spiral, and offset from prolongation of tangent a distance equal to $\frac{1}{2} a$, or $\frac{1}{4} a$ from the circular curve. Measure also along the curve from the P.C. a distance $\frac{2}{3} L$ to the P.C.C. where the track will not be changed. The spiral will pass the old P.C. at $\frac{1}{3} a$ from it, and at a point $\frac{1}{4} L$ from the

P.C.C. will be $\frac{1}{8} o$ distant from the circular curve. The spiral is one and one half times as long as the circular curve replaced.

The o used must be that for the full spiral and for the sharper curve, $\frac{1}{3} D_0$, and the true position of the circular curve should be known. As the last fourth of this spiral is sharper than the main curve, the elevation of the outer rail up to the P.C.C. must be greater than that on the main curve, gradually reducing beyond to the regular amount.

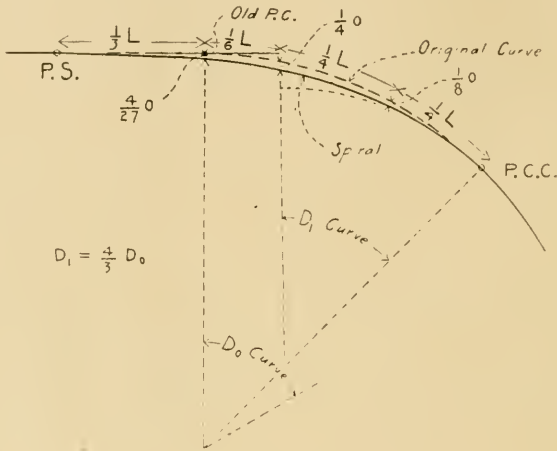


FIG. 9.

Thus, for a 3° curve, using $a=1$, the degree at the end of spiral will be $3 \times \frac{1}{3} = 4$, and the length of spiral required is 400 ft., $o=4.65$. The P.S. will be 133.7 ft. back of the P.C., the middle of spiral 66.7 ft. ahead of P.C., and the P.C.C. 266.7 ft. ahead of P.C. At the P.C. the track must be thrown in 0.69 ft., at the middle point 2.32 ft. from tangent (1.16 ft. from curve), and at the third quarter point .58 ft. from curve, while at the P.C.C. there will be no change. Between these points the track may be aligned by eye, or ordinates may be calculated by Table IX.

However, while such methods are easements, they are at best makeshifts and should give place to better methods.

COMPOUND CURVES.

The spiral may be used to connect curves of different radii, choosing that part of the spiral having curvature intermediate between the degrees of the two curves; thus, connect a 3° and an 8° curve by omitting the spiral up to $D=3^\circ$ and continuing until $D=8^\circ$. In Fig. 10, DKM is a D_1 curve, and LNP a D_2 curve, the

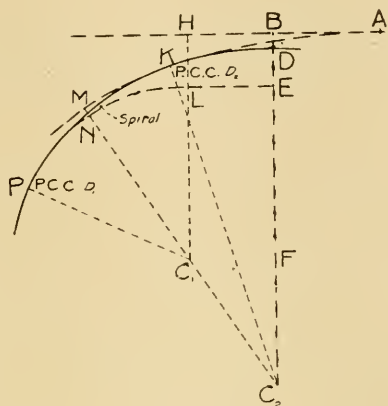


FIG. 10.

two curves having parallel tangents at M and N. D_2 is greater than D_1 . Call the distance MN o . It is desired to connect the two curves by a spiral shown by the full line KP. The degree of curve of the spiral at K must be D_1 , and at P, D_2 . Consider the spiral to be run backward from K to a tangent at A. Then the spiral from K to P is the portion of the regular spiral from where its degree is D_1 to the point where it is D_2 . Since the spiral diverges from the osculating circle at the same rate as from the tangent at the P. S., $PN=MK$ and the spiral bisects MN. MN, or o , is the offset for a spiral for a curve whose degree is D_2-D_1 . Hence, find o for a D_2-D_1 curve, and make the offset at MN. Measure MK and NP each equal to $\frac{1}{2} \frac{D_2-D_1}{a}$, thus locating the P. C. C. of each curve K and P. Run in the spiral from K or P by the method for point on spiral heretofore described, AK being omitted. The angle between tangents at K and P is \angle for a D_2 spiral minus \angle for D_1 spiral, and may also be expressed as $\frac{1}{2} (D_1+D_2)$ times KP in stations. Thus, with $a=2$, to connect a 3° and 8° curve, $o=2.27$,

the value for a 5° spiral. The portion of the spiral used will be 250 ft. long. K is 125 ft. from M, and N is 125 ft. from P. If greater accuracy is required, the *x* Cor. for this length should be subtracted from 125. The angle between tangents at K and P is $\frac{1}{2} \times 2.50 (3^\circ + 8^\circ) = 13^\circ 45'$.

The spiral may also be used to connect two curves having a given offset between them.

TO INSERT IN OLD TRACK. It may be desired to insert a spiral between the two curves of an existing compound curve by first replacing a part of the sharper curve with a curve of slightly smaller radius.

In Fig. 11, let AB be a D_1° curve and BG a D_3° curve, B being the P.C.C. and the D_3° curve having the smaller radius. It is desired to go back on the D_3° curve to a point D and there compound with a D_2° curve which shall be run to a point E where its tangent shall have the same direction as the tangent to the D_1° curve produced backward to F has at F. The radial distance EF corresponds to the offset of the usual spiral and will be called *o*. It is desired to locate D and F so that a selected curve, D_2° , will give a calculated or assumed distance EF as *o*.

The distance EF is made up of FK and KE, the first being the divergence of the D_1° curve from the D_3° curve in the distance BF and the second the divergence of the D_2° curve from the D_3° curve in the distance DE. Call the distance BF L_1 , and DE, L_2 . For the small angles used these divergences may be calculated accurately enough by the approximate formula for tangent offset, $y = .87 DL^2$, and we shall have

$$EF = .87 (D_2 - D_3) L_2^2 + .87 (D_3 - D_1) L_1^2 = o, \text{ or} \\ (D_2 - D_3) L_2^2 + (D_3 - D_1) L_1^2 = 1.15 o \dots \dots \dots (30)$$

Since the amount of D_1° curve in BF plus the amount of D_2° curve is DE (total angle) must be equal to the amount of D_3° curve taken out, we have

$$D_2 L_2 + D_1 L_1 = D_3 (L_2 + L_1) \text{ or} \\ (D_2 - D_3) L_2 = (D_3 - D_1) L_1 \dots \dots \dots (31)$$

Combining (30) and (31) and solving,

$$L_1^2 = 1.15 \frac{(D_2 - D_3) o}{(D_3 - D_1)(D_2 - D_1)} \dots \dots \dots (32)$$

$$L_2^2 = 1.15 \frac{(D_3 - D_1) o}{(D_2 - D_3)(D_2 - D_1)} \dots \dots \dots (33)$$

Having L_1 and L_2 , the points D, E and F may be located, and the D_2° curve may be run in from D as far as necessary. The problem is then identical with that of putting a spiral between two curves having an offset o (EF) between their parallel tangents.

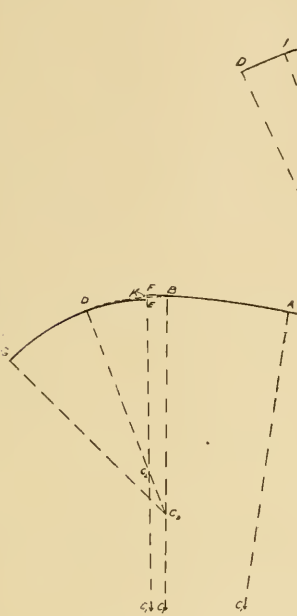


FIG. 11.

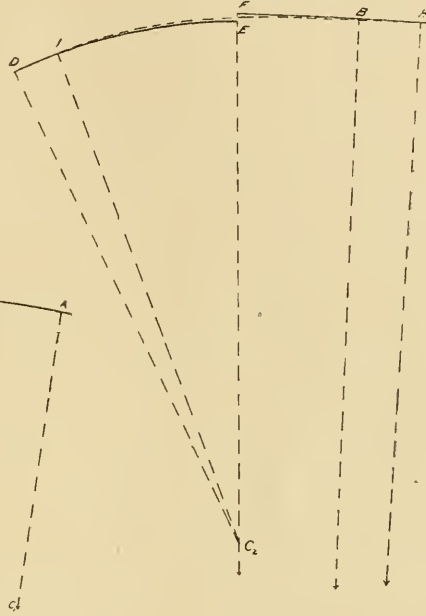


FIG. 12.

By the principles governing the placing of a spiral between two curves, it is seen that the length of the connecting spiral L' is that of a spiral for a curve of degree equal to the difference of degree of the two connected; that is

$$L' = \frac{D_2 - D_1}{a}$$

The offset is equal to that for a $(D_2 - D_1)$ degree curve from a tangent or

$$o = .0725 (D_2 - D_1) L'^2 = .0725 a L'^3 \dots \dots \dots (34)$$

Half of this spiral will lie on one side of the offset and half on the other, hence in Fig. 12 $\frac{1}{2}L'$ to the right of F will give the beginning of the spiral H, and $\frac{1}{2}L'$ to the left of E will give the end of spiral I.

The method of field work will then be as follows: Measure from B, the P. C. C. back on the D_1^0 curve a distance $BH = \frac{1}{2}L' - L_1$ to locate the point of spiral H. Measure from B on the D_3^0 curve the distance $BD = L_1 + L_2$ to D, the new P. C. C., run in the D_2^0 curve to I, DI being $L_1 + L_2 - \frac{1}{2}L'$. The spiral is then to be run in from H to I.

The field work for the spiral is simple. The spiral may be run in by offsetting from the D_1^0 curve HF (Fig. 12), knowing that the offset from the curve to the spiral is the same as that of a spiral from the tangent using the distance from H as the distance on the spiral. Likewise the remainder of the spiral may be offsetted from the D_2^0 curve IE using distances from I in the calculations.

If the field work on the spiral is to be done by deflection angles, the spiral may be run in from H by using as deflection angles the sum of the deflection angle for the circular curve HF and the spiral deflection angle from a tangent for the same distance; or the transition spiral may be run backward from I in a similar manner. In either case the work will be no more difficult than for spirals for simple curves.

As an example let us consider that a 2° and an 8° curve are compounded at B. Consider that the degree of the new curve to be run in is $8^\circ 30'$, and that the value of a to be used is 2. Then $D_1 = 2$, $D_3 = 8$, $D_2 = 8\frac{1}{2}$. For a spiral from 2° to $8^\circ 30'$, the value of the offset σ (EF) is the same as the σ for a $6^\circ 30'$ curve from a tangent. Hence $\sigma = 4.99$. By formula (32), $L_1 = .271$, and by formula (33), $L_2 = 3.255$. Hence the point D will be back on the D_3^0 curve $325.5 + 27.1$ or 352.6 ft. from B. The length of the spiral to be used will be $L' = \frac{8\frac{1}{2} - 2}{2} = 3.25$. Of this 162.5 ft. will be to the left of E and 162.5 ft. will be to the right of F. Hence H and I, the ends of the spiral, may be readily located and the spiral may be run in.

By this method the value of a may be chosen beforehand, the value of σ may be easily calculated, and the preliminary field work is small. It may be stated that the limiting values of D_2 will be, on the one hand, a value so near D_3 that the resulting L_2 will carry the new point of compound curve back to the end of the old curve, and on the other hand such that the length of the

D_2 curve shall be at least equal to half the length of the transition spiral, a value which may be shown to be $D_2 = \frac{1}{2} (4D_3 - D_1)$.

For large angles the above method is subject to slight error.

CONCLUSION.

The problems and methods here presented are only a few of the many applications which may be made. For particular conditions the engineer may readily develop other methods.

The preceding methods have generally been based upon the principle that spiral is to be of the same degree of curvature at the end as the main curve, and may need slight modification when not so. The value of σ and the angle in the circular curve omitted must be that for the spiral used. Thus with $a=2$ the spiral at the end of 300 ft. will be a 6° curve. It may, however, be then compounded with a curve of different radius, as a $6^\circ 30'$ curve, provided the offset is 3.93 and the central angle between the P. C. and the P.C.C. is 9° . Generally, in order to utilize the problems given for old track, etc., the formulas will need to be modified if D_s does not agree with D_1 .

In elevating the outer rail, the superelevation must begin with 0 at the P.S. and increase regularly with the distance along the spiral to the full amount for the main curve at the P.C.C. If the degree-of-curve of the spiral at any point is known, the superelevation will be the amount for such a curve.

In the field work with curves having the transition spiral, most of the usual formulas of the various location problems, like "Required to change the P. C. so that the curve may end in a parallel tangent," may be used without modification with curves having transition endings, by simply considering the whole intersection angle including the angle in the spirals. This is true whenever the same amount of spiral is used with the new curve. If the degree-of-curve changes and with it the length of the spiral, the difference between the σ 's in the two cases must be allowed for. With a little practice in using such formulas with spirals, the engineer will find no difficulty.

The transition spiral has the merit of comparative simplicity and extreme flexibility. It is a natural method, since it is so similar to the methods used in laying out ordinary circular curves. Like circular curves, the length along the curve is the principal term, and the degree-of-curve, central angle, deflection angles and ordinates are obtainable from this variable. It may be used with any main curve, even of fractional degree; any length of chord may be used in measurement under the same restrictions as circular curves, and as it is not necessary to restrict the measurements to a common chord, intermediate points may be readily located. The calculation for angles and distances are easily made. If desired, the tangent and the circular curve may be run out and the spiral put in by co-ordinates, one half from the tangent and one half from the circular curve. This is especially applicable to location work and to short spirals.

The engineer need not be frightened by the mathematics in the demonstration of the formulas; the principles and methods may be understood without mastering the demonstrations. Experience has shown that the ordinary transit man, with a little thought and study, can understand and use the transition spiral as easily as circular curves, and that young assistants without previous training readily take up the work.

It may be said in reference to other easements that the use of the cubic parabola, except for the relation between x and y , has no properties of value for a transition curve which are not merely approximations of the transition spiral. Within small limits, the radius of curvature and the angles to be used approach somewhat closely to those for the transition curve. As soon as x differs materially from the length of curve, a correction has to be made. The radius of curvature finally begins to increase. The investigation of the cubic parabola in reference to its radius of curvature, its angle turned, the angular deflection to points on it, and the length of the curve, require as long mathematical equations as those governing the transition spiral. Many attempts have been made to utilize this curve, but both field work and computations are too intricate and inconvenient if the curve has any considerable length, and it has no advantage over the transition spiral.

EXPLANATION OF TABLES.

In Tables I-VII, the columns give the following properties:

1. The distance in feet from the P. S. along the spiral to a point on the spiral; i. e. $100 L$. The full length of spiral will give values for the terminal point, the P.C.C. of main curve.
2. D , the degree-of-curve of the spiral at any point. It becomes D_1 at the P.C.C.
3. J , the spiral angle or change of direction of the spiral to this point.
4. θ , the spiral deflection angle at the P.S. from the initial tangent to this point.
5. a , the offset from the initial tangent to the P.C. of main curve produced backward. This value must be taken from the line for the full length of spiral.
6. y , the ordinate from the initial tangent as the axis of X.
7. x COR., an amount to be subtracted from the distance in feet from the P.S. along the spiral to find the abscissa, x , of the point.

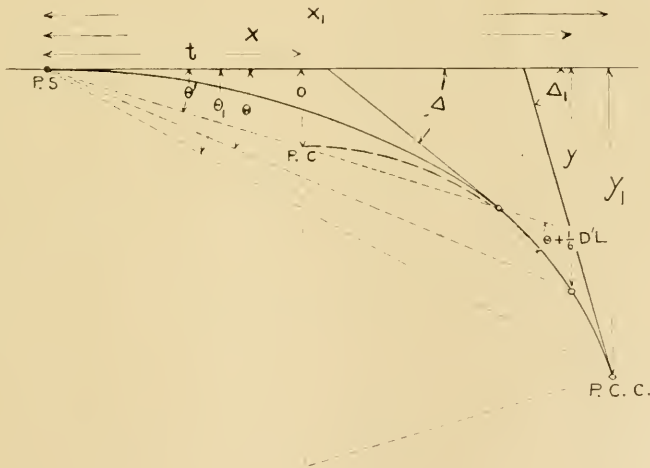


FIG. 13.

8. t COR., an amount to be subtracted from half the full length of the spiral in feet to find t , the abscissa of the P.C. Enter the table with full length of the spiral used.

To find the long chord to P. S., subtract $\frac{8}{15}$ of x COR. from the length of the spiral in feet.

Intermediate values may be found by interpolation.

For other values of a , multiply the tabulated values of D , Δ , θ , σ , and y in Table I opposite the given distance from P.S. by the a of the desired spiral, and x Cor. and t Cor. by the square of a . For inaccuracies of this method see page 89. If a and D or σ are given, first find L .

Table IX permits ordinates to be calculated from σ . See Fig. 5.

Table X gives values of σ and L for values of a and D .

With transit at intermediate point on spiral, for deflection angle ψ , see page 96.

For full nomenclature, see page 75.

For equations and summary of principles, see page 84.

For fuller explanation of tables and errors of interpolation, see page 88.

For choice of a , see page 90.

TABLE I. TRANSITION SPIRAL.

1" in 100 feet.

$a=1.$

| Length | D | L | θ | o | y | x COR. | t COR. |
|--------|-----|---------|----------|-------|-------|----------|----------|
| 10 | 0.1 | 0 00.3 | 0 00.1 | .000 | 0 000 | 0.0000 | 0.0000 |
| 20 | 0.2 | 01.2 | 00.4 | .001 | .002 | | |
| 30 | 0.3 | 02.7 | 00.9 | .002 | .008 | | |
| 40 | 0.4 | 04.8 | 01.6 | .005 | .019 | | |
| 50 | 0.5 | 07.5 | 02.5 | .009 | .036 | | |
| 60 | 0.6 | 0 10.8 | 0 03.6 | .016 | .063 | .0001 | |
| 70 | 0.7 | 14.7 | 04.9 | .025 | .100 | .0001 | |
| 80 | 0.8 | 19.2 | 06.4 | .037 | .149 | .0002 | |
| 90 | 0.9 | 24.3 | 08.1 | .053 | .212 | .0004 | .0001 |
| 100 | 1.0 | 30. | 10. | .073 | .291 | .0008 | .0001 |
| 110 | 1.1 | 0 36.3 | 0 12.1 | .097 | .387 | .0012 | .0002 |
| 120 | 1.2 | 43.2 | 14.4 | .126 | .503 | .0019 | .0003 |
| 130 | 1.3 | 50.7 | 16.9 | .160 | .639 | .0028 | .0005 |
| 140 | 1.4 | 58.8 | 19.6 | .199 | .798 | .0041 | .0007 |
| 150 | 1.5 | 1 07.5 | 22.5 | .245 | .982 | .0058 | .0010 |
| 160 | 1.6 | 1 16.8 | 0 25.6 | .298 | 1.191 | .0080 | .0013 |
| 170 | 1.7 | 1 26.7 | 28.9 | .357 | 1.429 | .0108 | .0018 |
| 180 | 1.8 | 1 37.2 | 32.4 | .424 | 1.696 | .0144 | .0024 |
| 190 | 1.9 | 1 48.3 | 36.1 | .499 | 1.995 | .0189 | .0031 |
| 200 | 2 0 | 2 00. | 40. | .582 | 2.327 | .0244 | .0041 |
| 210 | 2.1 | 2 12.3 | 0 44.1 | .673 | 2.690 | .031 | .0052 |
| 220 | 2.2 | 2 25.2 | 48.4 | .774 | 3.097 | .039 | .0065 |
| 230 | 2.3 | 2 38.7 | 52.9 | .885 | 3.538 | .049 | .0082 |
| 240 | 2.4 | 2 52.8 | 57.6 | 1.005 | 4.020 | .061 | .0101 |
| 250 | 2.5 | 3 07.5 | 1 02.5 | 1.136 | 4.544 | .074 | .0124 |
| 260 | 2.6 | 3 22.8 | 1 07.6 | 1.278 | 5.111 | .090 | .015 |
| 270 | 2.7 | 3 38.7 | 1 12.9 | 1.431 | 5.724 | .109 | .018 |
| 280 | 2.8 | 3 55.2 | 1 18.4 | 1.596 | 6.383 | .131 | .022 |
| 290 | 2.9 | 4 12.3 | 1 24.1 | 1.773 | 7.091 | .156 | .027 |
| 300 | 3.0 | 4 30. | 1 30. | 1.963 | 7.850 | .185 | .031 |
| 310 | 3.1 | 4 48.3 | 1 36.1 | 2.166 | 8.66 | .218 | .036 |
| 320 | 3.2 | 5 07.2 | 1 42.4 | 2.382 | 9.53 | .255 | .043 |
| 330 | 3.3 | 5 26.7 | 1 48.9 | 2.612 | 10.45 | .298 | .050 |
| 340 | 3.4 | 5 46.8 | 1 55.6 | 2.857 | 11.42 | .346 | .058 |
| 350 | 3.5 | 6 07.5 | 2 02.5 | 3.116 | 12.46 | .400 | .057 |
| 360 | 3.6 | 6 28.8 | 2 09.6 | 3.391 | 13.56 | .460 | .077 |
| 370 | 3.7 | 6 50.7 | 2 16.9 | 3.681 | 14.72 | .528 | .088 |
| 380 | 3.8 | 7 13.2 | 2 24.4 | 3.988 | 15.94 | .603 | .100 |
| 390 | 3.9 | 7 36.3 | 2 32.1 | 4.311 | 17.23 | .686 | .114 |
| 400 | 4.0 | 8 00. | 2 40. | 4.651 | 18.59 | .779 | .130 |
| 410 | 4.1 | 8 24.3 | 2 48.1 | 5.01 | 20.02 | .881 | .147 |
| 420 | 4.2 | 8 49.2 | 2 56.4 | 5.38 | 21.51 | .994 | .166 |
| 430 | 4.3 | 9 14.7 | 3 04.9 | 5.78 | 23.08 | 1.118 | .186 |
| 440 | 4.4 | 9 40.8 | 3 13.6 | 6.19 | 24.73 | 1.254 | .209 |
| 450 | 4.5 | 10 07.5 | 3 22.5 | 6.62 | 26.45 | 1.403 | .234 |

TABLE I.—Continued.

| 1" in 100 ft. | | | | | | | $a=1.$ | |
|---------------|-----|-----------|--------|-------|-------|----------|----------|--|
| Length | D | J | H | o | y | x COR. | t COR. | |
| 460 | 4.6 | 10° 34'.8 | 3 31.6 | 7.07 | 28.24 | 1.566 | .261 | |
| 470 | 4.7 | 11 02.7 | 3 40.9 | 7.54 | 30.12 | 1.743 | .291 | |
| 480 | 4.8 | 11 31.2 | 3 50.4 | 8.03 | 32.07 | 1.937 | .323 | |
| 490 | 4.9 | 12 00.3 | 4 00.1 | 8.54 | 34.11 | 2.146 | .358 | |
| 500 | 5.0 | 12 30. | 4 10. | 9.07 | 36 23 | 2.374 | .396 | |
| 510 | 5.1 | 13 00.3 | 4 20.1 | 9.63 | 38.44 | 2.621 | .437 | |
| 520 | 5.2 | 13 31.2 | 4 30.4 | 10.20 | 40 73 | 2.888 | .482 | |
| 530 | 5.3 | 14 02.7 | 4 40.9 | 10.80 | 43.12 | 3.175 | .530 | |
| 540 | 5.4 | 14 34.8 | 4 51.6 | 11 42 | 45.59 | 3.486 | .582 | |
| 550 | 5.5 | 15 07.5 | 5 02.5 | 12.07 | 48 15 | 3.820 | .637 | |
| 560 | 5.6 | 15 40.8 | 5 13.6 | 12.74 | 50.83 | 4 18 | .697 | |
| 570 | 5.7 | 16 14.7 | 5 24.9 | 13.43 | 53.56 | 4.56 | .762 | |
| 580 | 5.8 | 16 49.2 | 5 36.4 | 14.14 | 56.40 | 4.98 | .831 | |
| 590 | 5.9 | 17 24.3 | 5 48.1 | 14.89 | 59 34 | 5.42 | .905 | |
| 600 | 6.0 | 18 00. | 6 00. | 15.65 | 62.39 | 5.89 | .984 | |
| 610 | 6.1 | 18 36.3 | 6 12.1 | 16.44 | 65 52 | 6.40 | 1.069 | |
| 620 | 6.2 | 19 13.2 | 6 24.4 | 17.26 | 68 77 | 6.94 | 1.159 | |
| 630 | 6.3 | 19 50.7 | 6 36.9 | 18.10 | 72 11 | 7.51 | 1.255 | |
| 640 | 6.4 | 20 28.8 | 6 49.6 | 18.97 | 75.56 | 8.13 | 1.358 | |
| 650 | 6.5 | 21 07.5 | 7 02.5 | 19.87 | 79.11 | 8.78 | 1.467 | |
| 660 | 6.6 | 21 47. | 7 15.1 | 20.82 | 82.79 | 9.48 | 1 57 | |
| 670 | 6.7 | 22 27. | 7 28.5 | 21.78 | 86.56 | 10.22 | 1.69 | |
| 680 | 6.8 | 23 07. | 7 41.8 | 22.77 | 90.43 | 11.00 | 1.82 | |
| 690 | 6.9 | 23 48. | 7 55.3 | 23.78 | 94 42 | 11.82 | 1.96 | |
| 700 | 7.0 | 24 30. | 8 09 3 | 24 84 | 98.50 | 12.70 | 2.10 | |

TABLE II. TRANSITION SPIRAL.

| 1" in 80 ft | | | | | | $a=1\frac{1}{4}$ | |
|-------------|-----------------------|-------|-------|------|------|------------------|----------|
| Length | D | J | H | o | y | x COR. | t COR. |
| 10 | 0° 07 $\frac{1}{2}$ ' | 0 00' | 0 00' | 0.00 | 0.00 | 0.00 | 0.00 |
| 20 | 0 15 | 0 01 | 0 00 | 0.00 | 0.00 | | |
| 30 | 0 22 $\frac{1}{2}$ | 0 03 | 0 01 | 0.00 | 0.01 | | |
| 40 | 0 30 | 0 06 | 0 02 | 0.00 | 0.02 | | |
| 50 | 0 37 $\frac{1}{2}$ | 0 09 | 0 03 | 0.01 | 0.04 | | |
| 60 | 0 45 | 0 13 | 0 04 | 0.02 | 0.08 | | |
| 70 | 0 52 $\frac{1}{2}$ | 0 18 | 0 06 | 0.03 | 0.12 | | |
| 80 | 1 00 | 0 24 | 0 08 | 0.05 | 0.19 | | |
| 90 | 1 07 $\frac{1}{2}$ | 0 30 | 0 10 | 0.07 | 0.26 | | |
| 100 | 1 15 | 0 37 | 0 12 | 0.09 | 0.36 | | |
| 110 | 1 22 $\frac{1}{2}$ | 0 45 | 0 15 | 0.12 | 0 48 | | |
| 120 | 1 30 | 0 54 | 0 18 | 0.16 | 0.63 | | |
| 130 | 1 37 $\frac{1}{2}$ | 1 04 | 0 21 | 0.20 | 0.80 | | |
| 140 | 1 45 | 1 14 | 0 25 | 0.25 | 1.00 | | |
| 150 | 1 52 $\frac{1}{2}$ | 1 25 | 0 28 | 0 31 | 1.23 | 0 00 | 0.00 |

TABLE II.—Continued.

| Length | D | J | H | o | y | r COR. | t COR. |
|--------|-------|-------|------|-------|-------|----------|----------|
| 160 | 2 00 | 1 36 | 0 32 | 0 37 | 1 49 | 0.00 | 0.00 |
| 170 | 2 07½ | 1 48 | 0 36 | 0 45 | 1 77 | | |
| 180 | 2 15 | 2 01 | 0 40 | 0 53 | 2 12 | | |
| 190 | 2 22½ | 2 15 | 0 45 | 0 62 | 2 50 | | |
| 200 | 2 30 | 2 30 | 0 50 | 0 73 | 2 90 | | |
| 210 | 2 37½ | 2 45 | 0 55 | 0 84 | 3 36 | | |
| 220 | 2 45 | 3 01 | 1 00 | 0 97 | 3 87 | | |
| 230 | 2 52½ | 3 18 | 1 06 | 1 10 | 4 42 | | |
| 240 | 3 00 | 3 36 | 1 12 | 1 25 | 5 02 | | |
| 250 | 3 07½ | 3 54 | 1 18 | 1 42 | 5 67 | 0.1 | |
| 260 | 3 15 | 4 13 | 1 24 | 1 59 | 6 38 | 0.1 | |
| 270 | 3 22½ | 4 33 | 1 31 | 1 79 | 7 15 | 0.2 | |
| 280 | 3 30 | 4 54 | 1 38 | 1 99 | 7 98 | 0.2 | |
| 290 | 3 37½ | 5 15 | 1 45 | 2 21 | 8 86 | 0.2 | |
| 300 | 3 45 | 5 37 | 1 52 | 2 45 | 9 81 | 0.3 | |
| 310 | 3 52½ | 6 00 | 2 00 | 2 70 | 10 74 | 0.3 | |
| 320 | 4 00 | 6 24 | 2 08 | 2 98 | 11 91 | 0 4 | |
| 330 | 4 07½ | 6 48 | 2 16 | 3 26 | 13 06 | 0 4 | |
| 340 | 4 15 | 7 13 | 2 24 | 3 57 | 14 28 | 0 5 | |
| 350 | 4 22½ | 7 39 | 2 33 | 3 89 | 15 57 | 0 6 | |
| 360 | 4 30 | 8 06 | 2 42 | 4 23 | 16 95 | 0 7 | 0 1 |
| 370 | 4 37½ | 8 33 | 2 51 | 4 59 | 18 40 | 0 8 | 0 1 |
| 380 | 4 45 | 9 01 | 3 00 | 4 97 | 19 92 | 0 9 | 0 2 |
| 390 | 4 52½ | 9 30 | 3 10 | 5 38 | 21 54 | 1 0 | 0 2 |
| 400 | 5 00 | 10 00 | 3 20 | 5 80 | 23 23 | 1 2 | 0 2 |
| 410 | 5 07½ | 10 30 | 3 30 | 6 26 | 25 00 | 1 4 | 0 2 |
| 420 | 5 15 | 11 01 | 3 40 | 6 72 | 26 86 | 1 6 | 0 3 |
| 430 | 5 22½ | 11 33 | 3 51 | 7 22 | 28 82 | 1 7 | 0 3 |
| 440 | 5 30 | 12 06 | 4 02 | 7 74 | 30 87 | 2 0 | 0 3 |
| 450 | 5 37½ | 12 39 | 4 13 | 8 28 | 33 02 | 2 2 | 0 4 |
| 460 | 5 45 | 13 13 | 4 25 | 8 84 | 35 25 | 2 4 | 0 4 |
| 470 | 5 52½ | 13 48 | 4 36 | 9 41 | 37 59 | 2 7 | 0 5 |
| 480 | 6 00 | 14 24 | 4 48 | 10 03 | 40 02 | 3 0 | 0 5 |
| 490 | 6 07½ | 15 00 | 5 00 | 10 67 | 42 56 | 3 4 | 0 6 |
| 500 | 6 15 | 15 37 | 5 13 | 11 33 | 45 20 | 3 7 | 0 6 |
| 510 | 6 22½ | 16 15 | 5 25 | 12 03 | 47 95 | 4 1 | 0 7 |
| 520 | 6 30 | 16 54 | 5 38 | 12 74 | 50 79 | 4 5 | 0 8 |
| 530 | 6 37½ | 17 33 | 5 51 | 13 48 | 53 76 | 5 0 | 0 8 |
| 540 | 6 45 | 18 13 | 6 04 | 14 26 | 56 84 | 5 4 | 0 9 |
| 550 | 6 52½ | 18 54 | 6 18 | 15 07 | 60 02 | 6 0 | 1 0 |
| 560 | 7 00 | 19 36 | 6 32 | 15 90 | 63 34 | 6 5 | 1 1 |
| 570 | 7 07½ | 20 18 | 6 46 | 16 76 | 66 72 | 7 1 | 1 2 |
| 580 | 7 15 | 21 01 | 7 00 | 17 65 | 70 26 | 7 8 | 1 3 |
| 590 | 7 22½ | 21 46 | 7 15 | 18 57 | 73 90 | 8 4 | 1 4 |
| 600 | 7 30 | 22 30 | 7 29 | 19 52 | 77 68 | 9 2 | 1 5 |

TABLE III. TRANSITION SPIRAL.

1 in 60 feet.

 $a=1^2_3$.

| Length | D | L | H | o | y | x COR. | t COR. |
|--------|------|-------|------|-------|-------|----------|----------|
| 10 | 0 10 | 0 00 | 0 00 | 0.00 | 0.00 | 0.0 | 0.0 |
| 20 | 0 20 | 0 02 | 0 01 | | | | |
| 30 | 0 30 | 0 04 | 0 01 | | | | |
| 40 | 0 40 | 0 08 | 0 03 | | 0.03 | | |
| 50 | 0 50 | 0 12 | 0 04 | | 0.06 | | |
| 60 | 1 00 | 0 18 | 0 06 | 0.03 | 0.10 | | |
| 70 | 1 10 | 0 24 | 0 08 | 0.04 | 0.17 | | |
| 80 | 1 20 | 0 32 | 0 11 | 0.06 | 0.25 | | |
| 90 | 1 30 | 0 40 | 0 13 | 0.09 | 0.35 | | |
| 100 | 1 40 | 0 50 | 0 17 | 0.12 | 0.48 | | |
| 110 | 1 50 | 1 00 | 0 20 | 0 16 | 0.64 | | |
| 120 | 2 00 | 1 12 | 0 24 | 0 21 | 0.84 | | |
| 130 | 2 10 | 1 24 | 0 28 | 0 26 | 1.06 | | |
| 140 | 2 20 | 1 38 | 0 33 | 0.33 | 1.33 | | |
| 150 | 2 30 | 1 52 | 0 37 | 0.41 | 1.63 | | |
| 160 | 2 40 | 2 08 | 0 43 | 0.50 | 1.98 | | |
| 170 | 2 50 | 2 24 | 0 48 | 0.59 | 2.38 | | |
| 180 | 3 00 | 2 42 | 0 54 | 0.70 | 2.82 | | |
| 190 | 3 10 | 3 00 | 1 00 | 0.83 | 3.32 | | |
| 200 | 3 20 | 3 20 | 1 07 | 0.97 | 3.88 | | |
| 210 | 3 30 | 3 40 | 1 13 | 1.12 | 4.48 | 0.1 | |
| 220 | 3 40 | 4 02 | 1 21 | 1.29 | 5.15 | 0.1 | |
| 230 | 3 50 | 4 24 | 1 28 | 1.47 | 5.90 | 0.1 | |
| 240 | 4 00 | 4 48 | 1 36 | 1 67 | 6 69 | 0 2 | |
| 250 | 4 10 | 5 12 | 1 44 | 1.89 | 7.58 | 0.2 | |
| 260 | 4 20 | 5 38 | 1 53 | 2.13 | 8.52 | 0.2 | |
| 270 | 4 30 | 6 04 | 2 01 | 2.38 | 9.54 | 0.3 | |
| 280 | 4 40 | 6 32 | 2 11 | 2.65 | 10.64 | 0.4 | |
| 290 | 4 50 | 7 00 | 2 20 | 2.94 | 11.82 | 0.4 | |
| 300 | 5 00 | 7 30 | 2 30 | 3.26 | 13.07 | 0.5 | |
| 310 | 5 10 | 8 00 | 2 40 | 3.60 | 14.43 | 0.6 | 0.1 |
| 320 | 5 20 | 8 32 | 2 51 | 3.96 | 15.87 | 0.7 | 0.1 |
| 330 | 5 30 | 9 04 | 3 01 | 4.34 | 17.40 | 0.8 | 0.1 |
| 340 | 5 40 | 9 38 | 3 13 | 4.75 | 19.02 | 0.9 | 0.2 |
| 350 | 5 50 | 10 12 | 3 24 | 5 18 | 20.74 | 1.1 | 0.2 |
| 360 | 6 00 | 10 48 | 3 36 | 5.64 | 22.56 | 1.3 | 0.2 |
| 370 | 6 10 | 11 24 | 3 48 | 6.12 | 24.50 | 1 4 | 0 2 |
| 380 | 6 20 | 12 02 | 4 01 | 6.63 | 26.53 | 1.7 | 0.3 |
| 390 | 6 30 | 12 40 | 4 13 | 7.16 | 28.67 | 1.9 | 0.3 |
| 400 | 6 40 | 13 20 | 4 27 | 7.73 | 30.92 | 2.2 | 0.4 |
| 410 | 6 50 | 14 00 | 4 40 | 8.34 | 33.27 | 2.4 | 0 4 |
| 420 | 7 00 | 14 42 | 4 54 | 8.96 | 35.73 | 2 8 | 0 5 |
| 430 | 7 10 | 15 24 | 5 08 | 9.61 | 38.32 | 3.1 | 0.5 |
| 440 | 7 20 | 16 08 | 5 23 | 10.30 | 41.07 | 3.5 | 0.6 |
| 450 | 7 30 | 16 53 | 5 38 | 11.01 | 43.90 | 3.9 | 0 6 |

TABLE III.—Continued.

1° in 60 ft.

$a=1\frac{2}{3}$.

| Length | D | Δ | θ | o | y | x COR. | t COR. |
|--------|-------|----------|----------|-------|--------|----------|----------|
| 460 | 7 40' | 17 38' | 5°53' | 11.75 | 46.86 | 4.3 | 0.7 |
| 470 | 7 50 | 18 24 | 6 08 | 12.50 | 49.94 | 4.8 | 0.8 |
| 480 | 8 00 | 19 12 | 6 24 | 13.35 | 53 16 | 5.4 | 0.9 |
| 490 | 8 10 | 20 00 | 6 40 | 14.19 | 56 52 | 5.9 | 1.0 |
| 500 | 8 20 | 20 50 | 6 56 | 15.07 | 60.01 | 6.6 | 1.1 |
| 510 | 8 30 | 21 40 | 7 13 | 16 00 | 63.64 | 7.2 | 1.2 |
| 520 | 8 40 | 22 32 | 7 30 | 16.94 | 67.36 | 8 0 | 1.3 |
| 530 | 8 50 | 23 24 | 7 48 | 17.93 | 71.25 | 8.8 | 1.5 |
| 540 | 9 00 | 24 18 | 8 05 | 18.95 | 75.31 | 9.6 | 1.6 |
| 550 | 9 10 | 25 12 | 8 23 | 20.03 | 79.53 | 10.6 | 1 8 |
| 560 | 9 20 | 26 08 | 8 42 | 21.13 | 83.88 | 11.5 | 1 9 |
| 570 | 9 30 | 27 04 | 9 00 | 22 26 | 88.31 | 12 6 | 2.1 |
| 580 | 9 40 | 28 02 | 9 20 | 23 42 | 92.92 | 13.7 | 2.3 |
| 590 | 9 50 | 29 00 | 9 39 | 24.67 | 97.70 | 14.9 | 2.5 |
| 600 | 10 00 | 30 00 | 9 59 | 25.91 | 102 66 | 16 2 | 2.7 |

TABLE IV. TRANSITION SPIRAL.

1° in 50 ft.

$a=2$.

| Length | D | Δ | θ | o | y | x COR. | t COR. |
|--------|-------|----------|----------|------|------|----------|----------|
| 10 | 0°12' | 0°01' | 0°00'' | 0.00 | 0.00 | 0.0 | 0.00 |
| 20 | 0 24 | 0 02 | 0 01 | | | | |
| 30 | 0 36 | 0 05 | 0 02 | | 0.02 | | |
| 40 | 0 48 | 0 10 | 0 03 | 0 01 | 0.04 | | |
| 50 | 1 00 | 0 15 | 0 05 | 0.02 | 0.07 | | |
| 60 | 1 12 | 0 22 | 0 07 | 0.03 | 0.13 | | |
| 70 | 1 24 | 0 29 | 0 10 | 0.05 | 0.20 | | |
| 80 | 1 36 | 0 38 | 0 13 | 0.07 | 0.30 | | |
| 90 | 1 48 | 0 49 | 0 16 | 0.10 | 0.42 | | |
| 100 | 2 00 | 1 00 | 0 20 | 0.15 | 0.58 | | |
| 110 | 2 12 | 1 13 | 0 24 | 0.19 | 0 77 | | |
| 120 | 2 24 | 1 26 | 0 29 | 0 25 | 1.00 | | |
| 130 | 2 36 | 1 41 | 0 34 | 0.32 | 1.28 | | |
| 140 | 2 48 | 1 58 | 0 39 | 0.40 | 1.60 | | |
| 150 | 3 00 | 2 15 | 0 45 | 0.49 | 1.96 | | |
| 160 | 3 12 | 2 34 | 0 51 | 0.59 | 2.38 | | |
| 170 | 3 24 | 2 53 | 0 58 | 0.71 | 2.86 | | |
| 180 | 3 36 | 3 14 | 1 05 | 0.85 | 3.39 | 0 1 | |
| 190 | 3 48 | 3 37 | 1 12 | 1.00 | 3 99 | 0.1 | |
| 200 | 4 00 | 4 00 | 1 20 | 1.16 | 4.65 | 0 1 | 0.0 |

TABLE IV.—Continued.

1" in 50 ft.

a=2.

| Length | D | J | H | o | y | r COR. | t COR. |
|--------|-------|-------|-------|-------|--------|--------|--------|
| 210 | 4 12' | 4 25' | 1 28' | 1.35 | 5.38 | 0.1 | 0.0 |
| 220 | 4 24 | 4 50 | 1 37 | 1.54 | 6.19 | 0.2 | |
| 230 | 4 36 | 5 17 | 1 46 | 1.76 | 7.07 | 0.2 | |
| 240 | 4 48 | 5 46 | 1 55 | 2.00 | 8.04 | 0.2 | |
| 250 | 5 00 | 6 15 | 2 05 | 2.27 | 9.09 | 0.3 | |
| 260 | 5 12 | 6 46 | 2 15 | 2.55 | 10.22 | 0.4 | |
| 270 | 5 24 | 7 17 | 2 26 | 2.85 | 11.45 | 0.4 | |
| 280 | 5 36 | 7 50 | 2 37 | 3.18 | 12.75 | 0.5 | |
| 290 | 5 48 | 8 25 | 2 48 | 3.54 | 14. 8 | 0.6 | 0.1 |
| 300 | 6 00 | 9 00 | 3 00 | 3.91 | 15.68 | 0.7 | 0.1 |
| 310 | 6 12 | 9 37 | 3 12 | 4.32 | 17.31 | 0.9 | 0.1 |
| 320 | 6 24 | 10 14 | 3 25 | 4.75 | 19.03 | 1.0 | 0.2 |
| 330 | 6 36 | 10 53 | 3 38 | 5.21 | 20.87 | 1.2 | 0.2 |
| 340 | 6 48 | 11 34 | 3 51 | 5.70 | 22.81 | 1.4 | 0.2 |
| 350 | 7 00 | 12 15 | 4 05 | 6.22 | 24.87 | 1.6 | 0.3 |
| 360 | 7 12 | 12 58 | 4 19 | 6.77 | 27.05 | 1.8 | 0.3 |
| 370 | 7 24 | 13 41 | 4 34 | 7.34 | 29.35 | 2.1 | 0.3 |
| 380 | 7 36 | 14 26 | 4 49 | 7.95 | 31.79 | 2.4 | 0.4 |
| 390 | 7 48 | 15 13 | 5 04 | 8.60 | 34.35 | 2.7 | 0.4 |
| 400 | 8 00 | 16 00 | 5 20 | 9.28 | 37.04 | 3.1 | 0.5 |
| 410 | 8 12 | 16 49 | 5 36 | 10.00 | 39.85 | 3.5 | 0.6 |
| 420 | 8 24 | 17 38 | 5 53 | 10.73 | 42.79 | 4.0 | 0.7 |
| 430 | 8 36 | 18 29 | 6 10 | 11.53 | 45.88 | 4.4 | 0.7 |
| 440 | 8 48 | 19 22 | 6 27 | 12.34 | 49.14 | 5.0 | 0.8 |
| 450 | 9 00 | 20 15 | 6 45 | 13.20 | 52.55 | 5.6 | 0.9 |
| 460 | 9 12 | 21 10 | 7 03 | 14.09 | 56.05 | 6.3 | 1.0 |
| 470 | 9 24 | 22 05 | 7 21 | 15.02 | 59.73 | 6.9 | 1.2 |
| 480 | 9 36 | 23 02 | 7 40 | 15.99 | 63.55 | 7.7 | 1.3 |
| 490 | 9 48 | 24 00 | 8 00 | 17 00 | 67.55 | 8.5 | 1.4 |
| 500 | 10 00 | 25 00 | 8 19 | 18.05 | 71.72 | 9.4 | 1.6 |
| 510 | 10 12 | 26 01 | 8 39 | 19.15 | 76.00 | 10.4 | 1.7 |
| 520 | 10 24 | 27 02 | 9 00 | 20.27 | 80.04 | 11.4 | 1.9 |
| 530 | 10 36 | 28 05 | 9 21 | 21.45 | 85.08 | 12.6 | 2.1 |
| 540 | 10 48 | 29 10 | 9 42 | 22.68 | 89.88 | 13.8 | 2.3 |
| 550 | 11 00 | 30 15 | 10 04 | 23.96 | 94.85 | 15.1 | 2.5 |
| 560 | 11 12 | 31 22 | 10 29 | 25.27 | 99.97 | 16.5 | 2.8 |
| 570 | 11 24 | 32 29 | 10 48 | 26.62 | 105.19 | 18.0 | 3.0 |
| 580 | 11 36 | 33 38 | 11 11 | 28.01 | 110.62 | 19.6 | 3.3 |
| 590 | 11 48 | 34 49 | 11 34 | 29.48 | 116.27 | 21.3 | 3.6 |
| 600 | 12 00 | 36 00 | 11 58 | 30.97 | 122.13 | 23.2 | 3.9 |

TABLE V. TRANSITION SPIRAL.

1° in 40 feet.

$a=2\frac{1}{2}$.

| Length | <i>D</i> | <i>L</i> | <i>θ</i> | <i>o</i> | <i>y</i> | <i>x</i> COR. | <i>t</i> COR. |
|--------|----------|----------|----------|----------|----------|---------------|---------------|
| 10 | 0° 15' | 0° 01' | 0° 00' | 0.00 | 0.00 | 0.0 | 0.0 |
| 20 | 0 30 | 0 03 | 0 01 | | | | |
| 30 | 0 45 | 0 07 | 0 02 | | 0.02 | | |
| 40 | 1 00 | 0 12 | 0 04 | 0.01 | 0.05 | | |
| 50 | 1 15 | 0 19 | 0 06 | 0.02 | 0.09 | | |
| 60 | 1 30 | 0 27 | 0 09 | 0.04 | 0.16 | | |
| 70 | 1 45 | 0 37 | 0 12 | 0.06 | 0.25 | | |
| 80 | 2 00 | 0 48 | 0 16 | 0.09 | 0.37 | | |
| 90 | 2 15 | 1 01 | 0 20 | 0.13 | 0.53 | | |
| 100 | 2 30 | 1 15 | 0 25 | 0.18 | 0.73 | | |
| 110 | 2 45 | 1 31 | 0 30 | 0.24 | 0.97 | | |
| 120 | 3 00 | 1 48 | 0 36 | 0.31 | 1.25 | | |
| 130 | 3 15 | 2 07 | 0 42 | 0.40 | 1.60 | | |
| 140 | 3 30 | 2 27 | 0 49 | 0.50 | 2.00 | | |
| 150 | 3 45 | 2 49 | 0 56 | 0.61 | 2.45 | | |
| 160 | 4 00 | 3 12 | 1 04 | 0.74 | 2.97 | | |
| 170 | 4 15 | 3 37 | 1 12 | 0.89 | 3.57 | | |
| 180 | 4 30 | 4 03 | 1 21 | 1.06 | 4.24 | 0.1 | |
| 190 | 4 45 | 4 31 | 1 30 | 1.25 | 4.99 | 0.1 | |
| 200 | 5 00 | 5 00 | 1 40 | 1.45 | 5.81 | 0.2 | |
| 210 | 5 15 | 5 31 | 1 50 | 1.68 | 6.72 | 0.2 | |
| 220 | 5 30 | 6 03 | 2 01 | 1.93 | 7.74 | 0.2 | |
| 230 | 5 45 | 6 37 | 2 12 | 2.20 | 8.85 | 0.3 | |
| 240 | 6 00 | 7 12 | 2 24 | 2.51 | 10.05 | 0.4 | |
| 250 | 6 15 | 7 49 | 2 36 | 2.84 | 11.37 | 0.5 | 0.1 |
| 260 | 6 30 | 8 27 | 2 49 | 3.19 | 12.77 | 0.6 | 0.1 |
| 270 | 6 45 | 9 07 | 3 02 | 3.57 | 14.29 | 0.7 | 0.1 |
| 280 | 7 00 | 9 48 | 3 16 | 3.98 | 15.94 | 0.8 | 0.1 |
| 290 | 7 15 | 10 31 | 3 30 | 4.42 | 17.70 | 1.0 | 0.2 |
| 300 | 7 30 | 11 15 | 3 45 | 4.89 | 19.59 | 1.2 | 0.2 |
| 310 | 7 45 | 12 01 | 4 00 | 5.40 | 21.61 | 1.4 | 0.2 |
| 320 | 8 00 | 12 48 | 4 16 | 5.94 | 23.76 | 1.6 | 0.3 |
| 330 | 8 15 | 13 37 | 4 32 | 6 51 | 26.05 | 1.9 | 0.3 |
| 340 | 8 30 | 14 27 | 4 49 | 7.12 | 28.46 | 2.2 | 0.4 |
| 350 | 8 45 | 15 19 | 5 06 | 7.77 | 31.03 | 2.5 | 0.4 |
| 360 | 9 00 | 16 12 | 5 24 | 8.46 | 33.74 | 2.9 | 0.5 |
| 370 | 9 15 | 17 07 | 5 42 | 9.18 | 36.62 | 3.3 | 0.5 |
| 380 | 9 30 | 18 03 | 6 01 | 9.95 | 39.64 | 3.7 | 0.6 |
| 390 | 9 45 | 19 01 | 6 20 | 10.75 | 42.82 | 4.3 | 0.7 |
| 400 | 10 00 | 20 01 | 6 40 | 11.60 | 46.16 | 4.9 | 0.8 |
| 410 | 10 15 | 21 00 | 7 00 | 12 47 | 49.65 | 5.5 | 0.9 |
| 420 | 10 30 | 22 03 | 7 21 | 13 39 | 53.28 | 6.2 | 1.0 |
| 430 | 10 45 | 23 07 | 7 42 | 14.38 | 57.10 | 6 9 | 1.2 |
| 440 | 11 00 | 24 12 | 8 04 | 15.39 | 61.12 | 7.8 | 1.3 |
| 450 | 11 15 | 25 19 | 8 26 | 16.45 | 65.32 | 8.7 | 1.5 |

TABLE VI. TRANSITION SPIRAL.

1° in 30 ft.

 $a=3\frac{1}{2}$.

| Length | <i>D</i> | <i>J</i> | <i>H</i> | <i>o</i> | <i>y</i> | <i>x</i> COR. | <i>t</i> COR. |
|--------|----------|----------|----------|----------|----------|---------------|---------------|
| 10 | 0 20' | 0° 01' | 0° 00' | 0.00 | 0.00 | 0.00 | 0.00 |
| 20 | 0 40 | 0 04 | 0 01 | .00 | .01 | | |
| 30 | 1 00 | 0 09 | 0 03 | .01 | .03 | | |
| 40 | 1 20 | 0 16 | 0 05 | .02 | .06 | | |
| 50 | 1 40 | 0 25 | 0 08 | .03 | .12 | | |
| 60 | 2 00 | 0 36 | 0 12 | .05 | .21 | | |
| 70 | 2 20 | 0 49 | 0 16 | .08 | .33 | | |
| 80 | 2 40 | 1 04 | 0 21 | .12 | .50 | | |
| 90 | 3 00 | 1 21 | 0 27 | .18 | .71 | | |
| 100 | 3 20 | 1 40 | 0 33 | .24 | .97 | 0.01 | |
| 110 | 3 40 | 2 01 | 0 40 | .32 | 1.29 | .01 | |
| 120 | 4 00 | 2 24 | 0 48 | .42 | 1.68 | .02 | |
| 130 | 4 20 | 2 49 | 0 56 | .53 | 2.13 | .03 | |
| 140 | 4 40 | 3 16 | 1 05 | .67 | 2.66 | .05 | .01 |
| 150 | 5 00 | 3 45 | 1 15 | .82 | 3.27 | .06 | .01 |
| 160 | 5 20 | 4 16 | 1 25 | .99 | 3 97 | .09 | .01 |
| 170 | 5 40 | 4 49 | 1 36 | 1.19 | 4 76 | .12 | .02 |
| 180 | 6 00 | 5 24 | 1 48 | 1.41 | 5.65 | .16 | .03 |
| 190 | 6 20 | 6 01 | 2 00 | 1.66 | 6.65 | .21 | .035 |
| 200 | 6 40 | 6 40 | 2 13 | 1.94 | 7.75 | .27 | .05 |
| 210 | 7 00 | 7 21 | 2 27 | 2.24 | 8.97 | .35 | .06 |
| 220 | 7 20 | 8 04 | 2 41 | 2 58 | 10 31 | .44 | .07 |
| 230 | 7 40 | 8 49 | 2 56 | 2.95 | 11 77 | .54 | .09 |
| 240 | 8 00 | 9 36 | 3 12 | 3.35 | 13.38 | .67 | .11 |
| 250 | 8 20 | 10 25 | 3 28 | 3.78 | 15.11 | .83 | .14 |
| 260 | 8 40 | 11 16 | 3 45 | 4.25 | 17.00 | 1.00 | .17 |
| 270 | 9 00 | 12 09 | 4 03 | 4.76 | 19.02 | 1.21 | .20 |
| 280 | 9 20 | 13 04 | 4 21 | 5.31 | 21.20 | 1.45 | .24 |
| 290 | 9 40 | 14 01 | 4 40 | 5.90 | 23.55 | 1.72 | .29 |
| 300 | 10 00 | 15 00 | 5 00 | 6.53 | 26.05 | 2.05 | .34 |
| 310 | 10 20 | 16 01 | 5 20 | 7.20 | 28.72 | 2 41 | .40 |
| 320 | 10 40 | 17 04 | 5 41 | 7.92 | 31 57 | 2.83 | .47 |
| 330 | 11 00 | 18 09 | 6 03 | 8.69 | 34.59 | 3.30 | .55 |
| 340 | 11 20 | 19 16 | 6 25 | 9.49 | 37.80 | 3.82 | .64 |
| 350 | 11 40 | 20 25 | 6 48 | 10.35 | 41.19 | 4.42 | .74 |
| 360 | 12 00 | 21 36 | 7 11 | 11.25 | 44.78 | 5.08 | .85 |
| 370 | 12 20 | 22 49 | 7 36 | 12.21 | 48.56 | 5.82 | .97 |
| 380 | 12 40 | 24 04 | 8 00 | 13.22 | 52.53 | 6.65 | 1.11 |
| 390 | 13 00 | 25 21 | 8 26 | 14.28 | 56.71 | 7.56 | 1.27 |
| 400 | 13 20 | 26 40 | 8 52 | 15 39 | 61.10 | 8.58 | 1 44 |
| 410 | 13 40 | 28 01 | 9 19 | 16 56 | 65.69 | 9.69 | 1 62 |
| 420 | 14 00 | 29 24 | 9 47 | 17.79 | 70 49 | 10.92 | 1.83 |
| 430 | 14 20 | 30 49 | 10 15 | 19.07 | 75.51 | 12 27 | 2.06 |
| 440 | 14 40 | 32 16 | 10 43 | 20.41 | 80.74 | 13.75 | 2.30 |
| 450 | 15 00 | 33 45 | 11 13 | 21.81 | 86 19 | 15.36 | 2.58 |

TABLE VII. TRANSITION SPIRAL.
1° in 20 ft. $a=5.$

| Length | D | J | H | o | y | x COR. | t COR. |
|--------|--------|--------|--------|-------|-------|----------|----------|
| 10 | 0° 30' | 0° 01' | 0° 00' | 0.00 | 0.00 | 0.0 | 0.0 |
| 20 | 1 00 | 0 06 | 0 02 | | 0.01 | | |
| 30 | 1 30 | 0 13 | 0 04 | 0.01 | 0.04 | | |
| 40 | 2 00 | 0 24 | 0 08 | 0.02 | 0.09 | | |
| 50 | 2 30 | 0 37 | 0 12 | 0.05 | 0.18 | | |
| 60 | 3 00 | 0 54 | 0 18 | 0.08 | 0.31 | | |
| 70 | 3 30 | 1 13 | 0 24 | 0.12 | 0.50 | | |
| 80 | 4 00 | 1 36 | 0 32 | 0.19 | 0.74 | | |
| 90 | 4 30 | 2 01 | 0 40 | 0.26 | 1.06 | | |
| 100 | 5 00 | 2 30 | 0 50 | 0.36 | 1.45 | | |
| 110 | 5 30 | 3 01 | 1 00 | 0.48 | 1.94 | | |
| 120 | 6 00 | 3 36 | 1 12 | 0.62 | 2.51 | | |
| 130 | 6 30 | 4 13 | 1 24 | 0.79 | 3.20 | | |
| 140 | 7 00 | 4 54 | 1 38 | 0.99 | 3.99 | 0.1 | |
| 150 | 7 30 | 5 37 | 1 52 | 1.22 | 4.90 | 0.1 | |
| 160 | 8 00 | 6 24 | 2 08 | 1.48 | 5.96 | 0.2 | |
| 170 | 8 30 | 7 13 | 2 24 | 1.78 | 7.15 | 0.3 | |
| 180 | 9 00 | 8 06 | 2 42 | 2.11 | 8.49 | 0.4 | |
| 190 | 9 30 | 9 01 | 3 00 | 2.49 | 9.98 | 0.5 | |
| 200 | 10 00 | 10 00 | 3 20 | 2.90 | 11.62 | 0.6 | 0.1 |
| 210 | 10 30 | 11 01 | 3 40 | 3.36 | 13.45 | 0.8 | 0.1 |
| 220 | 11 00 | 12 06 | 4 02 | 3.86 | 15.44 | 1.0 | 0.2 |
| 230 | 11 30 | 13 13 | 4 24 | 4.41 | 17.63 | 1.2 | 0.2 |
| 240 | 12 00 | 14.24 | 4 48 | 5.01 | 20.01 | 1.5 | 0.3 |
| 250 | 12 30 | 15 37 | 5 12 | 5.66 | 22.60 | 1.8 | 0.3 |
| 260 | 13 00 | 16 54 | 5 38 | 6.37 | 25.38 | 2.2 | 0.4 |
| 270 | 13 30 | 18 13 | 6 04 | 7.12 | 28.39 | 2.7 | 0.5 |
| 280 | 14 00 | 19 36 | 6 32 | 7.94 | 31.62 | 3.3 | 0.6 |
| 290 | 14 30 | 21 02 | 7 00 | 8.82 | 35.10 | 3.9 | 0.7 |
| 300 | 15 00 | 22 30 | 7 29 | 9.76 | 38.83 | 4.6 | 0.8 |
| 310 | 15 30 | 24 02 | 8 00 | 10.76 | 42.73 | 5.4 | 0.9 |
| 320 | 16 00 | 25 36 | 8 31 | 11.82 | 46.92 | 6.3 | 1.1 |
| 330 | 16 30 | 27 13 | 9 04 | 12.95 | 51.36 | 7.4 | 1.2 |
| 340 | 17 00 | 28 54 | 9 37 | 14.15 | 56.05 | 8.6 | 1.4 |
| 350 | 17 30 | 30 37 | 10 11 | 15.43 | 61.09 | 9.9 | 1.7 |
| 360 | 18 00 | 32 24 | 10 46 | 16.75 | 66.31 | 11.3 | 1.9 |
| 370 | 18 30 | 34 14 | 11 19 | 18 16 | 71.63 | 13.0 | 2.2 |
| 380 | 19 00 | 36 06 | 12 00 | 19.65 | 77.35 | 14.8 | 2.5 |
| 390 | 19 30 | 38 02 | 12 38 | 21.21 | 83.41 | 16.8 | 2.8 |
| 400 | 20 00 | 40 00 | 13 17 | 22.87 | 89.83 | 19.0 | 3.2 |

TABLE VIII. TRANSITION SPIRAL.

1° in 10 ft.

 $a=10.$

| Length | D | L | H | o | y | x COR. | t COR. |
|--------|-------|-------|--------|-------|-------|----------|----------|
| 10 | 1 00' | 0 03' | 0° 01' | 0.00 | 0.00 | 0 00 | 0.00 |
| 20 | 2 | 0 12 | 0 04 | .01 | .02 | | |
| 30 | 3 | 0 27 | 0 09 | .02 | .08 | | |
| 40 | 4 | 0 48 | 0 16 | .05 | .19 | | |
| 50 | 5 | 1 15 | 0 25 | .09 | .36 | | |
| 60 | 6 00 | 1 48 | 0 36 | .16 | .63 | 0.01 | 0.00 |
| 70 | 7 | 2 27 | 0 49 | .25 | 1.00 | .01 | |
| 80 | 8 | 3 12 | 1 04 | .37 | 1.49 | .02 | |
| 90 | 9 | 4 03 | 1 21 | .53 | 2.12 | .04 | .01 |
| 100 | 10 | 5 00 | 1 40 | .73 | 2.91 | .08 | .01 |
| 110 | 11 00 | 6 03 | 2 01 | .97 | 3.87 | .12 | .02 |
| 120 | 12 | 7 12 | 2 24 | 1.26 | 5.02 | .19 | .03 |
| 130 | 13 | 8 27 | 2 49 | 1.60 | 6.38 | .28 | .05 |
| 140 | 14 | 9 48 | 3 16 | 1.99 | 7.97 | .41 | .07 |
| 150 | 15 | 11 15 | 3 45 | 2.45 | 9.79 | .58 | .10 |
| 160 | 16 00 | 12 48 | 4 16 | 2.97 | 11.87 | .80 | .13 |
| 170 | 17 | 14 27 | 4 49 | 3.56 | 14.23 | 1.08 | .18 |
| 180 | 18 | 16 12 | 5 24 | 4.23 | 16.87 | 1.44 | .24 |
| 190 | 19 | 18 03 | 6 01 | 4.97 | 19.81 | 1.88 | .31 |
| 200 | 20 | 20 00 | 6 39 | 5.79 | 23.07 | 2.42 | .40 |
| 210 | 21 00 | 22 03 | 7 20 | 6.70 | 26.65 | 3.09 | .52 |
| 220 | 22 | 24 12 | 8 03 | 7.69 | 30.58 | 3.89 | .65 |
| 230 | 23 | 26 27 | 8 48 | 8.78 | 34.86 | 4.85 | .81 |
| 240 | 24 | 28 48 | 9 35 | 9.96 | 39.49 | 5.99 | 1.00 |
| 250 | 25 | 31 15 | 10 23 | 11.24 | 44.49 | 7.33 | 1.23 |

TABLE IX. FACTORS FOR ORDINATES.

To find y , multiply o by the factor for the ratio found by dividing the distance of the point from the P.S. or P.C.C. by the half-length of spiral.

| Ratio to $\frac{1}{2}$ length | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 |
|----------------------------------|-------|------|------|------|------|------|------|------|------|------|
| Factor..... | .0005 | .004 | .014 | .032 | .063 | .108 | .172 | .256 | .365 | .500 |

TABLE X. OFFSETS FOR SPIRALS.

| D | 3° | | 4° | | 5° | | 6° | | 7° | |
|-----|------|-------|------|-------|-------|-------|-------|-------|-------|-------|
| | a | o | L | o | L | o | L | o | L | o | L |
| 0.8 | 3.06 | 3 750 | 7.24 | 5.000 | 14.06 | 6 250 | 24.34 | 7.500 | 38.46 | 8.750 |
| 0.9 | 2.41 | 3.333 | 5.71 | 4.444 | 11.14 | 5.555 | 19.22 | 6.667 | 30.41 | 7.778 |
| 1.0 | 1.96 | 3.000 | 4.64 | 4.000 | 9.04 | 5.000 | 15.60 | 6.000 | 24.71 | 7.000 |
| 1.1 | 1.63 | 2.727 | 3.84 | 3.636 | 7.48 | 4.546 | 12.88 | 5.455 | 20.42 | 6.364 |
| 1.2 | 1.36 | 2.500 | 3.22 | 3.333 | 6.30 | 4.167 | 10.84 | 5.000 | 17.16 | 5.833 |
| 1.3 | 1.16 | 2.308 | 2.75 | 3.077 | 5.36 | 3.846 | 9.26 | 4.615 | 14.63 | 5.384 |
| 1.4 | 1.00 | 2.143 | 2.37 | 2.857 | 4.61 | 3.572 | 7.99 | 4.286 | 12.65 | 5.000 |
| 1.5 | .87 | 2 000 | 2.07 | 2.667 | 4.01 | 3.334 | 6.95 | 4.000 | 11.04 | 4.667 |
| 1.6 | | | 1.81 | 2.500 | 3.51 | 3.125 | 6.11 | 3.750 | 9.71 | 4.375 |
| 1.7 | | | 1.60 | 2.353 | 3.13 | 2.941 | 5.41 | 3.529 | 8.59 | 4.117 |
| 1.8 | | | 1.43 | 2.222 | 2.80 | 2.778 | 4.81 | 3.334 | 7.62 | 3.889 |
| 1.9 | | | 1.30 | 2.105 | 2.50 | 2.632 | 4.35 | 3.158 | 6.90 | 3.684 |
| 2.0 | | | 1.16 | 2.000 | 2.27 | 2.500 | 3.91 | 3.000 | 6.22 | 3.500 |
| 2.2 | | | .96 | 1.818 | 1.88 | 2.272 | 3.22 | 2.727 | 5.13 | 3.182 |
| 2.4 | | | .80 | 1.667 | 1.57 | 2.084 | 2.72 | 2.500 | 4.33 | 2.917 |
| 2.6 | | | | | 1.20 | 1.923 | 2.32 | 2.308 | 3.67 | 2.692 |
| 2.8 | | | | | 1.14 | 1.785 | 1.99 | 2.143 | 3.17 | 2.500 |
| 3.0 | | | | | 1.00 | 1.667 | 1.74 | 2.000 | 2.78 | 2.333 |

| D | 8° | | 9° | | 10° | | 11° | | 12° | | |
|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|---|
| | a | o | L | o | L | o | L | o | L | o | L |
| 1.0 | 36.70 | 8.000 | | | | | | | | | |
| 1.2 | 25.53 | 6.667 | | | | | | | | | |
| 1.4 | 18.80 | 5.714 | 26.72 | 6.429 | | | | | | | |
| 1.6 | 14.45 | 5.000 | 20.47 | 5.625 | | | | | | | |
| 1.8 | 11.40 | 4.445 | 16.23 | 5.000 | 22.15 | 5.556 | | | | | |
| 2.0 | 9.28 | 4.000 | 13.20 | 4.500 | 18.05 | 5.000 | | | | | |
| 2.2 | 7.67 | 3.636 | 10.90 | 4.090 | 14.94 | 4.545 | 19.78 | 5.000 | | | |
| 2.4 | 6.43 | 3.337 | 9.17 | 3.750 | 12.50 | 4.167 | 16.63 | 4.584 | 21.54 | 5.000 | |
| 2.6 | 5.47 | 3.077 | 7.81 | 3.461 | 10.64 | 3.846 | 14.19 | 4.231 | 18.43 | 4.615 | |
| 2.8 | 4.74 | 2.857 | 6.77 | 3.214 | 9.21 | 3.571 | 12.19 | 3.927 | 15.83 | 4.285 | |
| 3.0 | 4.14 | 2.667 | 5.88 | 3.000 | 8.02 | 3.333 | 10.70 | 3.667 | 13.84 | 4.000 | |
| 3.2 | 3.62 | 2.500 | 5.15 | 2.812 | 7.04 | 3.125 | 9.39 | 3.438 | 12.15 | 3.750 | |
| 3.4 | 3.20 | 2.353 | 4.58 | 2.647 | 6.25 | 2.941 | 8.34 | 3.234 | 10.79 | 3.528 | |
| 3.6 | 2.86 | 2.222 | 4.08 | 2.500 | 5.59 | 2.778 | 7.44 | 3.056 | 9.61 | 3.334 | |
| 3.8 | 2.56 | 2.106 | 3.67 | 2.369 | 5.01 | 2.632 | 6.64 | 2.895 | 8.67 | 3.158 | |
| 4.0 | 2.32 | 2.000 | 3.30 | 2.250 | 4.52 | 2.500 | 6.02 | 2.750 | 7.81 | 3.000 | |
| 4.5 | 1.84 | 1.778 | 2.61 | 2.000 | 3.57 | 2.222 | 4.74 | 2.444 | 6.20 | 2.667 | |
| 5.0 | 1.48 | 1.600 | 2.11 | 1.800 | 2.90 | 2.000 | 3.86 | 2.200 | 5.01 | 2.400 | |
| 5.5 | 1.23 | 1.454 | 1.75 | 1.636 | 2.40 | 1.818 | 3.19 | 2.000 | 4.14 | 2.182 | |
| 6.0 | 1.03 | 1.334 | 1.47 | 1.500 | 2.02 | 1.667 | 2.68 | 1.834 | 3.48 | 2.000 | |

The question of the efficiency of easement curves is of considerable importance. The objection is sometimes raised that even if track is laid out with a carefully fitted spiral there would be no possibility of keeping it in place by the methods of the ordinary trackman. This identical objection could be made with the same force against carefully laid out circular curves, yet no engineer would recommend abolishing that practice. Even if, in relining, the transition curve is considerably distorted, it remains an easement, and will be in far better riding condition than a distorted circular curve. By marking the P.S. and the P.C.C. with a stake or post, with possibly on long spirals an intermediate point, the trackman will be able to keep the spiral in as good condition as though it were of uniform curvature.

Properly constructed spirals would frequently allow the use of sharper curvature—since the riding quality of curves may be the governing consideration in the selection of a maximum—and thus make a saving in construction. By fitting curves with proper transition spirals, roads using sharp curves may partially relieve the objection of the public to traveling by their routes. The introduction of fast trains has made it necessary to take every precaution to secure an easy-riding track. The disagreeable lurch and necessary "slow order" for fast trains at certain curves on many roads has been entirely eliminated by the construction of proper spirals, and passengers do not now know when such curves are reached. The transition curve has, then, a financial value largely overbalancing its cost. The adoption of such curves by many of our principal railways proves their efficiency, and the future will see a much more general adoption.

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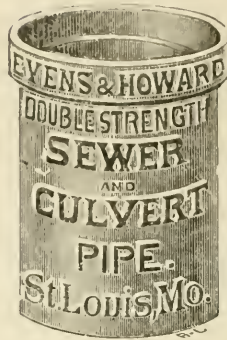
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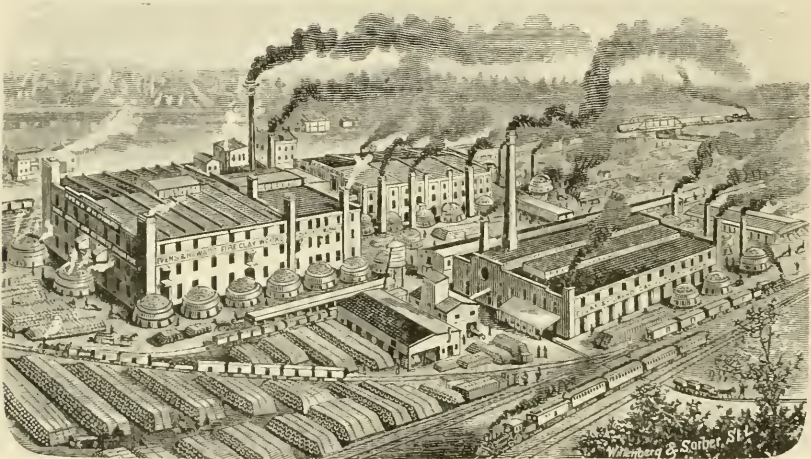
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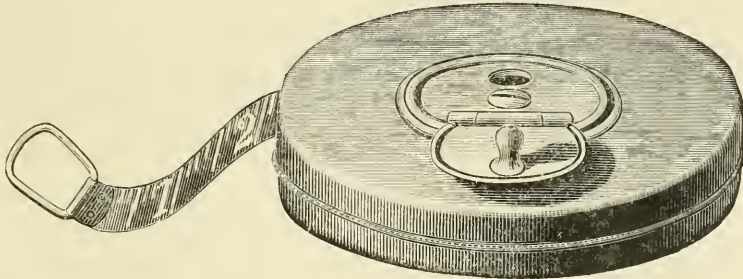
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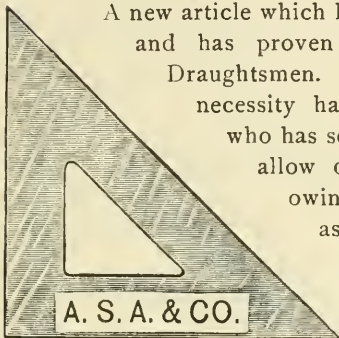
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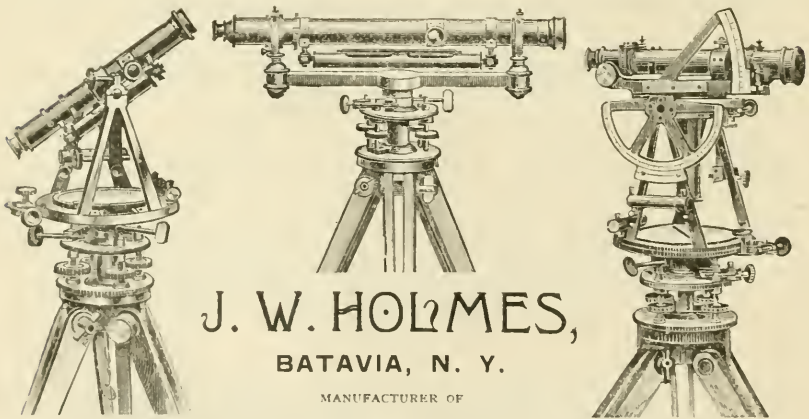
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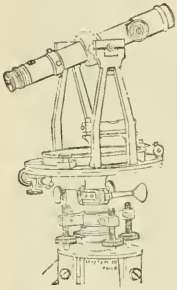
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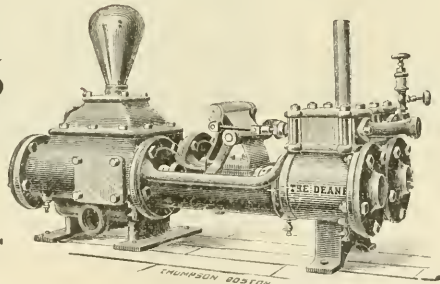
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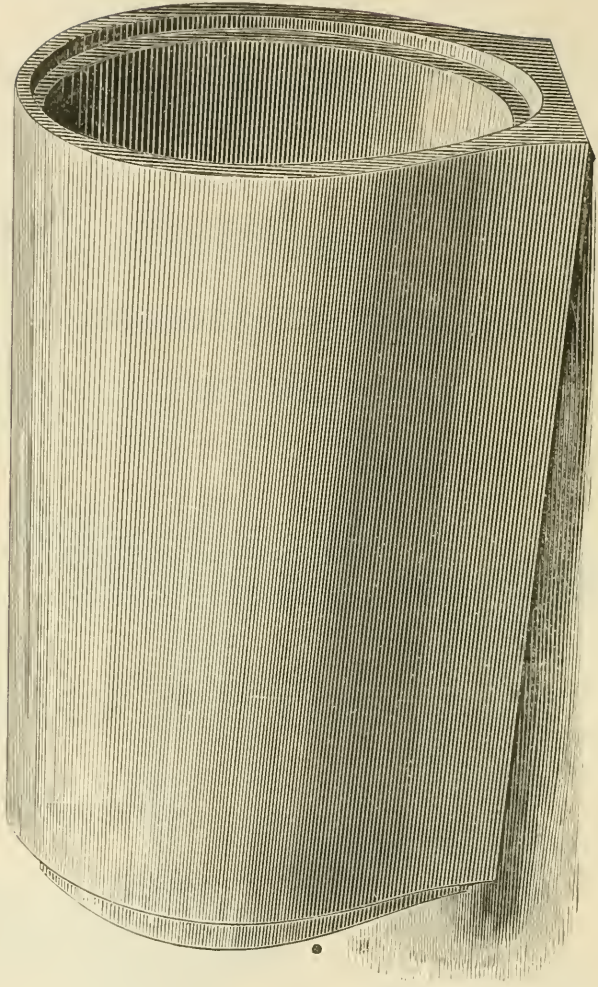
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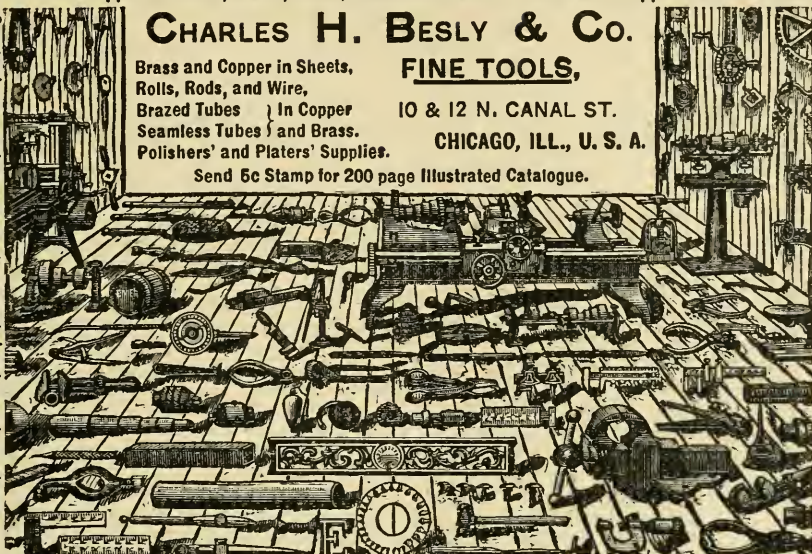
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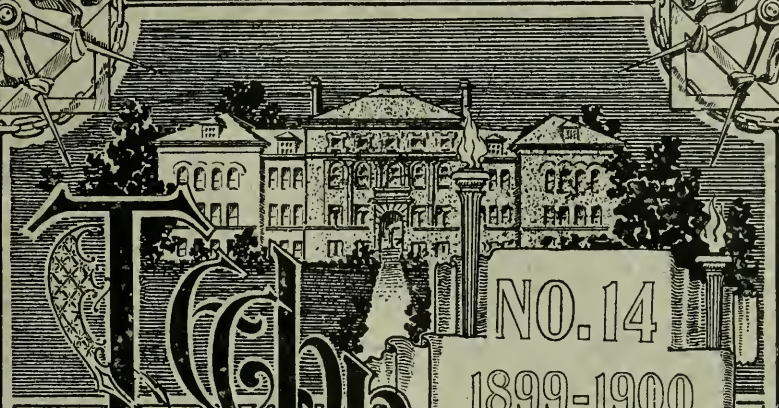
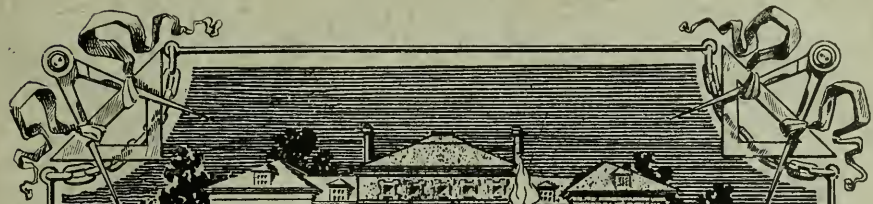
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UNIVERSITY OF ILLINOIS
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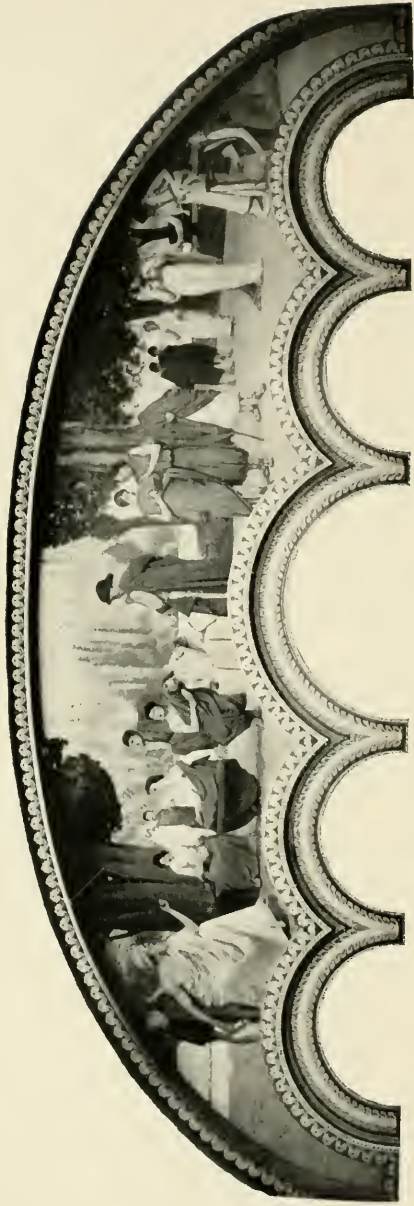


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FALLACIES IN GOOD-ROAD ECONOMICS.

BY IRA O. BAKER, PROFESSOR OF CIVIL ENGINEERING,
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It goes without saying that the engineer should know how to build good roads; and his duty as a citizen and his professional interest require that he should be acquainted with the facts and arguments relating to road improvements, as well as with the methods of construction. This is particularly true, since in the current literature on highway improvement, it is usually claimed that one of the conditions necessary to success is to commit the construction and maintenance of roads to engineers. In general, it is frequently as important for the engineer to understand the ways and means, as to be able to carry out the plan. Therefore it is believed that a discussion of a question in good-road economics is appropriate in an engineering magazine.

Recently there has been no lack of literature concerning the advantages of good roads; but some of it has done more harm than good, since its extreme views and fallacious arguments have antagonized many of those whose coöperation must be enlisted before any considerable improvement of the condition of the public highways can be secured. Farmers instinctively know that some of the leading arguments in favor of highway improvement are erroneous; and therefore discredit all reasons in favor of better roads, are indifferent to all suggestions as to methods of road improvement, and are suspicious of the motives prompting the agitation. The writer has an extended acquaintance with Highway Commissioners and County Supervisors in

the eastern part of central Illinois, and is certain that the above does not misrepresent the attitude toward the good road agitation of leading farmers in the corn belt. No reform or advancement can be made unless it be founded upon truthful statements and reasonable arguments; and no highway improvement of any moment can be secured unless the farmers and land owners believe the arguments and trust the motives of the advocates of good roads.

It is proposed to examine the arguments of some of the more prominent advocates of road improvement, with a view of determining the limitations as to permissible cost.

A WILD GUESS.

A favorite method of showing the wastefulness of bad roads is to compare the efficiency of horses on European and American roads. Some claim that a horse in Europe does twice as much work as in America, solely because of the better roads; while others claim that three horses in Europe do as much as four in America. The annual cost of bad roads to the American farmer is then said to be the annual cost of feeding one quarter to one half of all the horses in America plus the annual interest on the value of the superfluous horses. The results are truly appalling.

In the first place, the premissis is a mere guess, since it is impossible off-hand to state the relative efficiency of horses in Europe and in America. Doubtless there are poor roads in Europe, and there are surely some good ones in America.

In the second place, the above line of argument assumes that all horses are continuously upon the road. This assumption is seriously in error, since there are a large number of horses in the cities not in any way connected with the farms, and farther since the horses on the farms include a number too young to work, and still farther since most farmers require considerably more horses to raise the crops than to transport them to market.

Is it surprising that such arguments fail to convince the farmer of the disastrous cost of bad roads? It is astonishing that such estimates were ever seriously proposed. They are unworthy of further consideration, and are referred to here only because they are frequently quoted.

A ROUGH ESTIMATE.

Another favorite method of demonstrating the cost of bad

roads is to estimate the saving per horse due to improved roads. The annual saving per horse is variously estimated at from \$10 to \$20, and the saving in vehicles and harness is estimated as equivalent to \$5 per horse, making a total annual saving by good roads of \$15 to \$25 per horse.* This sum is then multiplied by the number of horses given in the census report or returned by the tax assessor, and the product is said to be the annual loss by the farmers due to bad roads. Using the smaller of these values, one author makes the annual loss in Illinois \$15 000 000, equivalent to \$272 for each square mile in the state.† Is this result even approximately correct?

1. No evidence is offered to show the actual loss by bad roads. Possibly a horse continually on the road could earn \$10 to \$20 per year more on good roads than on poor ones. But, on the contrary, farmers frequently claim that the damage to a horse through driving on "good roads," *i. e.*, on stone roads, is more than \$15 per annum. "The hard roads stiffen up a horse." The cost of keeping a horse shod is considerably more with stone than with earth roads. These losses due to good roads are reasonably certain, while the advantages claimed are problematic.

Possibly the damage to vehicles and harness is more with poor than with good roads; but farmers claim that vehicles wear out faster on stone than on earth roads.

In short, the advantages are not all on one side, and the saving claimed is not proven.

2. Even though a horse continually on the road could and would earn \$15 per annum more on good roads than on poor ones, the above estimate is grossly in error, since only a small per cent of the horses are on the road all the time, or since the average horse is on the road only a very small part of the time. Unquestionably a horse can do more work on good roads than on poor ones, but that does not prove that farmers, gardeners, etc., as a rule, would require fewer horses or that their horses would earn more with better roads.

*Problems of To-day, Richard T. Ely, 1890, New York, 3d ed., p. 148.
Road Legislation for the American State, Jeremiah W. Jenks, Baltimore, 1889,
p. 14. Report on Highways of Maryland, 1899, Baltimore, p. 410.

†Road Legislation for the American State, p. 14.

STATISTICAL COST OF WAGON TRANSPORTATION.

The Office of Road Inquiry of the United States Department of Agriculture, in Circular No. 19, as a result of "ten thousand letters of inquiry sent to intelligent and reliable farmers throughout the country," presents the statistics in Table I as to the length of haul, weight of load, cost per ton mile, and cost from farm to market. The table "represents the consolidated report from about 1 200 counties."

TABLE I.

DATA ON COST OF BAD ROADS.

| Ref. No. | Locality. | Average Distance Hauled, miles. | Average Load Hauled, tons. | Average Cost per ton-mile, cents. | Total Cost from Farm to Market, per ton. |
|----------|-------------------------------|---------------------------------|----------------------------|-----------------------------------|--|
| 1 | Eastern States..... | 5.9 | 1.108 | 32 | \$1.89 |
| 2 | Northern States..... | 6.9 | ..... | 27 | 1.86 |
| 3 | Middle-Southern States*..... | 8.8 | ..... | 31 | 2.72 |
| 4 | Cotton States..... | 12.6 | 0.688 | 25 | 3.05 |
| 5 | Prairie States..... | 8.8 | 1.204 | 22 | 1.94 |
| 6 | Pacific Coast and Mountain... | 23.3 | 1.098 | 22 | 5.12 |
| 7 | Whole United States..... | 12.1 | 1.001 | 25 | 3.02 |

*In one place in the Circular, designated "Middle States," and in two places "Middle-Southern States." Unquestionably the two terms apply to the same region.

The Circular determines that in 1895 the farm products amounted to 219 024 277 tons; and assumes that the farm products consumed on the farm are offset by the mine and quarry products, merchandise, etc., hauled over the public roads. It is farther assumed that one quarter of the timber cut for fuel and for the mill, and all of that used by the railroad, or a total forest product of 93 525 000 tons, is transported over the public highways. The conclusion is then reached that in 1895, 313 349 227 tons were hauled over the highways of the United States at a cost per ton of \$3.02 (the "cost from farm to market"), making a total cost of wagon transportation of \$946 314 665.54.

If the cost of transportation on the wagon roads of the country is \$946 000 000 annually, then indeed is highway improvement worthy of the most careful attention of statesmen, engineers, and farmers. This is more than six times the annual expenditures for public schools. It is approximately the ordinary expenses of the United States Government for two years. It is \$10000 0 000 more than the operating expenses of practically

all the railroads in the United States for the year 1899. It is more than the freight earnings of practically all the railroads of the country. "The immensity of this charge," to quote from the above circular, "will be best realized by comparing it with the value of all farm products in the United States for the year 1890—\$2 480 170 454, which value has probably diminished since that date." In other words, according to the above data, the annual cost of the transportation upon the public highways of the United States is equal to 38 per cent of the value of the farm crops. Or, since 70 per cent of the freight is assumed to be farm products, the cost of hauling directly and indirectly connected with marketing the crops is $38 \times 70 = 26.6$ per cent of the value of these products. According to the Report of the Eleventh Census, there are 5 442 756 farmers, planters, dairy-men, gardeners, florists, nurserymen, and vine-growers in the United States, and therefore the above cost of transportation is equivalent to \$157 for each "farmer." Again, according to the census the area of the farms is approximately 1 000 000 square miles; and therefore the above cost of transportation is \$946 per square mile, or \$1 48 per acre, which is more than one fourth of the annual rent of farm lands. Is this conclusion approximately true?

The above data is the result of an earnest and comparatively elaborate attempt to throw light upon a complicated question materially affecting the entire population of this country; and therefore the methods employed and the results obtained are worthy of a careful and detailed examination.

While the examination about to be entered upon is primarily to determine the cost of transportation upon wagon roads, incidentally it will illustrate some of the principles to be employed in deducing conclusions from statistics. The incidental purpose is worthy of a far more careful discussion than can be given to it in this connection.

ELABORATENESS OF THE INVESTIGATION. Owing to its seeming elaborateness, the above official investigation has carried great weight—witness the following from a State Highway Commission: "Although any one result may be considerably in error, the average of so many must be quite reliable." The statement that ten thousand letters of inquiry were sent out, apparently creates the conviction that the investigation was a

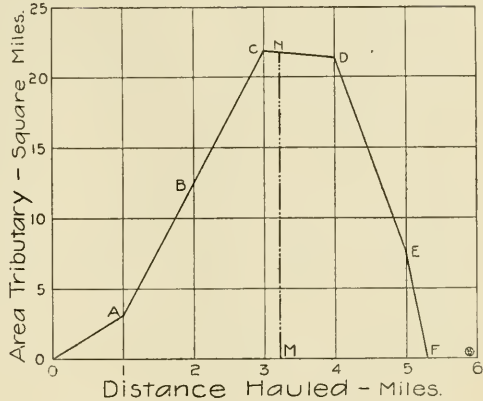
very elaborate one. The area to be covered was also very great; and the inquiries averaged only one to 300 square miles,—or say about three inquiries to two counties. This shows that the attempt was not on a very elaborate scale. The writer has inquired and has been officially informed that it is not known how many answers were received. The statement is that Table I “represents the return from about 1 200 counties,” or about one county in twenty-five. This shows that the number of answers was entirely inadequate to secure representative data for the whole country. Farther, the value of the answers will depend greatly upon their distribution. Inquiry has been made, but nothing can be learned of the distribution of the answers. However, the Circular prints twenty-six replies of “representative men,” of which eighteen, or 69 per cent, are from New Jersey. If the replies were bunched in anything like this proportion, then some parts of the country are indeed meagerly represented in Table I. At best, data for one county in twenty-five can not be accurately representative.

AVERAGE HAUL. The value of the reply as to the average haul will depend upon the manner of determining it. “The Road Inquiry Office has no copy of the letter of inquiry.” Apparently the letter merely asked for the average haul, and gave no instructions as to the method to be used in deducing it. A man on receiving such an inquiry and knowing that farm products were hauled to a certain town from all distances up to ten miles, would probably reply that the average haul was one half of $0+10$, or 5 miles. By many trials, the writer has found that in the great majority of cases this answer is accepted as correct; while in fact it is erroneous, and in many cases greatly so. This method of determining the average haul does not take into account the number of loads hauled each distance.

1. The correct determination of the average haul for any particular place is a complicated matter. To illustrate the difficulties, let us assume that the number of tons per acre is the same for all distances. For a certain distance out from a railroad station all of the land is tributary to this particular station, and hence out to this limit the number of tons hauled will vary as to the square of the distance. Beyond this limit only part of the land is tributary to this particular station, and consequently

as the distance increases the number of tons decreases and finally becomes zero.

This state of affairs is represented in Fig. 1. The area 0A1 represents the area tributary and within 1 mile of this station; the area 1AB2 represents the tributary area more than 1 mile and less than 2 miles from the station; and similarly for the other distances.



From 0 to B, for the

actual case considered, the area, and consequently the tons, increases as the square of the distance; and from B to C nearly as the square of the distance; and from C to F the area, and consequently the number of tons, decrease according to the location and distances between the railroad stations. The quantity sought is the center of gravity of the area 0ABCDEF. This could be determined by the ordinary mathematical process, or it may be found by accurately cutting the area from a sheet of cardboard and finding where it will balance on a knife edge held parallel to the vertical lines. The line NM is the position of the knife edge when the area 0ABCDEF is thus balanced, and therefore the distance 0M is the average haul.

The distance 0M is about 3.2 miles. This method of solution assumes that a road runs directly, i. e., diagonally, from the farm to the station; but as a rule the roads run only on the cardinal lines. Therefore the distance determined as above should be increased by about one fifth. Consequently the average haul for this particular station is about 3.64 miles.

2. The distance hauled will vary greatly with the locality. Farm product will be hauled much farther to a large city than to a small village; certain kinds of products will be hauled much farther than others; and the distance hauled will vary greatly with the kind of roads. If the letters of inquiry were sent to large cities where a considerable part of the freight traffic on the public highways was hauling vegetables, fruit, etc., over good

stone roads to market, then the result for the average distance hauled, even though correctly determined, is of but little value in determining the cost of hauling the average farm product to market. The writer could learn nothing about the distribution of the letters of inquiry; but in the circular giving the results of the investigation are published a number of "opinions of representative men," of which 69 per cent are from New Jersey. Doubtless a considerable part of the traffic in New Jersey is hauling perishable products on good roads to large towns and cities; and hence does not represent average conditions. Farther, a disproportionate per cent of these replies are from large cities. Obviously the value of the individual replies will depend upon the points from which they came.

3. The value of the average of several replies will depend upon the distribution of the replies. One part of the state furnishes more traffic and is better supplied with railroads than another. The replies should be distributed proportionately to the amount of traffic.

The above facts show some of the errors which vitiate the results. The problem is such that a farmer could not be expected to determine a result with any considerable accuracy for any particular place; and the nature of the investigation is such that a multiplicity of results does not insure a correspondingly accurate average.

The designation of the territories covered by Table I is too indefinite to permit a direct test of the data; but an examination of a railroad map shows that probably the average haul as given in Table I is considerable too great—at least for the states that furnish the bulk of the traffic. Portions of a state may be found which are relatively at a considerable distance from a railroad station, but in nearly every case it will be found that throughout that area there is but little traffic on the public highways.

The reliability of the value of the average haul as given in Table I can be approximately tested in another way. For example, Illinois has an area of 56 600 square miles, and has 10 752 miles of railways exclusive of sidings and second tracks; or 1 mile of railroad for each 5.3 square miles of area. Investigations also show that the distance between railroad stations averages a trifle under 4.5 miles. Therefore, if we consider a strip of land 5.3 x 1 miles laid transversely across the railroad

half way between railroad stations, then the maximum haul will be approximately $\frac{1}{2}$ of $5.3 + \frac{1}{2}$ of $4.5 = 4.9$ miles. This may be regarded as the average maximum distance of haul in Illinois. The average haul is probably approximately half this, or say 2.5 miles. There is a slight error in the above computation, since no account is taken of the fact that the railroads cross each other; and this error makes the result slightly too small.

By the preceding method of solution the average haul for Iowa is slightly less than that for Illinois; while that for eastern Kansas and eastern Nebraska are a little greater than for Illinois. Illinois, Iowa, eastern Kansas and eastern Nebraska furnish the bulk of the traffic from the "prairie states," and hence we conclude that the value of the average haul as given in Table I for the "prairie states," 8.8 miles, is perhaps three times too great.

Finally, notice that 30 per cent of the freight supposed to be hauled on the wagon roads is forest products, and therefore "the distance from farm to market" has little or nothing to do with this part of the traffic.

AVERAGE WEIGHT HAULED. The weight of the average load varies chiefly with the grade of the load and condition of its surface; and in most localities the latter varies greatly with the season, and is not the same for any two successive years. Farther, with earth roads the most of the freight is hauled when the roads are in their best condition. For these reasons, it is a matter of considerable difficulty to determine the weight of the average load for any particular place, much less for an average of several states. However, as this data is not directly used in determining the supposed cost of bad roads, this phase of the subject will not be discussed farther.

COST PER TON-MILE. No details are given as to the method employed in determining the cost per ton-mile of hauling crops from the farm to market. The prices given indicate that the wages of a wagon, team, and driver were assumed to be about 35 cents per hour; that the load was assumed to be approximately 1 ton; that the team was assumed to travel about 3 miles per hour; and that the team was assumed to haul a load only one way. There are three radical errors in this method.

1. The price per day is too great or the amount hauled per load is too small. The writer has considerable knowledge of

the prices actually paid for hauling on Illinois roads, and believes that the prices in Table I are the maximum rather than the average, and are perhaps a third too high.

2 The great bulk of teaming is done when the roads are at least in fair conditions, when the load is considerably more than 1 ton. In fact, there is very little of the crop hauled to market when the load is one ton or less. The writer has examined the records of several grain buyers in central Illinois, where at times the roads are as bad as anywhere, and finds that the average load is nearly a ton and a half.

3. The most important error in the whole investigation under consideration is the assumption that the chief business of the farmer is transporting his crops to market. The great bulk of farm crops is hauled to market when the farmer has nothing else to do, or when it is not a matter of much moment whether other work is delayed; and in this case the cost is merely nominal.

In many localities there is a choice of markets; and in central Illinois it is nothing uncommon for a farmer to haul corn four to six miles extra for a difference of one cent per bushel. Thirty-six bushels make a ton, and therefore he receives 36 cents per ton for the extra hauling, or say 6 to 9 cents per ton-mile. This result is approximately one third of that in Table 1.

The results in Table I for the cost per ton-mile may be approximately correct for gardeners, dairymen, etc., who are compelled to keep a team upon the road nearly every day of the year; but these are not representative "farmers," for according to the Eleventh Census of the United States there are 5 281 557 farmers and planters, and only 90 470 gardeners, dairymen, florists, nurserymen, and vine-growers. Again, the writer has frequently asked grain farmers: "What is it worth to haul crops to market?" and in a great majority of cases has received answers substantially as in Table I; but on asking: "What does it really cost you," the answer is almost invariably: "Nothing." The average farmer is not conscious that it costs him anything to haul his crops to market.

THE AMOUNT HAULED. In the computation of the cost of wagon transportation, the Circular referred to above assumes that the farm products consumed on the farm were offset by the hauling of lumber, coal, fertilizers, merchandise, etc., to the farm. In the first place, it is doubtful if there are as many tons

of freight hauled to the farm as there are of products consumed on the farm. In the second place, the offset ought not to be allowed, since almost always the freight hauled to the farm is brought back when a load of produce is taken to town, or is hauled back incidental to a trip for some other purpose, or is hauled when there is nothing else to do. In the third place, a considerable part of the farm product is driven to market on foot.

CONCLUSION. Above it has been shown for Illinois (1) that the average haul is probably less than one third of that given by Table I; (2) that the cost per ton-mile is not more than one third of the value given in Table I; and consequently for Illinois the average cost from farm to market is only about one third of one third, or one ninth, of that stated in the table.

In the light of this conclusion, it is astonishing that the results from the circular under review have so frequently been used with approval in newspaper and magazine articles, in public addresses, in governor's official messages, in resolutions by boards of trade, and in books on road improvement. When such arguments are the chief stock in trade of would-be road reformers, is it any wonder that farmers are indifferent? They instinctively know that conclusions such as those deduced above from Table I are ridiculous, and not unnaturally distrust the motives prompting the argument, and are hostile to all propositions for road improvement.

“DEFINITE SAVING BY GOOD ROADS.”

The Office of Road Inquiry, in Circular No. 19, as above, estimates the possible annual saving by road improvement as two thirds of \$943 314 665.54, or \$628 000 000. This is equal to an average of \$105 for each farmer, planter, fruit-grower, gardener, etc., in the United States; or an average of 78 cents for each acre of farm lands.

The above estimate is based upon a comparison of the data in Circular No. 19 above with that on the “Cost of Hauling Farm Products to Market or Shipping Point in European Countries, Collected by U. S. Consular Agents,” published in Circular No. 27 of the Office of Road Inquiry of the U. S. Department of Agriculture. The average cost as given in the latter circular (when translated) is 10 cents per ton-mile, and the difference between this and the average stated in Table I is 15 cents per ton-mile, which is two thirds of the total in Table I. Evidently

any conclusions based on Table I are greatly in error, as has already been shown.

Apparently the average cost of wagon transportation in Europe as stated in the preceding paragraph is more than that deduced in the preceding part of this paper, for this country. In the first place, the statistics from Europe are open to the criticisms made against the data in Table I. In the second place, the twelve results given in the circular vary from 4 to 30 cents per ton-mile, which is too wide a range and too few results for an accurate determination of the cost of wagon transportation in Europe. In the third place, some of the results are professedly the cost to transportation companies, and some the cost to farmers to whom the hauling of the crops to market is merely an incident of farm work. And finally the data for the cost of hauling not done by transportation companies is for hauling garden products, etc., to large cities, and is therefore not representative of the cost of transporting general farm products to market. The cost of wagon transportation on the very best roads of Europe ought not to be very much less than the ordinary cost of hauling farm crops to market in America, for in most cases the latter is done when the roads are in fair or good conditions, and when in their best condition earth roads are nearly as good as the best stone roads.

The above method of estimating the saving due to good roads is materially in error, if not very deceptive, since no account is taken of either the annual interest on the original investment or of the increased cost of maintaining the better roads. Of course, these items will vary greatly with the location and character of the road and with the amount of traffic; but this is no reason why they should be omitted in such estimates. An elaborate official report* in making "an approximate estimate of the actual amount of money that would be saved annually by good roads" neglects these items, when on a preceding page† it had been shown that the original cost of the roads of France varies from \$12 880 to \$2 580 per mile, and the annual cost of maintenance varies from \$258 to \$64, respectively. Of these higher priced roads, "national roads," there is one mile for each 8.7 square mile of territory; and of the lower

*Report of the Highways of Maryland, Baltimore, 1890, p. 408-9.

† *Ibid.*, p. 385.

priced roads, "neighborhood roads of the lowest grade," 1 mile for each 1.3 square miles of area. The original cost of the national roads of France is \$12 880 per linear mile of road or \$1 480 per square mile of tributary area, which at 5 per cent interest is equal to an annual charge of \$644 per linear mile of road, or \$74 per square mile of territory. The cost of maintaining these national roads is \$258 per linear mile of road, or \$30 per square mile of territory. Therefore the annual cost of these celebrated roads is: $\$644 + \$258 = \$902$ per linear mile of road; or $\$74 + \$30 = \$104$ per square mile of territory. Similarly, for the lowest grade of neighborhood roads the annual cost is: $\$129 + 64 = \193 per linear mile of road; or $\$100 + 50 = \150 per square mile of territory. The greater mileage of the cheaper roads makes the cost per square mile of benefited area greater than for the better roads. At 5 per cent interest the annual cost of all the wagon roads of France is: \$400 for interest plus \$180 for maintenance, or a total of \$580 per square mile of area. Clearly then the interest on the original cost and the expense of maintenance are important elements and should not be omitted.

ROAD TAXES WASTED.

It is frequently argued that because the annual road tax produces no hard roads that therefore at least a large part of the money is wasted. 1. In most states part of the tax is spent for new steel bridges. In Illinois a little more than one quarter of the road tax is so spent. Steel bridges are a substantial improvement, and would be almost imperative with stone roads. 2. Another considerable part of the taxes is used in renewing wood culverts and the floors of bridges, which expense would be practically the same whether the roads are improved or not. 3. A further sum is spent in improving the drainage, which would be required before good stone roads could be built. 4. Part of the road taxes is used to pay for mowing the roadsides, which would be desirable even if the road surface were improved. 5. Finally a considerable portion of the money is used in maintaining the earth surface; and if the roads were improved, a considerably larger sum would be required for a like purpose.

The claim is frequently made that a large part of the labor tax is wasted. Possibly in the early history of any community, when there is slight social intercourse among the farmers, more time was wasted in gossip than now; but at present the loss by

this practice is not very great. It is by no means uncommon for a farmer to give considerably more labor than is exacted; he uses the roads and desires to improve them for his own benefit. Farther a farmer would probably prefer to pay \$2 in labor than \$1 in cash; and hence the evils of the labor tax system may not be as serious as is generally claimed, since practically the farmer's vote determines the amount of road tax he will pay.

Admitting that there are inherent defects in the labor-tax system, it is not proven that they are greater than in the cash system. Cash-paid day labor and contract work in city affairs are not always ideally efficient. There is probably no universally "best system" of maintenance of highways. Some of the famous roads of Europe are maintained by a cash-tax and some by a labor-tax. There are no better roads, nor no more complete system of maintenance, than in France; and yet by far the greater part of the wagon roads of France are maintained by the labor-tax system. The fundamental defect in the construction and maintenance of American highways is the lack of intelligent and effective supervision.

REAL ADVANTAGES OF GOOD ROADS.

The object of this article is to call attention to the extravagance of some of the more common arguments in favor of road improvement, with a view to securing a more reasonable consideration of the matter. Incidentally, the preceding discussion shows that any considerable improvement of the public highways can not in general be justified entirely on financial grounds.

In conclusion some of the advantages of permanently good roads are as following, the first eight of which are financial and the last six are social:

1. Decrease the cost of transportation,—at some seasons only a little, and at others very considerable.
2. Give a wider choice of time of marketing crops.
3. Give a wider choice of the market place.
4. Decrease the cost of miscellaneous travel.
5. Permit sale of products that might otherwise go to waste.
6. Tend to equalize railroad traffic between the different seasons of the year.
7. Tend to equalize the produce market between different climatic conditions.

8. Permit the cultivation of crops not otherwise marketable.
9. Add to the comfort and pleasure of travel.
10. Permit more easy intercourse between farmers, and between rural and urban populations. This is an important benefit, particularly in a republican form of government.
11. Facilitate the consolidation of rural school. This is an important advantage, particularly to the coming generation.
12. Facilitate rural mail delivery.
13. Improve the sanitary condition, particularly in villages and towns.
14. Improve the appearance of the highway.

It is customary to include the increase in the price of land as one of the advantages of good roads; but the increase in price of land is simply the measure of the value of all of the above advantages, and hence should not be included.

By inquiry among farmers and real estate agents, it appears that in the corn belt of Illinois, farming land 1 mile from a railroad station sells for \$5 to \$10 per acre more than land 5 miles farther away. In other words, this is approximately the grain farmer's estimate of both the financial and the social value of good roads. Strictly, the above sum is a little more than the supposed value of good roads, for no form of improved road can ever put the more remote locality upon exactly the same basis as the nearer one, for even the best road can not eliminate the difference in distance. Either of the above sums is too small to justify any radical highway improvement.

Too much attention has been given to the supposed direct financial advantages of good roads, to the exclusion of the social advantages. Good roads are desirable for the same reason that a man buys a carriage or builds a fine house, i. e., because they are a comfort and a pleasure. Good roads are to be urged for the same reason that good schools are maintained, i. e., because they increase the intelligence and value of the citizen to society.

Farther, more attention should be given to the improvement of the present earth roads, and less to the advantages of roads which at present are impossible to many rural communities. Good roads will come by evolution rather than by revolution; and the improvement of earth roads is always the first step toward any kind of better roads.

EXTENSION AND RECONSTRUCTION OF CENTRAL STATIONS AND DISTRIBUTING SYSTEMS.

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As one of the latest of the great industrial developments of the latter part of the 19th century, the methods employed in the supplying of electricity for light and power purposes from Central Stations are particularly interesting. The early history and development of central station work is already familiar to most readers. From the beginning the progress made has been little short of phenomenal; invention has followed invention, apparatus has been built and installed, methods of financing and operating have been adopted only to be modified, extended and sometimes entirely replaced in a short time with something more productive of desired results. It is the purpose of this article to note some of the latest developments in central station work in this country, particularly with reference to extension and reconstruction of existing plants.

From the first the generating stations, as well as the distributing systems, were usually designed so that they could be extended to take care of the increase in business. It has frequently been found advisable to change entirely the original design because of the development of new apparatus, and frequently also the demands of new customers in unexpected localities. This is more especially true of station apparatus than it is of distributing systems. The Edison three-wire system of underground conductors was early adopted in nearly all of the large cities of the country, and proved to be a permanent investment almost from the very beginning. This system was originally used entirely for direct current distribution, but latterly has also been successfully used for alternating current distribution. The different systems of distribution usually employed in overhead work have undergone many changes, particularly in the design of transformers. Results that a few years ago seemed

impossible, have followed the efforts to reduce the cost of generating and distributing electricity.

Many systems have to-day an all-day efficiency of 75 to 85 per cent, while there are some systems still in operation having an efficiency of but 40 per cent. Generators now deliver 92 to 94 per cent, whereas formerly they delivered but 80 to 85 per cent. Engines and boilers have been improved so that to-day, with moderate size of units, a water rate of 12 to 14 pounds per horse-power per hour is frequently obtained, instead of 25 or 30 pounds as formerly. Contracts for very large units have recently been closed on which, by the aid of superheating devices, water rates of 9 and 10 pounds per horse-power per hour have been guaranteed.

The increased efficiency of apparatus is, however, not by any means the station manager's only criterion by which to estimate his probable net profit at the end of the year. The charges for interest and depreciation bear a close and very important relation to operating cost, because in many of the central stations of the country the period of maximum load is only about two or three months. During the remaining nine or ten months from 30 to 50 per cent of the entire plant, as an earning factor, is lying idle. Even during period of maximum load, all of the apparatus is in use but two or three hours per day, or less than 100 hours of the 8760 hours in a year. It is often necessary, therefore, to earn the interest for the whole year on from 30 to 50 per cent of the entire investment in perhaps one hundred hours.

The mistake has frequently been made to design and install plants of extremely high efficiency, and to lose sight of the fact that the saving made thereby has been more than counterbalanced by the interest and depreciation on the excessive investment. It must be evident, therefore, with what care the station manager must proceed when his business requires that additional investment be made in generating stations and in the distributing system.

It is necessary to have a well classified system of accounts and to have reliable statistics of operating costs and distribution expenses always at hand. A careful monthly analysis of all these costs, including interest and depreciation, is an indispensable aid in determining when improvements are possible and

most desirable. It is necessary also to closely observe the tendencies in the development of probable future business, particularly with reference to the load factor.

As nearly all central stations in large cities have been developed at least along similar lines, the writer will dwell at some length on the present installations in one of the large cities of the country, and later call attention to such features in other leading central stations as differ materially from those described.

In the City of Chicago practically all of the distinctively central station business is done by two allied companies—the Chicago Edison Company and the Commonwealth Electric Company. The former Company supplies the more populous and business districts of the City and confines its operations to the territory bounded by North Avenue, Ashland Boulevard, 39th Street and Lake Michigan. The franchise under which this Company operates provides that all conductors must be underground. As the franchise of the Commonwealth Electric Company permits operation over the entire City and allows overhead conductors except in the most populous parts of the City, this Company operates mainly in the outlying and suburban districts. The division of territory is shown in Figure 1, which is a map of the City of Chicago. The shaded portion shows the territory where current for incandescent or arc light, or for power purposes, is supplied. The largest portion of the incandescent light and power business is concentrated in a comparatively small area. The total kilo-watt hours, exclusive of series arc delivered to the Chicago Edison Company territory in 1899 was 22 600 000. Of this amount 17 400 000 kilo-watt hours was delivered to territory represented by the heavily shaded portion of Fig. 1, referred to later as District No. 1, an area of about .8 square miles. The total kilo-watt hours exclusive of series arc delivered to the Commonwealth territory was only 3 697 000. The total series arc delivered to Edison territory was 1 938 000 kilo-watt hours while that delivered to the Commonwealth territory was 3 095 000 kilo-watt hours. The series arc business consists almost exclusively of commercial lighting in the more populous districts where the City of Chicago operates its own street lights. In the outlying districts this business consists largely of street lighting.

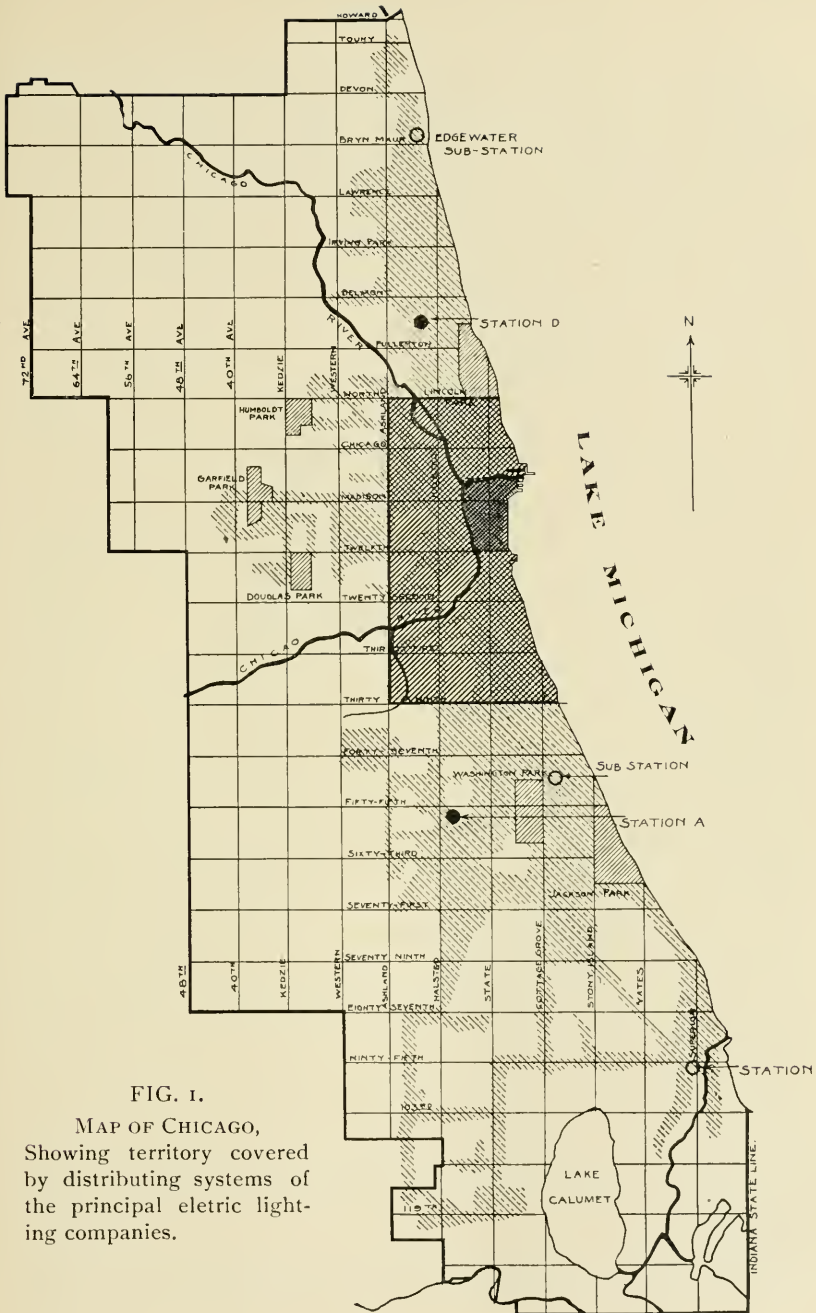


FIG. 1.

MAP OF CHICAGO,
 Showing territory covered
 by distributing systems of
 the principal electric light-
 ing companies.

The system of distribution employed by the Chicago Edison Company is a solid net work of underground conductors on the three-wire system extending from North Avenue to 39th Street, a distance of six miles, and from Lake Michigan to Center Street, an average distance of nearly two miles. The entire net work is divided into four different districts, all interconnected so as to make it continuous from end to end. The current is supplied at times from four generating stations, all operating in multiple through the common net work. The location of the different generating and distributing stations is shown in Figure 2.

The territory South and East of the Chicago River and North of 12th Street is known as District No. 1, and that West of the Chicago River as District No. 3, the territory South and North are known respectively as Districts No. 2 and No. 4.

District No. 1 was supplied originally from a generating station at No. 139 Adams Street, which is still the center of distribution. On this site is now located the Edison Building, which contains the Executive offices and offices of the various departments of the Company. The first floor and basement—known as Adams Street sub-station—contain two large storage batteries which are connected to a distribution switchboard in the basement, from which emanate at present, forty-one (41) feeders, to main points in the district which vary in length to 2900 feet and in cross-section from 250 000 circular mils to 1 000 000 circular mils. The distribution switchboard is connected to Station No. 1 by means of a trunk line 3340 feet long and having at present copper aggregating 66 000 000 circular mils in cross-section. The first of the storage batteries was put into service in June, 1898, and consists of 166 cells each containing eighty-seven type "H" plates manufactured by the Electric Storage Battery Company of Philadelphia. The second storage battery was put into service in October, 1899, and consists of 160 cells, each containing eighty-one type "H" plates. Each one of these batteries has sixty (60) end cells and is equipped with six 30-point 2500 ampere end cell switches, three on each side of the three-wire system, by means of which the battery can be discharged at three different potentials simultaneously if desired. By this means it is possible to put long or heavily loaded feeders on a bus having higher pressure and thus save investment in additional feeders. The batteries are charged

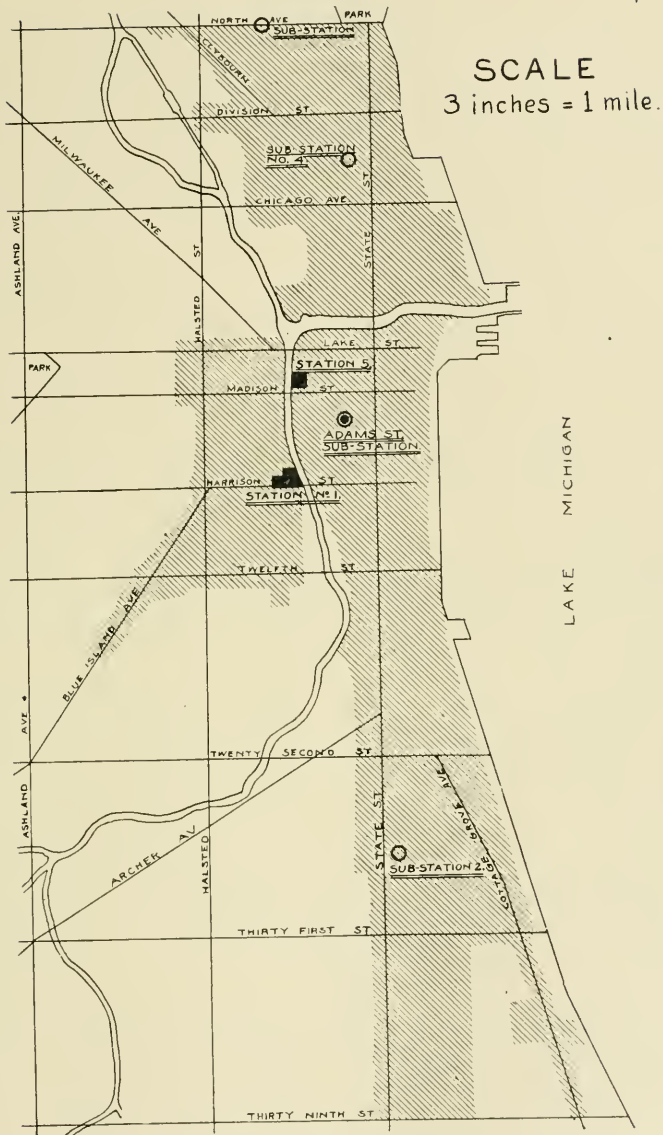


FIG. 2.
Location of Stations and Sub-Stations and Territory Supplied from Edison Three-Wire Systems.

direct from the generators in Station No. 1 without the use of boosters, and have a discharge capacity of 22 500 ampere hours at an 8 hour rate and 12 000 ampere hours at a one hour rate.

In station No. 1 there is installed a total capacity of 6400 kilo-watts in direct connected machines. Of this capacity there is 800 kilo-watts in double current generators which will deliver either 125 volts direct current, 80 volts three-phase alternating, or both simultaneously. The three-phase alternating current is delivered to induction regulators then to step-up transformers, where the pressure is raised to 4500 volts and transmitted to rotary converter sub-stations. Some of the advantages of these double current machines are that it is possible at all times to have an economical load on the engine, that one and the same engine and generator investment will answer for the peak of the load in two districts when these come at different times, as in the downtown business district and the residence district farther South. There is also a rotary converter installed in the station which takes current from the direct current bus bar at 250 volts and delivers three-phase alternating current at 160 volts, which is raised to 4500 volts for transmission. The four engine driven generators and rotary converter are run all in multiple when necessary.

In station No. 2 there is installed 850 kilo-watts in rotary converters, and a storage battery having a capacity of 2000 ampere hours at a one hour rate. This station was originally an independent non-condensing station feeding into its own net work. A part of the old steam apparatus is still in operative condition.

Station No. 4 is an independent non-condensing station having an installed capacity of 550 kilo-watts in direct connected generators. Two 100 kilo-watt rotary converters are soon to be put into service. These will receive current from a transmission line at 4500 volts from Station No. 1. The rotary converters will then carry the load about eighteen hours per day and the steam machinery will be run only during the peak. A new sub-station has been installed at No. 346 East North Avenue to take care of the business that was formerly supplied from Station No. 4. Two 100 kilo-watt rotary converters with the necessary transformers, regulators and switchboard apparatus were installed in a remodeled storeroom and connected to distributing system by "looping in" the feeder on the street. By reference

to Figure 2 it is seen that this location is 6400 feet distant from Station No. 4. It was found advantageous to do this rather than install a feeder that would deliver an equivalent load.

Station No. 5 consists of 2600 kilo-watts in direct connected generators for delivering low tension current to Edison system, 250 kilo-watts in rotary converter for delivering three-phase current for transmitting to North Avenue sub-station; about 1100 kilo-watts in single-phase alternating, 450 kilo-watts in 500 volt power and about 1900 series arc lamps. The low tension output is delivered by feeders from the bus bars direct to District No. 1 and No. 3. A large part of the single-phase alternating is delivered to the Western District, Commonwealth Electric Company.

The total load delivered to the entire low tension system and the division of load between the different stations and sub-stations on December 19th, 1899, is shown in Figure 3.

The maximum for the entire system considered as one, lasted from 4:30 until 5:00 o'clock. The short duration of peak is caused in the downtown district where a large number of office buildings and business houses close between 5:00 and 6:00 o'clock.

In general the curve shows a typical one for that month of the year, although the storage battery discharge was somewhat lighter than usual.

The division of load at the time of maximum was as follows:

| | | |
|-----------------------------------|-----------------|---------------|
| Station No. 1..... | 5800 kilo-watts | 46.3 per cent |
| Station No. 2..... | 595 " " | 4.6 " " |
| Station No. 4..... | 495 " " | 3.8 " " |
| Station No. 5..... | 4350 " " | } 36.1 " " |
| North Avenue sub-station..... | | |
| Adams Street Storage Battery..... | 1165 " " | 9.2 " " |

A division of the entire generated output for the year gives:

| | | |
|--------------------|----------------------------|---------------|
| Station No. 1..... | 15 304 045 kilo-watt Hours | 71.7 per cent |
| Station No. 2..... | 104 840 " " " | .5 " " |
| Station No. 4..... | 1 293 411 " " " | 5.4 " " |
| Station No. 5..... | 4 797 333 " " " | 22.4 " " |

The actual average cost per generated kilo-watt hour for 1899 at Stations No. 1 and No. 5 is about one half that of Sub-station No. 4, and only about one third that of Station No. 2. The last mentioned is run as a generating station only about three hours per day for two months in the year. The fact that this station gives a very poor economy, makes therefore, but little difference under these conditions. The old steam machinery is run during the time of peak in downtown districts when it is

necessary to run full load direct current on the double-current generators. An investment many times the second-hand value of the old apparatus is thus avoided at the main generating station. The interest and depreciation on this investment, if made, would have to be earned during the same time that the old apparatus is now run—about one hundred hours out of the year. In this particular case it is better, therefore, to operate the old apparatus during this short time, even at a poor economy. The

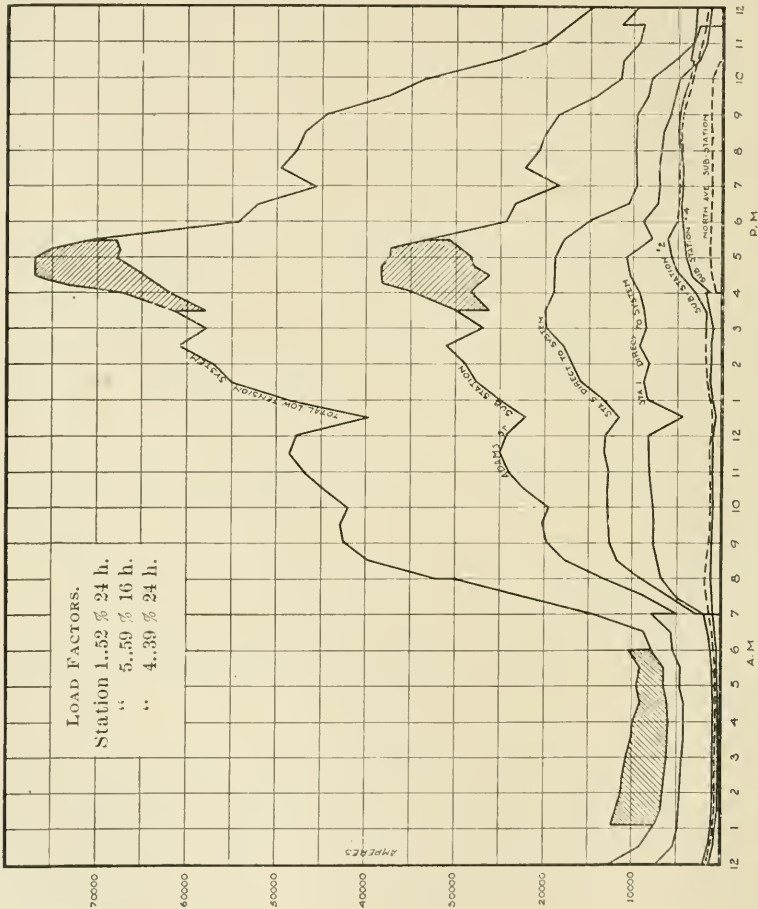


FIG. 3.

Curves showing the proportion of load delivered to system from the different stations and sub-stations.

condition of load as illustrated in Fig. 3 presented an opportunity of making a saving in operating by installing a pair of rotary converters at Station No. 4, to be operated from a three-phase transmission line from Station No. 1. The steam plant would then be operated only about six or seven hours per day, which, because of the reduction in labor and the running of engines at more economical loads, will make a considerable saving.

In many of the large cities, where the Edison three-wire system of underground distribution of direct current is employed, it will prove advantageous to employ three-phase transmission and install new rotary converter sub-stations where additional capacity is needed, instead of investing in additional copper for direct current feeders. A comparison of the investment required for transmitting different amounts of energy by the two methods is shown in Fig. 4. The results shown are based on the following, which conform to the present high prices on all apparatus and costs of installing:—

| | | |
|--|---------|---|
| Double current generators..... | \$45.00 | per kilo-watt, installed complete |
| Direct current generators..... | 30.00 | “ “ “ “ |
| Revolving field 3-phase generators.... | 25.00 | “ “ “ “ |
| Rotary converter sub-station..... | 50.00 | “ “ “ “ |
| Conduit..... | .45 | per duct foot. |
| 1 000 000 C. M. feeder..... | 2.50 | per foot of feeder. (This includes two 1 000 000 circular mil cables, one 350 000 circular mil cable for neutral and one 3-conductor No. 14 pressure cable, installed.) |

A comparison is thus shown between cost of installing feeders of sufficient cross-section to deliver a given amount of current at a given loss, and of installing rotary converters and three-phase transmission lines from a generating station for the same purpose.

An important item in the cost of direct current feeders is the duct capacity required—three (3) ducts for each feeder. This is particularly true in very large cities, where the streets are sometimes so badly honey-combed with conduit, water and gas mains, sewers, catch basins, etc., that there is no room whatever for any additional conduit without going to a considerable depth and building tunnels, which would necessarily be very expensive. The cost of a direct current feeder of given cross-section varies directly with its length. With rotary converter sub-stations

for delivering direct current, this difference is added to the cost of rotary converters, and if the cost is less it is subtracted, as in the case of revolving field three-phase generators.

With the rotary converter for the distance under consideration the current delivered is practically independent of the distance, and depends only upon the capacity of apparatus in the sub-station, while, with direct current feeders at a given loss, the current delivered depends upon the length and cross-section of feeder. A loss of 20 per cent has been assumed in each case, as this is, with the apparatus under consideration, the average loss between double-current generator and direct current side of rotary converter. This would include loss in induction regulators, step-up transformers, transmission line, step-down transformers and rotary converters. With revolving field machines generating at line voltage, this loss is only about 12 per cent.

At a distance of 3300 feet we find the current delivered by the two methods about equal. The first cost of a 1 000 000 circular mil direct current feeder at this distance is somewhat greater if revolving field machines are used but in most cases not enough to offset the increased cost of operating sub-station, such as labor, rental, insurance and repairs. After taking everything into consideration it is found advisable to install rotary converter sub-station for taking care of additional load at distances beyond 4000 feet from the generating station under the conditions assumed; namely, that we have a three-wire distributing net work which needs re-inforcing to carry additional load not to exceed six or eight hours per day and that the units installed will be about 600 horse-power engines direct-connected to double current generators and running at 150 revolutions per minute; that space for sub-station can be secured at moderate rental where most desirable for this purpose. Such a large number of items, which vary with the local conditions enter into the cost of these installations, that it is impossible to give figures that could be used generally. The comparative results shown in Figure 4 would hold in most cases and show at once the very large investment necessary to deliver a heavy load at any considerable distance by means of direct current feeders. Boosters are frequently used with fair results in order to raise the pressure on one or two long feeders from a station. In such cases the cost of the boosters must be considered as additional

investment in distributing system. All the different items entering into the cost per distributed unit of output by the different methods, including interest, depreciation, repairs, etc., must be carefully considered in each individual case.

Where the extensions necessary are such that large units can be employed it will very frequently be found advisable to install three-phase generating machinery and rotary converter sub-station at less than 4000 feet from generating station, instead of direct current feeders, because of the greatly decreased cost per kilo-watt in the large sizes of generators. With the revolving field type of generators there is the added advantage that much larger machines can be built than is possible with the direct current type.

Such an arrangement is already in contemplation for use in New York City, where ground has already been broken for what will be, at least for a time, the largest central station in the world. This plant will be equipped with extremely large units. The engines will develop normally about 5200 horse-power, and at a maximum 8000 horse-power, and will be direct connected to 3500 kilo-watt 25 cycle three-phase generators, delivering current at 6600 volts, and having heavy overload capacities. The existing system includes quite a number of generating stations, some of which run continuously and others only during time of maximum; a number of rotary converter sub-stations and a large capacity in storage batteries, divided between several stations and sub-stations. All of the current required to supply this immense system will then eventually be generated in a single station, located on the river front, where condensing water is available and coal can be delivered very cheaply from barges. The steam plant will be equipped with superheating devices, and, with the very large units employed, will probably give some remarkable results. Because of the large capacity in storage batteries located at so many different points it will be possible to nearly always run the engines at their most economical load. Some very large rotary converters are also being installed in the remodeling of this immense system. The larger sizes of rotary converters are built as six-phase machines, but are operated from three-phase lines, being connected with two-phases in multiple. Most of the rotary converters deliver direct current at 250 volts, as the storage batteries are sufficient to maintain

the balance on the system. For the same capacity, rotary converters delivering 250 volts are cheaper and better machines than those delivering 125 volts. In very large sizes they are very difficult to build for the lower voltage.

Storage battery sub-stations are used also very extensively in Boston. They are located at most desirable points on the system, and are operated with very little attendance. The system is so arranged that many of these storage batteries can be at least partly charged and again discharged without an attendant at the battery sub-station. In most of the generating stations busses at different potentials are operated. The stations and sub-stations are inter-connected by tie lines and feeders, some of which can be disconnected when necessary by means of electrically operated switches. A small motor is geared to a three-pole switch and the whole enclosed in a water-tight iron box installed in a man-hole. The motor is operated from the regular pressure wires, which still remain available also for indicating pressure at the station. Switching arrangements are provided so that battery sub-station can be disconnected from system and charged from a tie line fed from one of the auxiliary busses, giving a higher potential at the generating station.

In general the tendency among lighting companies using the Edison three-wire system is to establish rotary converter sub-stations or battery sub-stations and reduce the number of generating stations. Where very large extensions are contemplated, revolving field three-phase generators or double current generators are usually employed. Rotary converters working on twenty-five cycles have given excellent results. In a few cases sixty cycle three-phase generators have been installed with the idea of taking care both of the rotary converter sub-stations and of alternating current lighting as well. Some difficulty has been experienced in developing rotary converters for this frequency. Whenever additional direct current machines are installed in any of these large stations they are nearly always wound for 250 or 300 volts and connected to the outside bus bars for the system.

During the past few years immense sums have been invested in underground construction by lighting companies in all of the large cities. The original tube system of mains and feeders has been in some cases found inadequate and as a result much conduit has been laid. In case of heavy load on a tube feeder the

flexible couplings become heated and sometimes open up entirely. It becomes necessary then to dig up the streets every twenty feet where the joints occur until the trouble is located. The maintenance and repair account in such cases is enormous. The general practice to-day is to employ cable feeders drawn in conduit. The first cost of such feeders of equal cross-section is necessarily greater than that of tube feeders. The ease of repair and the greatly increased current carrying capacity for the same cross section of copper are the all important items. Tube mains are still quite generally installed and as these are rarely overloaded they are fairly satisfactory. In the best improved streets cable mains are also rapidly coming into favor. Paper insulation is used in most cases, although occasionally rubber insulation is still used for underground cables for lighting work. The thickness of paper insulation is usually $\frac{5}{32}$ " for feeder and $\frac{4}{32}$ " for mains for low tension work. Except for the smaller sizes the thickness of lead wall is usually $\frac{3}{32}$ " or $\frac{1}{8}$ ".

Several kinds of conduit are being laid, among which Camp tile, McRoy duct, National conduit and iron pipe are perhaps the most common. The first two are vitrified clay and are laid with butt joints, while the third is cement lined iron pipe with slip joints. Ordinary 3" iron pipe is also used under cable tracks and at street intersections where it is difficult to lay other conduit with proper bedding of concrete. Large manholes are built at all street intersections and smaller manholes at frequent intervals along the street. The cost per duct foot of conduit varies greatly and depends largely upon the number of ducts in a group, the kind and character of street paving and other local conditions. In many of the large cities especially, a good system of underground conduit is one of the important assets of lighting companies.

As an illustration of alternating current systems it may be noted that the outlying districts of Chicago were supplied at one time from a large number of small stations nearly all owned and operated by different lighting companies. The companies supplied single-phase alternating current for incandescent lighting, direct current series arc lighting and in a limited area some 500 volt current for power purposes. The territory south of 39th Street, for instance, was supplied by six independent companies, each operating its own plant. It was impossible for these companies

to all earn dividends on their several properties, so that eventually they were all combined into one large concern which now supplies the same territory with a much improved service from three generating stations instead of six, and will, in a short time supply this large area from a single generating station.

Because of the great distance over which current has to be transmitted there had accumulated a very heavy investment in line work. It was therefore necessary that any plans for a new generating station be made with a view to utilizing the existing line work to the greatest degree possible. This is being accomplished in the following manner: a new generating station is being built at 56th and Wallace Streets, the equipment consisting of three-phase generators direct connected to vertical cross-compound condensing engines; natural draft cooling towers; water-tube boilers with stokers; coal and ash handling machinery, and a large capacity for storage of coal—all designed to give the best possible results in economy of operation. The generators are 48 pole machines delivering sixty cycle current and have a fourth terminal for the common point known as the neutral. The voltage between any two of the outside leads will be 3800 and between neutral and any one of the outside leads, 2300 volts. The scheme of connections in Figure 5 shows one two-wire single-phase lighting feeder and one four-wire three-phase combined lighting and power feeder all connected to a four-wire three-phase bus bar. The 2300 volt single-phase feeders supplying the immediately surrounding territory are connected to bus bars through a single-pole three-throw oil switch, by means of which the different feeders can be balanced on the system. Each one of these single-phase feeders is equipped with a potential regulator, by means of which the voltage at the end of each one of these feeders can be regulated independently at the switchboard. If, at any time it becomes desirable to give service for polyphase motors, two additional wires can be run back to station and connected to bus bar through the single-pole three-throw oil switch, which is so designed that it can readily be converted into a three-pole single-throw switch. Additional lighting business would still be connected up single-phase on original feeder and regulation for lighting service remain independent as before. Standard transformers can be used throughout. For motor work the transform-

ers will, on the primary side, be star connected to the three outside wires of the system, and, on the secondary, be delta connected so that standard 220 volt three-phase induction motors can be used. Independent regulation of voltage will not be necessary for this class of motors.

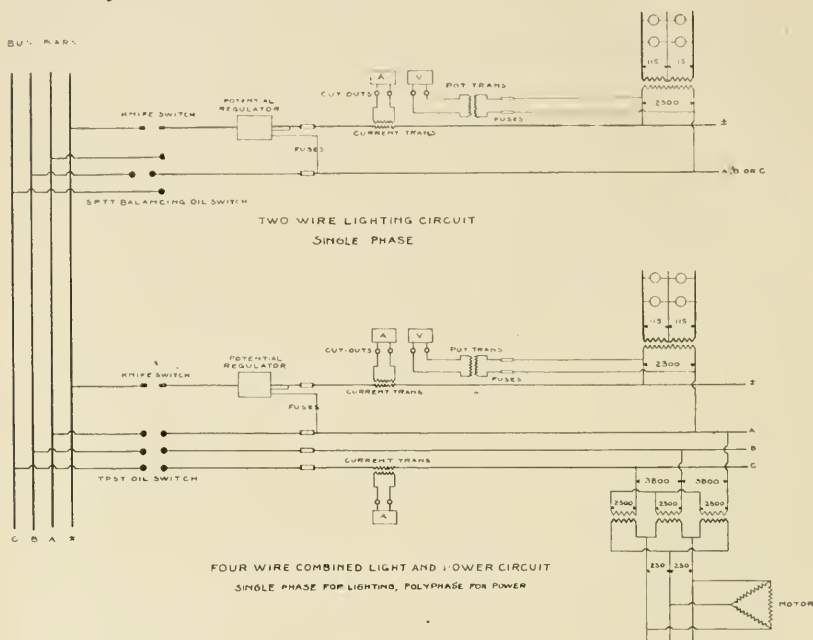


FIG. 5.

Scheme of distribution which utilizes existing single-phase circuits and is also adapted to poly-phase motors.

Two four-wire three-phase transmission lines will be run to a large sub-station near 50th Street and Cottage Grove Avenue. From this sub-station will emanate single-phase feeders as from generating station. It will contain a switchboard and one potential regulator for each of the single-phase feeders. An attendant will be needed only during the hours of heavy load, as the sub-station bus bar can be regulated at the generating station. Another four-wire three-phase transmission line will be run to a sub-station at 96th and Erie Streets in a similar manner.

The average efficiency of transmission from switchboard to customers' meter when territory was supplied from three differ-

ent generating stations, was about fifty per cent. The cost per generated unit of output will be reduced at least one-half. The net cost per distributed unit of output will thus be very greatly reduced, which, together with the fact that a very high efficiency lamp can be used because of better regulation, should show results at once gratifying both to the stockholders of the lighting company and to the customers.

The territory between North Avenue and Thirty-ninth Street, and West of Ashland Boulevard is supplied with single-phase alternating current distributed at 2000 volts and purchased from the Chicago Edison Company at Station No. 5. The block system of transformers with heavy three-wire mains is used in a considerable portion of this territory with excellent results.

The territory North of North Avenue, is supplied at present from a non-condensing generating station at No. 660 Lincoln Avenue, from which single-phase alternating current is distributed at 1100 volts, and also at 2200 volts. There is in addition also a single-phase transmission at 5000 volts to a sub-station at No. 1224 Ardmore Avenue, where an old Edison three-wire system of overhead distribution is utilized to distribute from two large transformers delivering 115 volts per side. A large portion of the business in this district is widely scattered, thus making the iron losses very considerable because of the necessity of using such a large number of small transformers. There is also some series arc and some 500 volt service supplied in this district. In general the conditions are very similar to those existing in the outlying districts of large cities and in a great many of the smaller cities.

Arc lighting still continues to be an important item with most lighting companies. Some of those operating direct current systems have replaced many of their series arcs with low tension enclosed arcs when this was practicable. Companies operating alternating current systems have also developed some good business in constant potential enclosed arc lighting. There still remains, however, a large amount of arc lighting that must be done by some series system, because of the large areas over which it is distributed. As a result small arc machines belted to line shafts are still to be found in many stations. Efforts to generate but one kind of current in any one station have

resulted in different methods all intended to dispense with the old line shafting and belts and their attendant heavy friction losses. In large stations where three-phase twenty-five cycle current is generated a favorite arrangement has been to have one synchronous motor direct connected to two arc machines. Where sixty-cycle current is generated a series alternating enclosed arc system has been used for street lighting with very satisfactory results. The constant current transformers used with this system can be connected either to single-phase, two-phase or four-wire three-phase generators. The primaries of these transformers are connected single-phase to a source of constant potential, while the secondaries deliver a constant current of variable potential. At full load the efficiency and power factor are good. The power factor, however, drops very fast with a decrease in load, which is not objectionable for street lighting as all lamps are started at the same time. This system is designed for street lighting and cannot be recommended for other service. The system is impracticable when street lights and commercial lights are run on the same circuits, unless the latter are so located that they could be put on a constant potential circuit. Considerable work has been done in developing constant current rectifiers, but thus far they have not passed the experimental stage. With any one of these methods, existing lines would be utilized. In the case of adopting the series alternating system, new lamps would be needed. The total investment required for lamps, reflectors, constant current transformers and auxiliary apparatus installed, would ordinarily not exceed Forty Dollars (\$40.00) per lamp. This is but little more than would be required to install arc machine sets driven by synchronous motors. The effectiveness of street lighting by means of the direct current open arc and the alternating series enclosed arc has been the subject of much discussion. Photometric measurements are of practically no value, as intensity of illumination is not desired. The best distribution of light, and consequently more uniform illumination of the street is most to be desired. In such plants as are devoted exclusively to arc lighting, and municipal plants in particular, there is still room for large direct coupled multiple-circuit direct current arc machines. That such comparatively large machines will soon be found on the market seems quite probable.

In the operations of central stations, as well as lighting and power plants in general, there are a great many matters, particularly those pertaining to small extensions to take care of increase in business, that must be given considerable thought. Sometimes these seem trivial, but mistakes or the exercise of poor judgement will in time involve considerable loss. This is equally true of the small stations, even though the total losses thus involved are not always traceable to the proper source. Failure to pay expected dividends would sometimes be less frequent if every item that goes to make up the cost per distributed unit of output were systematically and carefully considered, and the importance of such items as interest and depreciation with stations having a poor load factor were thoroughly understood.

CASES OF ECCENTRIC LOADING.

BY G. A. GOODENOUGH, ASSISTANT PROFESSOR OF MECHANICAL
ENGINEERING.

In a structure or machine there are usually members or links that are subjected to the action of two external forces only—*two-force* pieces, as they are usually called. The two forces are equal and opposite, and produce either tensile or compressive stress in the piece in question. The common line of action of the two forces may coincide with the geometric axis of the piece—which is usually a straight bar or rod—or it may not. In the first case the piece is centrally loaded, and the stress induced by the load has the same intensity throughout any section of the piece; that is, it is uniformly distributed over the section. When the line of action does *not* coincide with the axis of the piece, we have a case of eccentric loading. In this case, the stress is not uniformly distributed over the cross section, and with the same load and area of section, the maximum intensity

of stress will be greater than in the case of the same bar centrally loaded.

In the design of two-force pieces it is quite customary to assume central loading in all cases. Such an assumption is, however, far from the truth in many instances. In quiescent structures,—bridges, roof trusses, and the like—the struts, tie-rods, etc., are no doubt centrally loaded. On the other hand, central loading is the exception rather than the rule when we are dealing with the parts of moving machinery. Even in straight links, used merely to transmit motion from one part to another, the friction in the pins and eyes shifts the common line of action by an appreciable amount.

It is evident that in many cases the ordinary assumption of central loading may lead to a serious overestimation of the resistance of a piece; and it is incumbent therefore on the designer of machinery to take cognizance of cases of eccentric loading, and to investigate carefully the stresses called forth in such cases.

In the following pages a few of the many cases of eccentric loading arising in practice are pointed out and discussed. The treatment of the straight prismatic bar with eccentric loading is substantially that given in Merriman's *Mechanics of Materials*, Art. 108; it is repeated here merely for the sake of completeness.

In Fig. 1 is shown a straight prismatic bar so loaded that the line of action of the external force P is parallel to the axis AB and at a distance c from it. We are to determine the distribution of stress in any right section as CD , and thence to find the maximum intensity of stress. Consider the portion of the body above the section CD as a free body, and at the center O of this section insert two opposite forces OM and ON acting along the axis AB , and equal to the external force P . These forces being equal and opposite do not affect the equilibrium of the system. We have thus replaced the single external force P by the central

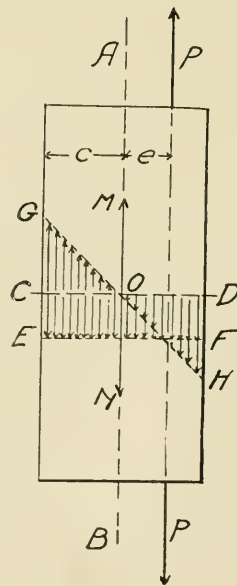


FIG. 1.

force OM and a couple consisting of the equal and opposite forces P and ON . The arm of the couple is e and its moment is Pe . The single force OM must be balanced by a stress in the section CD ; and since OM has the axis AB as a line of action this stress is uniformly distributed over the cross section. Denoting the intensity of the stress by S_1 , and the area of the section by f , we have

$$S_1 = \frac{P}{f}.$$

If this intensity S_1 be denoted in Fig. 1 by $CE (=DF)$, the line EF parallel to CD will indicate graphically the uniform distribution of stress over the section.

The couple of moment Pe tends to give the body under consideration a counter-clockwise rotation. Evidently this couple must be balanced by a stress with an equal moment and of opposite sense. The fibers to the right of AB will be subjected to tensile stress and those to the left to compressive stress; and according to Hooke's law, the stress—either tensile or compressive—in any fiber will be proportional to the distance of that fiber from the axis AB . Let DH be laid off to represent the tensile stress S_2 in the outer fiber, and let CG be laid off to represent the compressive stress in the outer fiber on the other side of AB ; then the law of the distribution of the stress induced by the couple is represented graphically by the line GH . Letting c denote the distance of the outer fiber from AB , the intensity of stress due to the couple at a point distant x from AB is

$$S_x = \frac{S_2 x}{c}.$$

For points to the left of AB , x may be considered negative, in which case the stress S_x will be negative; that is, compressive. We shall always consider tensile stress as positive.

Adding together the stress due to the central load and that due to the couple, the intensity of stress at a distance x from AB is

$$S_1 + S_x = S_1 + \frac{S_2 x}{c}.$$

From the general theory of flexure we have the well-known relation

$$M = \frac{SI}{c},$$

where M denotes the bending moment of the external forces, S the stress per unit area at the outer fiber, and I the moment of inertia of the section, with reference to an axis through AB and at right angles to the plane of the couple. We have, therefore, in the present case

$$Pc = \frac{S_2 I}{c},$$

from which

$$S_2 = \frac{Pcc}{I},$$

and

$$S_1 + S_2 = \frac{P}{f} + \frac{Pcx}{I} \dots \dots \dots (1)$$

The maximum intensity is

$$S_1 + S_2 = \frac{P}{f} + \frac{Pcc}{I} = \frac{P}{f} \left(1 + \frac{fcc}{I} \right) \dots \dots (2)$$

If r denote the radius of gyration of the section,

$$I = fr^2,$$

and

$$S_1 + S_2 = \frac{P}{f} \left(1 + \frac{cc}{r^2} \right), \dots \dots \dots (3)$$

which is the usual expression for the maximum intensity.

From (1) it is easy to determine whether or not there is a neutral line in the section. If $S_1 + S_2 = 0$, we have

$$\frac{P}{f} + \frac{Pcx_0}{I} = 0, \text{ or}$$

$$x_0 = -\frac{I}{fc} \dots \dots \dots (4)$$

Let c_1 denote the distance from the axis AB to the most remote fiber on the left of AB ; then if $\frac{I}{fc} < c_1$ there will be a neutral line in the section. If, on the other hand, $\frac{I}{fc} > c_1$ the neutral line lies outside of the section, and the stress over the section is of the same kind.

It is convenient to derive special equations for rectangular and circular sections. For the rectangular section of width h and thickness b , we have

$$I = \frac{1}{12}bh^3; f = bh; c = \frac{1}{2}h.$$

Inserting these values in equations (3) and (4) respectively,

$$S_1 + S_2 = \frac{P}{bh} \left(1 + 6\frac{c}{h} \right), \dots \dots \dots (5)$$

and

$$x_0 = -\frac{h^2}{12c} \dots\dots\dots (6)$$

For a circular section of radius r ,

$$I = \frac{1}{4}\pi r^4; f = \pi r^2; c = r.$$

From these we have

$$S_1 + S_2 = \frac{P}{\pi r^2} \left(1 + \frac{4c}{r}\right); \dots\dots\dots (7)$$

$$x_0 = -\frac{r^2}{4c} \dots\dots\dots (8)$$

As an application of formula (7) let us consider the case of the straight link, Fig. 2. This consists of a rod of circular cross section with eyes at the two ends.

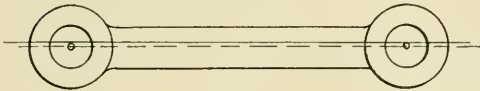


FIG. 2.

circular cross section with eyes at the two ends. The inner radius of the eye is equal to that of the cross section. If

the link merely supports a load the line of action of the external forces will evidently coincide with the axis, and the intensity of stress in the cross section will be

$$\frac{P}{\pi r^2}.$$

When, however, there is relative motion between the pins and eyes, the line of action is shifted a distance μr from the axis, μ being the coefficient of friction. Assuming $\mu=.20$,

$$c = \mu r = .2r,$$

$$\text{and } S_1 + S_2 = \frac{P}{\pi r^2} \left(1 + \frac{4 \times .2r}{r}\right) = \frac{P}{\pi r^2} (1 + .8) = 1.8 \frac{P}{\pi r^2}.$$

Thus the maximum intensity of stress is increased 80 per cent. by this comparatively small eccentricity.

From equation (8)

$$x_0 = -\frac{r^2}{4c} = -\frac{r^2}{.8r} = -1.25r;$$

hence the neutral line falls outside of the section.

A case of frequent occurrence in the design of machine parts is that shown in Fig. 3. The circumstances are such that it is not practicable to make the link straight, and the axis of a cross section, as CD lies at a distance c from the line AB , which joins the center of the pins, and is therefore—neglecting friction—the line of action of the external forces. The cross section is assumed to be rectangular. Let b_0 and h_0 denote the di-

mensions of the cross section of the link if straight and centrally loaded; and let b and h denote the corresponding dimensions of the eccentrically loaded section at CD . For the straight link the intensity of the uniformly distributed stress is

$$S_0 = \frac{P}{b_0 h_0}$$

The maximum intensity of stress in the section CD of the curved link is from (5)

$$S_1 + S_2 = \frac{P}{bh} \left(1 + 6 \frac{c}{h} \right).$$

If we impose the condition that $S_1 + S_2$ shall not exceed S_0 , we have

$$\frac{P}{b_0 h_0} \geq \frac{P}{bh} \left(1 + 6 \frac{c}{h} \right),$$

or

$$bh \geq b_0 h_0 \left(1 + 6 \frac{c}{h} \right)$$

Let $m h_0$ denote the distance of the right edge of the cross section at CD from AB , the line of action of the external forces; this is to be taken positive when measured from AB to the right, that is, when AB cuts the section in question, and negative when measured from AB to the left. Then the eccentricity is

$$c = \frac{h}{2} - m h_0;$$

hence

$$\frac{6c}{h} = 3 - 6m \frac{h_0}{h}.$$

Substituting this value in the preceding equation, we have finally

$$bh \geq b_0 h_0 \left(4 - 6m \frac{h_0}{h} \right) \dots \dots \dots (9)$$

The discussion of this equation leads to some interesting results: For any given values of b_0 , h_0 , and m we may vary b and h as we choose, subject to the restriction expressed by (9). Economy of material is obtained by making the product bh , and therefore the expression $4 - 6m \frac{h_0}{h}$ as small as possible. If m is positive, that is, if the section is cut by the line of action of the forces, this requirement is met by making h as small as pos-

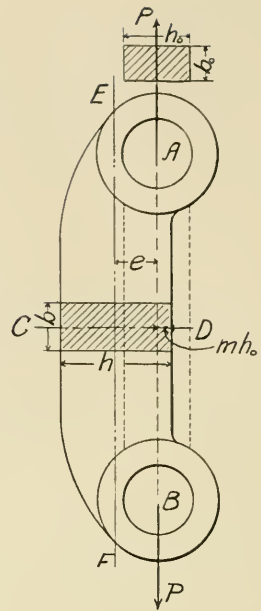


FIG 3.

sible ; on the other hand, if m is negative, that is, if the section lies wholly outside of the line of action, the product bh is made a minimum by making h as large as possible. In other words, when m is positive, keep the width h small and increase the area of the section by increasing the thickness b ; when m is negative, keep the thickness b small and add to the area of the section by increasing the width h . This principle is of importance in the design of the C-shaped frames of punches, shears, and presses.

When $m=0$, that is, when the edge of the section coincides with the line of action AB , (9) reduces to

$$bh \geq 4b_0h_0.$$

The section bh must be at least four times the section b_0h_0 , independent of the relative dimensions of the section.

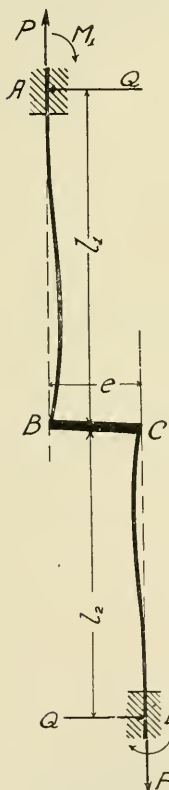


FIG. 4.

An arrangement sometimes used in steam engine design is shown in Fig. 4. Two rods, AB and CD , parallel and at a distance e from each other, are joined by a heavy clamp or coupling BC . A pull or thrust acting along the axis of AB is transmitted to CD through the clamp. The ends of the rods are restrained at A and D , respectively, but the restraint is of such a nature that either rod may move in the direction of the external force P . An example of this arrangement is seen in the valve rods of certain compound engines. The valve rod of the low pressure cylinder extends through its chest, and is clamped to the valve rod of the high pressure cylinder, as in Fig. 4. The steam chest stuffing boxes furnish the restraints at A and D .

Since the external forces P, P form a couple of moment Pe , an opposing couple must be furnished by reactions Q, Q at A and D . But in addition to the reaction Q , there must be at each support a couple to provide the restraint of the end of the rod. Let the moments of the couples at A and D be denoted by M_1 and M_2 , respectively. It will be assumed that the sense of each of these restraining couples

is the same as that of the couple formed by the forces P, P ; that is, clockwise, as the figure is drawn. If either couple has the opposite sense, this fact will be disclosed in the discussion by a negative value of M_1 or M_2 , as the case may be.

Let l_1 and l_2 , denote respectively the lengths AB and CD ; then the moment of the couple formed by the reactions Q, Q is $Q(l_1+l_2)$. Placing the algebraic sum of the moments of the four couples equal to zero,

$$Q(l_1+l_2) - Pe - M_1 - M_2 = 0,$$

or

$$Q(l_1+l_2) = Pe + M_1 + M_2.$$

This is one relation between the three unknown quantities Q, M_1 , and M_2 ; two more must be found.

Take a section of the rod AB at a distance x from the support A ; neglecting the small deflections of the rod, the bending moment at the section is

$$M = M_1 - Qx.$$

We have then

$$EI \frac{d^2y}{dx^2} = M_1 - Qx;$$

$$EI \frac{dy}{dx} = M_1x - \frac{Qx^2}{2} + C_1;$$

$$EIy = \frac{M_1x^2}{2} - \frac{Qx^3}{6} + C_1x + C_2.$$

At $A, x=0, y=0$, and $\frac{dy}{dx}=0$; hence $C_1 = C_2 = 0$, and the equations become

$$\frac{dy}{dx} = \frac{1}{2EI}(2M_1x - Qx^2);$$

$$y = \frac{1}{6EI}(3M_1x^2 - Qx^3).$$

The slope at the point B , for which $x=l_1$, is

$$\left(\frac{dy}{dx}\right)_B = \frac{1}{2EI}(2M_1l_1 - Ql_1^2);$$

and the deflection of the rod at this point is

$$y_B = \frac{1}{6EI}(3M_1l_1^2 - Ql_1^3).$$

Taking the point D of the rod CD as origin, the same procedure will give the slope and deflection of this rod at the point C . These evidently are

$$\left(\frac{dy}{dx}\right)_C = \frac{1}{2EI}(2M_2 l_2 - Q l_2^2);$$

$$y_C = \frac{1}{6EI}(3M_2 l_2^2 - Q l_2^3).$$

Because of the rigidity of the clamp, the slope of CD at C must be the same as that of AB at B ; hence

$$\left(\frac{dy}{dx}\right)_B = \left(\frac{dy}{dx}\right)_C,$$

or
$$2M_1 l_1 - Q l_1^2 = 2M_2 l_2 - Q l_2^2.$$

Further, if we neglect the slight angle through which BC is turned, the sum of the deflections at B and C must be zero; that is,

$$y_B + y_C = 0, \text{ or } 3M_1 l_1^2 - Q_1 l_1^3 + 3M_2 l_2^2 - Q l_2^3 = 0.$$

Collecting and rearranging the three equations of condition, we have finally

$$Q(l_1 + l_2) = Pe + M_1 + M_2.$$

$$Q(l_1^2 - l_2^2) = 2(M_1 l_1 - M_2 l_2).$$

$$Q(l_1^3 + l_2^3) = 3(M_1 l_1^2 + M_2 l_2^2).$$

Solving for M_1 , M_2 and Q , we obtain

$$\left. \begin{aligned} M_1 &= Pe l_2 \frac{2l_1 - l_2}{(l_1 + l_2)^2}. \\ M_2 &= Pe l_1 \frac{2l_2 - l_1}{(l_1 + l_2)^2}. \end{aligned} \right\} \dots\dots\dots(10)$$

$$Q = 6Pe \frac{l_1 l_2}{(l_1 + l_2)^3}. \dots\dots\dots(11)$$

It is convenient to introduce into equations (10) and (11) the ratio $l_1 : l_2$, which we will denote by m . Making this substitution,

$$M_1 = Pe \frac{2m - 1}{(m + 1)^2}. \dots\dots\dots(12)$$

$$M_2 = Pe \frac{m(2 - m)}{(m + 1)^2}. \dots\dots\dots(13)$$

$$Q = 6P \frac{em}{l_2(m + 1)^3} = 6P \frac{em^2}{l(m + 1)^3}. \dots\dots\dots(14)$$

The bending moments at B and C respectively are :

$$M_B = M_1 - Q l_1, \text{ and } M_C = M_2 - Q l_2.$$

Substituting for M_1 , M_2 , and Q their values in (12), (13), and (14), we obtain

$$M_B = -Pc \frac{4m^2 - m + 1}{(m+1)^3} \dots\dots\dots (15)$$

$$M_C = -Pc \frac{m(m^2 - m + 4)}{(m+1)^3} \dots\dots\dots (16)$$

It will be observed that $M_B + M_C = -Pc$, which must be the case, since the piece BC , considered as a free body, is held in equilibrium by the three moments M_B , M_C , and Pc .

If $m = 1$, that is if $l_1 = l_2$,

$$M_1 = M_2 = \frac{1}{4}Pc; \quad Q = \frac{3}{4}\frac{Pc}{l_1}$$

and

$$M_B = M_C = -\frac{1}{2}Pc.$$

Substituting these values in the general expressions for the bending moment and for the slope at a section a distance x from A , we have

$$\text{Moment} = M_1 - Qx = \frac{1}{4}Pc \left(1 - 3\frac{x}{l_2} \right);$$

and

$$\frac{dy}{dx} = \frac{Pc}{8EI} \left(2x - \frac{3x^2}{l_1} \right).$$

For $x = \frac{1}{3}l_1$, the bending moment reduces to zero; and for $x = \frac{2}{3}l_1$, $\frac{dy}{dx} = 0$. The deflections of the rods are therefore somewhat as

shown in the figure. The axis of the rod AB , originally straight, assumes a curve, which is more pronounced the greater the load P relatively to the I of the cross section. At $\frac{1}{3}l_1$ from A there is a point of inflection in the curve; and at $\frac{2}{3}l_1$ the slope is zero, that is, the tangent is parallel to the original position of AB . These results hold only for $m=1$, or $l_1=l_2$.

For $m = \frac{1}{2}$, $M = 0$, and for $m < \frac{1}{2}$, M_1 has a negative value, that is, its sense is counter-clockwise, or opposite to that of the moment Pc . Likewise for $m=2$, $M_2=0$, and for $m < 2$, M_2 is negative. In the first case there is no point of inflection in the curve AB : in the latter case there is none in the curve CD .

If $l_1=0$, $m=0$, we have the case of an ordinary cantilever supported at B and loaded at C . Putting $m=0$ in (15) and (16) we have

$$M_B = -Pc; \quad M_C = 0;$$

for $l_2 = 0$, $m = \infty$, and formulas (15) and (16) give

$$M_B = 0; \quad M_C = -Pc.$$

Thus as m passes from 0 to ∞ , M_B changes continuously from $-Pe$ to 0 and M_C from 0 to $-Pe$; for $m=1$, $M_B=M_C=-\frac{1}{2}Pe$.

The ordinary lap-welded joint, Fig. 5, may properly be considered an example of the case just discussed. Denoting the plate thickness by t , it is evident that t is precisely the eccentricity e . Assuming the length l_1 and l_2 to be equal, the bend-

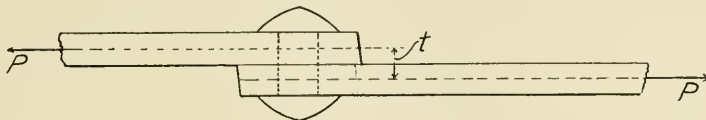


FIG. 5.

ing moment in the plate near the joint is $\frac{1}{2}Pt$. Consider a strip of plate of width b . The maximum intensity of stress due to the direct tension P and the bending moment $M=\frac{1}{2}Pt$ is

$$S_1+S_2=\frac{P}{bt} + \frac{Mc}{I} = \frac{P}{bt} + \frac{\frac{1}{2}Pt \times \frac{1}{2}t}{\frac{1}{12}bt^3} = 4\frac{P}{bt}.$$

This is four times the stress in a plate of equal area having the same load applied centrally. Therefore, compared with the solid plate the efficiency of the lap joint does not, in general, exceed 25 per cent. It is not unlikely that the excessive stress induced by the neglected bending moment is responsible for many of the fractures that have occurred in the lap-riveted joints of boilers.

In the arrangement shown in Fig. 6, two bars or rods AB and EF , respectively, have their axes in the same line, the line of action of the external forces. A third rod, CD , parallel to AB and EF , is rigidly joined to them by heavy clamps BC and DE . The external forces P, P having the same line of action, the reactions at A and F are zero; however, the deflection of the system of rods is of such a nature that restraining couples are required at these points. Let the moment of the couple at A be denoted by M_1 ; evidently then the moment of the couple at F must be $-M_1$, for, taking the system as a whole, the sum of the moments of the couples must be

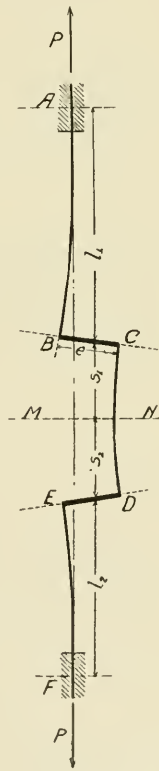


FIG. 6.

zero. The couples must clearly have opposite senses, that at A being counter-clockwise, and that at F clockwise, as the figure is drawn. Consider A as the origin, and let y denote the deflection of AB from the axis AF at a section distant x from A . The bending moment at the section is

$$M = M_1 + Py$$

From the general relation $EI \frac{d^2y}{dx^2} = M$, we have

$$EI \frac{d^2y}{dx^2} = M_1 + Py.$$

Let $\frac{P}{EI} = k^2$; then

$$\frac{d^2y}{dx^2} = k^2 y + \frac{k^2 M_1}{P}. \dots\dots\dots (a)$$

The solution of this differential equation gives

$$y = c_1 \varepsilon^{kx} + c_2 \varepsilon^{-kx} - \frac{M_1}{P}, \dots\dots\dots (b)$$

in which ε denotes the Napierian base 2.71828. This result may be verified by differentiation.

The expression for the slope is

$$\frac{dy}{dx} = kc_1 \varepsilon^{kx} - kc_2 \varepsilon^{-kx}. \dots\dots\dots (c)$$

To determine the constants c_1 and c_2 , we have at the origin A , $x=0$, $y=0$, and $\frac{dy}{dx}=0$. Inserting these values in (b) and (c) respectively, we obtain

$$c_1 + c_2 = \frac{M_1}{P},$$

$$c_1 - c_2 = 0;$$

whence

$$c_1 = c_2 = \frac{M_1}{2P}.$$

With this value of the constants, (b) and (c) become, respectively,

$$y = \frac{M_1}{P} \left(\frac{\varepsilon^{kx} + \varepsilon^{-kx}}{2} - 1 \right) = \frac{M_1}{P} (\cosh kx - 1) \dots\dots (d)$$

$$\frac{dy}{dx} = k \frac{M_1}{P} \left(\frac{\varepsilon^{kx} - \varepsilon^{-kx}}{2} \right) = \frac{kM_1}{P} \sinh kx, \dots\dots (e)$$

where $\cosh kx$ and $\sinh kx$ denote respectively the hyperbolic cosine and sine of kx .

When, as is always the case in practice, the value of $k = \sqrt{\frac{P}{EI}}$ is small, much simpler approximate expressions for y and $\frac{dy}{dx}$ may be obtained. Expanding ε^{kx} and ε^{-kx} into their respective infinite series,

$$\begin{aligned} \varepsilon^{kx} &= 1 + kx + \frac{k^2 x^2}{2} + \frac{k^3 x^3}{3 \cdot 2} + \dots \\ \varepsilon^{-kx} &= 1 - kx + \frac{k^2 x^2}{2} - \frac{k^3 x^3}{3 \cdot 2} + \dots \end{aligned}$$

If we neglect powers of k above the second, which we may legitimately do when k is a small fraction, we readily obtain

$$\begin{aligned} \frac{\varepsilon^{kx} + \varepsilon^{-kx}}{2} - 1 &= \frac{k^2 x^2}{2}, \\ \frac{\varepsilon^{kx} - \varepsilon^{-kx}}{2} &= kx. \end{aligned}$$

These values substituted in (d) and (e) give for the deflection and slope

$$\begin{aligned} y &= \frac{M_1}{2P} k^2 x^2 = \frac{M_1}{2EI} x^2, \\ \frac{dy}{dx} &= \frac{M_1}{P} k^2 x = \frac{M_1}{EI} x. \end{aligned}$$

These results are precisely those that would be obtained should we neglect the small deflection of rod AB , and consider the rod subjected to the constant moment M_1 . With this assumption,

$$EI \frac{d^2 y}{dx^2} = M_1,$$

$$\frac{dy}{dx} = \frac{M_1}{EI} x,$$

and

$$y = \frac{M_1}{2EI} x^2,$$

the constants of integration being zero. We will assume, therefore, that the deflection is so slight as to be negligible; with this assumption all sections of AB and CD are subjected to the same moment M_1 , and all sections of CD are subjected to the moment $Pe - M_1$. From the relation

$$M = \frac{EI}{\rho}$$

it follows that the radius of curvature ρ_1 of AB is constant since M is constant. AB is therefore a circular arc. Likewise EF

is a circular arc with the same radius ρ_1 , and CD is a circular arc with a radius ρ_2 given by the relation

$$Pc - M_1 = \frac{EI}{\rho_2}.$$

Let MN be the line on which the center of the arc CD lies and let s_1 and s_2 denote the length of the parts into which CD is divided by MN ; further let l_1 and l_2 denote, respectively, the lengths of AB and CD . The rigidity of the clamp BC imposes the condition that the slope of AB at B be equal to that of CD at C ; in other words, the radius of AB at the point B and the radius of CD at C must lie in the same line, the center line of BC . It follows from this that the angle θ , subtended by the arc l_1 is precisely equal to the angle subtended by the arc s_1 . This gives us the relation

$$\frac{l_1}{\rho_1} = \frac{s_1}{\rho_2}.$$

The same reasoning applied to the arcs l_2 and s_2 gives the relation

$$\frac{l_2}{\rho_1} = \frac{s_2}{\rho_2}.$$

Combining,

$$\frac{\rho_1}{\rho_2} = \frac{l_1}{s_1} = \frac{l_2}{s_2} = \frac{l_1 + l_2}{s_1 + s_2} = \frac{l - s}{s},$$

if we denote by l the distance AF , and by s the length of CD .

But,

$$M_1 = \frac{EI}{\rho_1} \text{ and } Pc - M_1 = \frac{EI}{\rho_2}; \text{ whence}$$

$$\frac{\rho_1}{\rho_2} = \frac{Pc - M_1}{M_1} = \frac{l - s}{s},$$

$$\frac{Pc}{M_1} = \frac{l}{s},$$

and finally

$$M_1 = Pc \frac{s}{l}; \dots\dots\dots (17)$$

$$Pc - M_1 = Pc \frac{l - s}{l}. \dots\dots\dots (18)$$

These formulas are deduced on the assumption that the three rods have the same cross section and therefore the same moment of inertia I . If the section of CD differs from that of AB and EF , as it should in general, (17) and (18) must be slightly modified. Let I_1 denote the moment of inertia of the section of

$A B$ or $E F$, and I_2 that of the section of $C D$; and let n denote the ratio $\frac{I_2}{I_1}$. Then

$$M_1 = P e \frac{s}{s + n(l - s)} \dots\dots\dots (19)$$

$$P e - M = P e \frac{n(l - s)}{s + n(l - s)} \dots\dots\dots (20)$$

The butt-riveted joint with one cover plate is an example of the case just discussed. The cover plate corresponds to the piece $C D$, Fig. 6; the length s , Fig. 7, may reasonably be taken

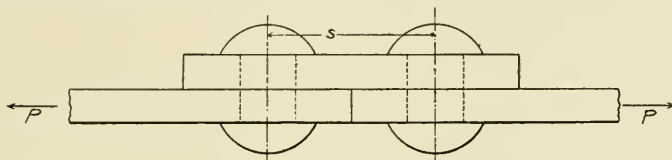


FIG. 7.

as the distance between the rows of rivets. Suppose each of the plates, including the cover plate, has a thickness t ; then $c = t$. The length l will depend upon the arrangement of the plates and joints; we may reasonably assume for the ratio $\frac{s}{l}$ a value between $\frac{1}{10}$ and $\frac{2}{10}$; taking $\frac{1}{10}$, the bending moments to which the plates and the cover plate, respectively, are subjected are :

$$M_1 = P e \frac{s}{l} = \frac{1}{10} P t;$$

$$P e - M_1 = P e \frac{l - s}{l} = \frac{9}{10} P t.$$

The maximum intensity of stress in the plate is then

$$S = \frac{P}{bt} + \frac{M_1 c}{I} = \frac{P}{bt} + \frac{\frac{1}{10} P t \times \frac{1}{2} t}{\frac{1}{12} b t^3} = \frac{P}{bt} (1 + .6) = 1.6 \frac{P}{bt};$$

that in the cover plate is

$$S = \frac{P}{bt} + \frac{\frac{9}{10} P t + \frac{0}{2} t}{\frac{1}{12} b t^3} = 6.4 \frac{P}{bt}.$$

Even supposing the ratio $\frac{s}{l}$ to be as great as $\frac{1}{4}$, the moment to which the plate is subjected is $\frac{3}{4} P t$, and the maximum intensity of stress is

$$S = \frac{P}{bt} + \frac{\frac{3}{4} P t \times \frac{1}{2} t}{\frac{1}{12} b t^3} = 5.5 \frac{P}{bt},$$

which is $5\frac{1}{2}$ times the stress induced in a centrally loaded plate of the same section and with the same load.

If we assume $\frac{s}{l} = 1.0$ we find that if the unit-stress in the cover plate is not to exceed the maximum unit-stress in the plates joined, the thickness l_1 of the cover plate must be about 4.6 times that of the other plates. With this thickness the maximum intensity of stress is reduced to about $1.02\frac{P}{bt}$, which is only 2 per cent greater than the intensity in the corresponding centrally loaded plate.

THE ARCHITECT IN COMPETITION FOR PUBLIC WORK.

BY W. H. REEVES, MEMBER OF ILLINOIS STATE BOARD OF EXAMINERS OF ARCHITECTS.

It has often been asserted that for an architect to be successful in receiving public work, he must be a clever lobbyist or a shrewd wire puller. Also, that the committee charged with the selection of the plans and architect neither take into consideration the merits of the drawings nor the ability of the selected architect to carry out the work placed in his charge.

Owing to this belief many of the most talented architects never try to secure public work. While it is quite true that, in many cases, the merits of the drawings and the ability of the architects do not receive due consideration, and the selection of an architect is made by some outside influence, these cases are very rare, and the large majority of public competitions have been decided in favor of the architect who has submitted the design that the committee believes best suited to the requirements, and who has shown by his drawings and his explanation of them,

that he understands thoroughly what the committee requires, and has proved his ability to execute them.

The selection of an architect and plans for a public building is almost invariably made by a competition conducted by the Board, or by their committee in charge of the work contemplated. The committee is composed of individuals, each member generally having some pet idea in regard to the new building. Some have a firm belief in their ideas and others care but little. Many of the ideas suggested are good, while others are so entirely impracticable that it would be impossible to incorporate them in a building, and it is usually those most desirous of having their ideas carried out that have ideas least worthy of consideration.

The successful architect should call early on the committee in charge of the work, after it has been decided to build, and obtain from each member his idea of what is wanted. It will be found that each person will express some views which should be carefully noted in making the drawings to submit in competition for the building. All points given by the members should be carefully considered, and those suggested that are good should be incorporated in the drawings, special mention being given to each one, either in the oral explanation or in the written description accompanying the drawings. Ideas suggested that could not consistently be used should be mentioned and good reasons given why they are not used in such a way that the person suggesting them may not feel that he has been ignored, but, on the contrary, that his suggestions have been carefully considered, and what has been shown on the drawings is best, reasons being given why this is so.

A successful plan must possess an individuality. All its good points must be clearly shown and thoroughly explained. The average committee know nothing about drawings, so it is necessary that they should be explained, so that the committee will see them as the building will appear. The architect who is fully conversant with his drawings and knows the important points to be emphasized, can hold the attention of the entire committee, and in so doing he has gained many points in his favor.

It is a mistake to divide the good points in a proposed building by submitting two or more sets of drawings in competition. Careful study should be made of the requirements, and the results

should be shown in a single set of drawings. The architect presenting them should be sure that he thoroughly believes his drawings to be the best that can be made for the contemplated building, and he should endeavor to impress the same upon the committee.

By offering more than one set of drawings this can not be accomplished, and the effort that should have been concentrated on one has been divided among two or more, and the architect before the committee advocates two different plans, with the result that the committee is confused as to which plan is best. They feel that the architect does not know this either, and as a result both are thrown out.

It has occurred several times within the knowledge of the writer that a single set of blue prints of working drawings for a building, which has been erected, has been successful in competition over well-executed perspective and floor plans. In every case it was found that, with the exception of the architect submitting the blue prints, each of the others submitted one or more alternate drawings, hoping that if one did not suit another would do so, and thus did not care to select their really best plan, and to make a fight to win or lose on it.

There is nothing more important for success in competitions than to find out what is required and to prepare one set of drawings accordingly, so made that every important point is covered, the architect being himself convinced that they meet all requirements, and making a fight upon this basis the chances for success are much in his favor.

CRITICAL STANDARDS FOR MODERN ARCHITECTURE.

BY C. H. BLACKALL, '77, SCHOOL OF ARCHITECTURE.

Architecture, although one of the most sternly practical of the fine arts, is, at the same time, the manifestation of art in the abstract which requires in some respects most elastic stretches of the imagination. It is essentially a convention in nearly all of its manifestations and in order to be properly appreciated requires a full development of the imaginative qualities. At the same time, it differs from the arts of painting and sculpture in being far more amenable to exact classification and analysis, permitting of a dogmatic study of its principles, and, to a very large extent, a consistently rigid application of them to the conception of design. Hence it has come that in all the creative periods of the past there has been manifested a strong tendency to formulate processes of architectural design, to establish canons of taste and specific vehicles of expression, and to subject all new architectural ideas to the test of arbitrary rules. That these canons have not always been good ones goes without saying; that even the fundamental rules of architecture have not always been observed is equally indisputable. It is so hard for one to forget the immediate environment, to study architecture with the right perspective effect, and to rid one's self of inherited or acquired mannerisms and traditions, that the code of ethics of architectural design which seems revolutionary, far advanced, ultra perfected, for one generation, may be cast aside and discounted as out of date by another. There are certain fundamental principles which have been admitted and recognized at all times; but in the practical application of these principles, and the elaboration of detail which is involved in any complex building, there is room for so wide diversity of opinion that what at one time seems wrong at another time is heralded as being the only true path to excellence. The development of the national architecture of the United States has been a slow and laborious one, until quite recent years, at least. Up to about the

time when H. H. Richardson taught architects to study books, our inspirations, instead of being drawn from Italy, the fountain head of good architecture, came to us in a more or less attenuated strain through England; and although our architecture twenty-five or thirty years ago showed the marks of its remote Italian ancestry, the principles involved therein, or, at least, the principles which were considered in those days as fundamentally necessary, were anything but Italian in spirit and were epitomized by the teachings of John Ruskin, a man who, in his generation, undoubtedly did more for art than any other one person during the century, but who, as is very often the case with enthusiasts, and especially with those who look at art from the outside rather than from within, carried his principles to an extreme which, while fascinating of itself, was of an impossible nature and could not be retained in the march of progress. It is with the differences between the teachings of John Ruskin, signifying the advanced thought of art in this country twenty-five or thirty years ago, and the present attitude of architectural criticism that this paper has to deal.

The key note of Ruskin's theory of criticism was that a work of art should, first, be truthful, and, second, that it should be beautiful. These conditions are so manifestly a part of all good architecture that it would hardly seem worth while to question them, but the present understanding of truth as relates to architecture, taking up only one phase first, is at present as far removed from Ruskin's idea as the east is from the west. It is understood that I am referring exclusively to productions of the United States, and the inquiry can be sharply focussed by considering for a moment what class of buildings are most typical of our present development and possibilities. To one who will look over the field of American architecture to-day in a critical sense it is evident that there are some manifestations which can fairly be called *sui generis*, namely, the designs for our modern commercial structures, which, while open to all sorts of criticism and to vast differences of judgment as to their absolute merit, still constitute in themselves the only purely American development of architecture which this country has so far seen, with the possible exception, however, of the colonial work, which never rose to very great heights. Accordingly, in undertaking to analyze the principles of design as applied to

our modern architecture, we can limit our study to the commercial work because it represents most truly the outcome of our architectural conditions and will show more clearly what we can do for ourselves in architecture than does our public monumental work, which is to a far greater degree copied from similar work abroad. It is only in our commercial buildings that we have been able to develop individual style. Now, the most marked quality of a typical modern commercial building is that it decidedly is not truthful. When we gaze upon a structure carried to a height of three or four hundred feet, when we walk through its corridors and appreciate how firm and rigid the construction is, when we are impressed by the tremendous proportions of the design and the seeming absolute stability of the construction, and then begin to realize that the massive walls are nothing but a veneer, that the solid construction may not be more than twelve inches thick and that the construction itself, which in past generations was expected to show itself in the design, is really a thin, spider-web-like skeleton composed of a metal new to the building arts and sciences, if we are to be guided by the old canons we must hold up our hands in horror at the desecration of vital principles.

If I were to epitomize in a single sentence the present attitude of architectural design from a critical standpoint, I would say it virtually claims that whatever is, is right. By this it need not be understood that the bars should be let down for indiscriminate and unlovely design, or that construction that will not hold together and which is vitally wrong should be condoled, but in a broader sense, whatever the development of modern life, modern necessities and modern desires have called into being must, by reason of its very existence, have at least a strong element of rightness inherent in it. It would be far more wrong for us to construct a twenty-story office building to-day on the principles of Ruskin than to treat the same problem in the naturally developed manner which has made such structures possible. The growth in American architecture up to the present time has resulted not from following tradition so much as by taking the path of least resistance. We no longer consider it necessary to mark our construction on the outside. We no longer find it advisable even to make our visible columns actual constructive members. We have learned that the column and the

arch in our modern construction are primarily decorative features, and that a column supporting absolutely nothing may at times be treated in a thoroughly rational and artistic manner. Instances of this are numerous, as for example, the series of entirely isolated columns which precede the Dewey Arch, or the columnar decoration of the entrance to the American Surety Building, New York. To properly judge of such as these we must define what we mean by rational. There is no question about the artistic results, but any course of reasoning which we can follow in matters of art depends almost entirely upon the point of view, and what we choose to consider as essential, and the present attitude of the architectural world, at least on this side of the continent, is to place considerations of decorative art very high in the scale, and to consider a thing rational if its use is successful from an artistic standpoint.

The disregard of the structural is not new, nor entirely peculiar to the nineteenth century. The Romans, with their ready system of borrowing, no less than the Greeks, with their keen sense of artistic proprieties, were never loath to use a column for decorative purposes. Furthermore, in our modern structures the whole system of inherited ratios is sometimes disregarded, and the proportions of the parts to the whole are counted of far more importance than relative scale of the individual features. Perhaps the best illustration of this is afforded by the American Surety Building in New York, which is crowned by a cornice extending through two stories, above which is a high species of attic, the attic and the cornice being proportioned absolutely to the building and not in the slightest degree to the relatively insignificant engaged columns which, with their simulated bases, extend through the three stories immediately below the cornice. The proportions from a classical standpoint would not bear the slightest analysis, but they are rational because satisfactory in result and beautiful in general effect.

The matter of truth, as considered in connection with modern buildings, is, after all, a matter of fact. In order to judge of any architectural design a certain amount of knowledge is presupposed. We must consider the purposes of the building, the materials of which it is built, and the manner in which it is put together. No person who possesses this fundamental knowledge, looking at a twenty or twenty-five-story office building,

would feel the slightest incongruity in the size of the walls or the application of the ornament. We know such walls are rarely more than sixteen inches thick, except when deliberately increased for decorative purposes. We know that structurally it is nothing but a skeleton, and we appreciate a sense of fitness in treating the exterior not so much like a solid wall as like an envelope, to be adorned, to be proportioned to itself, and in many respects to be a law unto itself, and not susceptible of judgment by the canons of the past.

This separation of the constructive from the purely decorative features of exterior design has opened great possibilities to modern architecture. By treating the design as a whole, neglecting window openings as such, forgetting the lines of the stories except where we wish to mark vertical proportions, by avoiding entirely the necessity for anything except the effect of the final building, we are able to consider the exterior from the point of pure design, uninfluenced, unimpeded and unhampered by mere structural necessities. And this is the very factor which has enabled us to develop so extraordinary a type of modern commercial building, in which, as a matter of fact, the construction is wholly independent of the design. The modern architectural engineer will say to the designer, "Tell me just what you want and I will construct it, and construct it well, no matter what it may be." And so we are enabled with perfect structural equanimity to pile fifteen or twenty stories over a great void, as is the case of the ball room of the Astoria, and feel that we are violating no necessarily accepted canons of modern taste. The fact is, the problem of the modern commercial building is so simple and the lines have been fixed so precisely by practical requirements that the architecture, *per se*, has been reduced or developed, whichever you choose to call it, to a matter of decoration, and instead of following the Ruskin theory of decorating our construction, we literally construct our decoration and with very little thought of the bones behind it. The construction is a matter of engineering; the design is simply a matter of good looks; and the beauty is as independent of structural necessities as Raphael's paintings in the Vatican are independent of the composition of the mortar used in the construction of the vaults upon which they are painted. In fact the comparison between applied decorative painting and

the applied decorative architecture of our facades is one which fitly illustrates the present attitude of architectural design towards structures of this type, and it is the failure to recognize this essential quality that so often interferes with real success in some of our modern buildings and which delayed so long the development of the type such as is represented by the more recent of our structures.

It must be admitted, therefore, that truth, in the Ruskin sense, is not a requisite condition of excellence in the design of the typical buildings we are considering. As regards the element of beauty, if, as the pre-Raphaelites claimed, a building must be true in order to be truly beautiful, if vain repetitions are the death of true art, if a building must bear its whole story on its face in order to possess the beauty of goodness, then our recent work can claim no real beauty. But from our present standpoint beauty is something to be taken on and put off like a garment, to conceal rather than to accentuate the construction, to be of fabric and form which need not necessarily reveal all of the bony structure, and whose success or failure is chiefly intrinsic rather than relative, whose canons are those of sense and sensibility rather than pride of ancestry or educated prejudice.

We must then define the attitude of the modern critic, and by critic I do not mean so much the one who stands off and views the results, but rather the one who is most intimately interested in the construction of the architecture itself. It has been said that one of the first essentials of success in any art is the ability to criticise one's own work and find wherein it is at fault. It is, therefore, of first importance that there should be some formulation of principles by which the architect can be guided in the criticism of his own work, and from among the mass of conflicting theories which have been put forward to confirm the fitness of our modern architecture, considering simply the results attained and the means to those attainments, there are, we might say, three rules to be observed, all of them rank heresy in a pre-Raphaelite sense, but all of them the outcome of what we really have tried to do in our successful buildings rather than what closet theorists have evolved. The first is that our work shall seem to be what we mean it shall seem to be. In other words, if we are aiming to produce a sumptuous effect it is not a success unless it really achieves that

result; if we are aiming to give an effect of breadth and stability, of solid construction, it must have that effect, quite irrespective of the means by which those effects are obtained; our buildings must look substantial to our educated observation, they must have the appearance of being well built, they must, in fact, seem to be just what we imagine them in our conception. The second rule is, that the work shall be beautiful, not beautiful in the sense of mere fitness to a canon or to a tradition, or to a hidden and somewhat indiscriminate system of construction, and not beautiful either relatively or intellectually, but beautiful in the absolute sense so that both general effect and details shall please the mind without any recourse to intellectual argument or reasoning. This seems like a broad statement, but, as an illustration of how this can apply, consider the buildings which were recently put forth in the Brochure series of the ten most beautiful structures in this country. The National Capitol, the Boston Public Library, the Congressional Library, the Madison Square Garden, St. Patrick's Cathedral, and Trinity Church, New York, are certainly far from conforming to the old canons of essential fitness, but no one questions their beauty, and their beauty is the kind which appeals to all classes of observers. And the third condition to be regarded is that our buildings shall be all that they seem to be, and be beautiful not merely for the present but for all time. This is almost fundamental in architecture. Our buildings must stand. This may not be true to construction, they may not express the plan on the outside, but if they are to be successful in any degree, they must endure.

So that, epitomizing the present way of considering architectural designs, I would say that they must have the elements of fitness to the idea, whatever it may be, of intrinsic beauty, and of permanence.

The purists may say that this is all wrong, that commercialism is the blight of the age, and that art has developed in spite thereof rather than through its aid. I can not agree with such a position. Our whole modern life has been most profoundly influenced by commercial development. Our artistic life has been made possible by our business successes. The architecture of this country before 1876 was a development from the cottage type up. Only of very recent years have monumental possibili-

ties been within our reach. Our private houses, especially those in the suburbs and country, show a growth which seems to have abruptly stopped since about 1885; but all of the real progress which has come of late years has been along the lines of observance of the principles which I have previously laid down. The architecture in this country which marks the close of the last decade of the century shows a cultivation of pure beauty for its own sake to an extent which we never knew before. Our clients demand beauty and they get it. To my mind, this is the most hopeful sign for the future, and one which, however we may vary as to dogmas or standards, is sure to bring about the right results in the long run.

THE TECHNICAL REQUIREMENTS AND DIFFICULTIES OF MURAL PAINTING.

BY NEWTON A. WELLS, PROFESSOR OF THE HISTORY AND PRACTICE OF
PAINTING.

Mural painting is by no means a mere enlargement of easel painting; its esthetic purposes and its technical difficulties are quite different. The dimensions of the easel picture make it easy of an inspection which encourages the display of tricks of execution both in the handling of the brush and the pigments. In mural painting these sources of esthetic pleasure, perfectly legitimate to easel painting, are entirely precluded by the extent of the surface and the distance which must intervene between it and the eye of the spectator. Again, the easel painting, set in a comparatively deep gold frame, or in a wide "mat," is so cut off from its immediate surroundings as to be practically independent of them. The subject of the easel painting may be drawn from any phase of human thought or interest possessing pictorial qualities, for, because of its very portability, the location of the easel painting can be changed at the caprice of the owner or at the dictate of changing taste or fashion. This independent existence of the easel picture makes its treatment,

also, a matter of great freedom; every trick of brush and texture of surface is admissible, pigment may be spread thinly or loaded thickly, every intensity of color and gradation of light and shade may be indulged—every degree of imitation of nature's appearance. Whatever the appearance, the subject, or the treatment, there will always be some one who is pleased with it, and willing to give it a place upon the walls of his dwelling.

It is not so with mural painting, which must become the surface of the wall upon which it is placed, a part of the building in which it is housed. Mural painting is of too monumental a character to meet either the desires or the means of the ordinary picture purchaser, and for this reason it must find its greatest employment in the decoration of public instead of private buildings. This being the case, it follows that the subjects suitable for this kind of representation must be of such a universal interest as to appeal to the general public, and that, too, for generations to come. Such subjects should be significant of, or at least appropriate to, the uses of the buildings which they embellish.

Again, these subjects should be treated with a moderation and reposeful dignity which never wearies or oppresses the frequenters of the building. Morbid or intensely emotional subjects, although perfectly legitimate in illustration and easel painting, when introduced into monumental work of a decorative character, finish by irritating the mind and oppressing the spirits through their very insistency upon the attention. The same is true of strong and garish colorings. Color should be so harmonized and subdued that it does not take away from the feeling that the wall is there to be regarded as a wall, and that it does not make so sudden a transition from the decorative character and coloring of other architectural features of the interior as to seem not to belong to them. These are requirements which too many modern mural painters seem to forget, painting their wall surfaces as if they were independent of all surroundings. Such mural paintings make holes in the walls on which they are placed instead of decorating them.

Another requirement of mural decoration is that its surface should be "flat," or lusterless, so as not to interfere with seeing the work to advantage from every point of the interior.

Owing to the great expanse of surface to be covered and the

enormous amount of labor involved, it is very essential that the mural painter should have his design carefully wrought out, even to the minutest details; he will find it a vast saving of time and trouble in the end.

Doubtless no two painters follow exactly the same method of procedure, and I will try only to explain the one followed by myself in the execution of the decorations of the Library of the University of Illinois.

The subjects being imaginary ones, and the spaces which they were to fill being of given dimensions and shapes, it was necessary to first work out each conception to a given scale. This I did in the drawings reproduced in Plates V and VI, between pages 68 and 69, doing the work very roughly as to detail, and entirely from imagination, but trying to give each figure its relative size and place upon the scale that it must finally fill. These first scale drawings were made about $\frac{1}{4}$ inch to the foot. As soon as these were satisfactorily worked out, the models were called in and a careful study made of each; the animals were studied and photographed at the horse and cattle markets of Paris, where I was then prosecuting the work; landscape studies for the background settings were made in the public parks and gardens of Paris and Versailles. I must except the studies for the Forge, which were made in one of the great foundries of the city of Cleveland, Ohio.

As soon as these studies were completed, I proceeded to lay out the panels to a scale of $2\frac{1}{4}$ inches to the foot, which was large enough to admit of carefully working out all the details. Upon these enlarged panels the figures, animals and backgrounds were then drawn from the separate studies. In working out these more careful and enlarged scale drawings, I found it desirable to make more or less change from the original imaginary studies. These changes can be observed by a comparison of the studies (Plates V and VI) with the re-productions from the completed paintings (Plates I-IV, frontispieces).

When these enlarged panels were finally completed to my satisfaction, I pinned over them a stout parchment tracing paper through which the drawing was perfectly visible, and painted upon this with oil colors diluted in spirits of turpentine, which causes the pigment to dry flat, and with something of the same effect that the finished work should have. This procedure saved

the labor of tracing and transferring for the color studies, and permitted as many trials at the color scheming as was desirable to reach a satisfactory result, and this without the danger of injuring the scale drawing. The color schemes do not require to be worked out in detail, only the broad masses with their relative intensities and tonal values are necessary or desirable at this stage. When all of this work had been accomplished, occupying a period of six months, I was ready to attack the walls themselves.

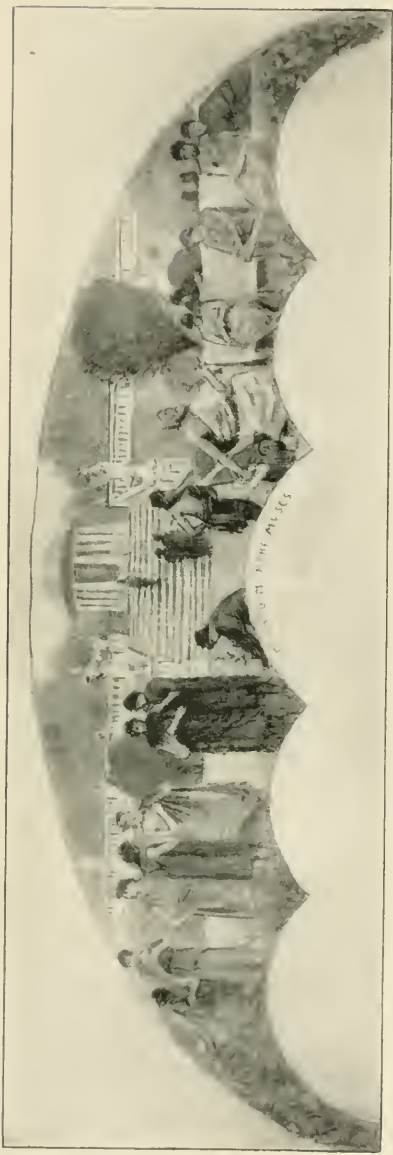
These were prepared by first giving them two coats of white lead in oil. As soon as this was dry, the surface was covered with a cement made of white lead, with just enough oil, varnish and turpentine to make it workable with a stiff brush. Upon this freshly covered surface was stretched a plain and unprepared canvas, and nailed all around the edges. It was then rolled down until completely imbedded in the white lead, and then immediately covered with a coat of the same, diluted with oil and turpentine. This required a full month to dry hard in an artificially heated atmosphere, after which the surfaces were covered with a coat of preparation made of lead, Spanish whiting, oil and turpentine. When this had become perfectly hard, the surfaces were rubbed down with fine sand-paper and were ready for the pictures.

While the walls were in process of drying I busied myself with the preparation of the full-sized working cartoons. These were drawn upon Manila paper with charcoal, or, I should have said *traced*, because they were drawn by the aid of a stereopticon, a lantern-slide having been made from each of the large scale drawings. These scale drawings had been previously laid out in squares equivalent to feet upon the wall surface, and it was only necessary to enlarge the drawing until these squares were one foot square, then pin up the paper upon the screen and trace the drawing, squares and all. With line and chalk the wall was also laid out in foot squares, when it was only necessary to apply the cartoon to its proper place upon the squares, and then transfer the drawing by means of sliding under it, when its upper edge had been secured in place with small tacks, a large sheet of transfer paper, and then going over the lines with a hard blunt point. This saved the trouble of pricking the outlines and then pouncing them by the old method. The trans-

fer paper I made myself by spreading upon a large sheet of Manila paper a mixture of lamp-black and mutton tallow, stirred together while the tallow was hot, and spread upon the paper with a rag while the mixture was still warm. One such transfer paper served for all four of the panels.

After the outlines were in place I was ready to attack with the color. For this work I used the oil colors put up in tubes of quadruple size, with the exception of zinc white, which I bought in bulk. Instead of thinning and tempering my colors with turpentine, I used a medium made by dissolving white wax in petroleum—ordinary kerosene—over a hot water bath. Enough wax should be added to make a jelly when cold. Of this medium I added about one part to two parts of pigment when mixing my colors on the palette. It has the double advantage of drying slowly and allowing of perfect deliberation in the work, and it does not change color or darken at all that I can discover during the process. This, and the fact that the dried color readily softens by the application of a little turpentine to its surface, makes it easy to join the work of each succeeding day, or after any lapse of time, without a break or visible "lap." The wax has, also, the additional advantage of producing a perfectly flat and lusterless surface with a delicate and ærial bloom like that of real fresco, and not the least of its good qualities is its preserving influence upon the color, protecting it from the contact of coal-gas, the *bete noir* of decorators in our climate.

Decorative pictures of smaller dimensions might be executed to greater advantage upon prepared canvas in the studio perhaps, but wall spaces of the size and shape of those in the Library (about 12 × 40 feet) could not be thus handled.



ORIGINAL STUDY IN CHALK FOR THE SACRED WOOD — REPRESENTING COLLEGE OF LITERATURE AND ARTS.



ORIGINAL CHALK STUDY FOR ARCADIA — REPRESENTING COLLEGE OF AGRICULTURE.



ORIGINAL CHALK STUDY FOR THE FORGE.
REPRESENTING COLLEGE OF ENGINEERING.



ORIGINAL CHALK STUDY FOR LABORATORY OF MINERVA.
REPRESENTING COLLEGE OF SCIENCE.



Since T is horizontal and W vertical, and since the tension along AB is equal and opposite to their resultant, completing the parallelogram of forces, we have

$$\frac{FB}{AF} = \frac{W}{T}$$

writing d for FB and l for AF and transposing we have

$$d = \frac{lW}{T} \dots\dots\dots (2)$$

This principle can therefore be used to represent the fall of potential in a cylindrical conductor carrying a single load if l represent the length and T the cross-section of the conductor, d the fall of potential and W the current flowing. And moreover, since the deflection of the cord at any point x is proportioned to the distance Ax , the position taken by the cord will represent graphically the fall of potential along the conductor.

Now let two weights W' and W'' be attached to the cord at F' and F'' (Fig. 1), and let the section of cord to the right of the weights be lowered until horizontal, the tension on the cord as before remaining constant.

First, we can consider the section of cord $B B'' G$ as fixed at B and write as before

$$d' = \frac{l' W''}{T}$$

where d' is the deflection below the horizontal $B E'$, l' is the horizontal distance between B and B' or F and F' , and W'' is the load at B' .

Now passing to B , the deflection here is caused by the weight W' and the tension along $B B'$. This latter is the resultant of W'' and T , and can be resolved at B into its two components. We may therefore write for the deflection d at B

$$d = \frac{l(W' + W'')}{T}$$

The total deflection at F'' is therefore

$$d'' = d + d' = \frac{l(W' + W'')}{T} + \frac{l' W''}{T}$$

Hence the principle can be used to represent graphically the fall of potential along any cylindrical conductor carrying any number of loads. By selecting proper units it can be made direct reading in volts, amperes, circular mills and feet.

The application is as simple as the principle. A scale-beam, having a small pulley attached to an arm which holds it vertically under the knife edge, is placed in front and at one end of a vertical board, upon which is stretched suitable cross-section paper. At the other end of the board is a vertical rod or guide, upon which slides a stirrup. To the latter is fastened one end of the cord which then passes over the pulley on the scale-beam, then vertically down, where it is wound up on a small drum. Small weights represent loads in amperes. The tension is varied for different cross-sections by moving a rider on the scale-beam, and then bringing the beam back to its zero position by manipulating the drum. By sliding the stirrup up or down the last section of the cord to the right is made horizontal.

In use this instrument was found to be easy of manipulation and accurate within one per cent. The sources of error to be guarded against are friction of the pulley bearing and of the knife edge, and a deflection of the cord due to its own weight.

To extend this principle to alternating currents it is necessary to consider the reactance as well as the resistance of the conductor. The fall of potential along a conductor due to an alternating current is

$$V = IJ \dots\dots\dots(3)$$

J being the impedance.

This may be written

$$V = \frac{I R}{\frac{R}{J}} = \frac{I R}{\cos \varphi}$$

giving the fall of potential in terms of the resistance and the angle of lag.

Applying this correction to (1) we have

$$V = \frac{k L I}{A \cos \varphi} \dots\dots\dots(4)$$

and (2) becomes

$$d = \frac{l W}{T \cos \varphi}$$

To adapt the computator to this law only requires that the scale-beam be movable concentrically about the knife edge, while the relative positions of pulley and knife edge remain fixed. This will be clear from Fig. 2.

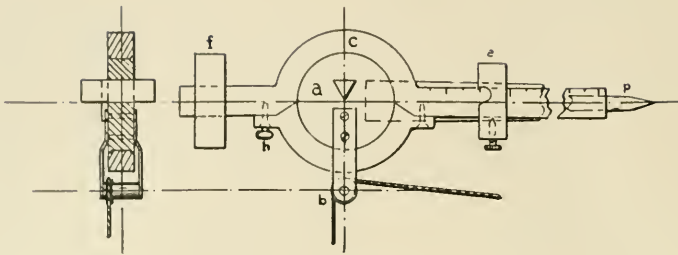


FIG. 2.

A steel knife edge is attached to the brass disc *a*, the bearing edge being placed at the centre of *a*. The pulley *b* is carried by *a* and is held vertically under the knife edge by two arms as shown. The scale-beam *d* has a split collar *c* which turns freely about *a*, but may be clamped in any position by the thumbscrew *h*. The rider is shown at *c* and a counter-balance at *f*. The pointer *p* is attached to *a* and enables us to bring *a* back to zero.

In the position shown the horizontal tension on the cord is the product of the weight *c* into the ratio of its lever arm to that of the pulley *b*. Call this *T*.

Now let the beam be turned down through some angle φ and clamped. The tension becomes

$$T^1 = T \cos \varphi$$

and the condition required in equation (4) is satisfied.

The angle through which we must turn the beam is of course the angle of lag of the current in the conductor, referred to the E.M.F. at its terminals. This depends on the frequency, the size of the conductor, and the distance between conductors.

Fixing the frequency and the distance between conductors fixes the angle of lag for each size of conductor, and this angle should be automatically indicated by the position of the rider. This may be accomplished as follows: Plot a curve which is the locus of the intersections of arcs, whose radii represent in the scale chosen the cross-section in circular mills, with lines drawn from the same centre, making the corresponding angle with the axis of abscissæ. It is somewhat more convenient to lay off these angles negatively. A curve will be obtained similar to those shown in Fig. 3. Here the scale is twenty thousand circular mills per division. Curve I. is plotted for twenty-five

and curve II. for sixty cycles, the conductors in each case being assumed eighteen inches apart.

These curves may be laid off on the cross-section paper, and in use the beam would be lowered until the point of intersection of edge of beam and curve coincided with the position of the rider index.

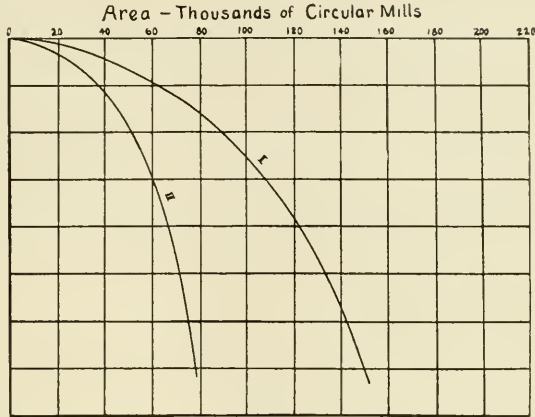


FIG. 3.

The next step is to make the pointer shown in Fig. 2 wide and cut a slot in it, corresponding to either of these curves. A pin on the rider fitting in the slot will automatically adjust the angle between beam and pointer as the rider is moved along. The pointers could easily be made interchangeable and the proper one selected for each computation. Since there are but few frequencies in general use, and an assumption of eighteen inches between conductors in all cases is sufficiently accurate for all practical work, there need be but three or four pointers for each instrument. If desired all the necessary slots could be made in one wide pointer, and an interchangeable pin on the rider serve to bring into use the proper one.

While the above instrument is not complex the following modification is simpler.

Equation (3) may be written

$$V = \frac{I}{\frac{1}{J}} = \frac{I}{J}$$

J being the admittance.

Thus while for direct currents the tension on the cord is proportioned to the cross-section, and hence to the conductance, the same instrument may be used for alternating currents if the scale divisions are made proportional to the admittance. This can

easily be done, using the curves shown in Fig. 3, and one scale for each frequency used, laid off on the beam, the divisions being marked in circular mills.

This construction does not show the angle of lag, but this is easily obtained, as the ratio of the reading on the scale of conductances to that on the scale of admittances gives the power factor and a graphical construction gives the angle of lag. This method of finding the angle is useful as the E.M.F. at the end of the line is the vector resultant, and not the algebraic difference of the impressed E.M.F. and the fall of potential along the line.

SLAG ADULTERATION OF PORTLAND CEMENT.

BY HALBERT L. CHIPPS, '99, ASSISTANT IN CIVIL ENGINEERING.

Recent correspondents in the engineering press* have called attention to the presence of metallic iron in some Portland cements, claiming that it is an evidence of slag adulteration.

An investigation was made by the writer in order to determine the percentage of metallic iron in different brands of slag, Portland, and natural cements. One hundred grams of each brand was weighed out, and the poles of a powerful horse-shoe magnet were passed through and through the cement for fifteen minutes, the iron thus removed being collected and weighed. At the end of that time the yield of iron was evidently nearly exhausted.

In order, however, to ascertain whether substantially all of the iron was separated by this method, 100 grams of a particular brand was placed in a beaker and a considerable quantity of gasoline was added, gasoline being used as it would not cause the cement to set. Then the mixture was stirred with the magnet until the iron was completely exhausted. Three brands of cement by this method yielding quantities of iron which agreed very

*Engineering News, July 13 and 27, 1899.

closely with those obtained from the dry cements, the latter results were taken as correct.

The percentages of iron contained in the cements tested were as follows :

SLAG CEMENTS.

| | |
|----------------------------------|-----------------|
| Brier Hill "Portland," | 0.067 per cent. |
| Illinois Steel "Portland," No. 1 | 0.120 " |
| " " " No. 2 | 0.120 " |

PORTLAND CEMENTS.

| | |
|---------------------------|----------------|
| Hilton's English Portland | 0.005 per cent |
| Alsen German " | 0.005 " |
| Star Stettin " | 0.005 " |
| Lehigh American " | 0.005 " |
| Alpha " " | 0.005 " |
| Saylor's " " | 0.020 " |
| Chicago AA " " | 0.050 " |

New York Rosendale, Louisville Star, Akron, and Milwaukee natural cements were also tested. None of these showed any metallic iron, although small quantities of magnetic, or black, oxide of iron were found in the Akron and Milwaukee brands.

An examination of the iron from the Portland and slag cements was made with the aid of a powerful microscope. All the iron from both classes of cements was found to be brittle and not malleable, showing that it contained a large percentage of carbon.

The material from the various brands of Portland cement agreed very closely in appearance ; that from the different slag cements was also quite uniform in character. Between the material from the slag cements and that from the Portland cements, however, some difference was noted ; the percentage of globular particles being somewhat less in the iron from the Portland than in that from the slag cements ; and the former showing more flaky and thread-like particles.

Certain large globules of metallic iron, some of them the size of pin heads, which were found in the slag cements and which greatly increased the percentage of iron, may be assumed to be particles which were carried out by the blast of the furnace, and which escaped fine grinding in the process of manufacture. The large percentage of iron found in two of the Portland cements might of course lead to suspicions of slag adulteration

However, it was noted that the appearance of the iron under the microscope was the same as that found in the other five brands ; that is, it showed a large proportion of flaky and thread-like particles such as might be abraded from the metal surfaces between which the cement is ground. Also it seems possible for round particles to be formed in this way ; or, if not originally round, to be made so by abrasion.

It seems unfair, then, to assume that a cement showing a proportion of iron as high as 0.05 per cent. can be condemned as being adulterated with slag, on this test alone. It may be added, however, that a much smaller percentage of iron (say, less than 0.02 per cent.) may be assumed to prove the absence of such adulteration.

The black oxide of iron which was found in two of the natural cements is evidently a constituent of the rock from which the cement is made. The absence of metallic iron from these cements may be explained by the fact that the rolls are not abraded by the soft materials of which the cement is made, and also by the absence of any temptation for slag adulteration on account of the cheapness of this class of cements.

An investigation was also made to determine the reliability of pat tests* as an evidence of slag adulteration. A number of pats were made of slag and Portland cements mixed in various proportions, the smallest percentage of slag cement being 10 per cent. The Portland cements used were Alsen, Star Stettin, Hilton's, Alpha, and Lehigh, these being used because they contained very small percentages of metallic iron. Tests were made of pats both exposed to air and kept under water. The pats kept under water invariably showed a greenish color of the interior, ten per cent. slag adulteration being easily detected in this way. The effect of ten per cent. adulteration with slag cement was also noted on the pats exposed to air, causing yellowish or brownish blotches to appear on the surface of the pat, although this test was not found as reliable as the former.

It may be concluded from these experiments that briquettes or pats kept under water, which show a greenish color of the interior, contain sulphides and hence are probably adulterated with slag ; also that if discolorations of the exterior of pats

*See Baker's *Masonry Construction*, 9th ed., pp. 62-63.

exposed to air are very noticeable, slag adulteration is probably present in considerable quantity.

The writer acknowledges his indebtedness to Prof. S. W. Parr, of the Department of Applied Chemistry, for microscopic examination and chemical analysis of the iron.

THE BOURBONNAIS RAILWAY ARCH.

BY C. L. EDDY, CIVIL ENGINEERING, '00.

The object of this article is to test the different theories of the masonry arch by applying them to an arch which for years has successfully carried a heavy railroad traffic.

This arch was built for a railway in France, and was designed by Vaudray. It has a span of 124 feet, and a rise of 6.92 feet. The thickness at the crown is only 2.67 feet, and at springing 3.60 feet. The arch is remarkable for its boldness.

Before the bridge was built the design was tested by constructing an experimental arch of the above proportions, and 12 feet wide. The center of this arch was struck after four months, when the total settlement was 1.25 inches, due mostly to the mortar joints, which were about one quarter inch. The arch stood the test of a uniformly distributed load of 500 pounds per square foot, and also the test of a five-ton weight falling one and one half feet on the key.

In applying the several theories of the masonry arch to the structure, a longitudinal section of the arch one foot wide was taken, which was assumed to carry its proportion of a railway train weighing 4000 pounds per linear foot, and also a filling of earth 3 feet deep at the crown. Assuming that the weight of the train was uniformly distributed over a width of 8 feet, there would be a live load of 500 pounds per linear foot on the

section of the arch taken. The earth was assumed to weigh 100 pounds per cubic foot, and hence the weight of the train may be considered as having the same effect as 5 feet of earth filling. Therefore the live and dead load at the crown is equivalent to 8 feet of earth, or 800 pounds per square foot.

It is not known what load the arch was designed to carry, but it is thought that the loads assumed above are at least approximately correct, and are sufficient to give a fair test of the different theories of the arch. The earth is assumed to exert a pressure both horizontally and vertically.

The arch was tested according to three methods, viz: (1) By the Rational theory, (2) by the Scheffler theory, and (3) by the Common theory.* In this particular case, since the arch is so very flat, all three of these theories give practically the same results.

To apply the theories, the half span of the arch was divided into six equal parts, and then the division next to

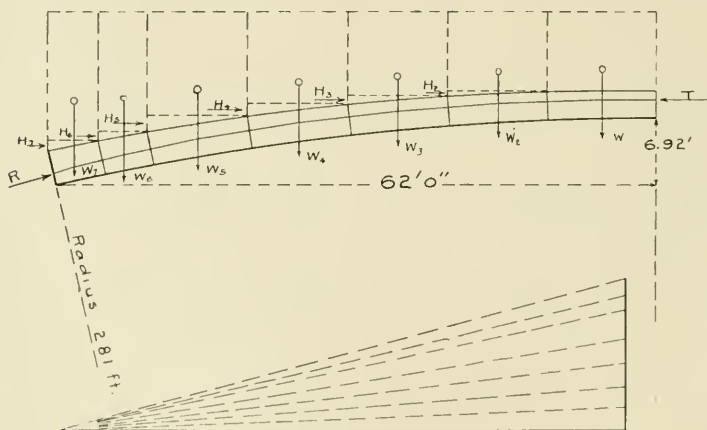


FIG. 1.

the springing line was subdivided into two equal parts, so as to more accurately locate the joint of rupture. The weight of train and earth on each division was found for a strip one foot wide, and also the weight of the masonry in each division. The sum of these weights was taken as acting at their common center of gravity.

*For detailed explanation of these theories, see Baker's *Masonry Construction*, pp. 466-81.

It was assumed that the crown thrust was the least possible consistent with equilibrium, and that it acted at the upper limit of the middle third of the crown joint.

Fig. 1, page 78, shows a section of half the arch, the upper horizontal line showing the upper limit of the earth embankment, assumed to be equivalent to the actual live and dead loads. The vertical forces, W_1, W_2 , etc., represent the sum of the vertical components of the earth pressure and the weight of the masonry of the several arbitrary sections. The horizontal forces, H_1, H_2 , etc., represent the horizontal components of the earth pressure against the vertical projection of the backs of the several sections. The arch is held in equilibrium by (1) the vertical forces W_1, W_2 , etc., (2) by the horizontal forces H_1, H_2 , etc., (3) by the resultant R , and (4) by the thrust T at the crown. T is the unknown quantity and may be found for any given joint by taking moments of all the forces to the right about the lower end of the middle third of that joint.

Table I was constructed to locate the joint of rupture—that joint for which the crown thrust is a maximum. In this table we let

W_1 = the total weight of the first division in pounds,
 W_2 = " " " " second " "
 etc.

X_1 = the moment arm of each W about joint 1 in feet.
 X_2 = " " " " " " " 2 "
 etc.

H_1 = the horizontal thrust of first division in pounds.
 H_2 = " " " second " "
 etc.

k_1 = the moment arm of each H about joint 1, in feet.
 k_2 = " " " " " " " 2, "
 etc.

Y = the moment arm of T about each joint, in feet.

The column headed total thrust gives the value of T for each joint, and from these values it is seen that the joint of rupture is at the springing line.

In Fig. 1 is shown the force diagram using the maximum crown thrust as determined in Table I. The lower triangle of the force diagram represents the three forces acting upon the section of the arch next to the crown, the base being the maxi-

TABLE I.
DATA SHOWING POSITION OF JOINT OF RUPTURE.

| No. of Joint | Arms of W | | | | | | | Arms of H | | | | | | Y | $\frac{\sqrt{Wx}}{Y}$ | $\frac{\sqrt{Hk}}{Y}$ | Total Crown Thrust Pounds | |
|--------------|---------------|---------------|---------------|---------------|---------------|--------------|--------------|-------------|-------------|-------------|-------------|-------------|-------------|-----|-----------------------|-----------------------|---------------------------|----------------|
| | $W_1 = 13900$ | $W_2 = 13680$ | $W_3 = 14050$ | $W_4 = 15400$ | $W_5 = 16870$ | $W_6 = 9150$ | $W_7 = 9850$ | $H_2 = 138$ | $H_3 = 252$ | $H_4 = 398$ | $H_5 = 605$ | $H_6 = 422$ | $H_7 = 455$ | | | | | |
| 1 | 5.5 | | | | | | | | | | | | | | 1.1 | 69,500 | 0 | 69,500 |
| 2 | 15.5 | 5.0 | | | | | | 2.2 | | | | | | | 1.6 | 175,593 | 190 | 175,788 |
| 3 | 25.7 | 15.0 | 4.7 | | | | | 3.2 | 2.5 | | | | | | 2.5 | 247,872 | 429 | 248,301 |
| 4 | 35.7 | 25.1 | 14.9 | 4.9 | | | | 4.5 | 3.8 | 2.8 | | | | | 3.8 | 291,870 | 711 | 292,581 |
| 5 | 45.7 | 35.2 | 25.0 | 14.9 | 4.7 | | | 6.1 | 5.4 | 4.5 | 3.0 | | | | 5.5 | 319,140 | 1061 | 320,201 |
| 6 | 50.7 | 40.1 | 29.9 | 19.8 | 9.6 | 2.1 | | 7.0 | 6.4 | 5.4 | 4.0 | 2.7 | | | 6.4 | 336,096 | 1295 | 337,391 |
| 7 | 55.7 | 45.2 | 35.0 | 25.0 | 14.7 | 7.2 | 2.1 | 8.1 | 7.5 | 6.5 | 5.1 | 3.8 | 2.8 | | 7.5 | 343,513 | 1541 | 345,054 |

mum crown thrust found in Table I, the vertical line being the combined weight of earth and stone of the section, and the hypotenuse representing the resultant pressure on arbitrary joint between the first and second sections. The second triangle in the force diagram represents the forces acting upon the second section from the top; and similarly for succeeding triangles and sections.

In this arch the horizontal component of the earth thrust is so small as to be practically inappreciable, and hence has been entirely omitted. Owing to this omission, the Rational and Scheffler's theories become essentially the same. Farther, since in this case the arch is a very flat segment, the joint of rupture is at the springing, and therefore the Common theory is substantially the same as the Rational and Scheffler's.

Since the first section is in equilibrium under the action of the three forces shown in the force diagram, the three must intersect in a point; and therefore if through the intersection of W_1 and T we draw a line parallel to the hypotenuse of the first triangle, the intersection of this line with the first joint gives the center of pressure on that joint. In a similar manner the centers of pressure on the successive joints are found as shown in Fig. 1.

A masonry arch may fail in any one of three ways, viz: (1) by the crushing of the stone, or (2) by the sliding of one

voussoir on another, or (3) by rotation about an edge of some joint.

The stability against sliding depends upon the angle between the resultant pressure on a joint and the normal to that joint. An examination of Fig. 1 shows that the maximum value of the above angle is $1^{\circ} 00'$, and occurs at the third joint. The tangent of $1^{\circ} 00'$ is .0175. The coefficient of friction for stone upon stone varies from 0.45 to 0.75, and for the purpose of this discussion we will assume the average to be 0.50. Therefore the factor against sliding is $\frac{.0175}{.50} = 28.6$, which shows that the forces resisting sliding are 28.6 times greater than the forces tending to produce sliding. In this investigation the effect of the adhesion of the mortar has been neglected. To include this would very greatly increase the stability of the arch against sliding. Therefore there is no danger of this arch failing by sliding on a joint.

The stability against overturning depends upon the maximum distance between the center of pressure and the center of the joint, and is measured by the ratio of half the length of the joint to the above distance. Both at the springing and at the crown, the center of pressure is at the extremity of the middle third, and therefore this ratio is 3. Consequently the minimum factor against overturning is 3, and therefore the arch is safe against this mode of failure.

The maximum compression, P is given by the formula

$$P = \frac{Q}{l} + \frac{6Qd}{l^2}$$

in which Q is the maximum resultant pressure on a joint as given in Fig. 1, l the length of the joint, and d the distance between the center of pressure and the center of the joint. An inspection shows that P is a maximum for the joint at the crown. Using pounds and inches, the above formula becomes

$$P = \frac{345054}{2.67 \times 12 \times 12} + \frac{6 \times 345054 \times 0.89 \times 12}{(2.67 \times 12 \times 12)^2} = 1047$$

pounds per square inch.

It is reasonably certain that the stone, at least approximately, sustains this compression, and since it successfully stands, we assume that this value is safe. The maximum compression in

*For the method of deducing this formula, see Baker's Masonry Construction, p. 448.

the above arch is much greater than is usually permitted in engineering structures. For example, the granite in the Rookery office building of Chicago is subjected to a compression of only 420 pounds per square inch; the piers of the Brooklyn Bridge, also of granite, are loaded to a compression of only 400 pounds per square inch; while the granite piers of the Saltash Bridge are subjected to only 125 pounds per square inch. We may conclude from this comparison that either the Bourbonnais arch is unsafe, or that the above named masonry is needlessly extravagant. Since the theories show that the arch is safe, and since it does stand, we may say that so far as crushing is concerned the masonry of the other structures named is extravagant. It may be possible that had Vaudray known to what compression the masonry in his arch would be subjected, he would have altered his design; but the bridge as it stands reflects credit on his engineering ability.

A comparison of the Bourbonnais Bridge with a few other arches may be interesting. The Waterloo Bridge, London, built by the celebrated engineer, Rennie, has a span of 120 feet, only 4 feet less than the Bourbonnais arch, but has a rise of 32 feet, nearly five times that of Vaudray's bridge, and a thickness at the crown of nearly twice the latter. The bridge at Neuilly, France, built by Perronnet, has a span of 128 feet, 4 feet more than the Bourbonnais bridge, a rise of 32 feet, 5 times that of the Bourbonnais arch, and a thickness at the crown of 5.13 feet, practically twice Vaudray's arch. The railroad bridge at Maidenhead, England, built by Brunel, has a span, too, of 128 feet, with a rise of 24 feet, and a thickness at the crown of 5.25 feet. These comparisons show that Vaudray was exceedingly bold in his design. He is exceeded in his boldness only by Edwards, the "country mason" who designed and built the famous Pont-y-Prydd Bridge, which has a span of 140 feet, a rise of 35 feet, and a thickness at the crown of 1.5 feet.* It is hoped, then, that in the future, there will be less obscurity of such an engineering structure as the Bourbonnais Bridge, and that Vaudray may receive, in part at least, the credit which is due him for this masterpiece.

*For an analysis of this remarkable masonry arch, see THE TECHNOGRAPH, No. 7.

THE MANUFACTURE OF TERRA-COTTA AND ITS USE AS A BUILDING MATERIAL.

BY H. A. WEBBER, '97, ARCHITECT, CHICAGO.

Terra-cotta has been manufactured for twenty-five centuries or more, but in its early history it was used for tablets and statuettes instead of for structural purposes. The Greeks and Romans employed it very successfully for ornamental forms, and fine examples of their work remain in excellent preservation. As early as the fourteenth century, in Italy, entire façades of great beauty were constructed of this material, and from that time it grew rapidly in favor.

Terra-cotta is almost always made into hollow blocks, formed with webs inside to give additional strength and to keep the pieces true while drying and burning. Solid blocks of clay will neither dry nor burn uniformly and do not hold their shape, besides the length of time required for burning would depend on the size of the block, making it impracticable to burn different sizes in the same kiln. The hollow form obviates this difficulty by securing a nearly uniform thickness throughout, and the handling, setting and supporting of overhanging members is greatly facilitated because of the lightness of the material. By this method of manufacture the blocks can readily be made to conform to steel supporting members, for which they usually serve the double purpose of an ornamental covering and fire-proofing.

In describing the manufacture of terra-cotta the natural order will be to follow the work through the factory, step by step, from the time the contract for the work is received until the finished product is fitted and marked, ready for shipment to the building. It is necessary to have a complete system of classifying and indexing the work, thoroughly identifying each piece of every job, as well as the molds and drawings for the same, so that its stage of progress in the factory or at the building may be known at any time. A complete set of the architect's drawings for the proposed building is sent to the factory with the

order for the terra-cotta. This includes the general drawings for the building, all steel diagrams, and the scale and full size details of the terra-cotta work, though some architects prefer not to detail all the work in advance, but have the terra-cotta company submit full size drawings, during the progress of the work, of sections and profiles and even of ornamental work which they propose to use. This gives the architect an opportunity to re-study and modify his scale details. All the drawings furnished are sent to the drafting room at the factory, where accurate and complete shop drawings are made of all the terra-cotta work. They show its relation to the steel and to all other work with which it may come in contact, and locate all necessary anchor holes. The dividing into courses and blocks is carefully studied, and then laid out and figured on the working drawings. As the jointings of the work may be of great importance, making or marring the appearance of the design, they should be submitted to the architect for approval. If the ordinary vertical joint can not be placed in a suitable position on ornamented work, it may sometimes either follow a curved line of the design or cross the lines of the ornament in a normal direction, the latter being the better way. Pieces jointed in any other way are not likely to join properly on account of unequal shrinkage. In work having an ornamental pattern repeated, the joint can generally be placed either between the patterns or in the centre of each.

The number of different molds required will depend largely upon the way in which the work is divided, and it may happen that the system of jointing best suited to the design will not be the cheapest to execute. For economy in manufacture, the molds should be relatively large, since it costs more to press a great number of small pieces than a smaller number of larger pieces. In general, the most economical size for molds varies between two and eight cubic feet, depending on the shape and character of the block; but, if necessary, the work can be made in much larger pieces. In architectural sculpture, where jointing is objectionable, pieces may be made as large as thirty or more cubic feet and weighing a half to three-quarters of a ton; and complete column shafts, ten to twelve feet long, have been made in one piece. However, there is great risk in attempting such large work in which a slight variation of line is so detrimental, as the plain or fluted column. If the column is ornamented, then

a variation would not be so conspicuous. Naturally, it is cheaper to so divide the work that the largest number of pieces possible may be made in the same mold and be of the same length; but this may give undesirable jointing in one or more places. Adaptability to the design must be secured first and economy in manufacture afterwards. The working drawings dispose of all these matters and present the work as it will be in the completed building. These drawings follow, or rather direct, all the work through the factory; being continually in use by the draughtsmen, pressers, finishers, burners, fitters, makers, shippers and setters. Copies are kept on file all the time, and if any piece gets lost or destroyed before being set in the building, a duplicate may be produced by their aid.

After the working drawings have been approved a full-sized detail is made of each different kind of piece shown, corresponding with the figured dimensions on the working drawings and in accordance with the architect's details. They are to be used in making the plaster models, and are made larger than full size to allow for the shrinkage of the clay in drying and burning. For this purpose a shrinkage scale is used to lay out the details instead of the standard scale. It is sometimes called an expansion scale, and has its true length greater than the standard and its divisions increased in like proportion. A scale measuring $12\frac{3}{8}$ inches per foot is called a $\frac{3}{8}$ -inch shrinkage scale, and others are similarly named, $\frac{3}{4}$ -inch, $\frac{7}{8}$ -inch, 1-inch, etc., shrinkage scales. The shrinkage of different clays varies from about $\frac{1}{4}$ inch to 2 inches per foot in each direction, but clays having a shrinkage of either of these extremes are not suitable for manufacturing into terra-cotta for reasons that will be explained below. The usual shrinkage of terra-cotta clays varies from $\frac{3}{8}$ inch to 1 inch per foot, about two thirds of this amount occurring in the drying and the remainder in the burning.

The plaster details are next sent to the plaster shop, where the models and molds are made. A full size, shrinkage scale, plaster of Paris model is made for each piece shown in the plaster details. Various methods are used in making these models, but generally a metal templet, having the exact reversed profile of the required model, is run on a straight edge to produce straight running pieces and on the circumference of a circle or an ellipse to produce those curves. Curved work of more

irregular form, such as consoles, brackets, and scrolls, may be modeled in the soft plaster with a templet by the hand and eye, or the curved part of such models may be carved after the plaster has hardened. If the work is yet more complex, it should be left for the modelers to make in clay. If the design calls for ornamented mouldings, the background of the plaster model is left low so that the ornament may be added in clay by the modelers. To obtain models with mitres, angles, or returns, two pieces, straight or curved, are sawn to the required mitre angle and cemented together with fresh plaster.

Models requiring ornament are now sent to the modeling department, where this is added in clay by expert modelers. The great variety and the high class of ornamental work now in demand makes it necessary for a first-class terra-cotta company to keep a large force of artists to do the modeling. In rare cases an architect reserves the right to select the modeler who is to mould his work. In such instances the company doing the work is required to provide him with a suitable room and all necessary appliances to work with, such as clay, framing, scaffolding, etc. Occasionally the architect will have the molding done under his personal supervision, and furnish the models complete ready for use, a certain specified amount being deducted from the contract price to pay for the modeling. This is done not only to insure good work, but from a desire to stamp the work with an individual touch and taste. In such cases it is usual to specify that all models and molds are to be destroyed on completion of the work, and that no copies of them are to be preserved. When the modeling is done at the factory and by the company, as nearly all of it is, the architect either examines the models or has photographs of them submitted for his approval.

If there is much ornamental work and only a few pieces are required from certain molds, it will naturally be quite expensive. In case there is but a single piece required of some model, which often happens in the key for an arch or a decorated panel, it is cheaper and quicker to model the piece in terra-cotta clay direct, not making any plaster model or mold, and this is often done, both for plain and ornamental work. If there are but a very few pieces of an extremely complex nature it may be better to model them in terra-cotta direct. Where there is heavily projecting ornamental work on a plain molded background, such

as lions' heads, gargoyles, etc., on a cornice, which would make an inconvenient form to mold, the background pieces may be pressed separately by the pressers and the ornament added by the modelers while the block is yet in a plastic condition. Work that is to be deeply undercut can be modeled to great advantage in this way, and effects may be obtained that are impossible in cut stone. Delicate gothic ornament can be entirely undercut and raised free from the background, except at a few necessary points of contact, giving light and shade effects and suggestions of plasticity and of modeling which are unknown in stone or marble. In this process each piece, instead of being a duplicate of one model, is modeled separately and shows the little accidental and intentional variations which reveal the true artist. For architectural sculpture, the entire work is modeled in clay without the use of a plaster background, and the modeler either works from the architect's full size details, the plaster details, the architect's scale drawings, photographs of ornament, models already approved, or composes under instructions from the architect.

When the clay ornament has hardened sufficiently, the models are sent back to the plaster shop to have the molds cast upon them. These are also made of plaster of paris, in slabs about two inches thick or more, depending on the size and shape of the model. The number and shape of the slabs also depends on the form of the model, for the mold must be so made that the model will slip from it, or rather so the mold may be taken from the model a piece at a time, and afterward from the block of terra-cotta which has been pressed into it. A very complicated and irregular piece may require a mold made in many pieces. For work that is irregularly undercut, small pieces of the mold must be fitted under and between projections in such a way that they may be removed without injuring the block of clay, but for most models it is sufficient to have one slab on each of five sides, leaving the back open. These slabs are fitted to each other accurately and in such a way that the blocks pressed into the molds are exactly alike and uniform in size. In fact, the mold serves this purpose as well as if it was made in one piece like a box; but unlike a box mold, it may be taken off the block, after it is pressed, a piece at a time. Of course, it would be impossible to use a mould in one piece for terra-cotta as is done in the manufacture of bricks. By this method a mold may be

made for any piece that may ever be designed, no matter how irregular it may be. Having determined the number and shape of the pieces making up the mold, they are cast in plaster upon the model, one at a time, and allowed to harden. The soft plaster receives a perfect impression of all lines and surfaces of the model with an accuracy that it would be impossible to secure in any other way, and as long as the mold is uninjured it will produce exact duplicates of the original model. If it is a small mold, the plaster of paris is strong enough in itself, but for large molds it must be re-enforced by embedding small bars of iron in it, so it will withstand the force used in pressing the terra-cotta. The pieces are fitted to each other and secured by clamps and are then ready for use. These molds are very durable, considering the material of which they are made, but they wear out by crumbling at the edges if used too long or too often. The plaster naturally takes up some moisture from the wet clay and becomes softened at the thin edges, but if allowed to dry after using each time they will last very long. A mold for ordinarily plain work will last to press from sixty to ninety blocks. If it has much ornamental work, with many fine lines and thin edges, it will not last for more than thirty or forty. Any number of molds can be cast on one model. It may happen on a large building that there will be as many as a thousand pieces of terra-cotta alike, and this would require ten to fifteen molds, depending on the nature of the piece.

One of the great difficulties with the manufacture of terra-cotta is the unequal and irregular shrinkage of different pieces. So long as this exists it is impossible for mouldings to always member perfectly or run in a true straight line in the finished work. The best developed factories produce work that overcomes these defects in a great measure, but there are always uncertainties on account of this feature in the clay. If the clay was perfectly homogeneous it might yet be impossible to secure exactly uniform shrinkage because of the inequalities of volume at the angles and intersections of the shell, though an effort is made to secure uniform thickness of all walls and webs of each block. These difficulties are greatest in the production of plain ashlar work, for it is a hard problem indeed to keep the face of every block in a true plane, and without this the wall will have a wavy appearance. Where the requirements are very exacting

it is often necessary to put ashlar blocks on the rubbing-bed. The extra precaution taken in making the shell thicker and using more webs, together with the probability of having to rub some of it to a plane surface after burning, makes ashlar more expensive than would be supposed.

The molds now being ready for use are sent to the presses. It must be remembered that they were made to provide for a certain proportion of shrinkage, corresponding to the particular clay to be used. Clays are designated as fat and lean or soft and hard. The fat clay contains the smaller proportion of silica, is easier to work, shrinks a great deal, and loses its shape easily in burning. The lean clay has a great deal of silica, is hard, difficult to work, shrinks little and retains its shape well in high temperature. Neither of the two extremes is well adapted for manufacturing into terra-cotta, but a middle grade is sought. This can be tempered to the proper degree of hardness by mixing the lean and fat clays. The fat can be made lean by adding silica in the form of sand or ground and calcined flints, or by adding ground clay that has been burned. The color of the clay depends chiefly upon the oxides of iron which it contains. The clay which has been prepared by thoroughly crushing, grinding and mixing with heavy machinery, is furnished to the presses in a very stiff, plastic condition, and the pressing is begun. The mold is first lined with a layer of clay and pressed and rubbed into form by the hand and afterward pounded down into close contact with the mold at every point. This pressing and pounding results in thoroughly kneading and condensing the clay into a compact nearly homogeneous mass, which gives great strength and tenacity of the finished product. The shell of clay is about one inch thick for average size blocks. It is thinner than this for small pieces, while for very large pieces it is two or three inches or more in thickness. After the shell has been thoroughly pressed and pounded into the mold, cross partitions or webs are arranged in both directions and also pressed and compacted as much as possible. As before stated, it is necessary to keep the thickness and density of the clay as nearly uniform throughout the block as possible to secure uniform shrinkage, without which it will warp and twist in burning. The webs serve to support and preserve the shape of the block while it is yet soft after being turned out of the mold as well as

while it is being burned, and also to give greater strength to the finished product. If the block is not of an unusually large size it may be turned out of the mold immediately; that is, laid on its open side or back and have the mold taken from it, piece by piece. For extra large pieces, however, the clay will not be stiff enough to support itself at once, and they must stand in the molds several hours. When turned out of the mold, if the block is perfect and has had no thin edges or corners pulled off in slipping from the mold, and if there is no special work to be done on it in finishing the surface or in cutting it to fit in some particular location, it is taken to steam drying rooms. Here it is arranged so as to dry as nearly uniformly over bottom sides and top as possible. If it can be kept straight and true, free from cracks or checks and homogeneous until it has dried thoroughly, a first-class finished product is assured with proper burning.

As suggested above, the block may need special work of some kind after leaving the mold, and in this case it is taken to the finishers. The finisher goes over the block carefully, restoring any bits of clay that may have been pulled off by the mold, as well as truing the block up with straight edge and square. He will also do the finishing of the surface, unless this has been done in the mold, for there are various methods of finishing to exposed surface of terra-cotta. It is usually left perfectly smooth when it is to be glazed, but rarely if not to be glazed. In which case some texture is given to the surface by markings of different kinds. In ornamental work some architects have the finish made to represent a chiseled surface, as if the block had been carved out of a hard material, but this is considered wrong in principle by the best architects, and it is certainly contrary to the spirit of a plastic material. Modeled work should be left as it comes from the hand of the modeler. Other work is usually finished with a combed surface, the markings running in vertical planes or else being cross-hatched. This may be produced by having the interior of the mold combed or by combing the face of the block with suitable tools while it is yet soft. All work done on the face of the soft block, such as rubbing and pressing with combs, scratchers and trowels, renders it more compact and finished, and adds to the value of the material.

Terra-cotta is well adapted to receive a variety of color fin-

ishes. These are produced in three general ways. The first is the natural color which the clay has after burning, which is called the body color. This furnishes all the ordinary brick colors, as buff, brown, red, gray, salmon, white, etc. These match the given color of the bricks approximately, but as the brick and terra-cotta to be used together are rarely if ever made of clay having exactly the same composition, their color will differ somewhat. To obtain the various tints that may be desired recourse must be had to the second general method.

This consists in coating the terra-cotta block with the desired tint before it is burned. Any tint may be obtained in ceramic pigments, as clays, ochre, lime, metallic oxides, etc. These are combined by the chemist in the proper proportion, ground and mixed with water, and sprayed onto the surface of the block. After burning it is of course as durable as the terra-cotta itself. This tint is called a slip, and is said to be slipped on. It is applied so as to completely cover the face of the block and fill the pores to a certain extent, but not heavily enough to obliterate or conceal the texture of the surface. It is also called a semi-glaze, because it is only partly vitrified, not being fired sufficiently to produce the true glaze. This process, if well done, is a very valuable one to the terra-cotta, aside from the matter of coloring. It forms a very hard, impervious coating, which is a perfect preventive of efflorescence and cement stains. Cement will rarely stain the very best terra-cotta, but efflorescence is likely to occur except in a very hard body or one protected by a vitreous coating. Some companies have secret methods of treatment whereby they can prevent the green efflorescence on a light body without using the slip. This tint may be applied as an even flat wash, or it may be spotted to match spotted bricks. Flat ornament of a very interesting kind and strictly permanent may be made by outlining ornament on the block and filling in with one or more colors, having the background natural or of another color. The block is then burned and afterwards covered with a transparent glaze, rendering the ornament permanent. The possibilities of this kind of work, akin to china painting, are almost without limit.

The third general method for color finishing is that of glazing or enameling. A true glaze is transparent, enamel being an opaque glaze. Glaze is applied much in the same way

as the "slip," except that it is put on a great deal heavier and produces a smooth, glassy surface. The block is also smooth before glazing, so that no texture or tool marks of any kind appear. It is necessary that there be a certain similarity in substance between the clay body and this vitreous coating in order that the glaze shall adhere properly without cracking or blistering. A silicious enamel will not adhere well to a fat clay body, and the fusing point of the component parts of the enamel must be lower than the melting point of the clay. Adding oxide of lead to the enamel lowers its fusing point and also makes it less hard and durable, but for clay that will not stand a high temperature, it is necessary to use an enamel with a low fusing point. Or, if a silicious enamel must be used on a fat body the terra-cotta may be burned first, then the enamel applied and both fired again, which will result in a firm union. It gives better results to fire the ware twice when using certain colors of enamel, for they will not adhere properly to the unbaked body. The transparent enamel or true glaze allows the full body color of the clay to show through, producing rich color effects. White enamel is used for lighting purposes and various other colors are used for architectural effect. Some recent work done in Chicago included an order of gold enamel tiles, which now crown the highest roof in that city. Occasional objections are raised to the glaring appearance of enamelled work, and it is ordered with a dull finish made by the sand-blast process, though it would seem that such a surface would quickly become weatherstained in a dusty and smoky atmosphere. Salt glaze, which is a silicate of soda, is probably the oldest glaze known. This is not used for architectural terra-cotta, but it is made as follows: Salt is thrown into the kiln when the firing is about complete. It is volatilized and decomposed by the heat, and the soda combines with the free silica in the clay and forms a hard coating of silicate of soda. A very high temperature is required and the clay must be a hard clay, containing much silica. This clay is practically indestructible.

The work having received its slip or glaze, if any is required, is taken to the kiln. The kilns for burning terra-cotta are made similarly to those for any other earthen ware, being really scientifically arranged ovens, lined with fire-brick and so constructed that the flame does not come in contact with the

ware. Means are provided for ascertaining the temperature at all times, and different temperatures are required for different clays and enamels. From four to seven days are required to burn the ware, and after the heat has been withdrawn the kiln must remain closed until it has cooled, which requires almost as long as the firing. Each piece stands in the kiln on lugs, called "spare edges," formed on an end which is not a face end, provision for which is made in the mold. Each piece is free from contact with any other piece and rests on a fire clay slab. No finished face carries any direct weight, and therefore the probability of distortion is reduced to a minimum.

When cool the ware is sent to the fitting room. Here the "spare edges," and other projections that will prevent each piece from properly jointing with its neighbors, are cut off, and the pieces all laid together as they are to be in the wall. Although a carefully estimated amount of shrinkage was provided for, it is not likely that all the work has shrunk exactly to this extent. The amount allowed must be as much as will ever occur, because if the work shrinks more than provided for it will either run short in the wall or require large mortar joints to make up the deficiency. If it shrinks less than provided for, it may usually be cut down to the required size. Ornamental work presents some difficulty here, for it may be such that it can not be cut down without spoiling the ornament. In ornamental moulding courses this is especially liable to make trouble, as it may be necessary to cut off part of an egg and dart, or a leaf, or a bead, and so the blocks may not member properly after being cut. In other kinds of work the jointing is always arranged so as to leave an opportunity for cutting if possible. With this sort of work, therefore, all precautions possible are taken in laying out the joints, estimating the proportion of shrinkage and providing pieces of more than one length so they may be interchanged to make up the total length without cutting; but still it is probable there will be some unforeseen results from the burning. As stated above, the work is laid together in the fitting room with the proper allowance for joints, and the amount, if any, to be cut from each piece is ascertained. For this work a force of stone-cutters, or rather terra-cotta cutters, is maintained. The work having been thus carefully fitted at the factory, it is sure to lay up properly at the building. After the work is fitted and

laid together, each piece is lettered and numbered according to the index given on the working drawings, which indicates the exact position the piece will occupy in the building, and the work is then ready for shipment. The working drawings are used as a key by the setters at the building. The terra-cotta companies do not feel that their responsibility should cease upon the delivery of the ware, but prefer to have their contracts include the setting, and on large work it is now the general custom to have manufacturers set the work in the building.

The entire process up to the shipment of the material has required somewhere from three weeks' to a year's time, depending on the amount required and the general character of the work. A single small order, requiring molds and modeled ornament, made and fitted ready for shipment, will require three weeks as a minimum, though, by paying extra cost for night work and special attention to rushing a job, a small order may be turned out in fourteen days. Work for which the factory has molds already in stock can be turned out in less time than if models and molds have to be made.

The setting of the work in the building is an important matter. Of course, all projecting work should be well anchored in place, and usually the simplest method of anchoring is the best. The facing of small piers and mullions should be anchored to the backing, but there is no need of anchoring ordinary ashlar work. It is well to have the iron or steel either galvanized or coated with tar, or copper wire may be used where suitable.

Opinions seem to differ in regard to filling terra-cotta blocks in order to give them extra strength. Blocks required to carry an unusual load, as under the jambs of openings and in the arches of a heavy masonry wall, have been known to fail. Attempts to strengthen them by running full of cement have resulted in the rupturing of the terra-cotta, caused by the slight expanding of the cement on setting. Filling with ordinary concrete or brick work does not destroy the block, but it is very doubtful whether such filling adds to the strength. Unquestionably, the best solution of the problem is to require the terra-cotta to be made strong enough in itself to carry the load that is to come upon it, in which case special pieces can be made with thicker shells and more interior webs so as to carry almost

any load that may come upon them. However, the supporting strength of terra-cotta is very rarely called into question. It is expected to be fully as strong without filling as the common brick backing, and it certainly is so, but it should be well-filled and bonded with the brickwork, as this bonds the walls together and prevents any tendency on the part of the terra-cotta facing to buckle or bulge. If the terra-cotta is set with cement and their joints and the brick backing is laid with lime mortar and thick joints, the backing will settle more than the facing and thus throw a great load on the terra-cotta. Extreme cases of this sort of work have occurred where the entire face of the terra-cotta was sheared off, leaving the webs bonded into the brickwork. Since there are so many more joints in the brickwork than in the terra-cotta facing, it is difficult to equalize the shrinkage of the two. The best results will be obtained by setting the terra-cotta with a rich lime mortar, raking out the joints to be pointed later with another material, and laying the brick backing either in cement mortar or in cement and lime mixed, with neat, thin joints.

The pointing of terra-cotta is done with various materials, lime putty and white sand, putty and fine sand, stained to suit, and pure cement being the most common. The cement should be non-staining, unless the terra-cotta is proof against stain. Lead and painter's putty are also coming into use, and for glazed work, where it is desirable to suppress the joints as much as possible, painter's putty is excellent. If the edges of the block are rubbed true and straight a very thin joint is possible and it will stand the weather well. Lead seems to give variable results. In some cases it becomes loose in the joints, so that long strips of it can be lifted out of place. This might be expected when the lead contracts with the cold, and it is possible that on becoming warm again it will not expand so as to fill the joint just as it did originally. Joints need not be raked out, to prevent the blocks from chipping, until the wall has settled, as is sometimes specified. Naturally the strength of the block is in the shell, and by raking out the joint the weight is thrown off of that part of the shell and onto the weakest part of the block. The need of protecting from chipping only occurs in some thin projecting parts of a block, which are not expected to carry a load, or in cases of unequal loading.

The question of the durability of terra-cotta is an interesting one. All other building materials have their weaknesses. Timber will either decay or be destroyed by fire, iron is destroyed by heat or moisture, and every stone disintegrates under the action of the elements. Terra-cotta resists all the elements and forces of nature better than any other building material, and it is the most durable of any in use at the present day. The best terra-cotta usually runs higher than the best brick in crushing strength, tests having run as high as 11,000 pounds per square inch on solid cubes. A recent series of tests for tensile strength showed a large number of briquettes which did not yield at 1,500 pounds per square inch, which was the limit of the testing machine used, but some of a poorer quality broke as low as 300 pounds per square inch. Terra-cotta weighs about 125 pounds per solid cubic foot, and from 60 to 70 pounds per cubic foot in hollow blocks.

Little can be said of the cost of terra-cotta except in a very general way, for it cannot be very accurately expressed in terms of the quantity required. Every job will have a price of its own, depending on the manner in which the terra-cotta is used, the amount and kind of ornament and upon various other considerations. It is very difficult to make a close estimate without complete data on the cost of much previous work, and this is only possessed by the manufacturer. In general, it will cost more than pressed brick and less than cut stone; but for certain kinds of stone, plain ashlar, which is its cheapest form because worked entirely by machinery, is cheaper than terra-cotta ashlar. The following rule is given for approximate estimates of cost. Compute the weight of the total volume of terra-cotta at sixty pounds per cubic foot, and allow from \$40.00 to \$80.00 per ton, depending on the amount and kind of ornament. The cost also varies a great deal with the kind of finish. The semi-glazed work has practically become the standard, and no extra charge is figured for that, but glazed work costs from 30 to 100 per cent extra, for some kinds are produced only with much work and time, requiring two or three coatings of enamel with as many firings. For ordinary glazing only one coating and one firing is required, the enamel being applied directly to the unbaked terra-cotta, but for some colors it is necessary to put on a second coating of transparent enamel after the block and first coating

has been fired, when the whole is fired for the second or third time.

Practically no goods are kept in stock, and there is but little work that can be called stock, nearly every job requiring special molds. Molds for a great deal of the work done are usually preserved, but the percentage of old molds available for new work is very small. This is inevitable, of course, from the nature and uses of the material, and it will always be so. The cost can therefore be reduced by the use of stock forms as with some other kinds of material, but in the case of small jobs of no great importance an architect might send his design to the terra-cotta manufacturers and let them fit all the work which they could from old molds and that which they could not fit might be altered slightly to conform to profiles for which they already have molds. It is possible to do this in some cases without materially changing the design. It is not a satisfactory plan, of course, and it is very rarely followed, and then only for the purpose of reducing the cost on small or unimportant work. The manufacture of Terra-Cotta has now reached such a high state of development that any further progress is not likely to decrease its present cost very materially.

The plasticity of the raw material and the durability of the finished product renders it very popular for ornamental work, while its adaptability for use with steel skeleton construction assures its greatly increased use in the future. It forms a large item in the bill of materials for a modern high office building, where the entire facing is often of terra-cotta. The use of terra-cotta in the United States has developed almost entirely in the past fifteen years. The product in 1898 amounted to \$1,979,825, which is 2.77 per cent of the total product of all materials in clay for that period. Almost the entire output is made in five states, while New Jersey and Illinois together make more than one-half the amount. The product of these five states in 1898 was as follows: New Jersey, \$635,000; Illinois, \$510,000; New York, \$367,854; Missouri, \$168,000, and Pennsylvania, \$147,000. Illinois boasts the largest exclusive architectural terra-cotta factory in the world.

A MEASURING TANK FOR A JET METER.

BY CHARLES VICTOR SEASTONE, '95, ASSISTANT IN THEORETICAL AND APPLIED MECHANICS.

A jet of water issuing from a vertical pipe offers a simple method for measuring the amount discharged when its velocity head is known. An apparatus containing such a vertical pipe and a device for measuring the velocity head of the jet may be termed a jet meter. This method of measuring the discharge of water is not generally appreciated by engineers. Experimental work in the Hydraulic Laboratory of the University of Illinois, during the past two years, shows that the jet meter offers promising developments along several lines, and the apparatus herein described is one result of the investigation.

The measuring tank for such a jet meter, which it is the purpose of this article to describe, furnishes a comparatively simple, accurate and inexpensive method for measuring the discharge of water. It consists essentially of a tank of three compartments with a short wrought-iron vertical discharge-pipe and a glass tube for measuring the velocity head. Fig. 1 shows the longitudinal section, Fig. 2 the plan, and Fig. 3 the end elevation. The water to be measured enters the tank at *A*, passes downward and through the compartment *B*, and is discharged through the pipe *P*. The rectangular opening *R* in the outflow compartment *E* terminates in a spout *D*, which may be detached when desired. The velocity head used is the height to which water rises in the glass tube *T*. The discharge is computed by the formula $Q = c a \sqrt{2gh}$, in which *a* is the area of the pipe, *h* the velocity head, and *c* a co-efficient to be determined by experiment.

With the apparatus under consideration three sizes of pipe were used,—2-in., 3-in. and 4-in. diameter. This pipe is ordinary, black pipe, and in each case the actual diameter was 0.1 inch in excess of the nominal size. These pipes are 12 inches long and project 2 inches into compartment *B*. The ends were planed, the outer edges beveled, and all burs removed from the inner edges. A 6-inch flange-union *E* with bushings serves as a connection

for the different sizes, and the method of their attachment is shown in detail in Fig. 1. The change from one size to another may be quickly made. For satisfactory operation the velocity must be fairly uniformly distributed over the cross-section of the pipe, and this necessitates the use of the baffle board *a b c*.

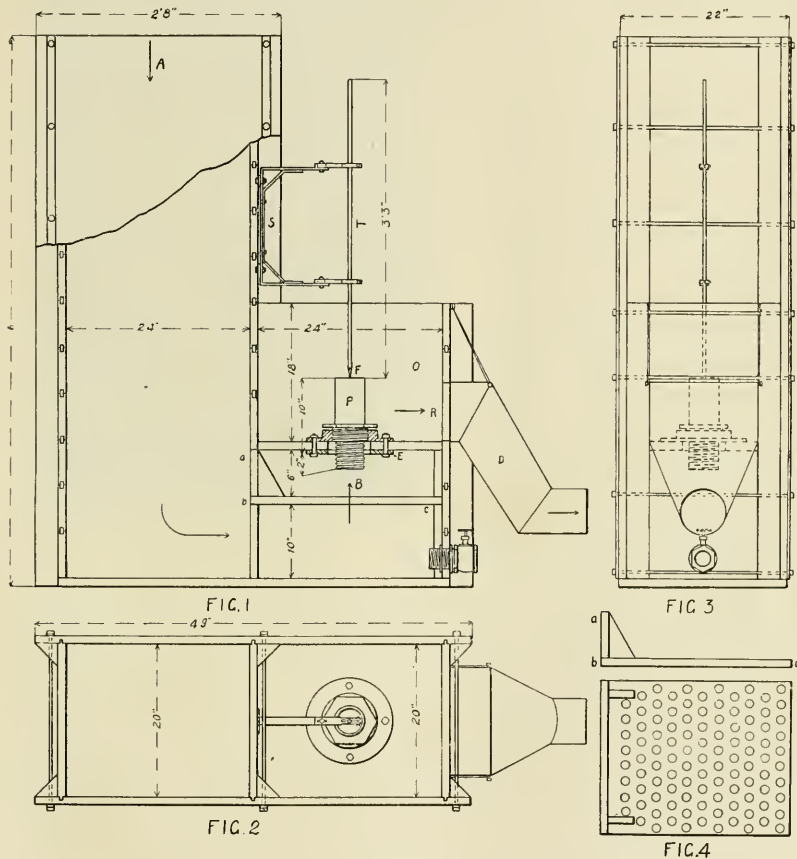


FIG. 1-4.

Fig. 4 shows this in detail, the vertical portion *a b* being solid. The horizontal board is provided with a number of 1-inch openings and serves to distribute the flow fairly uniformly over the compartment *B*.

The glass tube *T* in Fig. 1 has an internal diameter of 0.5 inch, and is provided with a brass tip *F*. This tip is about 1.5 inches long and the diameter is reduced to 0.19-inch at the end.

It has a bore of 0.12-inch, this being made small in order to reduce the fluctuation of the water column in the tube. The tube is graduated to half-tenths of a foot. It is adjusted concentrically and even with the top face of the discharge pipe. The tube is held in place by means of the clamps shown at *S*, Fig. 1. This arrangement permits a horizontal and vertical adjustment, enabling the tube to be easily set at the proper position.

Experiments were made to determine the effect of using glass tubes of different sizes. With the conical tip it was found not to be necessary to deduct the area of the tube from that of the discharge pipe. The effect of using tubes of different sizes was inappreciable, and it was shown that little error results from changing the size of tube. Without the tip, it was necessary to deduct the area of the tube from that of the discharge pipe in order not to affect the coefficients.

The apparatus was calibrated in the Hydraulic Laboratory of the University of Illinois. The source of supply was a stand-pipe 4 feet in diameter and 60 feet high, which is fed by a 6-inch main from the city water-works. The discharge was measured in a pit which has been carefully calibrated. This pit is 25 feet long, 8 feet wide and 3.5 feet deep. A thousandth of a foot rise is equivalent to 0.2064 cubic feet. The rise was measured with a hook gage reading to thousandths of a foot. Each experiment involved a rise in the pit of at least 0.5 feet, thus keeping the error of observation very low. It is fair to assume that the error of measurement did not exceed one quarter of 1 per cent.

Having adjusted the glass tube to its proper position, the 0

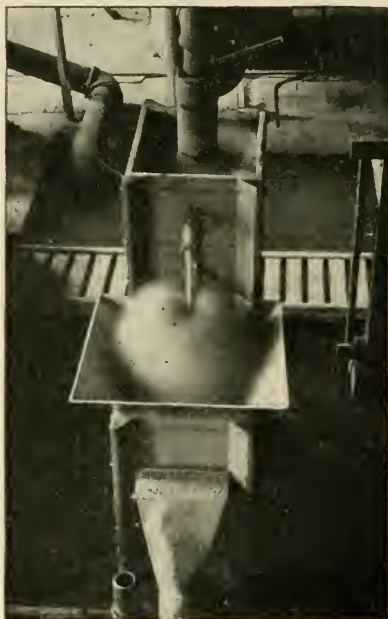


FIG. 5.—Top View.

reading of the hook gage in the pit was noted. Water was then admitted to the tank and allowed to run until a fairly uniform flow had been established. During this time the water was carried to a drain through a galvanized iron pipe attached to the spout *D*.

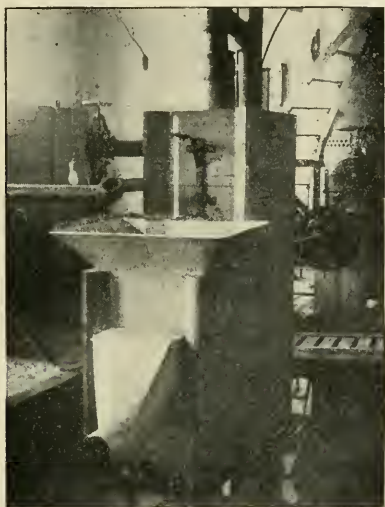


FIG. 6.—Side View.

The time was measured by a stop-watch. The height of the water column in the glass tube was recorded at equal intervals of time and the mean of these readings taken as the head. The flow was kept uniform. The fact that the water column stands 3 or 4 inches above the top of the jet, enables its height to be easily observed, and it may be read with an error of less than 0.01 ft.

Table 1 (page 102) gives the results of the experiments with the three different sizes of pipes. The diagram Fig. 7 gives the co-efficient of discharge with different velocity heads for the several sizes of pipe. Fig. 8 gives the actual discharge in cubic feet per second for different velocity heads. It will be seen that the form of the curve is essentially the same for the three sizes. The mean error of the co-efficient of discharge for these observations is one quarter of 1 per cent, and the probable error of a single observation one fifth of 1 per cent. It seems fair to assume that the apparatus will measure the discharge with an average error not exceeding one quarter of 1 per cent and a maximum error well within 1 per cent. It should be stated also that it is not best to use heads lower than 0.6 ft., as below this the co-efficient drops rapidly and the error of measurement is likely to be greater.

The advantages possessed by this device are obvious. It is portable, easily duplicated, simple in its operation, and the calculations are easily made. Weirs require more elaborate apparatus, and the writers's experience is that for measuring small

TABLE I.
EXPERIMENTS WITH JET METER.

| Diam. of Pipe. | HOOK GAGE. | | Duration of Ex- perim'ts | Velocity Head. | Actual Disch'ge. | $a\sqrt{2gh}$ | Co-efficient of Discharge. |
|----------------------|--------------|--------------|--------------------------------|-------------------|---------------------|--------------------|----------------------------------|
| | Begin. | End. | | | | | |
| <i>inches.</i> | <i>feet.</i> | <i>feet.</i> | <i>min. sec.</i> | <i>feet.</i> | <i>cu.ft.p.sec</i> | <i>cu.ft.p.sec</i> | |
| 4.1 | 0.843 | 1.833 | 3 35 | 2.56 | 0.950 | 1.176 | 0.808 |
| " | 0.942 | 1.812 | 3 10 | 2.53 | 0.945 | 1.170 | 0.808 |
| " | 1.079 | 1.881 | 3 03 | 2.33 | 0.904 | 1.122 | 0.806 |
| " | 1.014 | 1.800 | 2 59 | 2.30 | 0.902 | 1.115 | 0.800 |
| " | 0.993 | 1.813 | 3 09 | 2.28 | 0.895 | 1.110 | 0.806 |
| " | 1.199 | 1.844 | 2 56 | 1.63 | 0.756 | 0.938 | 0.806 |
| " | 1.136 | 1.826 | 3 14 | 1.54 | 0.734 | 0.912 | 0.804 |
| " | 1.002 | 1.826 | 4 15 | 1.27 | 0.667 | 0.829 | 0.804 |
| " | 0.852 | 1.831 | 5 27 | 1.10 | 0.618 | 0.772 | 0.800 |
| " | 1.251 | 1.849 | 4 03 | 0.76 | 0.508 | 0.642 | 0.791 |
| " | 1.119 | 1.872 | 5 18 | 0.70 | 0.489 | 0.615 | 0.794 |
| " | 1.203 | 1.954 | 5 26 | 0.68 | 0.475 | 0.606 | 0.784 |
| " | 1.187 | 1.776 | 5 03 | 0.50 | 0.401 | 0.520 | 0.771 |
| " | 1.179 | 1.755 | 4 58 | 0.49 | 0.399 | 0.517 | 0.771 |
| " | 1.031 | 1.834 | 7 03 | 0.47 | 0.392 | 0.506 | 0.773 |
| " | 1.415 | 1.838 | 4 12 | 0.38 | 0.346 | 0.453 | 0.764 |
| 3.1 | 0.940 | 1.831 | 5 29 | 2.58 | 0.559 | 0.675 | 0.828 |
| " | 1.032 | 1.784 | 4 55 | 2.28 | 0.526 | 0.634 | 0.829 |
| " | 1.200 | 1.801 | 4 00 | 2.24 | 0.517 | 0.620 | 0.822 |
| " | 1.181 | 1.753 | 4 58 | 1.32 | 0.396 | 0.483 | 0.819 |
| " | 1.186 | 1.833 | 5 55 | 1.19 | 0.376 | 0.458 | 0.821 |
| " | 1.148 | 1.737 | 6 53 | 0.74 | 0.294 | 0.361 | 0.814 |
| " | 1.104 | 1.765 | 7 57 | 0.71 | 0.286 | 0.354 | 0.808 |
| " | 1.295 | 1.787 | 7 26 | 0.45 | 0.228 | 0.282 | 0.808 |
| " | 0.954 | 1.754 | 13 01 | 0.40 | 0.211 | 0.265 | 0.796 |
| " | 1.083 | 1.825 | 12 25 | 0.38 | 0.206 | 0.260 | 0.793 |
| 2.1 | 1.111 | 1.765 | 9 04 | 2.26 | 0.248 | 0.289 | 0.858 |
| " | 1.114 | 1.784 | 9 18 | 2.26 | 0.248 | 0.289 | 0.858 |
| " | 1.183 | 1.777 | 8 15 | 2.21 | 0.248 | 0.287 | 0.863 |
| " | 1.108 | 1.885 | 10 55 | 2.16 | 0.245 | 0.284 | 0.863 |
| " | 1.113 | 1.673 | 7 58 | 2.12 | 0.242 | 0.281 | 0.860 |
| " | 1.325 | 1.734 | 5 59 | 2.02 | 0.235 | 0.274 | 0.858 |
| " | 1.195 | 1.827 | 9 50 | 1.78 | 0.221 | 0.257 | 0.857 |
| " | 1.290 | 1.817 | 9 02 | 1.48 | 0.201 | 0.235 | 0.856 |
| " | 1.088 | 1.788 | 12 06 | 1.44 | 0.199 | 0.231 | 0.860 |
| " | 1.310 | 1.814 | 9 00 | 1.37 | 0.193 | 0.226 | 0.853 |
| " | 1.198 | 1.713 | 10 07 | 1.11 | 0.175 | 0.203 | 0.861 |
| " | 1.297 | 1.733 | 10 03 | 0.82 | 0.149 | 0.175 | 0.854 |
| " | 1.070 | 1.677 | 15 56 | 0.64 | 0.131 | 0.154 | 0.849 |
| " | 1.199 | 1.726 | 14 01 | 0.62 | 0.129 | 0.152 | 0.852 |
| " | 1.229 | 1.750 | 14 09 | 0.60 | 0.127 | 0.149 | 0.848 |
| " | 1.317 | 1.758 | 13 00 | 0.52 | 0.117 | 0.140 | 0.837 |
| " | 1.336 | 1.779 | 13 59 | 0.46 | 0.109 | 0.131 | 0.833 |

quantities weir results may be in error as much as 2 per cent, even when the co-efficients are determined for this particular weir, and with weirs as ordinarily constructed by engineers, using the usual co-efficients, errors of 5 per cent may be reached. Orifices require standard conditions, like the condition of the edge and the flatness of the face for a distance away from the

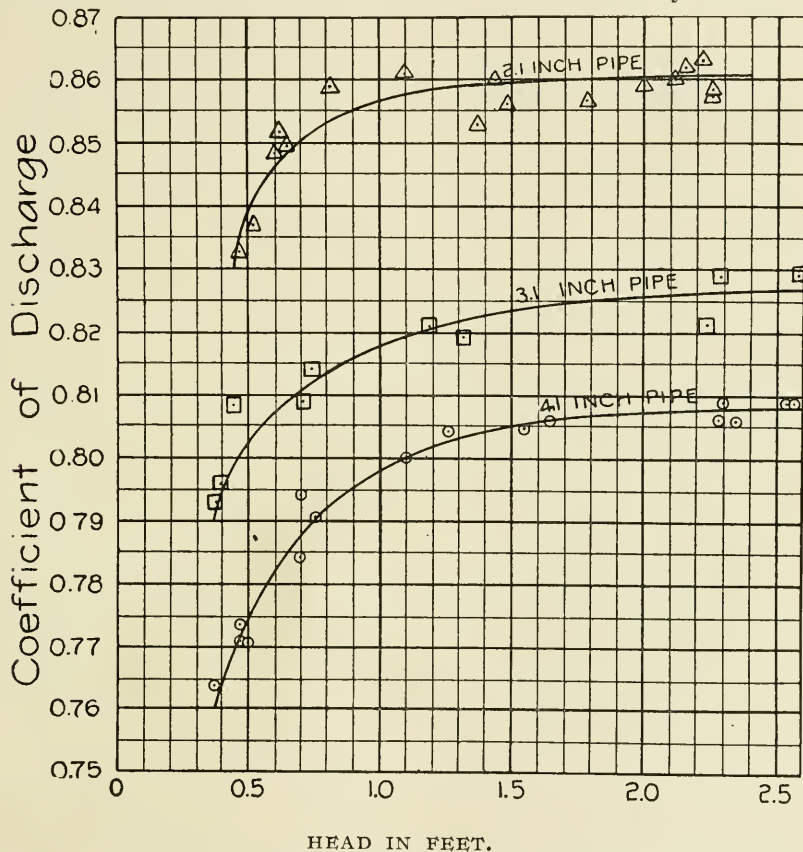


FIG. 7. RELATION BETWEEN THE CO-EFFICIENT OF DISCHARGE AND THE VELOCITY HEAD.

orifice, and for low heads are not reliable. Ordinary water meters of course are even more variable in their results. A feature of the jet meter is that the discharge varies as the half power of the velocity head, and hence that an error in the measurement of the head gives one half as great a proportional effect as the **proportional** error of observation, while with weirs the

proportional effect is three halves as great. For determining the discharge from pumps and for conditions where a head sufficient to raise the water into the tank is available, this method is convenient and efficient. From other experimental work it is known that this method is applicable for 6-, 8-, and 10-inch pipe.

Considerable work has been done in the Hydraulic Laboratory on the investigation of jets from pipes, and much valuable

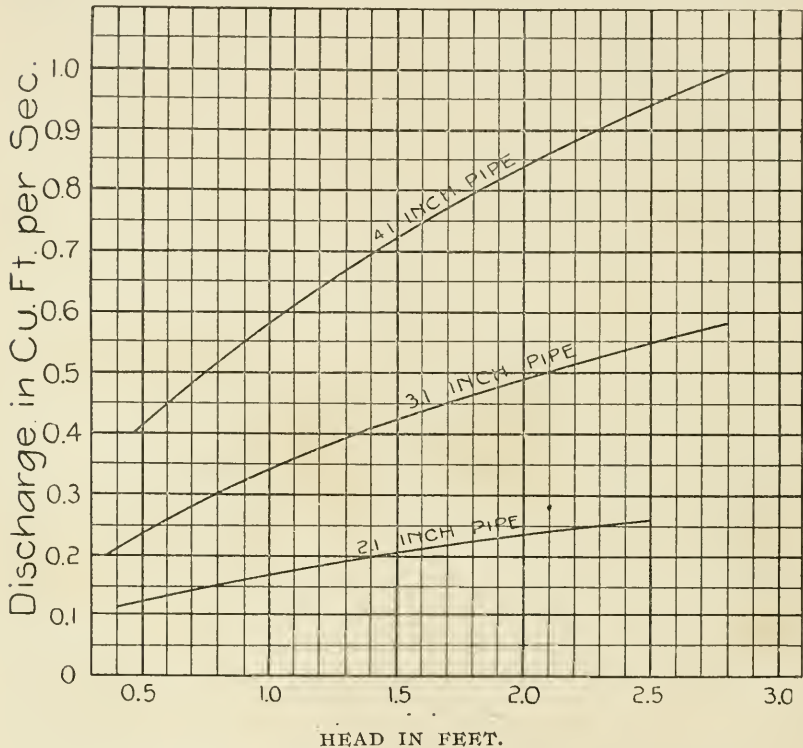


FIG. 8. RELATION BETWEEN THE DISCHARGE AND VELOCITY HEAD.

material has been obtained. These experiments are still in progress, and it is believed important developments in the use of jets for measuring the discharge of water will result.

The tank herein described was built for the department of mechanical engineering for use by Mr. E. L. Mayall in his thesis work on railway water stations. The design and development of the jet-meter method of measuring discharge is the joint effort of Prof. A. N. Talbot, Professor of Municipal and Sanitary Engineering, and the writer.

THE BEAR VALLEY DAM AS AN ARCH.

BY J. M. ALARCO, CIVIL ENGINEERING, '00.

Although the masonry arch has been employed in architecture during at least twenty centuries, it has only recently been applied to masonry dams. In spite of its antiquity and the well known practicability of the arch, the theory of its action is not as yet fully developed. There are as many theories of the masonry arch as text books, and several of these theories applied to standing arches show them failing, which proves that little is known on the subject.

It is not within the scope of this article to discuss the theory of the arch. The assertion can be made, however, that owing to our slight knowledge of it, the arch is not more extensively used in the construction of dams. There are only two dams of the pure arch, one in Zola, France, built about 1845, by the father of the noted French author; the other in San Bernardino County, California, built in 1884. We will briefly investigate the latter.

In the case of a gravity dam the weight of the masonry is the principal element of resistance against the pressure of the water; but in an arch dam the crushing strength of the stone, and not its weight, is the main force that resists the hydrostatic pressure.

As a class room example of the application of the theory of the masonry arch, the writer investigated the stability of two sections of the Bear Valley Dam,* and presents herewith the drawings of another section investigated by E. J. Schneider, a classmate. The sections were taken at 10, 20, and 30 feet, respectively, below the surface of high water. The dimensions were measured from a scale drawing of the dam received from the designer, Mr. F. E. Brown. The fact that the investigations were not made for publication, explains the heterogeneous character of some of the work that follows.

*For a description of this remarkable dam, see *Engineering News*, Vol. 19, p. 513-15.

In Fig. 1 is shown the section 10 feet below the surface. The half of the arch shown is divided into five equal sections purely for the purpose of analysis. The portion shown is held in equilibrium by the crown thrust (the reaction of the half not shown), by the thrust of the water on the convex surface of the dam and by the abutment reaction. The stability of the dam about any section is determined by the relation

$$T = \frac{\sum Wx}{y}, *$$

in which T is the crown thrust, W the normal reaction on any section, x the arm of W about the down stream end of the middle

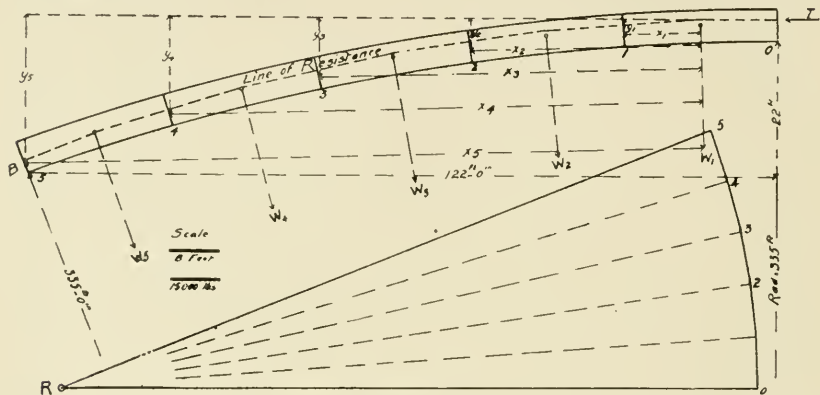


FIG. 1.

third of the joint under consideration, and y the arm of T about the inner end of the middle third of the joint under consideration. $W = 62.5 \text{ lbs} \times l \times d$, in which 62.5 is the weight of a cubic foot of water, l the length of one of the arbitrary sections into which the arch is divided for purposes of investigation, and d the depth of the section below the surface of the water. It is assumed that T is applied at the upper end of the middle third of the crown joint. It is also assumed that the stability of the section under consideration is uninfluenced by the weight of the dam above.

According to the commonly accepted theory of the masonry arch, it is required to find the maximum value of T in the above formula. The joint for which T is a maximum is known as the joint of rupture. Table I gives the data employed in finding T for the several joints of the three sections.

*For a more full explanation of this formula, as well as the theory of the masonry arch, see Baker's Masonry Construction.

From Table I we see that for the section 10 feet below the surface, the crown thrust is a maximum for the third joint. Therefore, we proceed to find the line of resistance as follows: The first section of the arch is held in equilibrium by T , W_1

TABLE I.

Data for Finding the Joint of Rupture and the Crown Thrust at Several Sections.

1. Section 10 feet below the Surface.

| Joint. | $W = 16000$ lbs. | | | | | ΣWx | y | Crown Thrust. |
|--------|------------------|-------|-------|-------|-------|-------------|-------|---------------|
| | x_1 | x_2 | x_3 | x_4 | x_5 | | | |
| 1 | 12.7 | | | | | 203,200 | 2.50 | 81,280 |
| 2 | 37.7 | 12.7 | | | | 803,200 | 5.25 | 153,000 |
| 3 | 62.7 | 37.7 | 12.7 | | | 2,080,000 | 9.75 | 213,000 |
| 4 | 87.0 | 62.7 | 37.7 | 12.7 | | 3,200,000 | 16.00 | 200,000 |
| 5 | 110.7 | 87.0 | 62.7 | 37.7 | 12.7 | 4,960,000 | 24.00 | 206,000 |

2. Section 20 feet below the Surface.

| Joint. | $W = 213000$ lbs. | | | | | | ΣWx | y | Crown Thrust. |
|--------|-------------------|-------|-------|-------|-------|-------|-------------|------|---------------|
| | x_1 | x_2 | x_3 | x_4 | x_5 | x_6 | | | |
| 1 | 9.0 | | | | | | 192,000 | 2.70 | 71,000 |
| 2 | 27.0 | 9.0 | | | | | 770,000 | 3.90 | 197,500 |
| 3 | 45.0 | 27.0 | 9.0 | | | | 1,620,000 | 5.75 | 282,000 |
| 4 | 62.7 | 45.0 | 27.0 | 9.0 | | | 2,958,000 | 8.50 | 348,000 |
| 5 | 80.3 | 62.7 | 45.0 | 27.0 | 9.0 | | 4,678,000 | 12.0 | 390,000 |
| 6 | 98.0 | 80.3 | 62.7 | 45.0 | 27.0 | 9 | 6,768,000 | 16.0 | 423,000 |

3. Section 30 feet below the Surface.

| Joint. | $W = 42,200$ lbs. for first Joint, and $W = 24,400$ lbs. for other Joints. | | | | | | ΣWx | y | Crown Thrust. |
|--------|---|-------|-------|-------|-------|-------|-------------|------|---------------|
| | x_1 | x_2 | x_3 | x_4 | x_5 | x_6 | | | |
| 1 | 11.2 | | | | | | 473,900 | 3.2 | 145,000 |
| 2 | 6.5 | 24.1 | | | | | 1,176,000 | 4.0 | 244,100 |
| 3 | 6.5 | 19.4 | 36.9 | | | | 2,192,000 | 5.2 | 420,000 |
| 4 | 6.5 | 19.4 | 32.2 | 49.7 | | | 3,507,000 | 6.6 | 527,000 |
| 5 | 6.5 | 19.4 | 32.2 | 45.2 | 62.7 | | 5,157,000 | 8.5 | 606,700 |
| 6 | 6.5 | 19.4 | 32.2 | 45.2 | 58.0 | 75.4 | 6,015,000 | 10.7 | 559,600 |

and the pressure on joint 1; consequently these three forces must constitute the three sides of a triangle. Therefore if we lay off, in the lower part of Fig. 1, $R_0 =$ maximum Crown

Thrust=213 000, and also make $O1=H'_1 = 16\ 000$ lbs, then $R1$ represents, in direction and amount, the resultant pressure on joint 1. To find the center of pressure on joint 1, draw through the intersection of H'_1 and T a line parallel to $R1$, and the intersection of this with joint 1, gives a center of pressure on that joint. The second section in Fig. 1 is held in equilibrium by $R1$, H'_2 and the pressure on joint 2. By a process similar to that employed in finding the center of pressure on joint 1, the centers of pressure for the other joints are found. A line connecting these centers of pressure is the line of resistance. This line is shown in Fig. 1 by a broken line.

A masonry arch may fail in either of these ways; viz.: (1) by sliding on any joint, (2) by rotating about the edge of any joint, and (3) by the crushing of the stone.

It is well known that a segmental arch will not fail by sliding, particularly when good cement mortar is employed; and therefore this method of failure will not be discussed.

The resistance to rotation is measured by the quantity $\frac{1}{2} \frac{l}{d}$ in which l is the length of the radial joint of the arch and d is the distance from the center of pressure to the center of the joint. In none of the three sections of the dam was d greater than $\frac{1}{6} l$; and therefore the factor against rotation is at least 3.

To determine the maximum pressure on any joint the following formula* was applied:

$$P = \frac{R}{l} + \frac{6 R d}{l^2}$$

in which P is the maximum pressure in pounds per square inch and R is the resultant pressure on the joint. The joint for

TABLE II.
MAXIMUM PRESSURE.

| Distance of Section below High Water. | Dangerous Section (Joint of Rupture) at Joint. | Maximum Pressure in lbs. per sq. in. |
|---------------------------------------|--|--------------------------------------|
| 10 feet. | 3 | 538 |
| 20 " | 6 | 905 |
| 30 " | 5 | 953 |

For the demonstration, see Baker's Masonry Construction, p. 322, § 593.

which P is a maximum is determined by inspection and trial. The results are shown in Table II.

The crushing strength of stone tested in small specimens varies from 24 000 pounds per square inch for trap rock to 5000 pounds per square inch for sandstone; and therefore the maximum pressure on the masonry of the Bear Valley dam is well within the safe crushing strength of granite cubes; and since the dam stands with no signs of failure, we must assume that the uncoursed rubble granite masonry is able to sustain the above pressure.

Notice that while there is some uncertainty as to the laws govern-

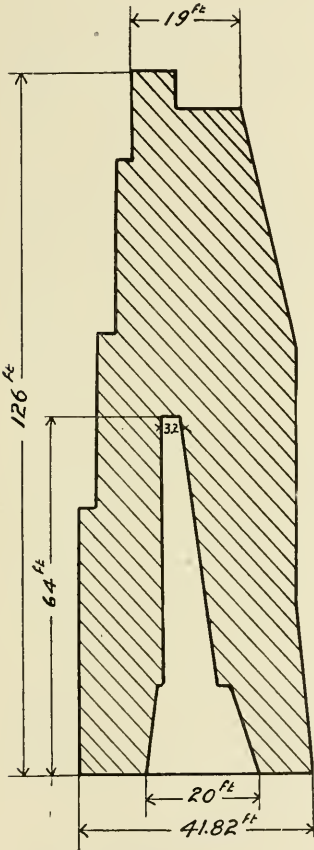


FIG. 2.

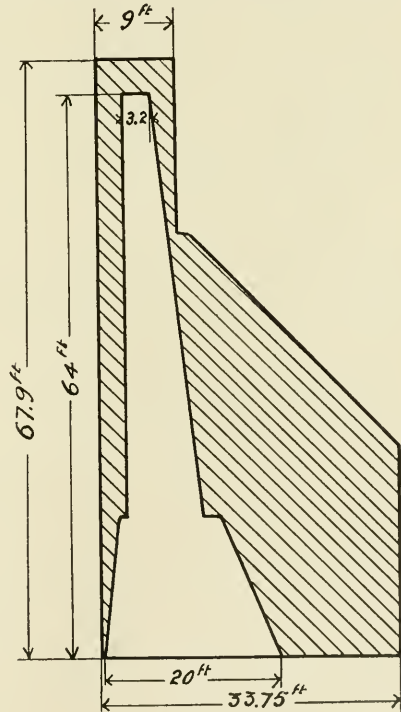


FIG. 3.

ing the action of a masonry arch, the analysis above is more definite than for an arch supporting earth, since in the latter case the amount, direction, and point of application of

the external forces are unknown, but in the arch dam these elements are known with reasonable definiteness.

To afford a comparison between the only arch dams in the world, Fig. 2 is presented. The differences in the cross section are quite striking. The Zola dam is 205 ft. long on top and has a radius of 158 ft. The Bear Valley dam is about 300 ft. long on the crest and has a radius of 335 ft. The other dimensions are shown in Fig. 2. "If the Zola dam is in the least danger of failing, as has been suggested, the Bear Valley dam should have failed long ago." The above investigation shows that the Bear Valley dam is in no immediate danger of failure.

To afford a comparison between the cross sections of arch and gravity dams, Fig. 3 is presented. The Alamansa dam of the Province of Valencia, Spain, the writer's native province, is a curved gravity dam having a radius of 86 ft., and is believed to be a fair representative of gravity dams. The differences in the cross sections shown in Fig. 3 are very striking. The lengths of the two dams are practically the same, but the volume of masonry in the gravity dam is three times that in the arch dam. Mr. Brown deserves unstinted credit as the pioneer in constructing arch dams in America.

It may interest the reader to know that at about the time the Bear Valley Dam was built, a number of leading American engineers were actively discussing the relative merits of gravity and arched dams. However, the existence of the Bear Valley Dam was not known until the discussion was almost concluded. A prominent engineer asserted in that discussion: "No experimental data exists to enable us to measure the thrust on arch dams with any degree of accuracy." The existence of the Bear Valley dam surely is a practical experiment on a large scale; and the above investigation is offered as interpreting this experiment, and shows that the line of resistance near the center and ends for no section, falls outside of the middle third of the joints, as claimed by the above engineer.

The fact that the maximum pressure in the Bear Valley Dam is so small may be accepted as evidence of the stability of the arch type. Further an inspection of the cross sections shows that the gravity dam contains several times as much masonry as the arch dam.

MISCELLANEOUS ENGINEERING DATA.

BY J. E. PFEFFER, '96, DESIGNER OF MOTIVE POWER APPLIANCES,
GATES IRON WORKS, CHICAGO.

The author offers the following miscellaneous data, the results of actual practice, which he has collected from various sources, the past year :

TUBULAR BOILERS.

The large majority of boilers now in use are of the horizontal tubular type. These vary in size from 36-in. diameter by 8 ft. long to 72-in. diameter by 20 ft. long. The length depends upon the diameter of tubes used. The tube length should usually be 48 times the diameter for best results. Tubes should be arranged with at least 1-in. spaces, and at least $2\frac{1}{2}$ in. between tubes and shell of boiler. When possible the middle vertical space should be 2 to 3 in. in width. The tubes as given in Table I permit a man-head in front tube sheet below tubes. A thickness of metal from $\frac{1}{4}$ in. to $\frac{3}{8}$ in. is found best in practice to withstand corrosion and burns.

The trade usually includes with the boiler front the grate bars, a bearing bar to support same, a soot or ash door with frame, a back arch plate or supporting bars, and a boiler stand for small boilers only.

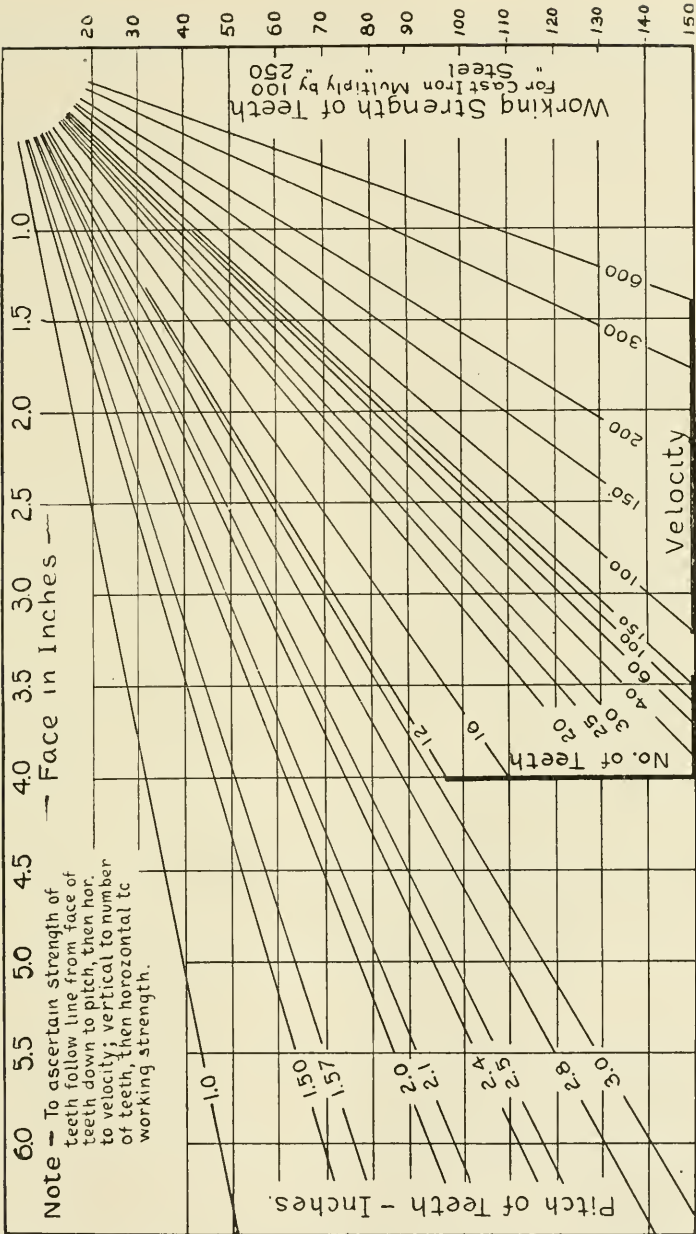
Duplex pumps are largely used for all purposes on account of their durability and easy action. For boiler feeders they possess points of inferiority, especially for hot water ; but all in all give the best satisfaction.

CORLISS ENGINES.

The data on the proportions of the main parts of Corliss engines in Table II represents the practice of one of the largest engines works of to-day.

STRENGTH OF GEAR TEETH.

Fig. 1 gives the working strength of cast-iron and steel gear teeth of any pitch and width, running at any velocity, and for various sizes of wheels.



TESTS OF A 10 H. P. OTTO GASOLINE ENGINE.

BY H. A. SOVERHILL, MECHANICAL ENGINEERING, '00.

The object of these tests is to determine the gasoline consumption per brake and indicated horse-power per hour, the mechanical efficiency of the engine, and also a heat balance.

The brake load was kept constant in each test. Tests were made to determine the friction of the engine at no load, and at intervals up to its full rated capacity.

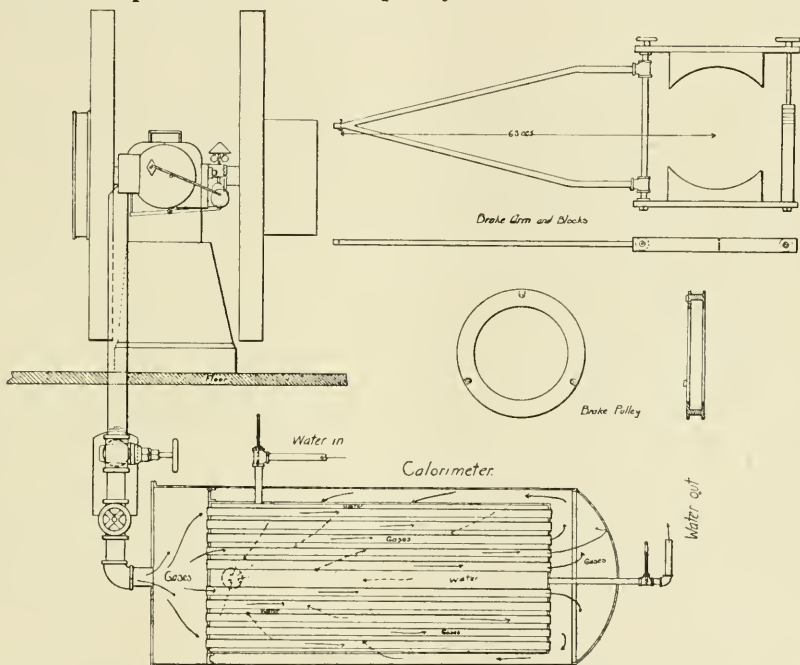


FIG. 1.

ENGINE.—The engine used is the regular 10 horse-power engine made by the Otto Gas Engine Co., Philadelphia, Pa. It is of the ordinary horizontal type, having $5\frac{3}{4}$ -inch cylinder with $12\frac{1}{2}$ -inch stroke and an average speed of about 310 R. P. M. The governing is effected by means of the ordinary "hit and miss" method.

GASOLINE TANK.—In preparing for these tests the gasoline

tank was fitted with a quarter-inch glass tube connected with the interior near the bottom and extending upward on the outside to the top of the tank and being open to the atmosphere. A narrow strip of paper was fastened behind the tube, then gasoline, in one pound quantities, was poured in and the rise in the tube recorded. The tank being long and small in diameter (5 inches) it was possible to get quite accurate readings.

JACKET WATER.—Instead of using the ordinary cooling tank, the water is taken from the city mains, passed through the jacket and allowed to run into a calibrated weighing can. The temperature of the jacket water was measured by thermometers placed in the water near the entrance to and exit from jacket. To prevent breakage of the thermometers, they were placed in a $\frac{3}{4}$ -inch gas pipe which had a $\frac{1}{2}$ -inch slot cut in one side. The thermometer is passed through a perforated cork, the cork is pushed into the bottom of the tube and allows the bulb to stick through the required distance. The thermometer and casing is now screwed into a properly placed tee in the water pipe.

EXPLOSIONS.—The number of explosions per minute was found by actual count. A counter was arranged to obtain the total number of explosions but did not work satisfactorily.

R. P. M.—The revolutions of the engine were kept track of by a Veeder continuous counter and by a speed recorder.

CARDS.—Indicator cards were taken with a special gas-engine indicator. The area of the piston was $\frac{1}{2}$ a square inch. This doubles the range of the ordinary spring, and makes the 150-lb. and 160-lb. springs equivalent to 300-lb. and 320-lb. springs respectively. Considerable trouble was experienced in getting the pencil arm of the indicator sufficiently strong to stand the impulse given to it by the high pressure of explosions occurring at nine and ten B. H. P.

I. H. P.—The indicated horse-power was found by the following formula :

$$I. H. P. = \frac{P l a n}{33\,000},$$

where P = mean effective pressure, l = length of stroke in feet, a = area of piston in sq. inches and n = number of explosions per minute. An engine constant was found by multiplying l by a and dividing by 33 000. The $I. H. P.$ is obtained by multiplying the engine constant by P and n , which is easily done on a slide rule.

B. H. P.—A prony brake, as shown in Figs. 1 and 2, was used in determining the brake horse-power. The brake arm

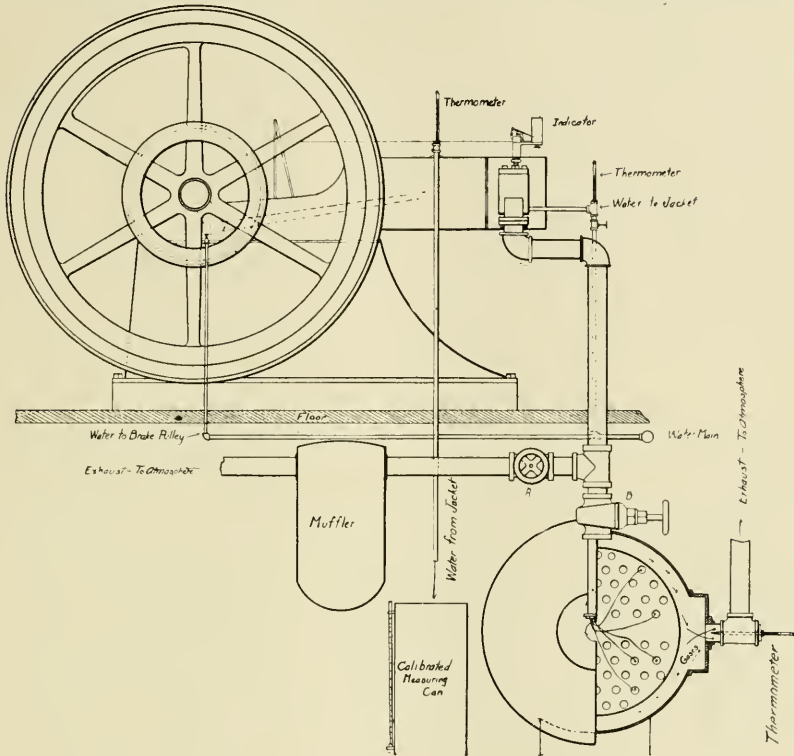


FIG. 2.

was proportioned in such a way as to lessen the work of computation by the formula :

$$B. H. P. = \left(\frac{2 \pi l w n}{33\ 000} \right),$$

in which $\pi = 3.1416$, $l =$ length of arm, $w =$ weight or pull on arm, and $n =$ number of revolutions. It will be seen that if l be taken $= 63.025$ inches, the quantity $2 \pi l \div 33$ will drop out. By making the brake arm 63.025 inches long, the formula then becomes :

$$B. H. P. = \frac{w n}{1000},$$

The rear end of the brake is weighted, as shown in figure 1, so as to balance the weight of the arm, thus causing scale readings to be equal to the brake load.

EXHAUST.—The exhaust temperatures were taken with a Schaeffer and Budenberg mercury pyrometer screwed into the exhaust pipe near the exhaust valve. This did not give satisfactory results for small horse powers and would not record high enough for the nine and ten horse-power tests.

READINGS.—Numerous tests were made. The following readings were taken every three or five minutes as desired: 1, length of test or time; 2, number of explosions per minute; 3, R. P. M.; 4, cards; 5, brake readings; 6, amount of gasoline used;—all of which are required in computing the results. The following auxiliary data was also observed: 7, amount of jacket water used; 8, rise in temperature of jacket water; 9, temperature of exhaust; 10, temperature of inside and outside air.

TABLE I.—DATA AND RESULTS.

| Number of test | Hours of test. | R. P. M. | Explosions per min. | I. H. P. | B. H. P. | Mech. Efficiency per cent. | GASOLINE. | | TEMPERATURES. | | | |
|----------------|----------------|----------|---------------------|----------|----------|----------------------------|----------------------------|----------------------------|---------------|-------|----------|----------------------------|
| | | | | | | | Per I. H. P. per hr., lbs. | Per B. H. P. per hr., lbs. | Jacket Water | | Exhaust. | Water per I. H. P. per hr. |
| | | | | | | | | | In. | Out. | | |
| 1 | 1½ | 312. | 25 | 2.11 | 0 | 0 | .622 | 0 | 90.5 | 160 | ..... | lbs. |
| 2 | 1 | 311 | 49.6 | 4.21 | 1.56 | 37 | .54 | 1.46 | 78.8 | 167.5 | ..... | ..... |
| 3 | 1 | 313.6 | 58 | 4.99 | 2.27 | 45 | .66 | 1.43 | 64.4 | 159 | 396.5 | 84 |
| 4 | 1 | 310.9 | 76.5 | 6.72 | 4.04 | 60 | .567 | .94 | 69.2 | 128 | ..... | ..... |
| 5 | 2 | 310 | 91 | 7.13 | 4.64 | 65 | .69 | 1.06 | 60.5 | 167 | 680.3 | ..... |
| 6 | 1 | 306 | 103.3 | 8.64 | 6.73 | 77.9 | .58 | .748 | 68.4 | 199 | ..... | 45 |
| 7 | 1¾ | 308 | 132.3 | 10.59 | 8.30 | 78.5 | .64 | .82 | 55.5 | 175 | 885 | 62.51 |
| 8 | 1 | 309.3 | 119 | 11.38 | 9.27 | 81.5 | .545 | .647 | 54.6 | 157.5 | ..... | 63 |
| 9 | 1½ | 307 | 148.3 | 12.15 | 10.5 | 86.56 | .56 | .64 | 63.6 | 118 | ..... | ..... |

In the test from which a heat balance is made, the valve marked *A*, Fig. 2, is closed and *B* is opened. This allows the exhaust gases to pass through the "calorimeter." This is a vertical Baragwaneth feed-water heater placed in a horizontal position as shown. When the gases enter the calorimeter they expand to about 17 pounds pressure absolute, pass through the tubes and give up heat at constant pressure. The thermometer placed in the exhaust pipe near the calorimeter shows a temperature slightly above that of the jacket water. The jacket water is taken from the city mains and throttled by means of a globe valve until about the desired amount flows through. The temperature at entrance and exit are taken, at places shown in

Figs. 1 and 2, and the amount of water passed through is weighed.

During the experiment 584 lbs. of water passed through the calorimeter and was raised 23.9° F. in temperature, or $584 \times 23.9 = 13957.6$ B. T. U. was carried away by calorimeter jacket-water. In the above calculation we have assumed that the air was taken in at the temperature of the exhaust from calorimeter, which was 88° F. In fact, the air was taken into the engine at a temperature of 78°, raised to whatever temperature it may be, and then reduced to 88° in the calorimeter. This leaves a rise of 10° not taken account of by the calorimeter. Air was taken in at every fourth stroke. By having the number of strokes, the cubic contents of cylinder, the weight of a cubic foot of air, and the specific heat of air, we have :

$$\text{Wt. of air used} = \frac{324.587 \times 1546 \times 30 \times 0.0807}{1728} = 70.5 \text{ lbs.}$$

Then the loss by difference of temperature of inlet and outlet air is $70.5 \times 10^\circ \times 0.2375 = 167.6$ B. T. U. This makes $13957.6 + 167.6 = 14125.2$ B. T. U. passing out through the exhaust.

There were 297.2 pounds of water used in the cylinder jacket, and it was raised through 103.1° F. That makes, therefore, the heat carried away by engine jacket, $297.2 \times 103.1 = 30\,646.8$ B. T. U.

The *B. H. P.* was 9.275, and the *B. T. U.* = $\frac{9.275 \times 33\,000 \times 30}{778} = 111\,802$. The amount of energy consumed by friction was found to be 2687.4 B. T. U.

The Chemical Department determined that one pound of the gasoline contained 17 200 B. T. U. Therefore, the *B. T. U.* supplied during the test was $17\,200 \times 3.94 = 67\,778$. This energy was distributed as follows :—

| | <i>B. T. U.</i> | <i>Per Cent.</i> |
|-------------------------|-----------------|------------------|
| Useful work..... | 11,802.0 | 17.41 |
| Friction of engine..... | 2,687.4 | 3.95 |
| Exhaust | 14,125.2 | 20.98 |
| Jacket water | 30,600.0 | 45.15 |
| Radiation, &c | 12,51 | 18.31 |
| Total | 100.00 | |

By using the data given by the calorimeter, we find that the temperature at the point of exhaust varied between 1800° and 2000° above 0° Fahrenheit.

RAILWAY TRANSITION CURVE TABLES FOR FIELD USE.

BY F. K. VIAL, '85, ASS'T ENGINEER CHICAGO AND WESTERN INDIANA R.R.

The benefits arising from the introduction of transition curves on railway alinement are now so generally recognized that it is important that instrument men should be familiar with such curves and be able to adapt them to any case that may arise. It is the purpose of this article to describe short methods for developing curve tables for field use for the several transition curves and to explain their application to special field problems.

The writers on the transition curve are numerous. Among them may be mentioned Elliot Holbrook, who described the curve in 1880; Wm. H. Searles, in 1882; C. D. Jameson, in 1889; A. M. Wellington, in 1890; A. N. Talbot, in 1891; C. L. Crandall, in 1893; A. Torrey, in 1893; C. R. Howard, in 1894. Treatments of spirals are found in the field books of Henck, Nagle, Godwin, Frost, Allen, and others, all of which are more or less valuable. It may seem presumptuous to attempt to add anything to what the above writers have brought out; yet while there is nothing more to be desired in the way of theory, there is an opportunity to simplify the method of treatment by tabulating results that are of a general nature, instead of following the custom of making tables for more or less numerous special cases.

The alinement of track by the different transition curve methods gives practically the same results. The form of spiral to be adopted will depend upon the ease of application and the facility of adaptation to the various problems that present themselves. Any one who has had extended experience in laying out spirals has found that frequently he is called upon to use a spiral not found in the tables he may be using. Tables should allow considerable freedom of choice, and it is believed that the tables here developed offer many advantages in flexibility and simplicity. The method of offsets from the tangent or from the

circular curve will not be considered; for while it may have its place in location work, it is the writer's opinion that there is nothing to be gained by its use in setting track centers, as it requires more labor and is less reliable than either of the above methods of deflection.

Two general tables will be constructed, Table I for the multiple compound curve here described, and Table II for the transition spiral. To make the reader familiar with the types of curves for which the tables are constructed, a simple statement of the several transition curves and the methods of their use will be given.

THE MULTIPLE COMPOUND CURVE.

A very common form of transition consists of a series of compound curves, the successive arcs generally having their degree of curve increased by constant differences. This is known as the multiple compound curve.

In Fig. 1 the chords are of equal length, and each subtends a circular arc. The degree of curve of each successive arc increases by a constant increment, hence the angle subtended by each chord increases in the same manner. For convenience, consider the chords to be 100 feet long, and the degree of curve for

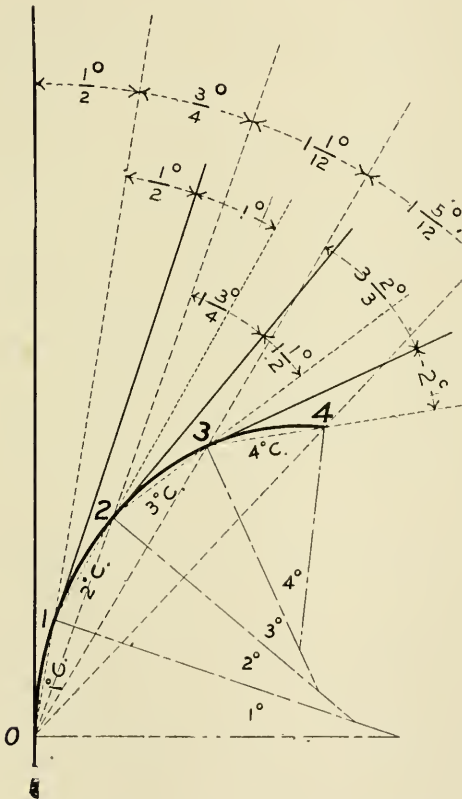


FIG. 1.

the first arc 1°, for the second 2°, for the third 3°, etc., to the

end of the curve. The change in direction at the end of any arc is equal to the sum of the angles at the center.

To determine the deflection angle to each chord point when the instrument is at the point of spiral (Sta. 0). In Fig. 1 the deflection angle for the first chord is evidently the deflection for a one degree curve for one station, or $\frac{1}{2}^\circ$, which may be written at once in Table I opposite Station 1, in the column headed "Instrument at 0." If the instrument man had no tables he would now move to Sta. 1, backsight on Sta. 0 and turn $\frac{1}{2}^\circ$ to get the auxiliary tangent through Sta. 1. The deflection angle from this tangent to Sta. 2 is 1° , and hence the angle between the first and second chord is $1\frac{1}{2}^\circ$. The angle between the first chord and the long chord from Sta. 0 to Sta. 2 is $\frac{3}{4}^\circ$, since Sta. 1 lies half way between Sta. 2 and Sta. 0,* and hence the deflection from the initial tangent at Sta. 0 to Sta. 2 is $\frac{1}{2}^\circ + \frac{3}{4}^\circ = 1\frac{1}{4}^\circ$, which is placed in the table opposite Sta. 2 in the column headed "Instrument at 0."

Having located Sta. 2, the instrument man would move to this point and backsight on Sta. 0, and to get the auxiliary tangent through Sta. 2, would turn $3^\circ - 1\frac{1}{4}^\circ = 1\frac{3}{4}^\circ$, and then would turn $1\frac{1}{2}^\circ$ more to locate Sta. 3. Hence the angle at Sta. 2, between the third chord and the long chord to Sta. 2, is $1\frac{3}{4}^\circ + 1\frac{1}{2}^\circ = 3\frac{1}{4}^\circ$. The angle at Sta. 0, between the long chord to Sta. 2 and the long chord to Sta. 3 is $1\frac{1}{2}^\circ$, since Sta. 2 lies one third the distance from Sta. 3 to Sta. 0, and hence the deflection angle from the initial tangent at Sta. 0 to Sta. 3 becomes $1\frac{1}{4}^\circ + 1\frac{1}{2}^\circ = 2\frac{3}{4}^\circ$, which is placed in the table opposite Sta. 3. The deflections for any desired number of stations can be obtained by continuing this method.

To determine the deflection angles when the instrument is at any station other than Sta. 0. Starting with the instrument at Sta. 1, the back deflection at Sta. 1 from the auxiliary tangent through Sta. 1 to Sta. 0 is $\frac{1}{2}^\circ$ (See Fig. 1) which is placed in the column headed "Instrument at Sta. 1," opposite Sta. 0. The deflection to Sta. 2 is 1° , which is placed in the table opposite Sta. 2. The instrument man would move to Sta. 2, backsight

*The statement that the angle between the first chord and the long chord is one half of that between the first and second chords is approximate, as is also the similar reasoning applied to the succeeding chords. The error when the total central angle is small may generally be neglected, as may be shown by an investigation. — Editors THE TECHNOGRAPH.

on Sta. 1, turn 1° back to the auxiliary tangent and $1\frac{1}{2}^\circ$ to Sta. 3, making $2\frac{1}{2}^\circ$ from the chord through Sta. 1 and 2. The angle between the auxiliary tangent at Sta. 1 and the chord Sta. 1 to Sta. 3 is $1^\circ + (\frac{1}{2} \text{ of } 2\frac{1}{2}^\circ) = 2\frac{1}{4}^\circ$, since Sta. 2 lies half way between Sta. 3 and 1.

In this manner the deflection angles are written for all chord points. Having tabulated the angles we note that the differences between successive deflections increase by $\frac{1}{3}^\circ$ and that the differences in successive columns increase by $\frac{1}{6}^\circ$; also that the differences in diagonal directions are constant. It is thus very easy to check the table. There is of course a little irregularity in the table in the first deflection each way from the instrument point, since that portion is a circular curve.

A little study will show that the results in Table I may be made general by varying the length of the chord used, and by varying the amount of increase in the curvature of the successive arcs. As derived, the chord length was considered to be 100 feet, and the amount of curve in the first chord 1° ; these may be made variable. To permit this general use of the table, the degree marks have been omitted, and the tabulated quantities may be used as co-efficients. Any length of chord may be used. Call the amount of curvature or angle of the first arc "rate of transition per chord;" since the curvature of the successive arcs increases by this amount. For any rate and any length of chord, multiply the rate of transition per chord by the co-efficient from Table I opposite the desired chord point.

THE SEARLES SPIRAL.—The basis of the spiral so admirably developed by Searles, is an increase of $10'$ in each successive chord angle. Applying $10'$ as the rate of transition per chord angle to the co-efficients in Table I, results are obtained which agree with Searles' tables very closely for a number of chord lengths up to 12, and the error is slight up to 16.

To show that this multiple curve does not locate the same spiral if different chord lengths are used, even when the length of curve remains the same, the following example may be used.

It is desired to connect a 6 degree curve to a tangent using a spiral 250 feet long, and 25 feet as the chord length. The eleventh chord then must subtend a 6° curve and central angle of $1^\circ 30'$. Dividing $1^\circ 30'$ by 11 we have $8\frac{2}{11}$ minutes as the rate of transition per chord. Applying this to the table, the de-

TABLE I.
CO-EFFICIENTS OF THE RATE OF TRANSITION PER CHORD FOR MULTIPLE COMPOUND CURVES OF THE SEARLES TYPE.

| Station. | Angle of Chord. | Total Cent. | Inst. at 0. | Difference | Inst. at 1. | Difference | Inst. at 2. | Difference | Inst. at 3. | Difference | Inst. at 4. | Difference | Inst. at 5. | Difference | Inst. at 6. | Difference | Inst. at 7. | Difference | Inst. at 8. | Difference | Inst. at 9. | Difference | Inst. at 10. | Difference. | Station. |
|----------|-----------------|-------------|-----------------|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|------------------|-----------------|-----------------|------------------|------------------|----------------|------------------|----------------|------------------|-----------------|------------------|-----------------|------------------|----------------|----------|
| 0 | 1 | 0 | 0 | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{1}{4}$ | $\frac{3}{4}$ | $\frac{3}{8}$ | 11 | 6 $\frac{1}{4}$ | $1\frac{1}{2}$ | $9\frac{1}{2}$ | $1\frac{1}{4}$ | 13 $\frac{1}{2}$ | $1\frac{1}{2}$ | 18 | $1\frac{1}{2}$ | 23 $\frac{1}{4}$ | $1\frac{3}{4}$ | 29 $\frac{1}{2}$ | $1\frac{1}{2}$ | 35 $\frac{3}{4}$ | $2\frac{1}{2}$ | 0 |
| 1 | 2 | 1 | $\frac{1}{2}$ | $\frac{3}{4}$ | 0 | 1 | 1 | 1 | $\frac{2}{4}$ | 14 | 5 $\frac{1}{2}$ | $1\frac{1}{2}$ | 8 $\frac{1}{4}$ | $1\frac{1}{2}$ | 12 | $1\frac{1}{2}$ | 10 $\frac{1}{2}$ | $1\frac{1}{2}$ | 21 $\frac{1}{2}$ | $2\frac{1}{2}$ | 27 $\frac{1}{4}$ | $2\frac{1}{2}$ | 33 $\frac{3}{8}$ | $2\frac{1}{2}$ | 1 |
| 2 | 3 | 3 | $\frac{1}{4}$ | $1\frac{1}{2}$ | 1 | 0 | 0 | $1\frac{1}{2}$ | 1 $\frac{1}{2}$ | 14 | 3 $\frac{3}{4}$ | $1\frac{3}{4}$ | 6 $\frac{3}{8}$ | $2\frac{1}{2}$ | 10 $\frac{1}{4}$ | $2\frac{1}{2}$ | 14 $\frac{1}{2}$ | $2\frac{1}{2}$ | 19 $\frac{1}{2}$ | $2\frac{1}{2}$ | 25 | $2\frac{1}{2}$ | 31 $\frac{1}{4}$ | $2\frac{3}{4}$ | 2 |
| 3 | 4 | 6 | $2\frac{1}{8}$ | $1\frac{1}{2}$ | $2\frac{1}{4}$ | $1\frac{1}{4}$ | $1\frac{1}{2}$ | 1 $\frac{1}{2}$ | 0 | 2 | 2 | $1\frac{3}{4}$ | 4 $\frac{3}{4}$ | 8 $\frac{1}{4}$ | 8 $\frac{1}{4}$ | $2\frac{1}{2}$ | 12 $\frac{1}{4}$ | $2\frac{1}{2}$ | 17 | $2\frac{1}{2}$ | 22 $\frac{1}{2}$ | $2\frac{1}{2}$ | 28 $\frac{1}{2}$ | $3\frac{1}{2}$ | 3 |
| 4 | 5 | 10 | $3\frac{3}{8}$ | $1\frac{1}{2}$ | $2\frac{1}{4}$ | $1\frac{1}{2}$ | $3\frac{1}{4}$ | $2\frac{1}{2}$ | 2 | 2 $\frac{1}{4}$ | 0 | $2\frac{1}{2}$ | $2\frac{1}{2}$ | 5 $\frac{3}{4}$ | 5 $\frac{3}{4}$ | $2\frac{1}{2}$ | 9 $\frac{3}{8}$ | $2\frac{1}{2}$ | 14 $\frac{1}{4}$ | $3\frac{1}{2}$ | 19 $\frac{1}{2}$ | $3\frac{1}{2}$ | 25 $\frac{1}{2}$ | $3\frac{1}{2}$ | 4 |
| 5 | 6 | 15 | $5\frac{1}{2}$ | $2\frac{1}{2}$ | $5\frac{1}{4}$ | $5\frac{1}{4}$ | $5\frac{1}{4}$ | $4\frac{1}{4}$ | 4 $\frac{1}{4}$ | $2\frac{1}{4}$ | $2\frac{1}{2}$ | 0 | 0 | 3 | 3 | $2\frac{1}{2}$ | 0 $\frac{3}{4}$ | $3\frac{1}{2}$ | 11 $\frac{1}{2}$ | $3\frac{1}{2}$ | 16 $\frac{1}{4}$ | $3\frac{1}{2}$ | 22 | $3\frac{3}{4}$ | 5 |
| 6 | 7 | 21 | 7 $\frac{1}{2}$ | $2\frac{1}{2}$ | 8 | $7\frac{3}{4}$ | $7\frac{3}{4}$ | 6 $\frac{5}{8}$ | 6 $\frac{5}{8}$ | $2\frac{1}{2}$ | $2\frac{1}{2}$ | $2\frac{1}{2}$ | 3 | 3 | 0 | $3\frac{1}{2}$ | $3\frac{1}{2}$ | $3\frac{1}{2}$ | 7 $\frac{3}{4}$ | $3\frac{1}{2}$ | 12 $\frac{3}{4}$ | $3\frac{1}{2}$ | 18 $\frac{1}{4}$ | $4\frac{1}{2}$ | 6 |
| 7 | 8 | 28 | 10 | $2\frac{1}{2}$ | $10\frac{1}{2}$ | $10\frac{1}{2}$ | $10\frac{1}{2}$ | 9 $\frac{3}{8}$ | 9 $\frac{3}{8}$ | $2\frac{1}{2}$ | $2\frac{1}{2}$ | 3 | 6 $\frac{1}{4}$ | 3 $\frac{1}{4}$ | 3 $\frac{1}{4}$ | $3\frac{1}{2}$ | 0 | $3\frac{1}{2}$ | 4 | $3\frac{1}{2}$ | 8 $\frac{1}{4}$ | $3\frac{1}{2}$ | 14 $\frac{1}{8}$ | $4\frac{1}{2}$ | 7 |
| 8 | 9 | 36 | $12\frac{3}{4}$ | $3\frac{1}{2}$ | $13\frac{1}{2}$ | $13\frac{1}{2}$ | $13\frac{1}{2}$ | 13 | 13 | 3 $\frac{1}{4}$ | 11 $\frac{3}{4}$ | 9 $\frac{1}{8}$ | 9 $\frac{1}{8}$ | 7 $\frac{1}{4}$ | 7 $\frac{1}{4}$ | $4\frac{1}{2}$ | 4 | $4\frac{1}{2}$ | 0 | 4 $\frac{1}{2}$ | 4 $\frac{1}{2}$ | $4\frac{1}{2}$ | 14 $\frac{1}{4}$ | $4\frac{1}{2}$ | 8 |
| 9 | 10 | 45 | $15\frac{1}{2}$ | $3\frac{1}{2}$ | $16\frac{1}{2}$ | $16\frac{1}{2}$ | $16\frac{1}{2}$ | $16\frac{1}{2}$ | $16\frac{1}{2}$ | $3\frac{1}{2}$ | $15\frac{1}{2}$ | $13\frac{3}{4}$ | $13\frac{3}{4}$ | 11 $\frac{1}{2}$ | 11 $\frac{1}{2}$ | $4\frac{1}{2}$ | 4 | $4\frac{1}{2}$ | 4 $\frac{1}{2}$ | 4 $\frac{1}{2}$ | 4 $\frac{1}{2}$ | 4 $\frac{1}{2}$ | 14 $\frac{1}{4}$ | $4\frac{3}{4}$ | 9 |
| 10 | | 55 | $19\frac{3}{4}$ | $3\frac{1}{2}$ | $19\frac{3}{4}$ | $19\frac{3}{4}$ | $19\frac{3}{4}$ | $20\frac{1}{2}$ | $20\frac{1}{2}$ | $3\frac{1}{2}$ | $19\frac{1}{2}$ | 18 | 18 | 15 $\frac{1}{2}$ | 15 $\frac{1}{2}$ | $4\frac{1}{2}$ | $4\frac{1}{2}$ | $4\frac{1}{2}$ | 4 $\frac{1}{2}$ | 4 $\frac{1}{2}$ | 4 $\frac{1}{2}$ | 4 $\frac{1}{2}$ | 15 $\frac{1}{2}$ | 5 | 10 |

flections for instrument at Sta. 0 become $4' 5''$, $10' 14''$, $19' 05''$,
 - - - - $2^\circ 37' 30''$ for Sta. 10, 250 feet from Sta. 0. The total
 central angle is $7^\circ 30''$, which is found by multiplying the factor
 $8\frac{2}{11}$ minutes by the co-efficient opposite Sta. 10 in column headed
 "Total Central Angle" If it had been desired to use a 50 foot
 chord length, then the 6th chord would subtend a 6 degree curve
 and a 3° degree central angle, and the rate of transition for each
 chord becomes $\frac{1}{6}$ of $3^\circ = 30$ minutes and the deflection for Sta. 5
 (250 feet from Sta. 9) is $2^\circ 45'$. The position of the curve then
 depends on the chord length, and may vary between the limits
 given by a circular curve, using but one chord (when the deflec-
 tion is $\frac{1}{2}$ the central angle) and the true railroad spiral (when
 the number of chords is great, and the deflection is $\frac{1}{3}$ the central
 angle). The central angle is constant for every case. This
 shows an objectionable feature of the multiple compound curve.

One great feature of the Searles' method of treatment is the
 development of a set of deflection angles which remains constant
 for all chord lengths. The idea of giving deflections from inter-
 mediate points is also extremely useful. There are said to be
 over 500 spirals calculated in the Searles Table, yet these tables
 are comparatively rigid, because the rate of transition for a
 chord length is fixed. It frequently happens that a trestle is
 located on a curve, and it becomes necessary to give the center
 for each bent on the transition at the end of this curve, and for
 this case the tables of Searles do not give the desired quantities.
 This feature will be taken up in the discussion of Table II, for,
 while Table I applies perfectly to this case, it is considered that
 multiple curves are not the most desirable.

THE TORREY EASEMENT CURVE.—Another development of
 the multiple compound curve is made by A. Torrey, Chief En-
 gineer of the M. C. R. R., in his little work on Curve Easements.
 Here several different rates of transition are developed for a
 given chord length, also a constant transition for varying chord
 lengths. Table I may be used to produce these tables, and a
 comparison will show that the results agree quite closely.

MODIFIED MULTIPLE COMPOUND CURVE.—In the multiple
 compound curves heretofore considered the central angle of the
 first chord is equal to the constant angular increase for the suc-
 cessive circular arcs (rate of transition per chord). Making the
 central angle of the first chord equal to one half of the constant

angular increase would be more rational. This is done in Fig. 2, where the angles subtended by successive chords are $\frac{1}{2}^\circ$, $1\frac{1}{2}^\circ$, $2\frac{1}{2}^\circ$, etc., and the degree of the curves 30', $1^\circ 30'$, $2^\circ 30'$, etc. As before these values may be made general and the degree marks omitted.

A table of deflections for a multiple compound curve of this kind can be worked up in the same manner as for Table I, or the deflections for a 30' curve to the points in question may be subtracted from quantities taken from Table I. Thus by the latter method for Sta. 10, a 30' curve for 10 stations subtends an angle of 5° , and the deflection would be $2\frac{1}{2}^\circ$, which subtracted from $19\frac{1}{4}^\circ$ gives $16\frac{3}{4}^\circ$ as the deflection for Station 10 for this curve. Table A shows the deflection for 10 stations for this form of multiple compound curve.

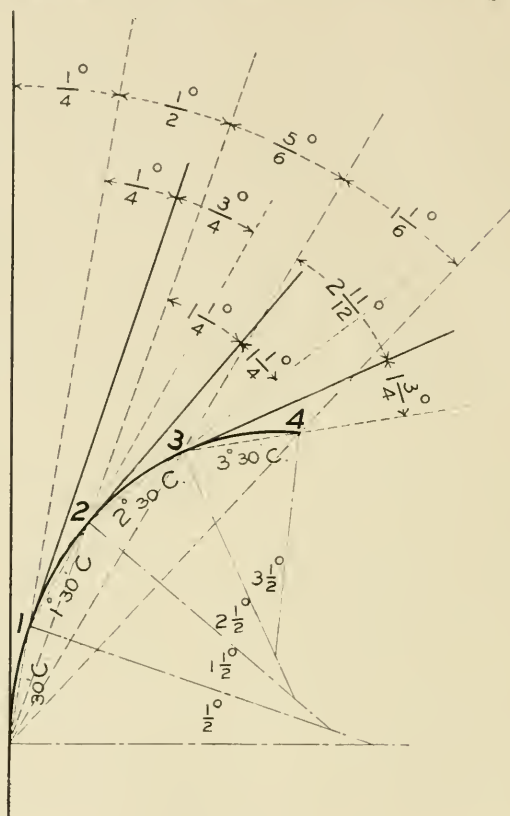


FIG. 2.

Table A shows the deflection for 10 stations for this form of multiple compound curve.

THE TRANSITION SPIRAL.

In the modified multiple curve, shown in Fig. 2, the degree of curve at the middle of the successive arcs is seen to be proportional to the distances of these points from 0. If, then, we conceive the length of the arcs to be made very small, and the number of arcs very large (the constant angular increase for the successive arcs being changed, at the same time, in such a way as to retain the original degree of curve of

TABLE A.
DEFLECTIONS FOR MULTIPLE COMPOUND CURVES.

| Station. | Chord Angle. | Total Central Angle. | DEFLECTION. | | | |
|----------|----------------|----------------------|-----------------|----------------|-----------------|----------------|
| | | | Inst. at 0. | Difference. | Inst. at 1. | Difference. |
| 0 | | | 0 | | $\frac{1}{4}$ | |
| 1 | $\frac{1}{2}$ | | $\frac{1}{4}$ | $\frac{1}{4}$ | 0 | $\frac{1}{4}$ |
| 2 | $1\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{3}{4}$ | $\frac{1}{2}$ | $\frac{3}{4}$ | $\frac{3}{4}$ |
| 3 | $2\frac{1}{2}$ | 2 | $1\frac{1}{2}$ | $\frac{5}{6}$ | $1\frac{3}{4}$ | 1 |
| 4 | $3\frac{1}{2}$ | $4\frac{1}{2}$ | $2\frac{3}{4}$ | $1\frac{1}{6}$ | $3\frac{1}{2}$ | $1\frac{1}{3}$ |
| 5 | $4\frac{1}{2}$ | 8 | $4\frac{1}{4}$ | $1\frac{1}{2}$ | $4\frac{3}{4}$ | $1\frac{2}{3}$ |
| 6 | $5\frac{1}{2}$ | $12\frac{1}{2}$ | $6\frac{1}{2}$ | $1\frac{5}{6}$ | $6\frac{3}{4}$ | 2 |
| 7 | $6\frac{1}{2}$ | 18 | $8\frac{3}{4}$ | $2\frac{1}{2}$ | $9\frac{1}{2}$ | $2\frac{1}{6}$ |
| 8 | $7\frac{1}{2}$ | $24\frac{1}{2}$ | $10\frac{3}{4}$ | $2\frac{5}{6}$ | $11\frac{3}{4}$ | $2\frac{2}{3}$ |
| 9 | $8\frac{1}{2}$ | $32\frac{1}{2}$ | $13\frac{7}{6}$ | $3\frac{1}{2}$ | $14\frac{3}{4}$ | 3 |
| 10 | $9\frac{1}{2}$ | 50 | $16\frac{3}{4}$ | $3\frac{5}{6}$ | $18\frac{1}{2}$ | $3\frac{1}{3}$ |

In a similar manner additional columns may be filled out.

any point and to keep it at the same distance from 0) the points of compound will become consecutive, and we have the transition spiral. The degree of curve of this spiral evidently increases directly as the length, which is the definition of the transition spiral as described by Holbrook, and is the same curve as that developed by Jameson, Talbot, Crandall, Howard, and others.

An inspection of Table A shows that the deflection angle from 0 locating a point a given distance away is equal to (1) one third the central angle plus (2) one twelfth the rate of transition per chord. The rate of transition per chord varies inversely as the square of the number of chords in a given distance. If, then, the length of the arcs be made very small (the total length and curvature being kept the same), (2) becomes insignificant as compared with (1) and may be neglected, and it is seen that the deflection angle of the spiral is one third the central angle.

Since the degree of curve of the spiral increases uniformly as the distance from 0, it may be seen that the central angle will be that for an average of the degree of curve for every point of

the spiral, and this average degree of curve will be that of the middle point, or half of that at the end. Hence the central angle for any length of spiral from 0 will be one half of the central angle for a circular curve of equal length and of the same degree as that of the spiral at the end of the measured length. It is also known that the spiral deflects from a circular curve of the same radius at a given point of contact, at the same rate that the spiral deflects from the tangent at 0. The deflection angle between the tangent at the given point and a chord to a second point, is then equal to the deflection angle for this circular curve for a distance equal to the distance between the points, plus or minus the spiral deflection angle from 0 for an equal distance.

By a method similar to that for multiple curves, a table may be constructed which will give the angles for a spiral having the central angles set opposite the station number. Table II shows such a table where the central angle is one half of the square of the numbers of stations. Column headed "Instrument at 0" is filled in by taking one third the total central angle. For instrument at 1, 2, 3, etc., the principle that the desired angle is equal to the deflection angle for this length of a circular curve of the same degree of curve as the spiral at the instrument point plus or minus the spiral deflection angle from 0 for an equal distance is used. The table is then checked up by the method of differences.

Table II may be made general by considering the tabulated quantities to be coefficients to be applied to some flexible property of the spiral. The number of stations (or chords) to be used may be varied, and also the amount of central angle in a single chord length. To utilize this table in this general way, by analogy to the method for multiple curves, use the amount of central angle in a circular curve having a length equal to the chord length used as the angle to be multiplied by the co-efficients, and as before call this "the rate of transition per chord." This angle is double the amount of central angle in the first chord length of the spiral. For any rate and any length of chord, multiply the rate of transition per chord by the co-efficient from Table II opposite the desired point.

To show how Table II is used, take the following example :
What are the deflections for a spiral 200 feet long joining a

TABLE II.
CO-EFFICIENTS OF THE RATE OF TRANSITION PER CHORD FOR THE TRANSITION SPIRAL.

| Station, also Angle of Curve. | Total Cent'. | Angle. | Inst. at 0. | Difference. | Inst. at 1. | Difference. | Inst. at 2. | Difference. | Inst. at 3. | Difference. | Inst. at 4. | Difference. | Inst. at 5. | Difference. | Inst. at 6. | Difference. | Inst. at 7. | Difference. | Inst. at 8. | Difference. | Inst. at 9. | Difference. | Inst. at 10. | Difference. | Station. |
|-------------------------------------|--------------|--------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|--------------|-------------|----------|
| 0 | | | 0 | 1 | 1/4 | 1/4 | 1 1/2 | 1 1/2 | 3 | 3/2 | 5 1/2 | 2 | 8 1/2 | 1 | 12 | 1 1/2 | 16 1/2 | 1 1/2 | 21 1/2 | 1 1/2 | 27 | 1 1/2 | 33 1/2 | 1 1/2 | 0 |
| 1 | | 1/2 | 1 | 1/2 | 0 | 2/2 | 5 | 5 | 2 1/2 | 1 | 4 1/2 | 1 | 7 1/2 | 1 1/2 | 10 1/2 | 1 1/2 | 15 | 1 1/2 | 19 1/2 | 1 1/2 | 25 1/2 | 2 | 31 1/2 | 2 1/2 | 1 |
| 2 | | 2 | 2 | 2/2 | 2/2 | 0 | 0 | 1 1/2 | 1 1/2 | 1 1/2 | 3 1/2 | 1 1/2 | 6 | 1 1/2 | 9 1/2 | 2 | 13 1/2 | 2 | 18 | 2 | 23 1/2 | 2 1/2 | 29 1/2 | 2 1/2 | 2 |
| 3 | | 4 1/2 | 1 1/2 | 1 1/2 | 1 1/2 | 1 1/2 | 1 1/2 | 1 1/2 | 0 | 1 1/2 | 1 1/2 | 4 1/2 | 4 1/2 | 1 1/2 | 7 1/2 | 2 1/2 | 11 1/2 | 2 1/2 | 15 1/2 | 2 1/2 | 21 | 2 1/2 | 26 1/2 | 2 1/2 | 2 |
| 4 | | 8 | 2 1/2 | 1 1/2 | 3 | 1 1/2 | 2 1/2 | 1 1/2 | 1 1/2 | 1 1/2 | 0 | 2 1/2 | 2 1/2 | 2 1/2 | 5 1/2 | 2 1/2 | 9 | 2 1/2 | 13 1/2 | 2 1/2 | 18 1/2 | 2 1/2 | 24 | 2 1/2 | 4 |
| 5 | | 12 1/2 | 4 1/2 | 1 1/2 | 4 1/2 | 1 1/2 | 4 1/2 | 3 1/2 | 3 1/2 | 2 1/2 | 2 1/2 | 2 1/2 | 0 | 2 1/2 | 2 1/2 | 2 1/2 | 6 1/2 | 2 1/2 | 10 1/2 | 3 | 15 1/2 | 3 1/2 | 20 1/2 | 3 1/2 | 5 |
| 6 | | 18 | 6 | 1 1/2 | 6 1/2 | 2 | 6 1/2 | 2 1/2 | 6 | 2 1/2 | 4 1/2 | 2 1/2 | 2 1/2 | 2 1/2 | 0 | 2 1/2 | 3 1/2 | 3 1/2 | 7 1/2 | 3 1/2 | 12 | 3 1/2 | 16 1/2 | 3 1/2 | 6 |
| 7 | | 24 1/2 | 8 1/2 | 2 1/2 | 9 1/2 | 2 1/2 | 9 1/2 | 2 1/2 | 8 1/2 | 2 1/2 | 7 1/2 | 2 1/2 | 5 1/2 | 3 | 3 1/2 | 3 | 0 | 3 1/2 | 3 1/2 | 3 1/2 | 8 1/2 | 3 1/2 | 13 1/2 | 3 1/2 | 7 |
| 8 | | 32 | 10 1/2 | 3 1/2 | 11 1/2 | 3 | 12 | 2 1/2 | 11 1/2 | 3 | 10 1/2 | 3 1/2 | 9 | 3 1/2 | 6 1/2 | 3 1/2 | 3 1/2 | 3 1/2 | 0 | 4 1/2 | 4 1/2 | 4 1/2 | 4 1/2 | 4 1/2 | 8 |
| 9 | | 40 1/2 | 13 1/2 | 4 1/2 | 14 1/2 | 3 1/2 | 15 1/2 | 3 1/2 | 15 | 3 1/2 | 14 1/2 | 3 1/2 | 12 1/2 | 4 | 10 1/2 | 4 | 7 1/2 | 4 1/2 | 4 1/2 | 0 | 0 | 4 1/2 | 4 1/2 | 4 1/2 | 9 |
| 10 | | 50 | 16 1/2 | 5 1/2 | 18 | 4 | 18 1/2 | 4 | 18 1/2 | 4 | 18 | 4 | 16 1/2 | 4 | 14 1/2 | 4 | 12 | 4 1/2 | 8 1/2 | 8 1/2 | 4 1/2 | 4 1/2 | 0 | 4 1/2 | 10 |

6 40' curve, setting stakes every 20 feet? The elements of the spiral are as follows:

Number of chords 10.

Degree of curve at end of first chord $= 6^\circ 40' \div 10 = 40'$.

Rate of transition for 20 feet $= \frac{20}{100} \times 40' = 8'$.

Multiplying this rate of transition, 8', by the co-efficients in columns in Table II, headed Instrument at 0 and at 10, the following deflection angles are obtained:

| Instrument at 0. | | Instrument at 10. | |
|------------------|------------|-------------------|------------|
| Sta. | | Sta. 0 | 4° 26' 40" |
| 1 | 1' 20" | 1 | 4 12 00 |
| 2 | 5' 20" | 2 | 3 54 40 |
| 3 | 12' 00" | 3 | 3 31 40 |
| 4 | 21' 00" | 4 | 3 12 00 |
| 5 | 33' 20" | 5 | 2 43 40 |
| 6 | 48' 00" | 6 | 2 10 40 |
| 7 | 1° 5' 20" | 7 | 1 45 00 |
| 8 | 1° 25' 20" | 8 | 1 14 40 |
| 9 | 1° 48' 00" | 9 | 0 38 40 |
| 10 | 2° 13' 20" | 10 | 0 00 00 |

The stakes are set by turning the deflections with instrument at 0 (point of spiral). Moving the instrument to Sta. 10, with the vernier set at 4° 26' 40", backsight on Sta. 0. A check can now be applied to the stakes already set by turning the deflection for each chord point, setting the deflection for instrument at Sta. 10. The central angle is taken from table by applying the factor 8' to the co-efficient opposite Sta. 10 ($50 \times 8' = 6^\circ 40'$). To show that the spiral lies in the same position regardless of the length of chords used, take the above example and use a chord 40 ft. long, then the degree of curve at end of first chord $= \frac{6^\circ 40'}{5} = 1^\circ 20'$, and the rate of transition for 40 ft. chord equals 32', which applied to the factor opposite Sta. 5 gives $4\frac{1}{6} \times 32 = 2^\circ 13' 20''$ deflection for the end of spiral as above. Central angle equals $12\frac{1}{2} \times 32' = 6^\circ 40'$ as before. If only one chord is used the rate of transition is 13' 20', which applied to the co-efficient opposite Sta. 1 gives $2^\circ 13' 20''$ as the deflection from Sta. 0 to the end of the spiral as in each previous case. Thus the spiral is the same regardless of the number of chords used, which

is a great advantage over the multiple compound curve, especially of the Searles type.

THE HOWARD TRANSITION CURVE.—The method used by C. R. Howard in developing a general table consists in using a constant angular rate of transition per chord of 12 minutes, thus making the first deflection angle 2 minutes.

The chord length is varied to obtain any desired rate of transition in the spiral. By applying 12 minutes to the co-efficients in Table II, the deflection angles in the Howard table may be obtained. All other quantities are obtained by the use of supplemental general tables for co-ordinates, long chords, etc. There are serious disadvantages in that a given spiral is restricted to the use of a single chord length.

THE CRANDALL TRANSITION CURVE — Professor Crandall has calculated and tabulated the co-ordinates of P. C. of circular curve, end of spiral, distance between parallel tangents, excess of arc over tangent and circular curve for over 800 spirals to connect with curves of even degree of curvature, making it possible by interpolation to find the co-ordinates, offsets between tangents, etc., for the end of any desired spiral. The quantities in the table for deflection angles are co-efficients of $\frac{1}{3}$ the total central angle for chords $\frac{1}{20}$, $\frac{1}{10}$, $\frac{1}{5}$, or $\frac{1}{4}$ of the total length of spiral, giving an opportunity to move the instrument to quarter points and center of spiral. These tables are convenient in many ways. The principal objections are the necessity of multiplication and interpolation, and the restriction in the number of chords and instrument points; also that the tables refer to the end of a spiral only, no intermediate points being calculated and do not give values for curves whose degree of curve includes minutes.

THE JAMESON METHOD.—The method which Professor Jameson used in preparing tables for field use consists in assuming a certain number of offsets between tangents, and in tabulating spirals for these gaps for curves of even degree of curvature, thus giving a choice of a number of spirals for certain circular curves. The same objection will apply to this method as to Crandall's, and in addition it lacks the necessary flexibility for use in the field.

THE TALBOT RAILWAY TRANSITION SPIRAL.—The most general treatment of spirals yet published is by Professor Talbot

in his Railway Transition Spiral. The tables include eight rates of transition, and other rates may be obtained by direct multiplication. Deflections, central angles, and co-ordinates are calculated for 10 ft. intervals. The deflection angles are from the point of spiral, but no tabular values are given for the instrument at intermediate points of the spiral, nor for the instrument at the end of the spiral. This difficulty is partially overcome by the splendid relationship developed between the degree of curve, rate of transition, length of spiral, central angle, tangent offset, etc., whereby any necessary quantity is expressed in formulas in terms of the above mentioned elements, making it possible to calculate deflections, etc., for any point or from any point to any other. Thus, for the instrument at the end of the spiral the deflection angles may be obtained by adding the spiral deflection angle taken from the table to the deflection angle for an equal length of circular curve. These relations are undoubtedly the most general and simple yet developed, but the solution of some of the formulas would be tedious in the field.

To illustrate the application of the spiral use the following notation, which is similar to that used by Professor Talbot :

L = length in 100 ft. stations.

C = length of equal chords in hundreds of feet.

n = number of chords.

a = rate of transition for 100 foot chords.

r = rate of transition for a single chord.

D = degree of curve at any point,

Δ = total central angle.

θ = deflection angle from initial tangent.

o = distance between parallel tangents.

x and y = co-ordinates of any point.

By definition $L = n C$.

Since the rate of transition varies as the square of the chord length

$$r = C^2 a, \text{ or } a = \frac{r}{C^2}. \text{ Hence also } D = a L = \frac{r n}{C}.$$

The relations previously given become

$$\Delta = \frac{1}{2} D L = \frac{1}{2} a L^2 = \frac{1}{2} r n^2$$

$$\theta = \frac{1}{3} \Delta = \frac{1}{6} a L^2 = \frac{1}{6} r n^2.$$

It is also known that

$$o = .0727 a L^3.$$

The formulas here stated need little corrections under 20° of central angle. Spirals of larger central angle are seldom used for the purpose of easing ends of curves, though they may be used as a matter of economy in location work when more nearly fitting the topography of the country than would a circular curve.

In easing the ends of existing curves where tracks are not crowded together, and where there is plenty of room to operate, most tables will contain a spiral which may properly be chosen, but often there are limiting circumstances which make it desirable or necessary to use a special spiral. As an illustration of this, the following example may be cited. Some months ago it was desired to introduce spirals into a main line double-track 12 degree reverse curve. There was very little opportunity to modify the curves, since there were yard tracks on either side owned by other corporations, but by slightly changing the alinement it was found possible to get 80 feet of tangent between curves. This allowed the use of spirals 80 feet long, $\alpha = 15$, which is not to be obtained from Talbot's tables, except by multiplication by 3 or 15, but might have been found in Crandall's. Most excellent results followed the introduction of this spiral.

Shortly afterward another problem presented itself which is not covered by existing tables. As these problems arise unexpectedly, the field engineer must be prepared to meet these emergencies without losing time. The problem was this: A trestle was to be built on a 10 degree curve. In locating this curve an 8 degree curve was used for one station, then compounding with the 10 degree curve. Before the piles were driven, it was desired to replace the 8 degree curve with a spiral, retaining the same tangent, and a 10 degree curve. The station numbers from P.C. and bents were as follows:

Sta. 322 + 62.9, P. C. 8 degree curve.

| | |
|-----------|------------|
| + 68. | Bent No. 1 |
| + 83. | “ “ 2 |
| + 98. | “ “ 3 |
| 323 + 13. | “ “ 4 |
| + 28. | “ “ 5 |
| + 43. | “ “ 6 |
| + 58. | “ “ 7 |

+ 62.9, P. C. C. 10 degree curve.

The solution is as follows, using Table II and the formulas noted :

| | |
|---|----------|
| Radius 8° curve | 716.78 |
| " 10° " | 573.69 |
| Difference | 143.09 |
| Log. 143.09 | 2.155618 |
| Log. vers. 8° | 7.988199 |
| Log. <i>o</i> | 0.143817 |
| Log. .727 | 9.861534 |
| | 0.282283 |
| | 0.141141 |
| $o = 1.393 = 0.0727 D L^2$ | |
| $L^2 = \frac{o}{.727}$ | |
| $L^2 = 1.915$ | |
| $L = 1.384$ | |
| $C = .15$ | |
| $n = 9.227$ | |
| $r = \frac{DC}{n} = 9.75 \text{ minutes}$ | |
| $D = \frac{1}{2} r n^2 = 6^\circ 55.2'$ | |

For short spirals the ends are equidistant from P. C. of circular curve produced backward to a tangent parallel to the spiral tangent at P. S. In the above example the P. C. of 8° curve is at Sta. 322 + 62.9. Had the 10° curve been produced backward through 8 degrees, the P. C. would fall at 322 + 82.9 ; then P.S. equals 322 + 82.9 - $\frac{1}{2} L = 322 + 13.7$.

The deflections for 15 ft. chords corresponding with bent centers are readily found from Table II as follows :

In Table B, the first four columns are readily filled in. The central angle for each point is found by filling in the column of differences, noting that each station is 5.7 feet short of the point where full 15 ft. stations from P. S. would fall, and thus each co-efficient is $\frac{5.7}{15} = .38$ more than it should be for this case.

Thus the first difference becomes $(.50 - .38) r = 1.2$ minutes. It is not necessary to multiply out each co-efficient but simply to add r , (9.75'), to each successive difference. Find Δ for 9.3 ft.

by formula, $\Delta = \frac{1}{2} r n^2$, then add the successive differences. The deflection from the P. S. equals $\frac{1}{3} \Delta$, or this column may be found by differences as for Δ .

The first bent being at the top of slope, it is necessary to move the instrument to Sta. 4 of the spiral where the deflections for the remaining bents are easily found, remembering that each bent is 5.7 ft. short of a full station. By inspecting Table II we note that moving the instrument one full station of 15 ft. on the spiral changes the tabular difference for the adjacent station $\frac{1}{2} r$, (4.9 minutes), and the proportion $\frac{5.7}{15}$ of this gives 1.8 minutes to be subtracted from the product of the co-efficient in Table II into r . Here again only one difference need be calculated, since the differences in the vertical column increase by $\frac{1}{3} r = 3.25$. Summing each way from zero the deflection for each station is found, remembering that Station 9 to 10 is fractional. The differences for each successive bent are found by adding 1.6' to each previous difference in the horizontal column or by adding 4.9' in the diagonal direction.

With a few of these quantities filled out for each bent, the instrument can be used to locate the piles at right angles to the center line of each bent. Note that the first and last stations are fractional and their deflections are obtained by proportion. This example shows that Table II is adapted to such an extremely special case as the above.

The above notes on railway transition spirals have recently been worked out by the writer to be used in his own practice, and have not yet been reduced to a permanent form. This article is intended rather to point the way to flexible tables than to present a finished result.

UNIFORM CHORD LENGTH METHOD FOR THE RAILWAY TRANSITION SPIRAL.

BY ARTHUR N. TALBOT, PROFESSOR OF MUNICIPAL AND SANITARY
ENGINEERING.

In the preceding article on Railway Transition Curve Tables, Mr. F. K. Vial has given an interesting application of the method of differences to the construction of such tables. Moreover, Mr. Vial deserves credit for contributing to the development of transition curves by suggesting or using properties of these curves along two lines:

1. By considering in the multiple compound curve that both the chord length and the angular increment of the successive arcs may at the same time be made variable quantities, thus rendering a single table very flexible in its use. Also in the application of a similar process to the transition spiral for the method of uniform chord lengths.

2. By a modification of the methods of laying out the transition spiral by means of uniform chord lengths given by several writers, whereby the field work may begin with a fractional chord length, or end with a fractional chord length, or begin and end with fractional chord lengths—a modification of the general table being made for this purpose. It is also suggested that this process may be applied to the multiform compound curve.

The method of differences is, of course, in common use by makers of such tables and greatly facilitates table construction, its results and the results of the formulas giving a mutual check—sometimes one and sometimes the other method being the easier process. It is worth while, however, to call the attention of the general reader to the usefulness of the method of differences.

It would seem that the suggestion that fractional chords at the beginning and end of the spiral are made feasible by means of easily constructed tables will be of especial service in treatments of the spiral by uniform chord lengths, that is for those methods in which points are located by means of a number of

chords having a common length. Accepting this suggestion, it is seen to be no longer necessary to make the uniform chord length an aliquot part of the length of the spiral; thus, if the spiral is to be 203.2 feet long, ten 20-ft. chords, or eight 25-ft. chords, or thirteen 15-ft. chords, etc., may be used—the first or last chord or both being fractional. This also enables the regular stationing to be kept up or other regular points like the bents of a trestle to be located.

The treatment of the transition spiral published by the writer* makes the field work independent of the length of chord used or the stationing wanted, as is the case with circular curves, and the writer is of the opinion that for the majority of field problems the methods there outlined are the simplest as well as the most general. However, there are many problems where the use of a uniform chord length is advantageous, and, besides, many engineers prefer to use the method of uniform chord lengths. To meet this use the following method has been derived from the formulas given in *The Railway Transition Spiral*, and a general table is also presented. The notation used will be the same as that in the article in *The Technograph* No. 13, and the equation numbers will be the same.

Let C , expressed in hundreds of feet, be the chord length used, and let n (an integer) represent the number of full chords from the P. S. to a desired point. In the absence of a diagram to represent this, the reader may easily make a sketch, numbering the first chord after the P. S. 1, the second 2, etc. The angles may be marked on the same figure. Let θ_0 = spiral deflection angle at P. S. from initial tangent for a single full chord length, and θ_n for n chord lengths. For the instrument at other points than P. S., let n' be the number of chord lengths from the P. S. to the chord point at which the instrument is located, reserving n still as the number of chord lengths from the P. S. to the point to be located, and let ζ_n represent the deflection angle from tangent at the instrument point to this desired point. Thus, if the instrument be 5 chord lengths from the P. S., $n' = 5$, and to locate a point 8 chord lengths or 3 chord lengths from the P. S., $n = 8$ or 3, and ζ_n would represent the deflection angles at 5 to locate these points.

**The Railway Transition Spiral*, *The Technograph* No. 13, p. 73.

Then we have by substitution in formulas (1), (2) and (9) of The Railway Transition spiral :

$$D = a L = a n C, \text{ for any point on the spiral. (1')}$$

$$\Delta = \frac{1}{2} a L^2 = \frac{1}{2} a n^2 C^2 \text{ for any point on the spiral. (2')}$$

$$\theta_1 = \frac{1}{6} a C^2 = \frac{1}{3} \frac{C^2}{L^2} \Delta_1 = \frac{1}{6} \frac{D_1 C^2}{L_1}, \text{ for end of first full chord. } \left. \begin{array}{l} \\ \\ \end{array} \right\} (9')$$

$$\theta_n = \frac{1}{6} a L^2 = \frac{1}{6} a (nC)^2 = n^2 \theta_1, \text{ for end of } n \text{ full chords. } \left. \begin{array}{l} \\ \\ \end{array} \right\} (9')$$

$$\begin{aligned} \varphi_n &= \frac{1}{2} a L^1 (L - L^1) \pm \frac{1}{6} a (L - L^1)^3 = \frac{1}{2} a n^1 C (n - n^1) C \\ &\quad \pm \frac{1}{6} a (n - n^1)^3 C^2. \\ &= [3 n^1 (n - n^1) \pm (n - n^1)^3] \theta_1 \text{ (10')} \end{aligned}$$

In formula (10'), the arithmetical difference of the numbers of the chord points is taken, rather than the algebraic difference. If the latter is used, the signs of operation should all be plus.

In this method the first step is to calculate the value of θ_1 by means of formula (9'), using a and C or other terms. This gives a basis for computing the deflection angle for other points; thus for a point 5 chord lengths from the P. S., $n=5$ and the deflection angle by equation (9') is $25 \theta_1$. For the instrument at 5, ($n^1=5$) the deflection angle from the tangent at the instrument point to a point 8 chord lengths from the P. S. ($n=8$) is by equation (10'):

$$\varphi_n = [3 \times 5 (8 - 5) \pm (8 - 5)^3] \theta_1 = 54 \theta_1.$$

To locate a point 3 chord lengths from the P. S., the deflection angle is found to be $26 \theta_1$.

The values obtained from (9') and (10') may be considered as coefficients of θ_1 and a general table may be prepared. Table XI is a table of coefficients for a spiral up to 15 full chord lengths and for use with the instrument at any such chord point. To find the deflection angle from the tangent at any chord point, enter the column whose heading gives the number of the chord point at which the instrument is placed and take the coefficient opposite the number of the chord point to be located; then multiply the spiral deflection angle for a single chord length (θ_1) by this coefficient. Thus, as in example cited above, for the instrument at 5, the deflection angle from the tangent at this point to locate a point 8 chord lengths from the P. S. is found to be $54 \theta_1$, and to locate a point 3 chord lengths from the P. S. is $26 \theta_1$. This table may easily be extended. The variation in the tabular differences in horizontal, vertical, and diagonal directions is readily discerned, and if preferred the method of

TABLE XI.—CO-EFFICIENTS FOR DEFLECTION ANGLES.

To find the deflection angle from tangent at the instrument point, multiply the spiral deflection angle at the P. S. for a single chord length by the co-efficient found in the instrument-point column opposite the number of the chord point to be located.

| Chord Point Number. | INSTRUMENT AT CHORD POINT NO. | | | | | | | | | | | | | | | |
|---------------------|-------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| 0 | 0 | 2 | 8 | 18 | 32 | 50 | 72 | 98 | 128 | 162 | 200 | 242 | 288 | 338 | 392 | 450 |
| 1 | 1 | 0 | 5 | 14 | 27 | 44 | 65 | 90 | 119 | 152 | 189 | 230 | 275 | 324 | 377 | 434 |
| 2 | 4 | 4 | 0 | 8 | 20 | 36 | 56 | 80 | 108 | 140 | 176 | 216 | 260 | 308 | 360 | 416 |
| 3 | 9 | 10 | 7 | 0 | 11 | 26 | 45 | 68 | 95 | 126 | 161 | 200 | 243 | 290 | 341 | 396 |
| 4 | 16 | 18 | 16 | 10 | 0 | 14 | 32 | 54 | 80 | 110 | 144 | 182 | 224 | 270 | 320 | 374 |
| 5 | 25 | 28 | 27 | 22 | 13 | 0 | 17 | 38 | 63 | 92 | 125 | 162 | 203 | 248 | 297 | 350 |
| 6 | 36 | 40 | 40 | 36 | 28 | 16 | 0 | 20 | 44 | 72 | 104 | 140 | 180 | 221 | 272 | 324 |
| 7 | 49 | 54 | 55 | 52 | 45 | 34 | 19 | 0 | 23 | 50 | 81 | 116 | 155 | 198 | 245 | 296 |
| 8 | 64 | 70 | 72 | 70 | 64 | 54 | 40 | 22 | 0 | 26 | 56 | 90 | 128 | 170 | 216 | 266 |
| 9 | 81 | 88 | 91 | 90 | 85 | 76 | 63 | 46 | 25 | 0 | 29 | 62 | 99 | 140 | 185 | 234 |
| 10 | 100 | 108 | 112 | 112 | 108 | 100 | 88 | 72 | 52 | 28 | 0 | 32 | 68 | 108 | 152 | 200 |
| 11 | 121 | 130 | 135 | 136 | 133 | 126 | 115 | 100 | 81 | 58 | 31 | 0 | 35 | 74 | 117 | 164 |
| 12 | 144 | 154 | 160 | 162 | 160 | 154 | 144 | 130 | 112 | 90 | 64 | 34 | 0 | 38 | 80 | 126 |
| 13 | 169 | 180 | 187 | 190 | 189 | 184 | 175 | 162 | 145 | 124 | 99 | 70 | 37 | 0 | 41 | 86 |
| 14 | 196 | 208 | 216 | 220 | 220 | 216 | 208 | 196 | 180 | 160 | 136 | 108 | 76 | 40 | 0 | 44 |
| 15 | 225 | 238 | 247 | 252 | 253 | 250 | 243 | 232 | 217 | 198 | 175 | 148 | 117 | 82 | 43 | 0 |

differences may be used for calculating deflection angles for a particular case in place of a multiplication of these coefficients.

In case it is desired to begin the spiral with a fractional chord length, the following modification may be made. Let m be the ratio of this fractional chord length to a full chord length, and θ_m be the spiral deflection angle from the initial tangent for this fractional chord length, which from the general formula for θ may be seen to be $m^2 \theta_0$. Let θ_{n+m} be the spiral deflection angle from initial tangent to locate a point $(n+m)$ chord lengths away (n an integer and m fractional), and φ_{n+m} the deflection angle from tangent [at instrument point $(n^1 + m)$ chord lengths from P.S. to locate a point $(n + m)$ chord lengths from P. S. Substituting in formula (9) of the Railway Transition Spiral,

$$\theta_{n+m} = \frac{1}{6} a (n+m)^2 C^2 = (n+m)^2 \theta_0 = (n^2 + 2nm + m^2) \theta_0 = \theta_n + n (2m\theta_0) + \theta_m \dots \dots \dots (9'')$$

In equation (9''), the first term is the spiral deflection angle for n full chords, the second term is n times a constant, and the third term is the spiral deflection angle for the fractional chord. The calculations may be simplified by the method of differences.

For the instrument at a chord point $(n^1 + m)$ chord lengths from the P. S., the deflection angle from the tangent at this chord point to locate a chord point $(n + m)$ chord lengths from the P. S. is found from Eq. 10 of the Railway Transition Spiral to be

$$\begin{aligned} \varphi_{n+m} &= [3(n^1 + m)(n - n^1) \pm (n - n^1)^2] \theta_0 \\ &= \varphi_n + (n - n^1)(3m\theta_0) \dots \dots \dots (10'') \end{aligned}$$

In equation (10'') the first term is the deflection angle for full chords, and the second term is $(n - n^1)$ times a constant. If n^1 is greater than n , the second term is still added numerically to the first. Tabular differences may also be used.

As illustrations of the use of these methods, the examples cited by Mr. Vial may be used. In the spiral 200 feet long connecting with a 6° 40' curve, given on page 128, the spiral deflection angle for a 20-ft. chord by Eq. (9') is $\frac{1}{6} \times \frac{.20^2}{2} \times 6 \text{ } 40' = 1\frac{1}{3}$ minutes = θ_0 . The multiplication of $1\frac{1}{3}$ minutes by the co-efficients in Table XI. for instrument at 0 and for instrument at 10, gives the desired angles.

For the 138.4 ft. of spiral connecting with a 10 degree curve, given on page 133, the spiral deflection angle for a 15-ft. chord is found by equation (9') to be $1\frac{5}{8}$ minutes. The first point is to be located 9.3 ft from the P. S. Then $m = \frac{9.3}{15} = .62$. $\theta_m = .62^2 \times 1\frac{5}{8} = .62'$. In the table below, the integer of the number of the chord point in the column headed number of chord point is n and the fractional part is m . In the succeeding column headings for the instrument points, the integer is n^1 . Thus to determine the deflection angle with instrument at 0 to locate 323+43 by Eq. (9'') and Table XI,

$$\theta_{n+m} = (64 \times 1\frac{5}{8}) + (8 \times 2.01) + .6 = 2 \text{ } 00.7'$$

To determine the deflection angle with instrument at 322 + 83 ($n^1 = 4$) to locate 322 + 68 ($n = 3$), by Eq (10'')

$$\varphi_{n+m} = (11 \times 1\frac{5}{8}) + (1 \times 3.02) = 20.9'$$

To run in the spiral from P.C.C., this method may likewise be used if the P.C.C. is at n or at $n + m$ chord lengths from the P. S. If it is not, that is, if both the first and last chord lengths are to be fractional, the points on the spiral as far as the next instrument point may be set by the principle that the deflection angles will equal the difference between the deflection angle for

| Survey Station. | No. of Chord Point. | Central Angle. | INSTRUMENT POINT. | | | | |
|-----------------|---------------------|----------------|-------------------|-------|------|---------|------|
| | | | P.S. | 0.62 | 1.62 | 4.62 | 5.62 |
| 322+13.7 | P.S. | 0 | 0 | 1.2' | | 1 09.4' | |
| +23. | 0.62 | 1.8' | 0.6' | 0 | | 1 04.1' | |
| +38. | 1.62 | 12.8' | 4.3' | 4.6' | 0 | 53.0' | |
| +53. | 2.62 | 33.5' | 11.2' | 12.5' | | 38.6' | |
| +68. | 3.62 | 1 03.9' | 21.3' | 23.7' | | 20.9' | |
| +83. | 4.62 | 1 44.1' | 34.7' | | | 0 | |
| +98. | 5.62 | 2 34.0' | 51.3' | | | 24.1 | 0 |
| 323+13. | 6.62 | 3 33.6' | 1 11.2' | | | | |
| +28. | 7.62 | | 1 34.3' | | | | |
| +43. | 8.62 | | 2 00.7' | | | | |
| +52.1 | End. | 6 55.3' | 2 18.4' | | | | |

a circular curve and the deflection angle for a spiral from initial tangent, both for a distance equal to the distance to the desired point. After the next instrument point is reached, calculate deflection angles as though working from the P. S.

It may be seen that the method of uniform chord lengths has advantages where evenly spaced bents are to be located, especially where the rate a is fractional. It may also be used for usual chord lengths like 50 feet.

In the railway transition spiral, the value of θ is not exactly $\frac{1}{3} \Delta$ nor $\frac{1}{6} n^2 \theta$. The error in calling it this is best found by the second term of the series investigated in The Railway Transition Spiral. The real value of θ requires that the following angles be subtracted from the values found by the usual method: $\theta=4, 0.1'; 5, 0'2; 6, 0'3; 7, 0'.5'; 8, 0'.7'; 9, 1'.0; 10, 1'.4; 11, 1'.9; 12, 2'.4$. This correction is independent of the length of the spiral and rate of transition. These deductions may readily be made when necessary. For ϵ , the correction needed is almost exactly that for the θ which enters into it; thus in eq. (10') make the correction which would be necessary for a θ equal to $(n-n^1)^2 \theta$. This is easily made, but not often necessary. The same corrections for the spiral deflection angle are applicable to the quantities given by Mr. Vial for the transition spiral. In the multiple compound curve a similar deduction is necessary, and the amount of it for a given deflection angle is almost the same as that for an equal θ for the transition spiral. The error in the angle from chord points is likewise similar. Fortunately, for small deflection angles, these may be neglected.

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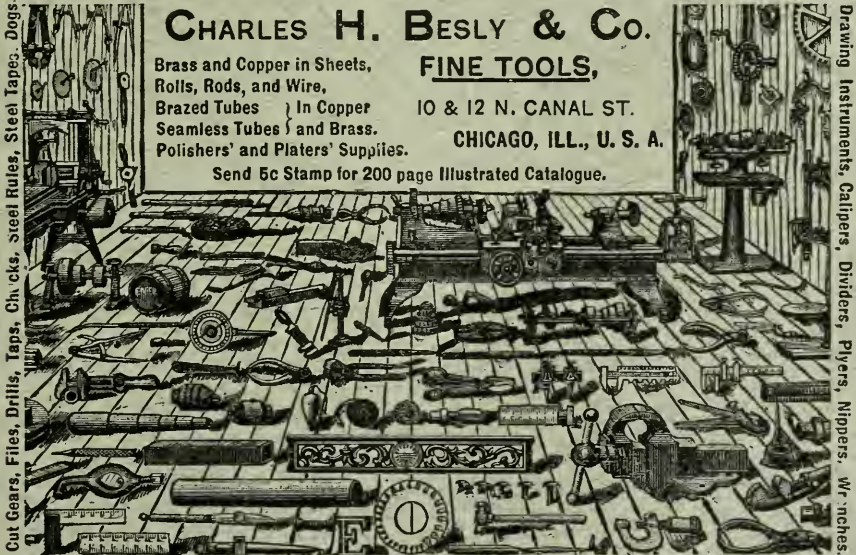
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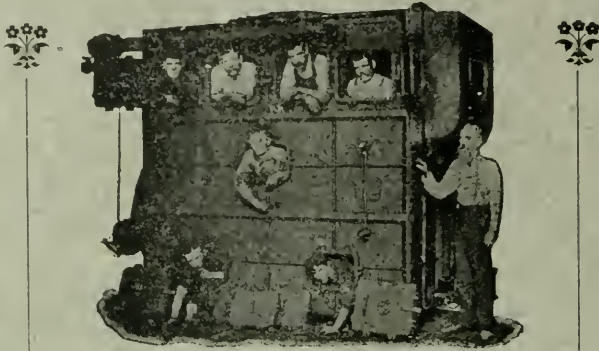


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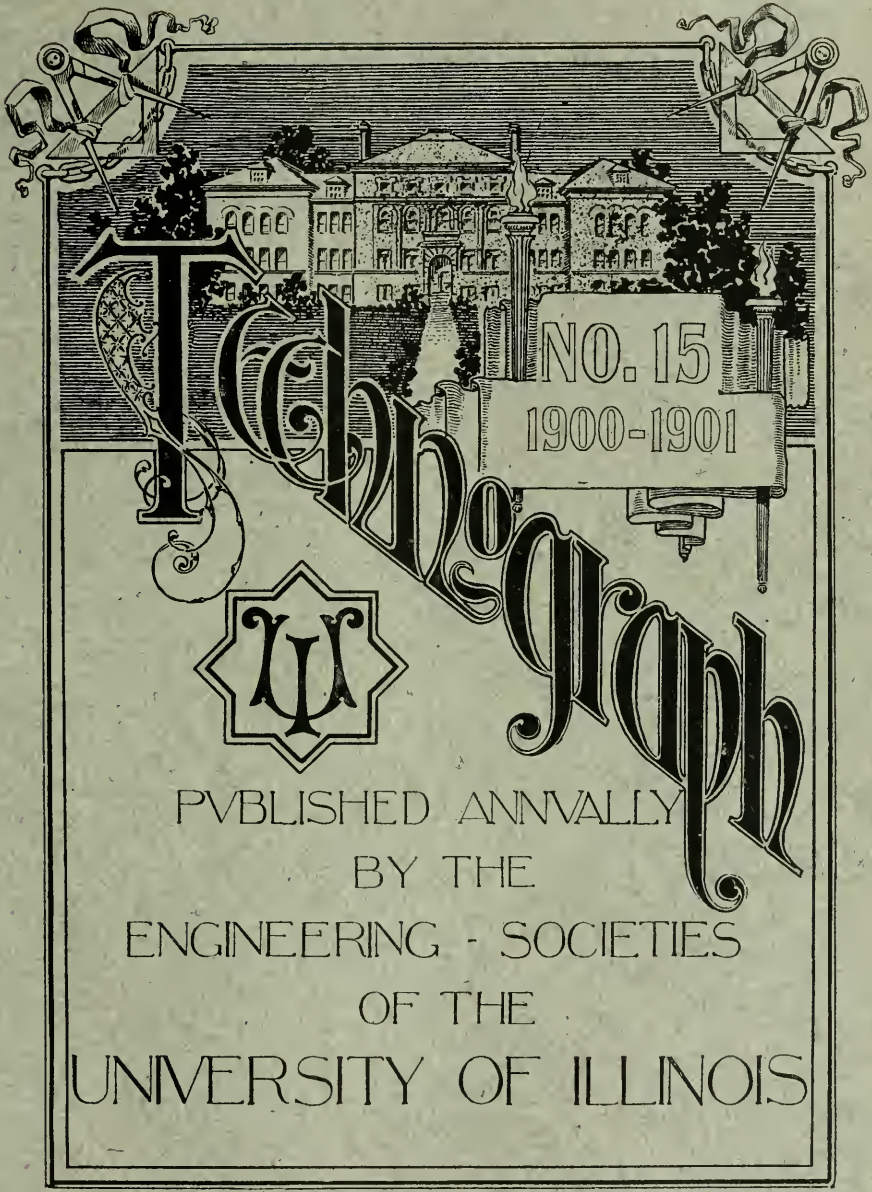
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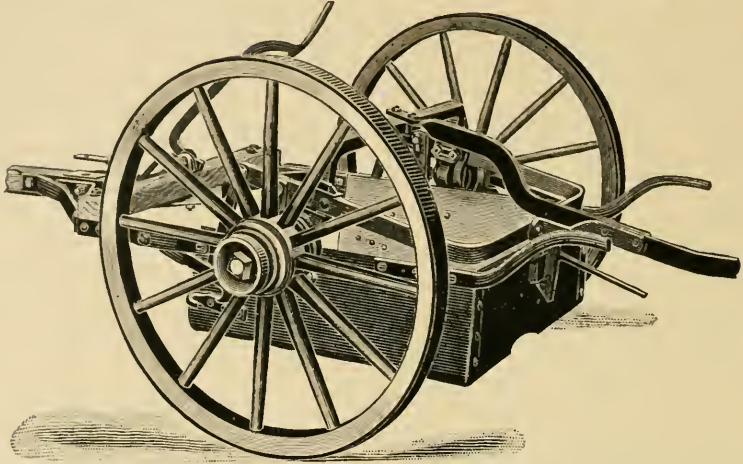
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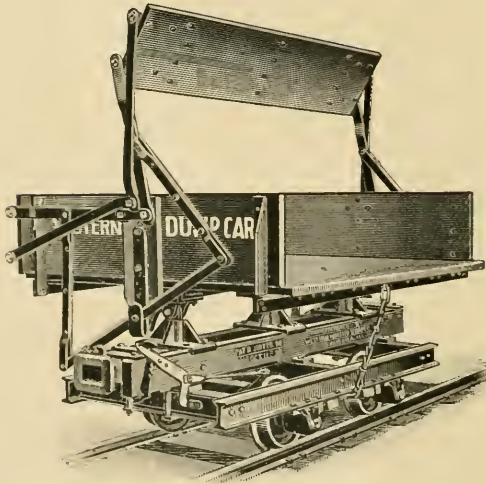
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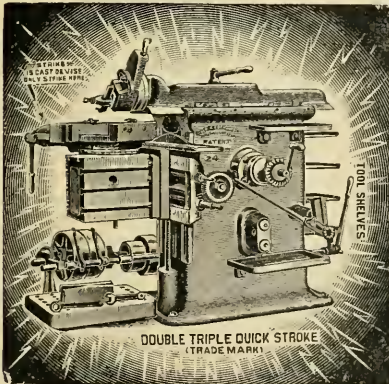
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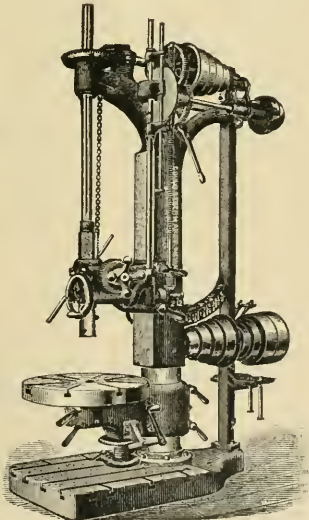
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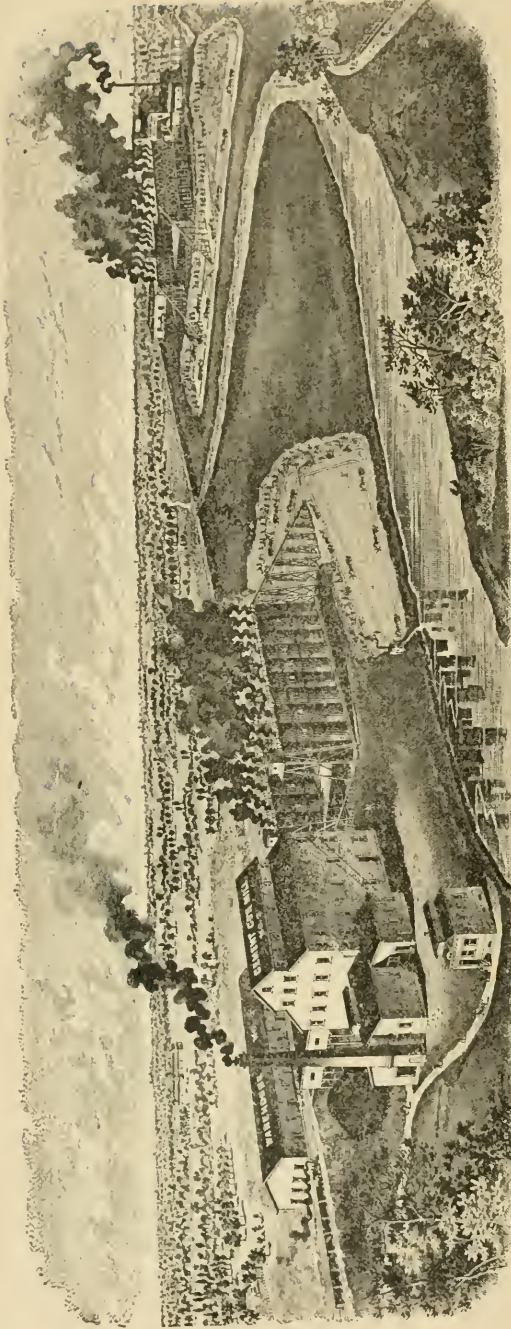
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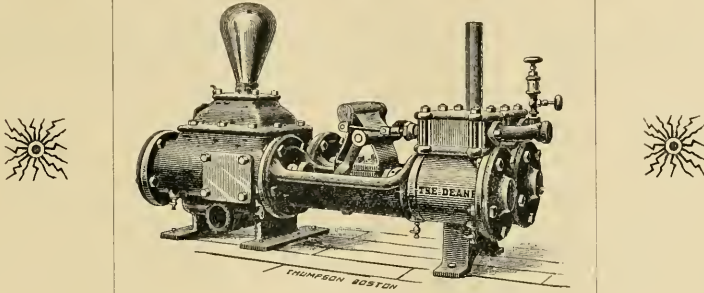
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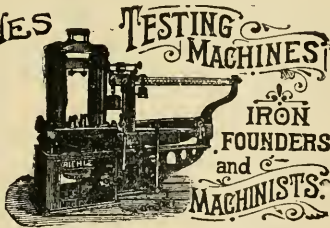
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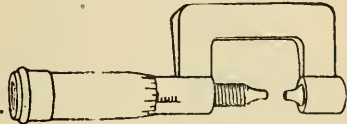
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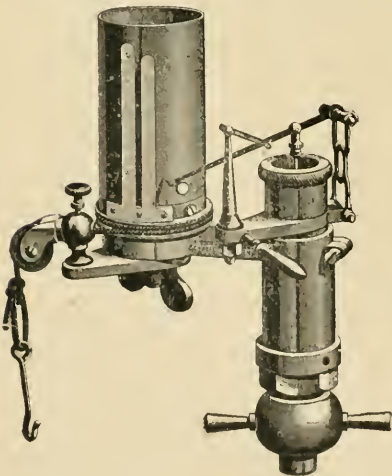
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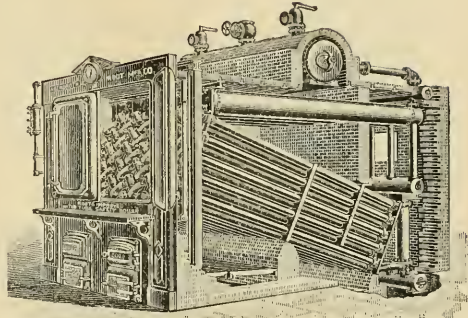
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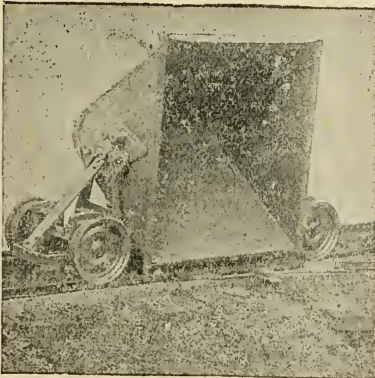
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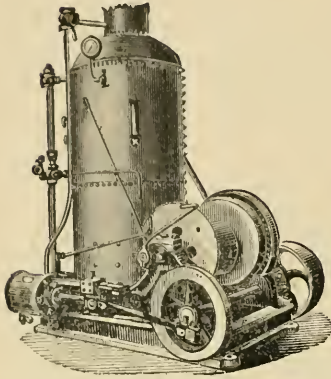
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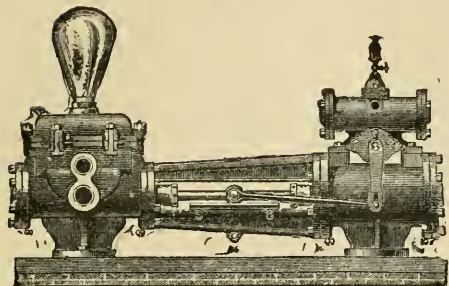
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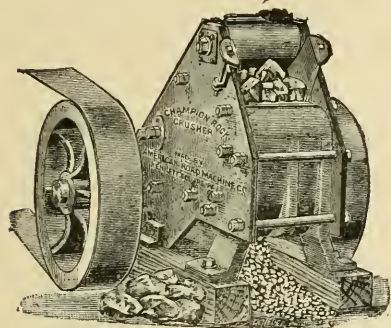
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| | |
|----------------------------|----------|
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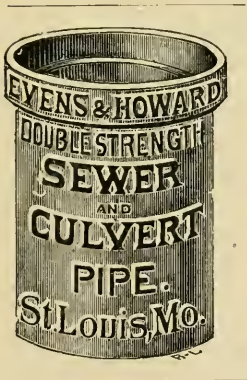
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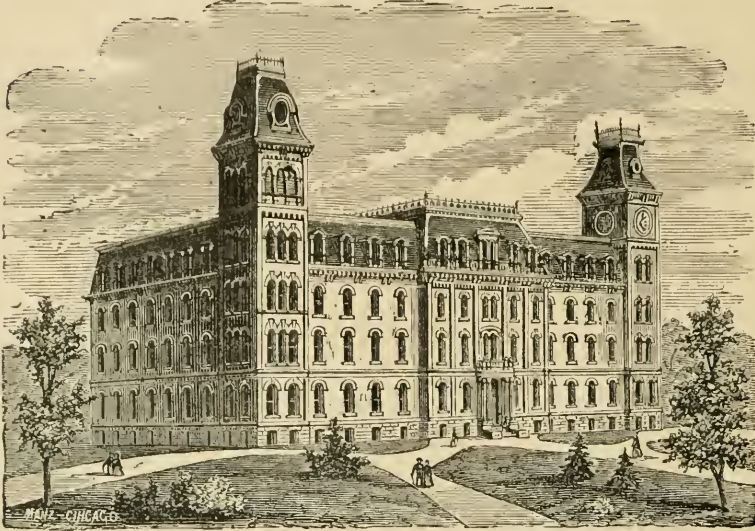
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UNIVERSITY OF ILLINOIS.

1900-1901.

THEORETICAL ESTIMATION OF THE INTERNAL SPEED VARIATION OF A 3500 HORSE-POWER VERTICAL CROSS-COMPOUND ENGINE.

BY W. L. ABBOTT, '84, CH. OPERATING ENGR., CHICAGO EDISON CO.

The object of the investigation forming the subject of this paper, was to determine the amount of the angular variation which would occur during a revolution, in the relative positions of the armatures of alternating current dynamos, if connected to two similar engines of the type described below, when running in parallel at the same number of revolutions per minute; and to see if the variation in phase would be great enough to put the dynamos out of step, or if the amount of cross current would be objectionable.

The engine to which the calculations apply is a vertical cross-compound Corliss $30 \times 80 \times 60$ condensing engine, built by the E. P. Allis Company, of Milwaukee, Wisconsin, and is to be directly connected to one ACH 40-2500-75 double-current General Electric generator for use at the Harrison street powerhouse of the Chicago Edison Company.

The condition of load under which the engine was assumed to be running was that of the economical rating, or 3500 I. H. P., with a constant speed of 75 revolutions per minute.

The indicator cards from which the determinations were made, were derived from a set of cards obtained from the Allis Company taken on Nov. 28, 1898, from the Allis Corliss cross-compound engine No. 4, of the South Side Elevated Railway Company of this city, while the engine was running under a steam

pressure of 150 pounds per square inch. The cards were used merely to get the steam distribution of a Corliss engine working at a moderate load, and the ordinates of the cards were increased to 170 pounds per square inch, the latter being the pressure at which the new engine is designed to operate.

The various steps of the investigation in their proper order may be briefly enumerated as follows:

1. From the known weights and velocities of the reciprocating parts, calculate the force due to inertia, as modified by the length of the connecting rod, and construct a curve showing the same for all positions of the piston.

2. Obtain a pair of indicator diagrams (head and crank end) from each cylinder and deduct from the ordinates of each the simultaneous back pressure shown on the diagram taken from the opposite end of the cylinder.

3. Multiply the ordinates of these combined diagrams by the number of square inches of piston area, and plot a new curve showing the total pressures on the piston at each point of the stroke.

4. Combine the pressures shown by this last curve with those of the inertia curve to get a curve showing the total pressures on the crosshead.

5. Resolve the pressures represented by the ordinates of the combined steam-pressure and inertia curve, to determine the rotative effect at the crank-pin, and plot a curve showing the tangential effort on the pin for all positions of the piston.

6. Combine the curves of tangential effort for each cylinder to obtain a curve of crank effort for all cranks.

7. Draw a line through this last curve to represent the mean effective pressure of the varying forces acting during one revolution. Now, disregarding the original base-line, assume the forces above and below this mean line as positive and negative respectively, and from these positive and negative forces calculate the acceleration and retardation which would be produced upon the rotating mass connected to the engine shaft. With ordinates obtained in this way plot a curve showing the resultant velocities attained during each interval of the stroke.

8. From this curve of velocities, whose integrated sum must be zero, calculate the distance traveled by the crank-pin ahead of or behind some other point assumed to be revolving with an

absolutely uniform motion at the same number of revolutions per minute, and plot a curve showing the amount of variation in the position of the pin, from normal, at the different points of the stroke. The maximum ordinate of this curve in degrees of arc or degrees of electrical phase, is the result we are seeking.

A more detailed description of the various methods employed in each of the above steps follows:

TABLE I.

WEIGHT IN POUNDS OF RECIPROCATING PARTS.

| | |
|--|-----------------------------------|
| Crosshead..... | 6 963 lb. |
| Connecting-rod (total 6500); one-half reciprocating..... | 3 250 " |
| Reciprocating weight—common to all cylinders..... | 10 213 " |
| H. P. Piston = 2120; rod = 1466. | 2 120 + 1 466 + 10 213 = 13 799 " |
| L. P. Piston = 8040; rod = 2042. | 8 040 + 2 042 + 10 213 = 20 295 " |

DERIVATION OF CURVE OF INERTIA.

| | |
|---|-----------------|
| Stroke | 5 ft. |
| R. P. M..... | 75 |
| $V = \frac{5\pi \times 75}{60}$ | 19.63 |
| V^2 | 385.34 |
| R , length of crank | 2.5 ft. |
| H = Weight of reciprocating parts on one crank. | |
| F_0 = Inertia of reciprocating parts at dead center (connecting rod infinite.) = $\frac{H}{g} \times \frac{V^2}{R}$ | 4.79 W |
| Crank | 30 in. |
| Connecting-rod | 165 in. |
| $\frac{\text{Crank}}{\text{Connecting-rod}} = \frac{R}{L}$ | $\frac{1}{5.5}$ |

Lay off MM' , Fig. 1, to represent stroke of piston.

Lay off MB' & $M'B''$ to represent pressure per pound of reciprocating parts at dead centres.

Straight line joining B' and B'' = inertia curve with infinite rod.

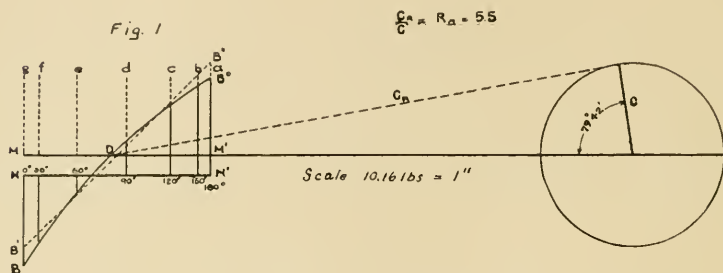
$$R_a = \frac{\text{Connecting-rod}}{\text{Crank}} = 5.5.$$

$$M'B = M'B'' - \frac{M'B''}{R_a}.$$

$$MB = MB' + \frac{MB''}{R_a}.$$

Lay off NN' parallel to MM' a distance below MM' represented by 1 pound to scale : then ordinates from NN' are proportional to combined effects of weight and inertia, and the number of pounds which they represent multiplied by weights of reciprocating parts give values in tables.

First Step: To deduce the curve of inertia, Fig. 1, the length of the connecting rod is first assumed to be infinite and the ordinates $B'M$ and $B''M'$, are determined. These ordi-



ORDINATE $a =$ INERTIA AT.....180°
 $b =$ 150°
 $c =$ 120°
 $d =$ 90°
 $e =$ 60°
 $f =$ 30°
 $g =$ 0°

| | H.P. | L.P. |
|-----|----------|---------|
| WT. | 13 799 | 20 295 |
| a | 69 000 | 101 475 |
| b | 63 480 | 93 357 |
| c | 49 680 | 73 062 |
| d | 24 840 | 36 531 |
| e | - 12 420 | 18 265 |
| f | - 48 300 | 71 032 |
| g | - 64 860 | 95 386 |

nates represent the force due to inertia per pound of reciprocating parts at the two dead-centers, and are deduced from the well known formula

$$F_o = \frac{W}{g} \frac{V^2}{R},$$

where F_o is the magnitude of the force above mentioned; W is the weight of reciprocating parts on one crank, and is assumed to be one pound in order to render the one curve applicable to both cylinders, or cranks; V is the velocity of the reciprocating parts, which are assumed to be concentrated at the center of the crank-pin, the velocity being based upon 75 revolutions per minute; R is the radius of the crank-pin circle, 2.5 feet.

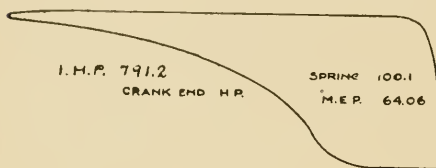
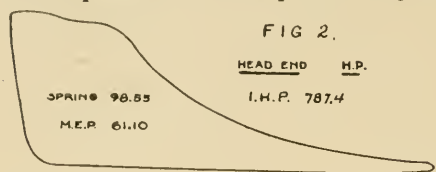
The magnitude of these forces at the respective dead-centers are equal, but opposite in direction. Ordinates from the straight line $B'B''$ to the base-line MM' correspond to forces due to inertia at various points of the stroke, and where the curve $B'B''$ intersects MM' at a point corresponding to the position of the piston at mid-stroke, the reciprocating parts are being neither accelerated nor retarded, and the force due to inertia is zero.

To determine the extent to which the curve $B'B''$ is modified by the influence of the finite rod whose length is $5\frac{1}{2}$ times that of the crank, as in the case under investigation, the approximate position of the piston corresponding to zero acceleration of the reciprocating parts, point D , is determined as follows: The line C_R , which represents to scale the length and direction of the connecting rod, is drawn tangent to the circle of crank-pin travel, and the point D is located at the intersection with MM' , the line of piston travel. This is very nearly the zero point of the inertia curve for the finite rod. The two maximum points on the new curve are next located by adding to MB' , and deducting from $M'B''$, which represent the forces due to inertia at the top and bottom centers respectively, an amount equal to $\frac{1}{5.5}$ of the force at those points. These points are represented by B and B° , Fig. 1. Having found these three points of the new curve of inertia, the complete curve BDB° may be constructed. In practice, an arc of a circle may be substituted for the theoretical curve without introducing any appreciable error.

Finally, a correction for the effect of the direct weight of the reciprocating parts is made by laying of $M'N'$ to represent to scale a force of one pound, and the new base-line NN' is drawn. (This correction is required for vertical engines only). Ordinates drawn to this base line from the curve BDB° , will represent the forces due to inertia per pound of reciprocating parts, and when the forces which they represent are multiplied by the weights of the reciprocating parts the products will be the resultant forces due to inertia and direct weight of the reciprocating parts. The magnitudes of the resultant forces at various points of the stroke are shown in tabulated form under Fig. 1.

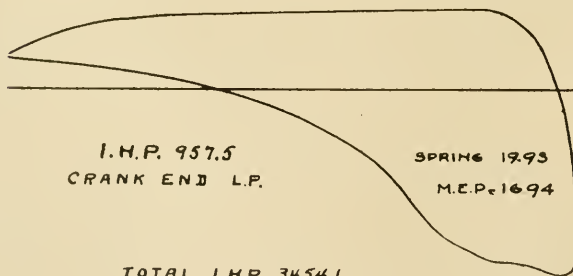
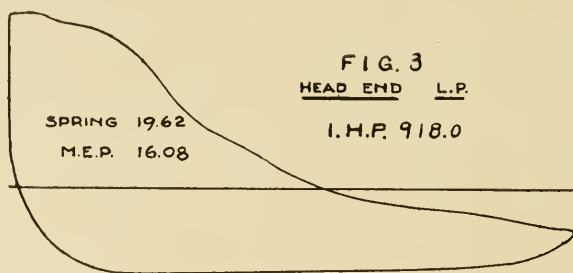
Second and Third Steps: Figs. 2 and 3 represent the indicator diagrams taken from each end of the two cylinders of the

engine. The ordinates of a diagram representing the resultant steam pressure on the piston may be obtained by deducting from



the ordinates of diagrams Figs. 2 and 3, the simultaneous back-pressures shown on the diagram from the opposite end of the cylinder. The ordinates of these resultant steam pressure diagrams are multiplied by the area of the piston to which they apply to get the total resultant steam pressure against the

piston. The ordinates of diagrams AAAA, Figs. 4 and 6, represent the total resultant steam pressure on the piston throughout the entire stroke.

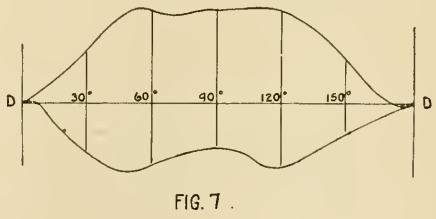
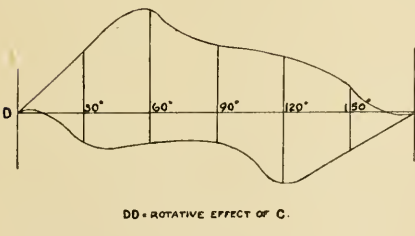
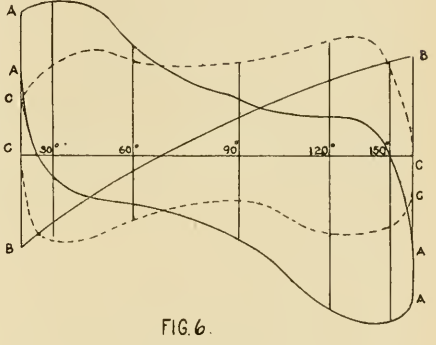
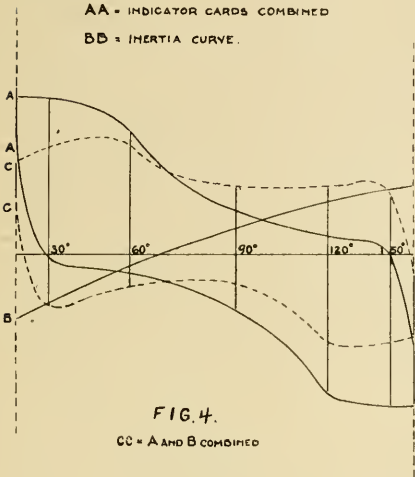


TOTAL I.H.P. 3454.1

Fourth Step: The curve of inertia *BB*, deduced as already explained, when plotted to the same scale as the resultant steam curves and combined with them, gives the curve *CCCC*,

whose ordinates represent the pressures on the crosshead due to the combined effect of the inertia of the reciprocating parts and the resultant steam pressure against the piston.

Fifth Step: From the combined steam and inertia curve CCCC, for each cylinder, the net pressure on the crosshead in the direction of the axis of the cylinder may be read for all positions



HIGH PRESSURE CYLINDER.

Scale 200,000 lbs = 1"

FIG 5

LOW PRESSURE CYLINDER.

Scale 200,000 lbs = 1"

of the piston. As part of this pressure acts against the guides and part in the direction of the axis of the connecting rod, that part which acts in the direction of the rod must be again resolved radially and tangentially at the pin in order to obtain the tangential pressure on the pin corresponding to a given pressure on the piston. The method which was employed in

his investigation, may be described as follows: As the instantaneous pressure on the crosshead multiplied by its corresponding velocity is equal to the simultaneous tangential pressure on the crank-pin multiplied by its velocity, it is clear that the tangential effort on the pin is equal to the product of the pressure on the piston into the ratio of the velocity of the piston to the velocity of the crank-pin. Now the velocities of the two ends of the connecting rod are in different directions, the crank-pin end always moving with constant velocity in a direction perpendicular to the instantaneous position of the crank, while the crosshead end always moves with variable velocity in a fixed direction parallel to the axis of the cylinder. In Fig. 8, BbA represents the first quadrant of the crank-pin circle, and the radius OB is drawn to represent the constant velocity of the crank-pin. The velocity of the crosshead or piston may be deduced from that of the crank-pin as follows: produce ab , the direction of the connecting rod, Fig. 8, until it intersects OA at f . Erect

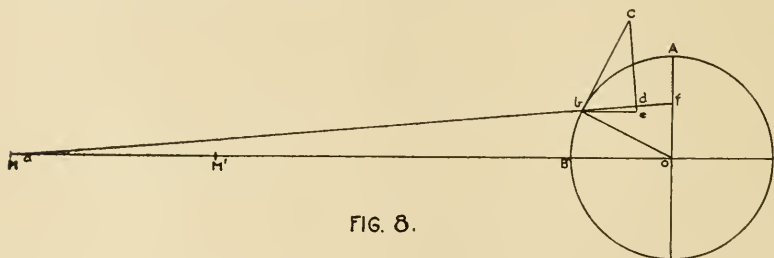


FIG. 8.

the perpendicular bc upon Ob at b equal to Ob . Then bc will represent the velocity of the crank-pin b , both in direction and magnitude. Draw cd perpendicular to the direction of the connecting rod. Draw be parallel to the direction of the velocity of the piston a to intersect cd produced. As the length of the connecting rod is fixed, the components of the velocities of the two ends resolved along the connecting rod must be equal. The component of the velocity of b in the direction of the rod is bd , and bd must therefore be the same component of the velocity of a ; hence be represents in direction and magnitude the velocity of a . As the sides of the triangle bce are perpendicular to those of the triangle Obf , the angles of the two triangles must be equal, and, as the sides bc and Ob are equal, the two triangles must be equal. Therefore $bc = Of$, and Of represents the vel-

ocity of the piston when the crank-pin occupies the position b . Let P be the pressure on the piston when the pin is at b ; then the tangential effort on the pin will be $P \times \frac{Of}{OA}$. If OA be made to equal unit length, then Of will be the factor by which the pressures on the piston must be multiplied to get the corresponding tangential effort on the pin. As indicated in

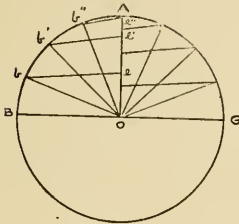


FIG. 9.

Fig. 9, this factor may be determined for any position of the piston and pin by merely prolonging the axis of the connecting rod till it intersects the perpendicular OA , when Oe , Oe' , Oe'' , &c, will be the required factors for positions b , b' , b'' , &c, of the pin. The ordinates of the diagrams of rotative effort, or tangential effort, on the crank-pin, Figs. 5 and 7, were obtained

by multiplying the corresponding ordinates of diagrams $CCCC$, Figs. 4 and 6, by a factor deduced as described above. In Figs. 5 and 7, DD is drawn to represent the diameter of the crank-pin circle.

Sixth Step: Fig. 10 shows the rotative effort on the pin for each cylinder, and is constructed from Figs. 5 and 7, with due respect to the relative positions of the high and low-pressure crank-pins. The diagram of crank effort for both cranks, Fig. 11, is derived by combining curves D_1 and D_2 of Fig. 10. MM represents the mean crank effort for all cranks during one revolution, and OO is the rectified crank-pin circle.

For convenience in estimating, the circle of crank travel OO , is divided into 12 equal spaces, and the applied force is assumed to be uniform within each space. The tangential effort during each space above or below the normal MM is represented by the mean height of each space above or below MM , and is exhibited in column F, Table II.

Seventh Step: The velocity gained or lost during each twelfth of a revolution was deduced as follows: The equivalent weight of the revolving parts at the crank radius (2.5 feet) is 3 367 600 pounds divided as follows: armature, 1 081 600 lb.; engine, 2 286 000 lb. The velocity of the crank-pin is

$$\frac{2.5 \times 2 \times 3.1416 \times 75}{60} = 19.63 \text{ feet per second.}$$

As the number of revolutions per second = $\frac{75}{60} = 1.25$, the number of spaces traversed per second = 15, and the time for each space is .0667 sec. The mass of the revolving parts is $\frac{W}{g} = \frac{3\ 367\ 600}{32.2} = 104\ 584$. Let A denote the velocity gained (or lost) during one space; then the average acceleration is $\frac{A}{.0667}$. From the law, force = mass \times acceleration,

$$F = \frac{W}{g} \times \frac{A}{.0667};$$

hence $A = .0667 F \div \frac{W}{g} = \frac{.0667}{104584} F$
 $= .0000006374 F.$

The velocity A gained or lost during each interval is shown in column A , Table II.

TABLE II.

| SPACE NO. | F | A | V' | V' | V | S'' | S | S | DEGREES OF ARC | DEGREES OF PHASE |
|-----------|---|--|--|--|---------------------------------------|---|---|--|----------------------------|---|
| | TANGENTIAL FORCE IN LBS ABOVE OR BELOW AVE. PRESSURE F = MEAN HEIGHT OF EACH SPACE | VELOCITY GAINED DURING EACH 1/20 OF A REVOLUTION A = $\frac{1}{20} F$ | VELOCITY ATTAINED UP TO THE END OF DIVISIONS ASSUMING 0 AT BEGINNING OF STROKE | V CORRECTED TO BRING 0 TO ITS PROPER PLACE V: V' = .035 | AVERAGE VELOCITY DURING EACH INTERVAL | SPACE ACTUALLY PASSED OVER DURING EACH INTERVAL | SPACE FROM NORMAL ASSUMING 0 AT THE BEGINNING OF STROKE | S CORRECTED TO BRING 0 TO ITS PROPER PLACE S = S' + .0019 | 5 x 22.92 1 FT. = 22.92 | THERE ARE 40 POLES ON THE GENERATOR, CONSEQUENTLY THERE ARE 20 CHANGES OF PHASE |
| 1 | -13500 | -.0086 | -.0086 | -.0416 | -.0375 | -.0025 | -.00280 | -.00060 | -0.137 | -0.274 |
| 2 | +57000 | +.0363 | +.0277 | -.0053 | -.0261 | -.00174 | -.00424 | -.00234 | -.0336 | -1.072 |
| 3 | +4500 | +.0029 | +.0306 | -.0024 | -.0012 | -.00008 | -.00402 | -.00242 | -.0365 | -1.110 |
| 4 | -10500 | -.0067 | +.0239 | -.0091 | -.0072 | -.00048 | -.00460 | -.00290 | -.0665 | -1.330 |
| 5 | +30000 | +.0191 | +.0430 | +.0100 | -.0015 | -.00010 | -.00490 | -.00300 | -.0688 | -1.376 |
| 6 | +1500 | +.0009 | +.0439 | +.0109 | +.0133 | +.00089 | -.00401 | -.00211 | -.0484 | -0.968 |
| 7 | +21000 | +.0134 | +.0573 | +.0243 | +.0155 | +.00103 | -.00498 | -.00108 | -.0247 | -0.494 |
| 8 | +30000 | +.0191 | +.0764 | +.0434 | +.0334 | +.00223 | -.00075 | +.00115 | +.0264 | +0.528 |
| 9 | -30000 | -.0191 | +.0573 | +.0243 | +.0390 | +.00260 | +.00185 | +.00375 | +.0859 | +1.716 |
| 10 | -48000 | -.0306 | +.0267 | -.0063 | +.0059 | +.00039 | +.00224 | +.00414 | +.0449 | +1.898 |
| 11 | -13500 | -.0086 | +.0181 | -.0149 | -.0097 | -.00065 | +.00159 | +.00349 | +.0800 | +1.600 |
| 12 | -28500 | -.0181 | -.0000 | -.0330 | -.0234 | -.00166 | +.00003 | +.00193 | +.0442 | +0.884 |

Now, if the velocity of the pin be assumed normal at the beginning of the stroke, the velocity attained up to the end of

the various spaces will be the algebraic sum of the velocities gained during each of the preceding spaces. These velocities attained up to the end of each space are shown in column V'' . As the actual velocity of the crank pin at the beginning of the stroke was not normal, as assumed, it becomes necessary to correct the values of V'' accordingly. The integrated sum of the velocities above and below normal attained during one revolution must be zero; therefore the correction to be applied is the

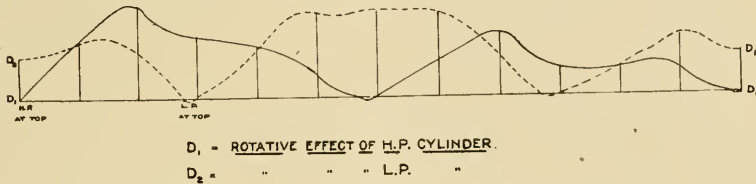


FIG. 10.

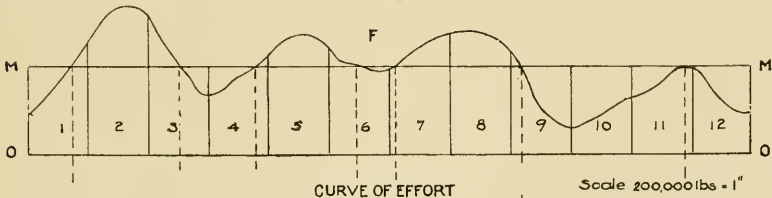


FIG. 11

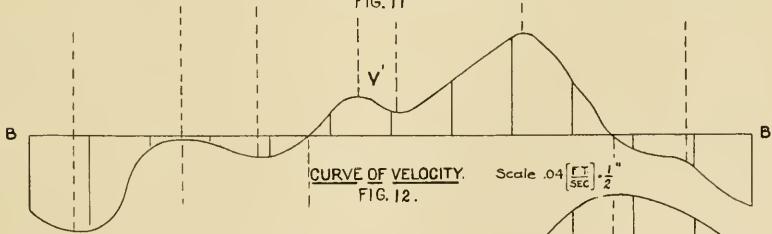


FIG. 12.

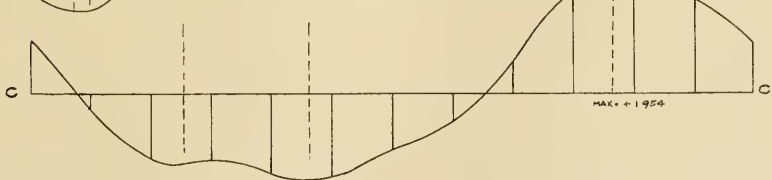


FIG. 13.

algebraic sum of the velocities V'' divided by the number of spaces (12 in this case). Thus the correction is .033, and this amount must be deducted from the values of V'' in order to ar-

rive at the true velocity attained up to the end of the successive intervals. With these true velocities given in column V'' , Table II., as ordinates, the curve of velocity V' , Fig. 12, is plotted. The line BB represents the mean velocity of the pin.

Eighth Step: From the curve of velocity V' , Fig. 12, ascertain the average velocity above or below the mean velocity, BB , during each space, shown in column V' , Table II. With these velocities given, the space actually passed over during each interval can be readily calculated by multiplying the values of V' by .0667, the time for one space. The figures in column S'' were deduced in this way.

If the position of the pin be assumed normal at the beginning of the stroke, its distance from normal up to the end of the respective intervals, will be the algebraic sum of the spaces actually passed over, ahead of, or behind the mean position, during each interval. Therefore the figures in column S' are equal to the integrated sum of the preceding figures in column S'' . As the position of the crank-pin at the beginning of the stroke was not zero, as assumed, a correction must be applied to the values of S' . Since the integrated sum of the distances ahead of or behind the mean position must equal zero, the value of the correction is equal to the ratio of the algebraic sum of the values of S' , to the number of spaces. The value of the correction is .0019, and is to be added to the values of S' to get the true distance from normal of the pin at the end of each interval, the figures for same being shown in column S . Since one foot corresponds to 22.92 degrees of arc, measured on the crank-pin circle, the number of degrees of arc from normal is the product of the true distances in feet from normal (column S) by 22.92 degrees of arc per foot. The number of degrees of arc from normal deduced in this way is shown in the penultimate column of Table II. Finally, as there are 40 poles on the generator there will be 20 changes of phase per revolution; therefore, one degree of arc is equal to 20 degrees of phase, and the number or degrees of phase from normal (shown in the last column of Table II) at the end of each interval may be calculated by multiplying the corresponding degrees of arc by 20. With the values of the degrees of phase from normal as ordinates, the curve of degrees of phase, Fig. 13, was plotted, in which CC represents the mean position of the crank-pin.

To insure the satisfactory operation of two alternating current generators when working in parallel, the maximum amount of angular variation should not be allowed to exceed $2\frac{1}{2}$ degrees of phase departure from the mean position during any revolution, and as the maximum variation shown by this final curve is well within the $2\frac{1}{2}$ degrees limit, the design of the unit in that respect may be considered satisfactory.

REGULATION AND ADJUSTMENT OF ARC LAMPS.

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The modern arc lamp is a simple mechanical and electrical mechanism, the growth of twenty-five years. Brush first put his single solenoid differentially-wound lamp on the market in 1875, since which time there have been various combinations of rods, chains, springs, ratchets, cog-wheels, and auxiliary levers for sale. This seems to be the natural tendency in the growth of the design of most apparatus, which is always followed by a plain, simple machine, free from the various auxiliary parts and accomplishing the result in the most direct manner.

The following are the different types of arc lamps in use, each of which may be operated from a direct or alternating-current circuit, using an open or enclosed arc: 1. Constant current series lamps. 2. Constant potential lamps used singly across a constant potential circuit. 3. Constant potential lamps used with one or more in series across a constant potential circuit. Each of these lamps requires a different method of regulation, depending upon the constant and variable factors of the circuit, and the relative action of one lamp upon another in the same circuit.

The constant current series lamp must necessarily regulate by the variation of its arc voltage. This is accomplished through a high resistance magnet placed in shunt with the arc, so that an increase of voltage across its terminals, due to the consumption of the carbons, will cause the magnet to bring the carbons nearer together, until the limit of the clutch movement is reached; then the carbon will drop and reduce the current in the shunt coil, so that the opposing force which may be a spring, weight, or series coil, will separate the carbons to their normal positions. This operation is repeated as often as the adjustment of the regulating mechanism will allow. A series coil is necessary to separate the carbons when the current is first turned on; this coil may be independent of the regulating magnet or it may work in opposition to it, either through a separate magnet or wound differentially on the same core with the shunt coil, the resultant magnetism increasing or decreasing, depending upon the current in the shunt winding.

The constant potential lamp used singly across a parallel circuit has become very popular since the introduction of the enclosed arc a few years ago which allowed the use of a high voltage arc and increased the life of the carbons. This lamp demands a smooth, uniform, high grade carbon, which will burn uniformly without blacking the globe and which will fit closely and move freely in the enclosing globe, thus preventing an unnecessary admission of air which reduces the life of the carbons. The quality of carbons used allows the clutch to operate directly upon the carbon and not through the medium of the objectionable carbon rod or chain, thus simplifying and reducing the length of the lamp, which fact renders it useful in low ceiling rooms.

Since the voltage of the circuit is constant, this lamp will regulate by a variation of current; thus requiring a series coil to regulate the feeding and to strike the arc when the current is turned on. When the voltage is switched onto the lamp, the rush of current through the series coil will cause the carbons to be separated a predetermined distance, depending upon the voltage of the arc. As the carbons burn away the current will reduce, allowing the magnetism to decrease and the carbons to descend to a point where the current will increase again and the magnet will draw the carbons farther apart. This operation is

continued within the limits of the adjustment of the mechanism.

A direct current lamp, used on a 110-volt circuit, will require a current of 5 amperes at 75 or 80 volts at the arc, and no change in adjustment will be necessary for not more than a 5-volt variation.

A direct current lamp used on a 220-volt circuit will require a current of 2.5 amperes at 135 volts at the arc. On account of its violent rays, this lamp is sometimes objectionable for indoor use, but this fault may be obviated by connecting two 110-volt lamps in series or by using a globe, composed of two layers of glass, one of which is clear and the other opalescent. The combination of these two layers of glass acts upon the violet rays and turns them into white light but with a material loss of intensity.

In the constant potential lamp it is always necessary for its successful operation, to have a constant resistance in the series with the arc, to maintain a constant current, and therefore the same intensity of light. In the constant current series lamp it is necessary to keep a constant voltage at the arc for the same reason; or, in other words, the energy or watts expended in the arc must be constant to obtain a uniform light. The resistance is also necessary to prevent an excess of current on starting up the lamp when the carbons are together. The resistance is not for the purpose of reducing the voltage of the line to that of the arc, as is sometimes supposed, but it is necessary for the successful operation of the lamp as mentioned before. As the carbons burn away, the current will decrease slightly and require an increase of voltage to maintain a constant current; this decrease in current will cause a decrease in the drop across the constant resistance, and since the line voltage remains constant, this decrease of voltage across the resistance will cause an increase of voltage across the arc and therefore increase the current slightly. This will continue until the clutch which holds the carbon is allowed to feed, thus increasing the current enough to energize the series coil so that it will draw the carbons apart to the proper length of arc as before. Take for example, the following case of an enclosed arc which burns at 80 volts and 5 amperes on a 110-volt circuit. If the arc burns away so that it requires 81 volts, due to its increased length and resistance, the current will decrease in proportion and therefore the drop across the constant

resistance of 6 ohms will decrease to 29 volts, and supply the necessary volts for the arc. In actual operation the amount and rate of variation of voltage will be very small and the lamp will burn on a variation of voltage from 75 to 85 volts at the arc.

Suppose we put this lamp that requires 80 volts across a 100-volt circuit, which may appear feasible at first sight. As the carbons burn away the resistance of the arc will increase and require more voltage to force the current through it; but since there is little or no resistance in series with it, the current will decrease at a very rapid rate and again increase rapidly, due to the shortening of the arc in feeding; this will cause the lamp to chatter and flicker constantly.

Where a 110-volt lamp is used on a 100-volt circuit, a part of the resistance should be cut out or short-circuited until the remaining resistance will take up about 25 volts when the current is at 5 amperes. When the voltage is 120, more resistance should be inserted, until it takes up about 40 volts at 5 amperes.

Alternating arc lamps differ from direct current lamps, in that while the poles are changing from positive to negative, the rate of consumption of the upper and lower carbons is nearly equal and the distribution of light is nearly the same above the horizontal drawn through the arc, as it is below it; while in the direct current lamp a large percentage of the light is below the horizontal.

Good results have been obtained with the alternating enclosed arc lamp allowing the frequency to be increased without objectionable humming, the arc to be maintained at a higher voltage, and an increased life of carbons. Two forms of regulating magnets for alternating lamps are in use; one depending upon the magnetic attraction of the armature, as in the direct current lamp, and the other upon the repulsion of an aluminum armature. This repulsion type of lamp will work satisfactorily on circuits varying from 90 to 115 volts and a frequency from 60 to 133 cycles per second, without any change in the adjustment of the regulating mechanism whatever, and the only change required in the lamp to accommodate the particular conditions between these limits, is to vary the number of turns on the choke coil, in series with the arc. This choke coil answers the same purpose as the resistance does in the case of the direct current constant potential lamp.

One of the greatest difficulties with alternating arc lamps is to prevent excessive noise or humming of the lamp parts at high frequencies. This is sometimes due to the enclosing globe not fitting properly.

The constant potential lamp, used in series with one or more lamps on a constant potential circuit, requires an individual regulation and must therefore be shunt controlled as in the constant current series lamp. If they were series-controlled a variation of current in one lamp would effect all the others. In this type of lamp the carbons are held apart by a spring or weight, acting in opposition to a high resistance magnet in shunt with the arc. When the current is turned on the voltage of the line is sufficient to energize the shunt coils so that they will bring the carbons together and draw the arc, the method of regulation then being similar to the constant current series lamp, except that all the lamps must be on at once. This method of striking the arc could not be used on a series circuit with all the carbons separated and the shunt coils in series on a constant current machine

If one lamp of a series draws a longer arc than the others in the same series, more of the resistance should be cut into that lamp and an equal amount cut out of the other lamp of the same series, if a series of two lamps; and if a series of more than two lamps, the amount cut out must be divided between the other lamps so that the remaining lamps will each burn proportionally higher, while the lamp that has more resistance cut in will burn more.

If one lamp burns with a lower voltage at the arc than the rest of the series, it can be raised by cutting out a part of its resistance and adding the same amount to the other lamp (or lamps, if more than one) of the same series. A dash-pot of some kind seems to be necessary to keep the working parts stable; this may be a separate plunger in air or the tight-fitting, central armature in a single solenoid lamp. When the arc is struck the carbon rod and those parts connected to it come up with such a force as to have considerable momentum, which tends to carry the carbon farther than intended, and if its progress is arrested suddenly, this momentum will be reversed and tend to send the carbon back, shorten the arc, and cause the carbons to be drawn apart again and repeat the operation as be-

fore; consequently the lamp will chatter, varying the current or voltage so as to produce a flickering light.

In installing constant potential lamps, a reliable fuse, which will safely carry the normal current of the lamp but which will blow at twice this current, should be connected in series with each lamp or series of lamps. This will insure safety from overheating of the regulating solenoid of the lamp, in case of a short circuit, or failure of the lamp mechanism to operate properly at any time; it will also serve to protect the mains leading to the lamp from the effects of abnormal current.

The main object in adjusting an arc lamp is to get it to pick up and feed properly at the correct voltage or current.

The system of forces acting in an arc lamp should always be in a balanced state, so that a small change in one will cause a correspondingly small change in the other elements, and consequently cause a delicate and active feed. The forces usually consist of an electro-magnet or magnets, and a spring or gravity. The relative value between the forces is shown by pulling down on the carbon rod where the lamp is burning; this tension will show the difference between the strength of the regulating magnet and the opposing force, and also that the opposing force is greater. If the rod pulls down too hard it shows that the voltage of the arc will have to increase considerably before the strength of the regulating magnet becomes equal to that of the opposing force and allows the lamp to feed. This tension, shown by pulling down the carbon rod, is an indication of the adjustment of the lamp and one soon learns from experience, the voltage at which the lamp will feed. The adjustment should not be too delicate or the lamp will be too unstable and will not pick up properly every time.

Another indication of the adjustment of an open arc lamp and of the voltage at which it is burning, is the shadow of an opalescent globe. If the arc hisses and the shadow is of a muddy color, the voltage is too low and the length of the arc on picking up, should be increased. All open arc lamps will hiss when first feeding but should not continue to do so. If the shadow is of a blue color the voltage is too high and the arc should be shortened. The lamp may pick up too high or it may feed too high, the proper voltage being shown by a clear globe with no shadows while it is burning.

The shadow should be in the upper part of the globe when the lamp is connected up properly, or, when cutting out the lamp the upper carbon should be red-hot.

The shadows are sometimes due to the size of the carbon. A smaller carbon will give a steadier light because the arc does not have to travel around so much, but will not last so long.

It sometimes becomes necessary, after lamps have been in use for a considerable length of time, especially when used for street-lighting, to clean, repair and readjust them. After the cleaning and repairing has been done, it is necessary that the lamp be tested and readjusted, as experience shows that whenever even one new part has been put into the lamp without being tested, it has caused trouble, and it is therefore always advisable that the lamp should be tested before putting it into use again. A careful examination should be made of all parts to see that the armatures are central with the cores and that they come down squarely and evenly, and that the carbons are accurately centered. When the top carbon rod is drawn up by hand, the lamp should cut out promptly and not "flash" the generator. In case the arc is very long or causes flashing, look at the contacts and see that they are clean and make a good square contact; also examine the centering of the armature. The cause of the trouble will usually be found in one of these places. The action of a bad feeding lamp may often be confounded with that of a bad flaming carbon; this can be readily distinguished after a few minutes' observation. The arc of a bad feeding lamp will gradually grow long until it flames, the clutch will let go suddenly, the top carbon will fall until it touches the lower carbon, and then pick up. A bad carbon may burn nicely and feed evenly until a bad spot in the carbon is reached, when the arc will suddenly become long, flame and smoke, due to impurities in the carbon. Instead of dropping, as in the former case, the top carbon will feed to its correct position to the limit of the clutch. The lamps rarely burn as well when first started as afterwards; this is principally due to the fact that the carbons require a little time to burn to the proper shape.

Do not imagine that every time a lamp hisses or flames a little that it is out of adjustment. As a rule, bad working is due to stickiness of the moving parts or to poor carbons. The

lamps once properly adjusted and operated with good carbons, should not get out of adjustment and should be left alone in that respect.

In some forms of enclosed arc lamps the return current passes from the lower carbon to the line by one or two rods of the frame, and the magnetic influence of the current is not balanced and consequently the arc is blown to one side of the carbons, causing them to burn obliquely and producing unsteadiness of the arc and objectionable shadows. In some forms of lamps the current returns through three side rods, equidistant from each other. The joint magnetic action of the current flowing through these three rods holds in balance the arc and the carbons burn evenly.

The consumption of the carbon is due to volatilization and oxidation of the upper carbon and oxidation of the lower. The rate of consumption of the lower carbon is about one-half that of the upper; this is due to the fact that it is at a higher temperature and also that it may deposit some of the carbon particles on the lower carbon rod. In the enclosed arc lamp the life of the carbon is longer, since the admission of air is slower and consequently the oxidation is reduced; while in the open arc the consumption is very rapid, due to the unlimited supply of air. In the former two gases are formed—carbon monoxide and carbon dioxide—which, when retained in the inner globe, attain a pressure higher than that of the atmosphere and therefore prevent a free admission of oxygen. In the open arc the upper carbon burns at the rate of about one inch per hour, while in the enclosed arc it burns at the rate of about one inch in twenty hours. The life of carbons in the alternating lamps is not quite as long as in direct current lamps.

Series arc lamps used on high potential alternating current circuits are now practical, and sometimes require a separate regulator for the system when the number of lamps in the circuit varies.

For a number of lamps operated on a constant potential alternating circuit a system has been perfected in which no regulating device of any kind is necessary outside of the lamp itself. Each lamp is self-regulating. The position of the armature core in the series magnet is depended upon to vary the impedance of the circuit. The lamp operates with 425 actual

watts at the arc on a current of 6.6 amperes at about 70 volts. Each lamp of the series is provided with an automatic cut-out, which upon extinguishing the lamp introduces a choke coil into the circuit consuming about 35 watts of energy. When a lamp is thus automatically cut out the remaining lamps of the series are not interfered with in any way.

A condenser connected around an alternating lamp may improve the regulation of the lamp and increase the power factors of the system. A suitable condenser for this purpose has not yet been found. Existing types are too large and expensive for practical use.

THE TROPENAS STEEL PROCESS.

BY EDWARD L. ADAMS, '96, THE SARGENT CO., CHICAGO ILL.

A great development has taken place within the past few years, in the application of steel castings to machine construction in lieu of forgings or castings of other metals. This has been due to a number of valuable characteristics of steel castings, which make their use suitable to a large variety of work. Chief among these features is the ability to obtain a metal of high tensile strength and ductility, in shapes difficult or impracticable to forge, and at a price in most cases lower than that of a forging. Machine parts formerly made in cast or wrought iron can be considerably reduced in weight by the substitution of steel. This fact has been appreciated by the railroad companies in particular, as applied to locomotives and car designs. As an instance of this, a reduction in weight of nearly four tons was made on a passenger locomotive by the substitution of steel castings for forgings and iron castings. Steel castings can also be made of high magnetic permeability, and have therefore been largely adopted by manufacturers of electrical machinery.

Steel for castings is now made by the three following processes or modifications of them: 1. The open hearth process. 2. The crucible process. 3. The Bessemer process. These will be discussed in relation to their application to the manufacture of small steel castings weighing from a few ounces to several pounds, the economical manufacture of which demands certain special characteristics of the molten metal over that employed for larger castings.

The open hearth process is particularly suited for the manufacture of large castings, owing to the comparative cheapness and uniformity of the melted metal. In making small castings of thin section, it is essential that the metal be very hot and fluid as it is poured into the mould, since molten steel cools with great rapidity and will otherwise not completely fill up the mould. It is commercially impracticable to make small castings from open hearth steel on account of the large amount of metal which would be lost by skulls in the ladles and by bad castings. Moreover, as ordinarily operated, the capacity of the furnace ranges from eight tons upward and this must all be tapped at one time. These facts necessitate having the pouring floor set with moulds to the capacity of the heat and thus in the manufacture of small castings a very large pouring floor is required.

Small castings are made very satisfactorily from crucible steel. The objections raised to this process are its high cost of operation and the large equipment required in proportion to the tonnage of material manufactured.

The Bessemer process recommends itself for a number of reasons as an acceptable method of producing steel for small castings. Presuming that a sufficiently hot and quiet steel of the proper quality can be obtained, one of the greatest advantages it offers is the elasticity in the quantity of its product. With a converter of, say, two tons capacity the output may be governed by the fluctuations in orders, or by the capacity of the moulding and pouring floors. The open hearth furnace, to be worked economically, must be run day and night in order to avoid the loss in gas and labor entailed in keeping the furnace hot while idle. But with the converter process, the principal sources of expense are stopped when the pouring is finished.

In order to obtain sufficiently hot steel by the Bessemer process, a number of modifications have been made in the original

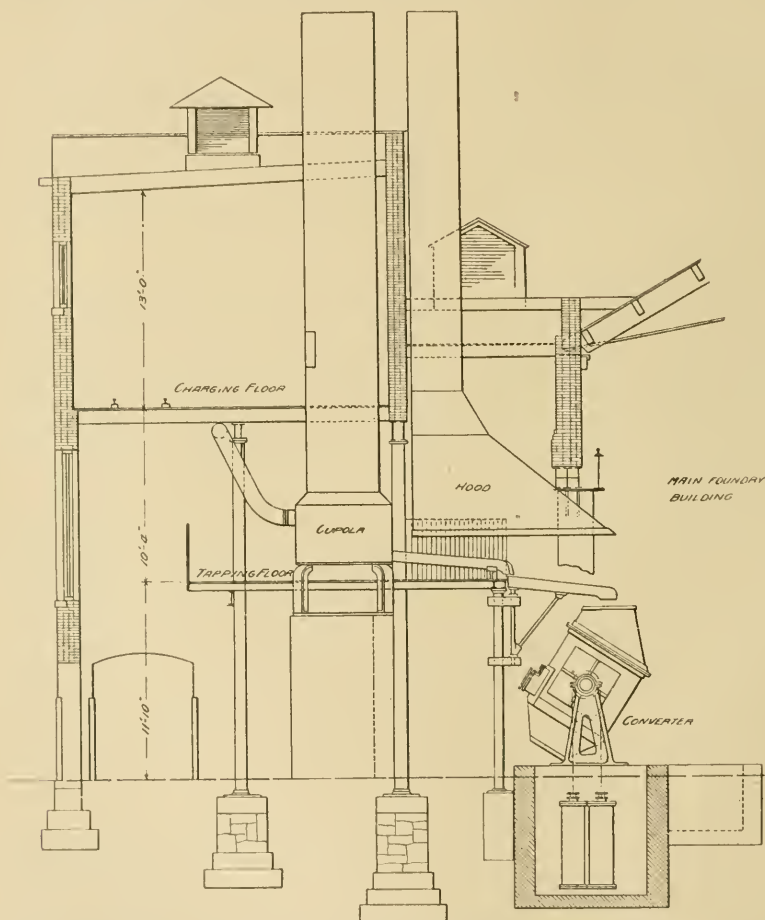
process, by variations in the method or place of introducing the blast. The best known of these methods are the Robert, the Walrand-Legenisel, and the Tropenas processes,—named after their inventors. In the Robert process, the blast is introduced on the side of the converter, while in the Tropenas, the blast is directed upon the surface of the bath. The Walrand-Legenisel process makes use of much smaller charges than the other two, and the blast is delivered in the ordinary way, at the bottom of the vessel. As to the success with which these various processes have fulfilled the practical requirements demanded of them—for uniform quality and cheapness of output,—it may be stated that the first two processes named have not met with the general approval which the claims put forth for them would warrant. The Tropenas process, though only recently introduced into the United States, is now being operated here in a number of foundries.

The largest installation of the Tropenas process in this country is at the works of The Sargent Company at Chicago Heights, Illinois. In this plant three converters of a capacity of two tons per blow, each give a total daily output of 50 tons. The accompanying drawings and photograph show the general arrangement of the converters, cupolas, and operating machinery.

The steel foundry-building covers a floor space 50 feet wide by 200 feet long, served by two electric traveling cranes. The three converters are placed in a row in an opening in the side wall at the south end of the main building. Behind these converters, in a separate addition erected for the purpose, are two cupolas which furnish the melted pig iron and scrap from which the steel is made. The cupolas are set on high foundations, and deliver the melted metal to the converters by gravity through hinged spouts which can be turned out of the way during the time of the blow.

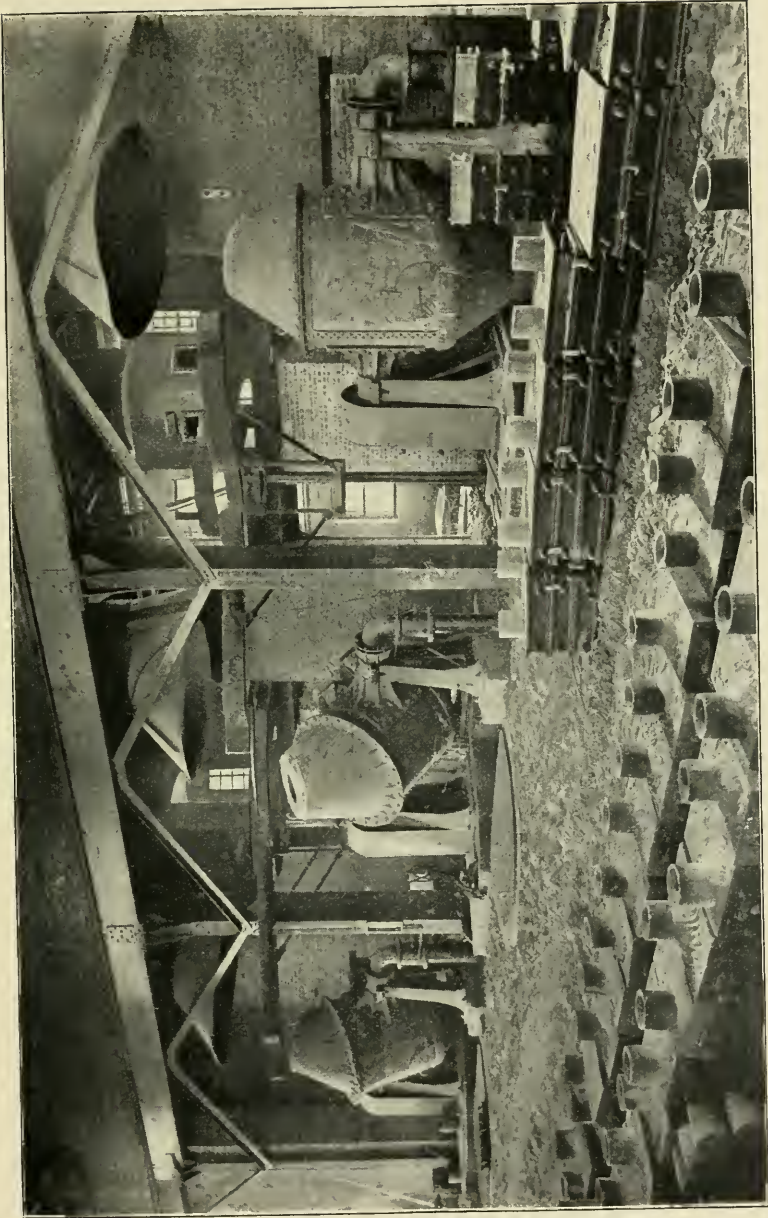
The converter is lined with ganister, and consists of a shell of $\frac{5}{8}$ -inch steel plate fitted with two hollow trunnions supported on pedestals. By means of the trunnions the converter may be tilted as desired for charging, for blowing, or for pouring the steel into the ladles. One of the trunnions is connected with the wind pipe from the blower, and conducts the blast to the wind boxes at the rear of the converter. On the converter trun-

nion opposite to that delivering the blast, a large sprocket wheel is fitted, over which passes a chain fastened to two pistons working in a pair of cylinders placed side by side in a pit below the floor line. This apparatus, operated by hydraulic power and controlled by valves at the blowing platform, furnishes the means of tilting the converter. The hydraulic pump, accumulator, etc., are situated in an adjoining room.

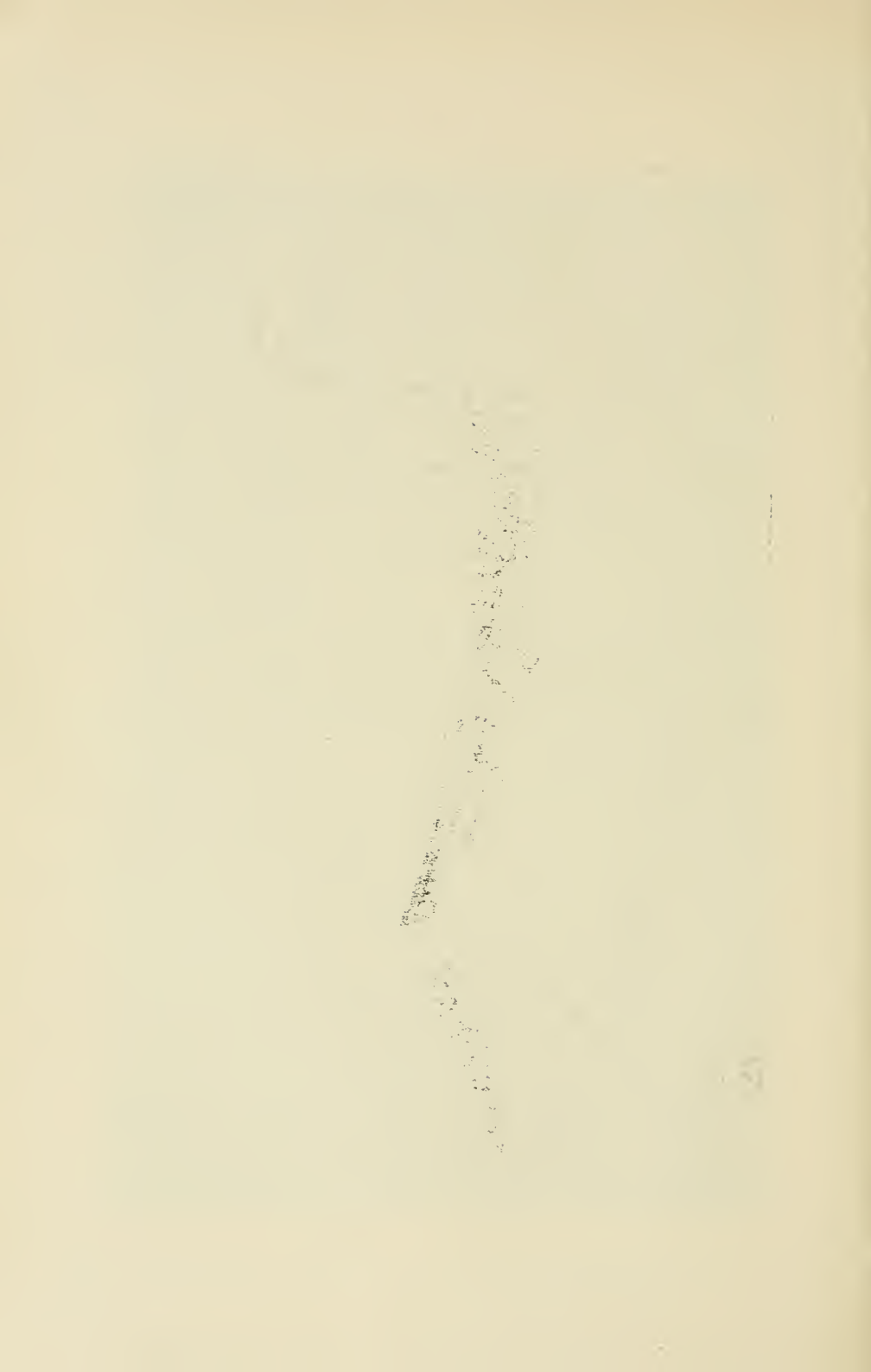


SECTION THROUGH CUPOLA ROOM SHOWING TROPENAS CONVERTER IN THE STEEL FOUNDRY OF THE SARGENT COMPANY.

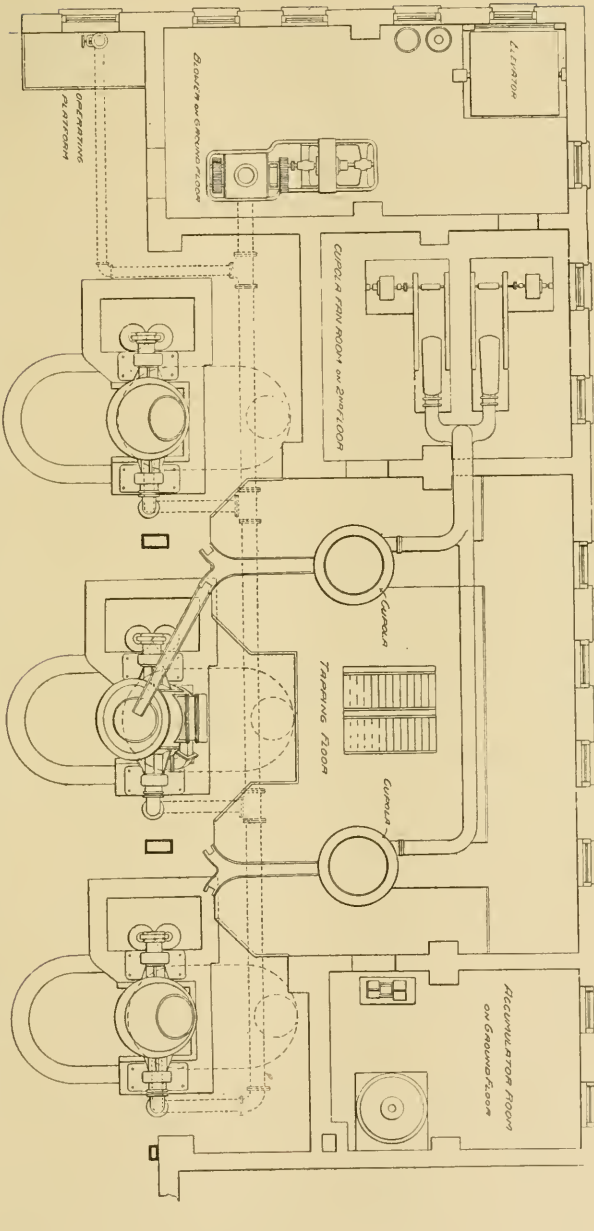
The air blast is obtained from a Root's rotary positive-pressure blower directly connected to a 65 H. P. motor. This blast



TROPENAS CONVERTERS IN THE STEEL FOUNDRY OF THE SARGENT COMPANY.



PLAN SHOWING TROPENAS CONVERTERS IN THE STEEL FOUNDRY OF THE SARGENT COMPANY.



is delivered to the converters through a twelve-inch main at a maximum pressure of $4\frac{1}{2}$ pounds per square inch. The pressure of the blast is regulated at the blowing platform by means of a gate valve on an 8-inch by-pass from the main air pipe. The quantity of compressed air required is from 770 to 880 cubic feet per minute per ton of pig iron treated.

The arrangement of the tuyeres is the chief peculiarity of the Tropenas over the other so-called "Baby" Bessemer processes. The wind boxes previously mentioned are independent of each other. The lower wind box connects with a row of horizontal round tuyeres known as "fining" tuyeres or "tuyeres of reaction," placed in a lining above the position of the surface of the bath. The upper wind box opens into a row of flattened tuyeres of a smaller section than that of the lower ones and about six inches above them. These tuyeres are known as "tuyeres of combustion." The blast for the upper tuyeres can be operated independently of the lower tuyeres. All the tuyeres are placed in the horizontal plane in order to prevent the blast from causing any gyratory action on the bath.

In the Walrand-Legenisel process, the air is blown through the bath at a considerably greater pressure than that used in the Tropenas process, and the metal is placed in a violent state of ebullition. The aim of the Tropenas process is to keep the bath as quiet as possible, the claim of the inventor being that "the most impure steel manufactured by the pneumatic process is that produced from a bath which has received the largest amount of churning in its molten state." For the same reason also the shape of the lining is such that the surface of the bath exposed to the blast is small in comparison with the quantity of metal in the bath.

The operation of the converter is as follows: The pig iron and scrap are first melted in the cupola. The chemical analysis of the pig iron employed is within the following limits:

Silicon . . from 2.50 to 3.50 per cent.

Manganese . from 0.50 to 1.25 per cent.

Carbon . . from 3.00 to 4.50 per cent.

The phosphorus and sulphur contents should be as low as possible, the sulphur not exceeding 0.06 per cent. and the phosphorus 0.07 per cent. The proportion of scrap which can be charged with the pig iron varies with the analysis of the pig

iron. Before the converters can receive the melted iron, its lining must be brought up to a high heat. This is done by means of an oil flame. When the proper amount of iron has been tapped into the converter, the blast is turned on in the lower tuyeres and the converter is turned up so as to bring the lower tuyeres just above the surface of the blast.

The complete operation of the blow is divided into three periods, the whole blow taking from 16 to 22 minutes, depending upon the quality of the metal charged. *The first period* is the time during which the silicon is being oxidized, and lasts until the carbon begins to become oxidized. In a normal blow, this period lasts from four to eight minutes, during which time about $4\frac{1}{2}$ pounds air pressure is carried and the upper tuyeres are not used. *The second period* commences when the carbon flame is well up above the mouth of the converter. The pressure is then reduced to 3 pounds and kept at that point until the carbon flame is perfectly white, when the upper tuyere valve is opened and the pressure is again slightly reduced. The second period is the boiling point and lasts from four to eight minutes. At the end of this period, the flame drops rather suddenly. In *the third period*, the blast is gradually increased and the flame again increases and fluctuates and finally begins to turn red, first at the top of the flame and then at the edges. At this point the blow is finished, the converter is lowered, and the blast turned off. There now remains in the converter a bath of nearly pure iron. The proper proportions of the carbon, manganese, and silicon contents of the steel required are brought up by additions of ferro-manganese or ferro-silicon, or both of these, to the bath in the converter and the metal is poured into the ladles as required. By changing the proportion of the final additions or "dose," steel may be obtained varying in quality from the softest to the hardest grades.

By the use of the upper tuyeres, the carbon monoxide liberated from the bath, is changed to carbonic acid gas, which adds to the temperature of the steel without increasing its cost. The steel thus obtained is very hot and fluid. The high temperature attained during conversion is mainly produced by the burning out of the carbon, manganese, and silicon. The iron charged into the converter has a temperature of about 2300° F., which is raised to about 3100° F. during the period of the blow. The

silicon furnishes the fuel for most of this rise in temperature, it being estimated that each one per cent of silicon thus burned is equivalent to a rise in the temperature of the bath of 500° F. As previously stated, the bath at the end of the blow before the dose is added, is nearly pure iron. Samples of this metal have shown on analysis only 0.20 to 0.25 of one per cent of impurities. From this metal castings may be produced of great magnetic permeability approximating that of Swedish iron.

In respect to the physical qualities of the steel produced by the Tropenas process high results have been obtained from tests. Tests made upon annealed specimens have shown 65000 pounds tensile strength per square inch, with an elongation in 2 inches of 35 per cent and a reduction in area of 40 per cent.

Among the factors tending to militate against the commercial success of the Tropenas Process are its complexity and the waste of metal during the operation. This loss in cupola and converter runs from 17 per cent. up.

A TOPOGRAPHICAL SURVEY OF THE RESERVOIR SYSTEM AT THE HEADWATERS OF THE MISSISSIPPI RIVER:

BY W. C. LEMEN, '95, TOPOGRAPHER, U. S. ENGINEER'S OFFICE, ST. PAUL,
MINN.

Surveys showing the detail configurations of a stretch of country are becoming more frequent as their advantages for a comprehensive study of the country shown, are better understood. A description of such a survey, covering approximately 600 square miles of territory, made with a degree of accuracy and detail used heretofore only in cities and on small areas, will possibly be of interest to students and engineers. Only an outline of the method, which contains some new features in topographical work, can be given. The results attained in the field work must be taken as approximate and not final, since a final discussion and report on the survey can not at present be made.

Before describing the survey itself, however, a brief history, giving the steps leading up to the creation of this reservoir system and certain general data as to its use, is thought will be of interest and will give the reader a better idea of the extent and object of a topographical survey of the reservoir system.

HISTORY OF, AND DATA RELATIVE TO, THE RESERVOIRS.—Reservoirs at the headwaters of the Mississippi River have, for some thirty years, had the attention and consideration of Congress through the army engineers. In 1869 a reconnaissance survey of the Mississippi Basin above St. Paul, Minn., was made under the direction of the U. S. Engineer's Office at St. Paul by a Mr. Cook of Minneapolis, but was paid for by private milling interests. This reconnaissance led to a survey by the general government in 1874 under Maj. F. W. Farquhar which was completed in four months' time. From this survey was obtained the area of the lakes and rivers, the probable flowage lines, the elevation of the lakes, and the slope of the river. Some gaging were made.

Following closely came the project for a reservoir system, under which the work was finally completed. The wording of the law providing for the reservoir system is: "the construction and maintenance of reservoirs, at the headwaters of the Mississippi River in the State of Minnesota, for the purpose of collecting the surface water, principally from precipitation in winter, spring, and early summer, to be systematically released so as to benefit navigation upon the Mississippi River below the dams and as far down as Lake Pepin. Reduction of heights of floods in the vicinity immediately below the dams is expected to obtain to some extent, but control of extended floods or freshets is not expected." No idea is here entertained of ever effecting the low water stages of the Lower Mississippi River, as many have erroneously thought and who have consequently considered the reservoir system to be a failure. Traffic on the Mississippi above St. Paul consists principally of large quantities of logs, which are floated to market. In 1896 this was given as in excess of 1 000 000 tons, and it is constantly growing. Steamboat navigation is only possible on certain stretches of the river.

Up to the present time five reservoirs have been built, the first four between 1881 and 1884, and the last was completed in

1895. Table I. gives some interesting data concerning these reservoirs. Up to June 30, 1896, the cost of this reservoir system has been \$8.78 per million cubic feet storage capacity. Of ten other reservoirs in United States, corresponding figures are: least \$50.73, greatest \$938.70.

TABLE I.

DATA CONCERNING RESERVOIRS AT THE HEAD OF THE MISSISSIPPI RIVER.

| Reservoir | Areas in Square Miles | | | | Capacity Cu. Ft. | Length in Feet | | | Height of Dam, Feet | Material in Dam |
|-----------------------------|-----------------------|---------------|--------------|----------|---------------------|----------------|----------------------|---------|------------------------|-----------------|
| | Watershed | High Water | Low Water | Overflow | | Dam | Embank' ^a | Overall | | |
| Winnibigoshish <i>a</i> ... | 1442.5 | 161.26 | 117.00 | 44.26 | 45024000000 | 114 | 000 | 114 | 25 | Concrete |
| Leech Lake..... | 116.0 | 233.80 | 173.19 | 60.61 | 33094000000 | 448 | 3152 | 3600 | 12 | Concrete |
| Pokegama <i>b</i> | 669.0 | 45.29 | 24.13 | 21.16 | 47000000000 | 232 | 378 | 610 | 9 | Timber |
| Pine River..... | 562.0 | 23.76 | 18.30 | 5.46 | 75000000000 | 235 | 440 | 675 | 20 | Timber |
| Sandy Lake..... | 421.5 | 16.52 | 8.00 | 8.52 | 31580000000 | 125 | 650 | 775 | 11 | Timber |
| Totals..... | 3202.0 | 480.63 | 340.62 | 140.01 | 93476000000 | | | | | |

a.—Includes Cut Foot, Sioux, and Cass Lakes.

b.—Includes White Oak, and Ball Club Lakes. Pokegama proper is only about half the area given.

The watershed of the Mississippi River above St. Paul is 36 081 square miles. The average yearly rainfall is 27 inches. Evaporation on the lake surface is about equal to the rainfall. The average run off for the years 1885–1895 was 15.9 per cent counting the lake areas, and 19.4 per cent not counting the lake areas. To determine this meteorological and hydrological observations were made at the three upper dams.

The average low water discharge for the summer season at St. Paul is 5 000 cubic feet per second. If all the reservoirs were full, their combined capacity is sufficient to maintain a flow of another 5 000 cubic feet per second for seven months of the year. In 1885 they did add an average of 2 000 cubic feet per second for 76 days during the low water season from August to November. This flow raised the water at St. Paul 1½ feet, and the effect of same disappeared at Winona, Minn., some miles below Lake Pepin, the prescribed lower limits in the project. Up to 1897 these results were steadily improved. During that year enough water was collected to double the average low water flow at St. Paul for five months. Since then very little water has been held in Leech Lake and Winnibigoshish Reservoirs owing to the weakness of the dams. These were

originally built of timber, but are now being replaced by concrete structures.

Those interested in the history or description of reservoir system or of the discharge of the Mississippi River above St. Paul, will find much of value in the Annual Reports of the Chief of Engineer's, U. S. A., as follows: 1892, p. 1824; 1893, pp. 2264-2289; 1894, p. 1733; 1895, p. 2203; 1896, pp. 1830, 1841, 1859; 1897, pp. 2138, 2142, 2264; 1898, pp. 1812, 1816, 1831; 1899, pp. 2182, 2227; 1900, pp. 2786, 2821.

OBJECT AND ADMINISTRATION OF SURVEY.—Shortly after the completion and first use of the dams, damage claims for overflowed lands were made. This had been expected, and some claims were paid. To determine what claims might justly be made a detailed topographical survey of the reservoir basins was started in June, 1899, under the direction of Maj. F. V. Abbott with Capt. A. O. Powell in personal supervision and T. M. Fowble and Horace Dunaway, '89, in charge of the two field parties. The writer was topographer in the later party, and can describe only the methods used under Mr. Dunaway, although in general the methods are the same in both parties. For much of the foregoing data and history thanks are due Mr. Dunaway.

Table I. shows the overflowed lands to be 140 square miles; to this may be added about 25 per cent. for the four feet extra which is taken above the flowage line, making a total of 175 square miles. Of this 107 is found in Leech Lake and Pokegama Reservoirs, and 25 square miles along Leech Lake River and Mud Lake. The 107 plus the 25 square miles, or 132 square miles in all, was to be surveyed by the party under Mr. Dunaway. It is stretched around 90 miles of shore line on Pokegama, 400 miles on Leech Lake, and along 50 miles of river valley, no account being taken of the winding of the river. Upon the reservoir basins 2-foot contour intervals were used; upon some 30 square miles below Leech Lake Dam, the country lying between the reservoirs and carrying the flood water from the upper reservoirs, 1-foot contour intervals are used.

Considering the extent of the country and the detail with which this work is being done, this survey is the largest of its kind that has ever been undertaken, so far as the writer can learn. About half of the field work and one-third of the mapping has been completed.

The reservoir system is glacial drift formation with very little symmetry in its drainage. It abounds in large tamarack and spruce swamps, cranberry marshes, hay meadow bogs, innumerable lakes of all sizes, and on the high ground heavy pine timber. The high ground is very broken presenting the appearance of an immense honey comb. This forms a tedious and most exasperating country in which to take topography, for when your swamp has been nearly circled you often discover in its center a number of pine covered knolls. These are surrounded by an almost impassable swamp, to go through which means to set the instrument upon stakes 1 to 6 feet in length, the observer standing in swamp-bog and water knee-deep. The high ground or knolls are covered with pines or the stumps of those noble trees. If the latter be the case, they are overgrown with a second growth of poplar filled in with hazelnut, tagalder, and poplar brush. This undergrowth, troublesome in winter, is simply impenetrable 5 feet by the eye in the summer. Heavy windfalls, caused by tornadoes or fires, are often met both on the high ground and in the swamps. In these windfalls, trees lay piled upon each other so as to make it necessary to travel in the air, or correctly speaking, in the tree tops. Winter time has its advantages for taking topography in such country.

Ice in those places does not leave the ground entirely until sometime in August unless heavy rains occur.

RELATIVE IMPORTANCE OF DIFFERENT FEATURES.—The relative importance of the different features of this survey should perhaps be touched upon. Exact elevations are of primary importance, especially on all stadia lines. Water will seek its level regardless of whether the engineer says it ought or ought not to go over such and such a divide; therefore every loop hole of the basin must be accurately tested. For this reason the modifications in the usual method of carrying elevations in stadia work, described further on, were made. While a main line of levels was carried from one reservoir to another, there are established bench marks at Pokegama and Leech Lake Dams, whose relative heights to the water in the reservoirs and flowage lines of reservoirs are known; their height above sea level has been determined only by a long line of ordinary levels.

Second in importance is the location of all section and quar-

ter section corners which bear any relation to the overflowed lands. Horizontal position, while necessary within reasonable limits, need not be precise, since a location relative to the section corners is desirable. Lastly, all topographical features should be taken, especially kind of timber, soil, cultivation, and any facts which may aid in estimating any damage by overflow.

LEVELS.—A double duplicate line of ordinary levels was run from one reservoir to another, upon which all topography elevations are based. Elevations were carried about the lakes by water levels. The closures on this line was well within the usual limit of 0.05 ft. $\sqrt{\text{dist. in miles}}$.

In this work an original method of duplicating a line while running in one direction was used. A 12-foot, self-reading rod, graduated to hundredths of a foot was used, being read to nearest half hundredth. The rod was first read direct on the turning point, then reversed end forend and read from the top down. Thus two lines were carried along, which should remain exactly 12 feet apart. All accidental errors were eliminated. Notes for one line were kept on the left hand page and for the other on the right hand page. A level party usually consisted of an observer, a recorder, and two rodmen. In heavy cutting an extra man was added.

SECTION CORNERS.—The location of these corners calls for some long stadia lines and forms a considerable part of the field work. A great deal of patience, perseverance, a knowledge of woodcraft and a quick eye are needed in discovering what now remains of these corners. The land survey of this country was made between 1869 and 1875. The original corner stakes are sometimes found in the swamps still in fair preservation.

GEOGRAPHICAL POSITION.—The azimuth and horizontal positions are carried by tertiary triangulation supplemented by a chained traverse line. The targets for all triangulation points were peeled poles with red and white flags for finders. A transit, reading directly to 20 seconds and by estimation to 10 seconds, set over the holes of the poles, was used in reading angles, four readings of the angles being made. The limit for the error of closure of triangles is 30 seconds, though this limit is rarely reached, an average closure being about 10 seconds. Sides of triangles range from 500 feet to 3 miles in length

On base lines, which are put in about every 6 miles or when work progresses from one township to another, closures of 1 in 500 in length and 1 minute in azimuth, after correcting for westing, are required. In all chaining a 300-foot steel tape is used. Fifteen pounds tension is put on the tape with a small spring balance. Corrections for difference in elevation of base stations, where necessary, and for difference of temperature are made on the base lines.

Azimuth observations are made upon Polaris along one side of the triangulation, preferable on the base line. A new azimuth is obtained for each township. These observations are made at any convenient time, and the azimuth of Polaris deduced from a table found in "Manual of Instruction" issued by the Commissioner of the General Land Office in 1890.

Permanent marks are left in pairs about every 2 miles at the triangulation points. A known azimuth is therefore always available at almost any point in the system for future work. These marks consist of a limestone slab about 4 inches \times 14 inches \times 18 inches with a copper bolt leaded in it, buried about 3 feet in the ground, surmounted by a 4-inch iron pipe 4 feet long. On top of the pipe is a removable iron cap fastened by brass burrs so a reading on the copper bolt is obtainable. The foot of the pipe is split and flared out to about 8 inches in diameter. This prevents any one pulling it up and keeps it from being heaved by the frost. The cap bears letters and figures indicating the bench mark's use, date, and number. Its elevation is also known.

Upon this triangulation skeleton is laid the detailed topography.

TOPOGRAPHY.—The three main features to be obtained are the shore line, the flowage line of the reservoir, and the contour 4 feet above this flowage line. This additional 4 feet is taken to give a certain margin of safety and to give an idea of the country immediately adjacent to the reservoir. This limit is sometimes reached upon the immediate shore of the lake or river, but more often is obtained by a gentle slope through swamps and wind falls.

Stadia courses are run following out these particular features. Starting from some triangulation point they are closed on it or some other portion of the system. Long stadia lines are

avoided when possible, though some courses are 5 miles in length. An average line is about 2 miles. The allowed error of closure on these lines is 5 minutes in azimuth, 1 in 500 in distance, and 0.2 of a foot in elevation regardless of the length of line. Exceptions are made where lines are run through very soft swampy country or of extreme length. Stadia rods are 15 feet long, graduated to feet and tenths. Instrumental manipulations are the same as are used on all stadia work so far as the measurement of distance is concerned.

The ordinary methods of carrying elevations with the vertical circle, which is almost universally associated with stadia work, was not considered sufficiently accurate for the needs of this survey. In following out a contour the elevation of each point must be known as soon as a shot is taken, which is not practical by the ordinary methods. For these reasons the following modifications were made. Instead of a vertical circle, a bubble equal in delicacy to those upon good ordinary levels was placed on the transit and levels were carried with it. The principal of "a gradienter screw as a leveling instrument"* was applied, without the gradienter screw itself, to give sufficient range in elevation to cover the ground. This range of ground is from 8 to 13 feet, though sometimes greater heights have to be reached owing to the character of the high ground.

As long as the difference of elevation is insufficient to take the rod out of the field of the telescope, the carrying of elevations is simply a matter of plain leveling. If, however, the rod is above the height of the instrument, the telescope must be inclined and some method used to measure the angle of inclination or the amount of this inclination in feet at the point taken.

This method may best be explained by an example. Suppose the head rodman has his stake 1 000 feet away and 10 feet above the "height of the instrument" which for convenience in recording is called E. I. When the telescope is level, the middle wire is just 10 feet below the foot of the rod. Assume the telescope reads 1 foot on the rod for 100 feet on the ground. Now elevate the telescope with the tangent screw until the lower wire occupies the position the upper wire did when the telescope was level, which can be done by noting the posi-

* Baker's Engineers' Surveying Instruments, page 209.

tion of the upper wire with reference to some small object such as a twig, knot on a tree, etc. Now the middle wire has been raised just one interval and the rod being 1 000 feet away this interval is 10 feet at the stake, and the elevation of the forward stake is = E. I. + 10 feet - rod reading (0 in this case). The E. I. is always equal to the elevation of the stadia stake plus the Height of Instrument above the Back Sight. This operation may be repeated any number of times, within a certain limit, each operation adding the interval (10 feet in this case) to the E. I. One-half intervals may be read without inclining the telescope by reading the upper or lower wire instead of the middle wire. A sample page of the notebook is shown on page 41, which will further illustrate this method.

In case of a slope downwards, the operation is reversed bringing the upper wire to coincide with the position of the lower one, etc. This method has been called "Drop Elevations", though a raise is more often used, since there is less range up than down, due to being able to use the full length of rod going down hill. When ten raises have been made an error in the elevation due to the inclined sight, becomes 0.01 foot for every 100 feet; therefore an incline of this amount is avoided. Five raises in the main stadia line are all that is considered good practice; this number is not often required. Another accumulative error occurs where considerable change of focus is necessary in the operations, and change of focus should be avoided if possible. The principal accidental error is inaccurately placing the wires, which accumulates or multiplies when the focus is changed. By reading the elevations both forward and back on the main line, using the plumb bob string for a sight, a duplicate line of levels is carried. This duplication eliminates errors of adjustment, curvature and refraction, which with shots that are often 1 000 feet long, are considerable. Excellent results are obtained by this method, an average closure of 0.10 being obtained.

A topography party usually consists of an observer, a recorder and four rodmen. Extra men are added in heavy cutting.

PLOTTING AND MAPPING.—Stadia courses were closed by plotting them on a large protractor-sheet during the early part of the work, but this method is unsatisfactory owing to the necessary crudeness of plotting a long line of short courses. It

Right Hand Page.

Observer: W. C. Lemen
Recorder: Chas. Williams

September 1, 1900.

Instrument B. & B. No. 3075.
Locality: Walker, Minn.

| Object. | Ver. A | Ver. B | Distance | | Elev. due Vert. Angle | Diff. of Elev. or Rod Read'g | Elevation | Remarks |
|--------------|-----------|-----------|----------|----------------------|-----------------------------|------------------------------------|-----------|---|
| | | | Read | Corr'ted | | | | |
| | □ | 506 | | H. I. = | | Mean = | 1300.05 | |
| □ 505 | 280-06-00 | 100-06-30 | 1014 | ^a 1054 | 10.44 | -6.44 | 1311.29 | E. I. = $\left\{ \begin{array}{l} 1304.75 \\ 1304.75 \end{array} \right.$ |
| W. S. | 160.95 | | 305 | | | 11.95 | 1292.85 | Mean E. I. = 1304.80 |
| Pt. on slope | 161-05 | | 310 | | 6.20 | +2.95 | 1307.75 | |
| □ 507 | 150-28-30 | 330-28-00 | 562 | 568 | 2.81 | +0.69 | 1305.75 | |

a. Corrections to distances are due to the fact that the stadia wires do not subtend exactly 1 foot on the rod for 100 feet on the ground.

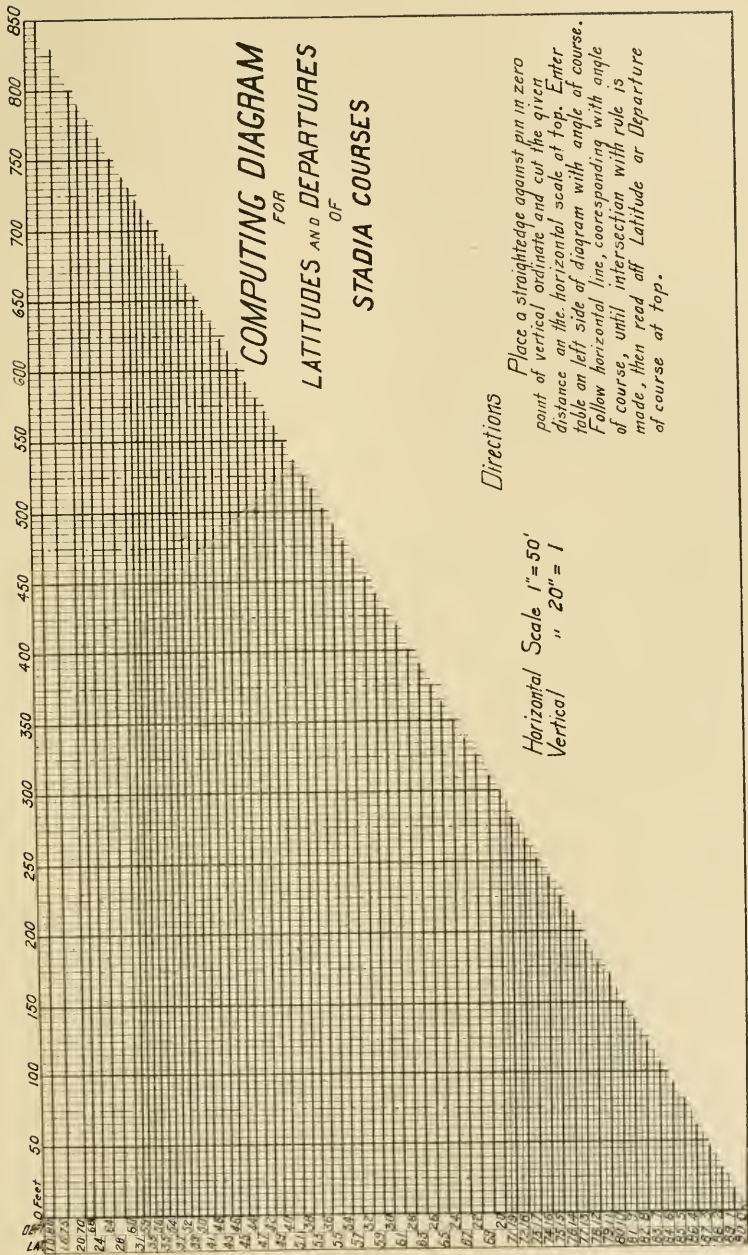
b. Index figures above readings indicate the number and direction of interval taken.

was therefore determined to compute the coördinates of all stadia stakes, the courses being closed before leaving the immediate vicinity. After several methods had been tried, among which was a "Trigonometer" made upon a 10-inch protractor circle, the diagram shown on page 43 was devised.

The Latitude of a course = distance \times $\cos. \alpha$, and the Departure of a course = distance \times $\sin. \alpha$, where α is the angle of deflection of the course from the true north and south line. By making the vertical ordinate unity and laying off on it the natural sines and cosines of all angles from 0° to 90° ; and laying the distance off on a line perpendicular to the unity ordinate, the multiplication may be performed graphically by following the directions given on the diagram. Care must be excised in laying off the natural functions on the unity ordinate, and the distance ordinate must be exactly perpendicular to it. The largest errors will be found in courses having a deflection angle close to 0° or 90° .

On a similar diagram, made upon the size indicated by the scales given, the horizontal scale running up to 1 200 feet, latitudes and departures are scaled off to the nearest foot, and courses are closed within the limit of 1 in 500 and often better. For greater distances than 1 200 feet, half the distance may be used, the results being doubled.

The scale of the map of this work is 1 inch to 800 feet. The triangulation points are plotted upon a rectangular projection. A complete sketch upon a small 8×10 inch sketch sheet is made of the ground in the field. Field plotting is done with a small half-circle celluloid protractor with a scale on the straight edge. The detail of the finished maps is filled in from these field sketches.



COMPUTING DIAGRAM
FOR
LATITUDES AND DEPARTURES
OF
STADIA COURSES

Directions

Place a straightedge against *mn* in zero point of vertical ordinate and cut the given distance on the horizontal scale at *top*. Enter table on left side of diagram with angle of course. Follow horizontal line, corresponding with angle of course, until intersection with rule is made, then read off Latitude or Departure of course at *top*.

Horizontal Scale 1" = 50'
Vertical " 20" = 1

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| 1.0 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 | 2.6 | 2.7 | 2.8 | 2.9 | 3.0 | 3.1 | 3.2 | 3.3 | 3.4 | 3.5 | 3.6 | 3.7 | 3.8 | 3.9 | 4.0 | 4.1 | 4.2 | 4.3 | 4.4 | 4.5 | 4.6 | 4.7 | 4.8 | 4.9 | 5.0 | 5.1 | 5.2 | 5.3 | 5.4 | 5.5 | 5.6 | 5.7 | 5.8 | 5.9 | 6.0 | 6.1 | 6.2 | 6.3 | 6.4 | 6.5 | 6.6 | 6.7 | 6.8 | 6.9 | 7.0 | 7.1 | 7.2 | 7.3 | 7.4 | 7.5 | 7.6 | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 | 8.2 | 8.3 | 8.4 | 8.5 | 8.6 | 8.7 | 8.8 | 8.9 | 9.0 | 9.1 | 9.2 | 9.3 | 9.4 | 9.5 | 9.6 | 9.7 | 9.8 | 9.9 | 10.0 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|

OIL ON RAILROADS AND WAGON ROADS.

BY D. S. HARRISON, CIVIL ENGINEERING, '01.

The use of crude oil on railways and highways is attracting the attention of the engineering profession all over the country. Oil was used primarily as a preventative of the destroying and disagreeable dust so frequently encountered on both wagon-roads and railroads. Its field, however, is by no means limited to that alone, as many advantages of its use have been discovered.

RAILROADS.

This invention is of considerable interest to the railroads, as the alleviation of the discomforts of travel is constantly receiving the attention of railroad officials.

The West Jersey and Seashore Division of the Pennsylvania Railroad was the first to introduce this use of oil, the first experiments being made in April, 1897. Patents had been issued to Mr. J. H. Nichol, Assistant Engineer of the Company, who originated the idea. The patent was issued for an Improvement in Railway Roadbeds, the ordinary roadbed, if dusty, being considered unfinished. "Competent counsel has advised that the patent covers the use of any liquid, except water, for the purpose."*

Some of the roads which have taken kindly to the innovation in the East are the Boston and Maine, Boston and Albany, and New York Central; and in the West, the Wisconsin Central, Burlington and Missouri, Chicago and Alton, and others.

The oil is a product of petroleum distillation, and is heavy, non-combustible, and penetrating, possessing a slightly disagreeable odor which disappears in a few days. The oil is generally applied by means of a system of pipes arranged on an ordinary flat car, the pipes receiving the supply through a hose which is connected directly to the commercial tank-car holding from six to eight thousand gallons. A four-inch pipe runs the

* Extract from circular issued by the West Jersey and Seashore Railroad.

length of the "oil-car," and is so arranged that the hose from the tank-car may be connected at either end. Near the center of the "oil-car," is a branch pipe which carries the oil to three sections of two-inch pipe,—one suspended transversely below the car extending to the ends of the cross ties, and one six-foot section at either side of the car. Each of these latter sections is connected with the supply pipe by a rubber hose, which allows them to swing out as far as desired and also permits them to be raised or lowered to conform to the surface encountered, as well as to pass obstructions, such as cattle guards, cars standing on adjacent tracks, etc. The movement of these side sections is controlled by means of chains fastened to the pipes and connected to an ordinary brake rod passing up through the floor of the car. Slits are cut in the under side of these three pipes, through which the oil is allowed to escape, the quantity being regulated by means of quick-acting gate valves, worked by levers from above.

Three men are required to properly operate the car in yards, while in open country but two are necessary. The train proceeds at a speed of about four miles an hour. At this rate about two thousand gallons of oil are used per mile of single track.

Gravel, sand and cinder ballasts are the ones in general use which most need such a treatment as this use of oil affords. These ballast materials are easily penetrated by the oil, which fastens together the fine particles and also forms a material not easily permeated by water.

Some of the advantages resulting from this use of oil are as follows:

1. The lifting of dust by passing trains is prevented. Thus, greater comfort to passengers is insured, and injury to furnishings of coaches and contents of freight cars is lessened. Wear on machinery is reduced, and the number of hot boxes is materially lessened.

2. The cost of track maintenance is reduced, for several reasons.

The oil almost immediately kills all vegetation between and immediately alongside of the tracks, thereby eliminating a constant source of trouble to trackmen. Rain water falling on an oiled roadbed does not easily penetrate it, but runs off into the side ditches. Hence in a degree washing is prevented and

less labor is required to maintain the surface of rails. Since less moisture remains in the ballast, alternate freezing and thawing produces less effect, and the rails escape surface bending from that cause. Greater safety results from the lessened probability of the tracks being "heaved," and of washouts occurring.

It has been noted that snow is less liable to lodge on treated roadbed, hence there is a less liability of yards becoming icy and dangerous.*

3. The life of the cross ties is materially lengthened. The oil not only prevents moisture from gathering around the tie and soaking in, but the oil penetrates the wood, thus preventing the absorption of water that otherwise might occur. After being applied three or four months the oil enters the tie a distance of from a quarter to half an inch, depending upon the closeness of grain. It is claimed that the life of the tie is increased from one to two years, which is a large item. Further, it has been found that the oil prevents the tie from becoming ignited by hot coals dropped by the engine.

The West Jersey and Seashore R. R. found the cost of treating a mile of gravel ballast on *single* track to be about \$45 for one application, the oil costing 2 cents a gallon. The president of the Boston and Maine in an annual report stated that they expended about \$200 per mile of *double* track in their treatment, but as the price paid for the oil, the amount used, or the character of the ballast was not stated, no comparison is afforded. Probably a mean of these figures or from \$65 to \$75, would be a fair estimate of cost for oiling one mile of single track under ordinary conditions.

The first application lasts a year. A lesser amount than stated applied for the two successive years is all that is required, the ballast by that time becoming thoroughly impregnated. The oil should be used immediately after extensive tie renewals, so that the ballast will be disturbed as little as possible afterward.

The increasing use of oil by the most important railroads seems to prove that the advantages claimed by the promoters

*Suggested to the writer by Mr. F. G. Jonah, Eng. M. of W., Chicago and Alton R. R.

are being substantiated. Many advertisements are now seen of "improved and dustless roadbeds."

WAGON ROADS.

From the point of view of the highway commissioner and the municipality, the use of oil on wagon roads possesses many advantages. Its use has by no means become general; and aside from occasional items in the papers, and mere mention in conversations, but little is seen or heard concerning it. However, many experiments have been made in different parts of the United States, from which favorable reports have been received.

California leads all states in the number of miles treated, as the long dry seasons of that country form ideal conditions for this use of oil, which furthermore is there obtainable at an exceedingly low price. Some of the other states, as New Jersey and Iowa, have used this method of laying dust with more or less success. It is interesting to know that the U. S. Government is now experimenting on a section of road in the vicinity of Washington, D. C.

It has been thought that this use of oil might resist the formation of mud; and on comparatively good hard roads, it may have such an effect, but it is exceedingly doubtful whether its use could produce much benefit on the mud roads of our prairie states.

The oil is applied either by a specially constructed tank-wagon or by means of the ordinary sprinkling cart, it first being heated to as high a temperature as possible. It is then thoroughly incorporated with the road surface, the affinity of the earth and the hot oil being very great. It is thought that under ordinary conditions about one hundred barrels of oil are required per mile for the first general treatment, while subsequent applications require considerably less.

The oil certainly accomplishes its purpose so far as the laying of dust is concerned. It also produces other beneficial results, but just what the possibilities are in such use it is difficult to determine. The question is being more and more discussed. Dustless Roadbed Companies are being formed and as there is a general trend towards better roads, it seems probable that the scope of the work will be widely extended.

THE ENGINEER AS A MANAGER OR SUPERINTENDENT.

BY J. J. RUTLEDGE. '94. STUDENT JOHN HOPKINS UNIVERSITY.

Every engineer in the course of his professional work is brought more or less into contact with labor, either as mechanics and operators of machinery or as common laborers. Those engineers who have become managers and superintendents in charge of manufacturing or kindred industries, are of course brought into direct personal contact with all kinds of labor. How he shall best manipulate and control labor so as to produce the best results is a question of considerable importance to the engineer, and to which he must devote much attention.

Should our present prosperity in industrial affairs continue during the next few years and young engineers continue to engage in manufacturing and other industries employing large bodies of men, as foremen, managers and superintendents, they will need to study the handling and controlling of a company of workmen. While it is true that our progress in material things is largely due to great investments of capital and the use of labor saving machinery, it is also true that these investments have been successful only when aided by executive ability and the extension of business principles to every department of work. The engineer has been an important factor in this work, especially during the last ten years.

As a manager or superintendent the engineer occupies a position peculiar to himself. It has been true in the past and is largely true today, that among those in active charge of industrial enterprises two classes of managers have been noticed. First, a mechanic or other employee possessing a natural shrewdness and some knowledge of human nature together with a degree of executive ability, has risen to the responsible position of foreman or manager, mainly by his own efforts. Second, the theoretical manager, or one who knows nothing of the working

details of the business, but who because of his business ability, possession of stock, or some outside influence has been placed in charge of operations.

The first man because of his training, gives a great deal of attention to details and is consequently very economical of operating expenses. He is energetic, self-reliant, and aggressive in management, but on the other hand he is apt to oppress labor, has generally no sympathy with improved appliances, and labor-saving ones in particular, and often either opposes their use openly, or secretly hinders their successful operation. In this he is often assisted by his employees. He is also bewildered by large operations or consolidations of interests demanding commensurate results. The second has in many instances, especially where he has had competent subordinates, been very successful. Indeed it is to such managers that we owe the introduction of labor-saving machinery and consequent reduction of cost, as well as the extension of business principles and methods. However, as he has no practical knowledge of details he is at the mercy of his subordinates, as he must depend wholly upon their honesty and faithfulness. He is, for the same reason, prone to underestimate the magnitude of the various problems that arise in construction, operation, and maintenance.

Between these two extremes lies the engineer. By virtue of his training he has some conception of the working details of his business, and he rapidly acquires a complete knowledge. Unlike the so-called practical man he is quick to take advantage of new appliances, while appreciating the extension of business methods to all departments of work. He is not apt to underestimate the administrative or mechanical problems that come up for his consideration. Comparatively young men, not long out of college, have successfully carried on large industrial operations requiring, besides a theoretical knowledge, the use of sound judgment, which reflects credit upon our present system of technical education.

While it is a fact that some men are natural managers and seem to have the executive ability inborn, it is also true that by careful attention to rules and the constant use of an alert mind, one can become an efficient foreman, manager, or superintendent. Moreover, labor is also changing, becoming more intelligent, even the coal miner now reads the daily paper before or after

his eight hours' work. The time is past in most industries when foremen or superintendents can accomplish results by abuse and threats. The successful man now is he who has a clear, ready mind, always active, who can act quickly, and whose judgment is uniformly good. Today more than ever before brains are at a premium.

To be a successful foreman or undermanager the engineer should first of all be a man of even temper; no matter how great the provocation he should never lose his self-control, as nothing so lowers the respect of his employees. There are times when the judicious display of wrath is useful, but they are rare, and a simulated wrath best serves the purpose. He should keep his own counsel, have no confidantes, least of all must he have such among his employees; he must also be able to hear and bear a great deal and say nothing. Once given, his promise should be faithfully kept, but as far as possible he should avoid making promises. In all his dealings with his men he should be firm and positive, allowing them no room for a misunderstanding of his orders. Men appreciate a definite answer even though it be sometimes a sharp one. He should learn to think and decide quickly, and his decision once made should be decisive and final. As far as possible within the limits of order and good-government, he should endeavor to secure and retain the respect and good-will of his men, as only by that means can the best results be attained. However, he should maintain a strict discipline, enforce a definite code of rules, and have a systematic way of doing things. He should ask no man to do that which he would not do himself, permit no intemperance or tale-telling, see everything without appearing to see, be absolutely impartial having no individual preferences, use his mind constantly, and habitually deport himself in a dignified manner.

As a foreman the engineer should employ men only after a careful inquiry as to past records, ability, and nature. This last is quite necessary, and by the study of men and human nature (no man can become a successful manager who is not a close student of human nature), he can so familiarize himself with men that upon observation and a few moments' conversation he can readily "size up" an applicant for employment and determine his worth. He ought early to secure the confidence of his superiors by the results attained, and then be careful not to

violate that confidence—not promising results unless he is perfectly sure of securing the same.

As superintendent or general manager every department under his control should be thoroughly organized, each under a competent head solely responsible to himself. In choosing his various heads of departments all selections ought to be made only after careful investigation, and changes made only when absolutely necessary. However, no man should stand between the general manager and success.

As the head of all departments he should if possible have the respect and good will of every subordinate, never over-riding them unless absolutely necessary. He ought to sustain the various heads in their dealings with their employees. Nothing is so stimulating to an undermanager or superintendent in time of trouble, as the knowledge that some one is backing him, and a word of encouragement at such times from those high in authority will often accomplish more than an increase in salary.

By a system of daily, weekly, and monthly reports of labor cost, supplies furnished, and finished material produced, he should acquire such a knowledge of the cost of production that he can very closely estimate the same in advance of any particular period. In the inspection of these reports he should not be over-exacting, as such a course may cause his subordinates to neglect needed repairs or to so manipulate reports, in order to make an economical showing, that they will not be true statements of cost.

If his employees are members of trades unions, he should deal with them as such, recognizing the different officers which they themselves have selected to look after their interests and to meet with their employers. He should meet them at intervals to adjust scales of wages, hours, conditions of labor and other items of mutual interest. He ought to insist upon carefully made scales of prices, signed by both parties, so that there shall be no cause for dispute or cessation of operations. In considering these questions he ought to strive to view them from two points of view--his own and his employees.

ELECTRICALLY OPERATED RAILWAY SIGNALS.

BY F. J. POSTEL, '99, ELECTRICAL ENGINEER, CHICAGO.

The introduction of railroads created the necessity of providing trains with some sort of protection against collisions with other trains.

Naturally the first system to suggest itself was to have pre-arranged meeting points for trains moving in opposite directions, and hence to maintain a certain minimum time interval between trains moving in the same direction. This is well enough as far as it goes, but should one train be delayed for any reason it would practically tie up the whole road. Not only would this occur, but should such an accident happen between stations, the following train after waiting the required length of time would be proceeding at full speed, and a rear end collision would be the most natural result. This system therefore is practical only when used in connection with some system of communication between stations, generally the telegraph. There must be a train dispatcher with absolute authority to issue or countermand all train orders regarding meeting places, etc., and station masters at all stations to receive these orders and transmit them to the trainmen. Stations must, of course, be provided with some form of signal which will indicate to trainmen whether or not there are orders awaiting them.

Various types of signals are in general use on the different roads. Perhaps the simplest is the common "train order board," which usually consists of an elliptical shaped piece of wood or sheet iron painted red and pivoted to revolve horizontally about its short diameter. When parallel to the track it is barely visible to an approaching train and indicates "No orders" or "All clear". When at right angles to the track the "board" is plainly visible and indicates "Stop for orders".

A much more satisfactory though costlier signal is the semaphore. A semaphore consists of one or more movable arms pivoted at or near the top of a pole, free to swing from a horizontal position to one almost vertical. Each arm or blade is

bolted to an iron casting, which also carries one or two lenses. The arm proper is a thin board 5 ft. long, tapering from 7 inches in width at the point where it is bolted to the casting to 10 inches at its outer end. The blade always extends out to the right side of the pole as viewed from an approaching train on the track it governs. When the blade is in a horizontal position it indicates "Stop for orders", and when in the "down" position, i. e., nearly vertical, it indicates "No orders—all clear".

The semaphore is thus primarily a signal of position and not of color, but the usual practice is to paint such a signal blade red. One may expect to find almost any color of signal blades, however, for there is no real standard in this matter. Likewise with the color of the lenses. About the only rule is that the color of the lens in front of the lamp at any time, and therefore the color of the light given out, must agree with the indication of the blade. Where only one lens is carried this is the same color as the arm; where two are carried they are usually red and green, the latter being used to indicate "All clear."

The pole is usually 25 ft. high and is fitted with an iron ladder reaching to the top. The blade is counter-weighted in such a way that gravity always tends to pull it to the "danger" position. This is an essential requirement of all railroad signals.

The telegraph is in common use and the theory of its operation well understood so that it will not be necessary to explain it. Its use in connection with the train order system is a most simple application. All the stations along the line have their relays connected in series. Each station reports the arrival and departure of all trains to the train dispatcher, who alone is responsible for the safety of all trains. Should he desire to issue any new orders to any train, or countermand any old ones, he calls up the station next to the one that has last reported the departure of that train and telegraphs the new order to the station master, who repeats it back to avoid mistakes and is then given the dispatcher's O. K. if correct. The station master will then leave his signal at "danger", indicating to the engineer of the approaching train that he must stop for orders. Unless the station master has received orders of some kind he clears his signal on the approach of a train and lets it pass. The signal, therefore, indicates only whether the station master has or has not orders for that train, nothing more.

The "telegraphic system" of block signaling when used in connection with the above has the great advantage that it gives the station masters more responsibility in practically maintaining a constant check on the dispatcher. The equipment for this system may be similar to the preceding, or better still, if provided with an additional local circuit installed from each station to the next. The operation, or rather the result is the same in either case.

When a train leaves "A", he reports its departure to the train dispatcher on the through wire, and to "B" on the local wire, if one exists—if not, then on the through wire. "B" who has already been ordered to let no trains pass him moving toward "A", orders "C" to block for him, i. e., to let no trains pass toward "B". On arrival and departure of train at "B", "B" notifies the dispatcher and "C" in the same way "A" reported. "C" then orders "D" to block for him and so on. If this is done on local wires it becomes an independent check on the dispatcher; if it is all done on one through wire, the dispatcher is able to see that the blocking is correctly done, but this is only a step back toward the simple train order system. This system is probably used on more lines of railroad than any other. The reason for this is its cheapness and effectiveness.

A somewhat more expensive, yet safer system than the "telegraphic", is the "controlled manual" system of block signalling. This system has much to recommend it. It resembles the "telegraphic" system to a large extent but goes a step farther in that it requires the labor of the men at the next station ahead, as well, to clear a signal. The equipment required to operate this system consists of a bell or telegraph circuit between adjacent stations (i. e., the stations at the end of the "blocks"), a short section of track circuit, the special locking machines, and of course the necessary signals at each station. Should a bell circuit be used in place of a telegraph circuit a special code would have to be arranged to cover all probable questions and answers that might come up. The only advantage of such an arrangement is in the fact that the bell circuit is much easier to keep in order, and its signals may be understood by any one having a copy of the code.

The track circuit consists of an insulated section of the track, having a battery connected across from rail to rail at

one end and a relay connected across from rail to rail at the other. The circuit is from the battery to one rail, through the rail to the relay, through the relay to the other rail and back to the battery. As this forms a closed circuit, a current is normally flowing through the relay and the armature attracted. When a train enters upon the section, the wheels short-circuit the battery, cutting the current off from the relay, releasing the armature.

The section is insulated by replacing the steel splice bars with bars made up of some insulating material. Very often these are simply wooden bars about 4 ft. long. However, steel bars properly insulated are preferable but more expensive. The track is well bonded with galvanized iron wire—about No. 8 B. & S.—fastened to the rails with channel pins or other suitable device. Ordinarily there are two bond wires to each joint.

The track batteries are usually of the gravity Daniel type and are placed in cast iron chutes or battery wells buried in the ground to prevent freezing. In practice it is found that two such cells connected in multiple give the best results.

Special locking machines control the levers which move the signals. They are so constructed that the lever of A's signal is locked in the danger position by the armature of an electromagnet controlled from B's machine. The circuit is made by means of line wires between the stations. At "A" the circuit includes simply the electromagnet. At "B" the circuit runs through the points of a relay controlled by the track circuit and through what is known as the "plunger." Practically, this is nothing more than a push button so arranged that when pushed the circuit between the instruments is broken until a train passes over the short piece of track circuit which is always placed just outside the block. This makes it impossible for "B" to again release "A's" lever until the train for which he has released it has passed entirely out of the block. Each instrument is provided with an indicator showing "clear" when neither has given permission to clear the other's signal and "blocked" when one of them has.

The operation is as follows: Should "A" desire to clear his signal he asks "B" to push the plunger or, as it is commonly called, "to plunge." If the block is clear "B" will do so and release "A's" lever allowing him to clear his signal. Should

the block be not clear "B's" plunging, even should he forget himself and do so, would have no effect, as has already been pointed out. This system then, not only puts the responsibility for clearing a signal on two men, but it gives them a partially automatic machine to help them.

To simplify the discussion the word "signal" has throughout been used to mean only one signal. In practice it is quite common for a second signal to be used in connection with the first. The first then becomes the "home" and the second the "distance" signal. The "distance" signal is usually placed from 1 200 to 2 000 feet ahead of the "home" signal and always gives the same indication that home signal does, being worked in connection with it.

The reason is simply this, that except under the most favorable conditions, a train approaching a signal at full speed could probably not be brought to a stop from the time the engineer first saw the signal until he reached it. But when a distant signal is placed some distance ahead of the home signal, the engineer has this additional distance in which to bring his train to a stop before reaching the signal which really indicates "danger."

When the signals are of the semaphore type it is common practice to cut a deep V shaped notch in the end of the blade of the distant signal and on many roads to paint the blade green. The blade will then carry a green lens and the indication may be said to be "caution—proceed with train under full control."

All of these systems depend to a greater or less extent upon men for their successful operation and therefore are to just that extent not perfectly reliable. The "automatic" system of block signalling is undoubtedly the safest and best; but unfortunately it is also the most expensive. The object of such a system is to provide that a train shall at all times have two signals behind it at danger in double track movements and also two ahead of it in single track movements. Automatic block signals may be either mechanical, electro-pneumatic or electric. Electro-pneumatic and electric signals are far more common than automatic mechanical signals. In electro-pneumatic signals the actual work of moving the signal is done by compressed air, while electricity is used only to actuate the valves. Electric signals

are worked entirely by electricity. While the former are always of the semaphore type, the latter may be either of the semaphore or of the "banjo" or "disk" type.

The track circuits are the same in either case. The section of road to be protected is divided up into insulated sections, the length depending on the conditions of operation, the location and local conditions in general. As a rule, the sections will be found to be between 1200 feet and a half mile, 2 000 ft. sections being very common. Each section is made just like the insulated track section in the "controlled manual" system already described, only that the sections are much longer in the former. The signal is placed at the beginning of the section or block and the track batteries at the far end.

In electro-pneumatic signals, the passing of a train onto the track section short circuits the relay, either opening or closing a local circuit, which in turn releases the air in the cylinder and lets the signal (now behind the train) fall to danger. When the train passes out of the section the track relay again becomes energized and picks up its armature, restoring the local circuit. This is made to open the inlet valve and close the exhaust by means of electro-magnets and the signal is cleared.

This applies only to the "home" signal, i. e., the one at the beginning of the block. When "distant" signals are used the circuit controlling such a signal passes through a circuit breaker on the home signal. The two signals are connected by means of aerial line wires. When the home signal falls to danger, it breaks the circuit of the distant one causing it also to fall to danger. When it returns "to clear" it restores the circuit allowing the distant "to clear" also.

It is quite common practice to mount the home signal of one block on the same pole with the distant of the next block ahead. The home signal is then always placed above, the distant below. Where the blocks are of about equal length this arrangement gives good satisfaction, but too often the blocks vary greatly in length. One distant signal may be 1 000 ft. ahead of its home signal and the next one probably 2 000 ft., so that the engineer will have to depend on his memory to know within what distance he must be able to stop his train should he find a distant signal at danger.

When the matter of expense is not the principal thing to be considered, it is a very good idea to have all distant signals at a uniform distance from their home signals.

Electric signals of the semaphore type are usually operated by motors. Several devices depending on the combination of electro magnets and clutches have been invented but none of them have ever come into general use. I believe, however, that such a combination can be successfully worked out and that its operation will depend upon a solenoid to do the pulling and upon electric clutches to hold the signal between successive pulls—the movement consisting of a series of jerks. Springs or dash pots will take up the vibration and make the motion practically continuous.

When motor operated semaphores are used, the short circuiting of the track relay is made to release a clutch, allowing the signal to fall to danger. When the train has passed out of the section or block, the track relay picks up its armature, which closes the motor circuit, pulling the signal to the clear position. It is then again clutched by a magnetic clutch and at the same time the motor circuit is broken. This is done to save battery. As such small motors run at very high speeds and as it is permissible to allow the signal from six to eight seconds to clear, a great reduction of speed is necessary. This is usually accomplished by means of a worm gear, although other forms are used.

“Banjo” signals derive their name from their resemblance to that instrument. They are also known as “disk” signals owing to the fact that their indications are given by means of disks. This type of signal is always operated by electricity. The “head” is usually about three and a half feet in diameter and something like eighteen inches deep and encloses the entire mechanism. A large pane of glass is inserted in both the front and back of the “head”. The disk swings from a position off to one side to a position in front of the glass. When the disk is in the latter position it indicates “danger”. When off to one side and no longer visible, the signal indicates “clear”. In practice a very small part of the disk is allowed to show when in the clear position, indicating that the signal is still intact.

The armature which carries the disk is $\frac{1}{2}$ shaped and is made to revolve between the poles of an electro magnet, much

as the armature of a bipolar motor revolves between its pole faces, only that in the present instance the armature carries no wires whatever. Such a construction gives a strong pull through quite an angle, the reason being that the air gap is only twice the amount of clearance which may be very small.

A lens of the color of the disk is also carried by this armature and is made to move in front of a lamp when the signal moves to danger. The whole is so counterweighted that gravity tends to pull it to danger. When the track circuit is normal and the track relay energized, the circuit of the Z armature magnet is closed and the disk drawn into the safety position, where it is held either by the armature itself, or else by a magnetic clutch of some kind. When the track relay is short circuited the local circuit is opened and the signal falls to danger. The local circuit of a distant signal passes through a circuit breaker on its home signal as in other automatic signals described. Signals of this type are cheaper than semaphores and have in their favor the fact that all their parts are enclosed. The disadvantage is that snow and ice are apt to collect on the glass panes and entirely obscure the signal.

Crossing bells for highway crossings are usually operated by electricity. The best arrangement is to have an insulated track section on either side of the crossing, the adjacent ends being connected to the two sides of an "interlocking" relay. Several such relays are on the market, but the general principle is the same in all. Either side being short circuited closes a local circuit and rings the bell. The other armature falling will make no change, but when the first is again picked up, i. e., when the train has passed the crossing, the bell will stop ringing. The bell is of course only for the protection of people using the crossing and is not intended as a signal for trainmen.

Electricity is applied in many other ways to railway signals. Among the most important applications not discussed in this paper are switch-boxes, electrically locked switches, switch indicators, disk indicators for towers, and train annunciators.

CONSTRUCTION OF A STEEL CHIMNEY.

BY A. H. NEUREUTHER, M. E., PERU, ILL.

Great difference of opinion exists among engineers as to the relative desirability of brick and steel chimneys. The brick chimney is more substantial, architecturally better in appearance, and does not lose so much heat by radiation; but must be larger than a steel one, since there is a loss of efficiency due to the infiltration of cold air through the brick work. The steel chimney is cheaper in first cost, occupies less space, does not require such extremely solid foundation, and is not so liable to crack and allow cold air to leak in.

The conditions which determined the choice of a steel stack in this case are readily seen from the accompanying section of chimney and boiler house. It was necessary to erect the new chimney without interfering with the operation of the plant, thus making it impossible to erect it on the old chimney site, nor even near it owing to other inconveniences, one of these being the delivery of the fuel to the plant—the boiler room is close to the edge of a hill and has a driveway from one direction only. To erect a chimney in any other position than that shown would have necessitated an excessive length of flue. In view of these conditions, together with that of having another driveway to the boiler house, and the esthetic feature of improving and beautifying the company's grounds, it was decided to place the chimney as close as possible to the boilers, in the position shown. The natural slope of the hill, before the erection of the retaining wall shown in the section, is shown by the line A B which already was outside of the property line. In order to get the necessary space for the driveway, without encroaching too much on city property, the chimney base and also the chimney had to be cut down to the smallest dimensions possible, consistent with strength.

Therefore it was decided to build a steel chimney lined with brick, approximately 86 feet high, having clear inside diameter

of 38 inches. This stack is rated at two hundred and thirty horse power, which may seem somewhat high when compared with some of the usual tables that apply mainly to brick chimneys, but it must be remembered that in a steel chimney there is no loss due to the infiltration of cold air through the sides to decrease the efficiency, as is the case with the brick chimneys. At present the chimney is serving two boilers, one of eighty and one of forty horse power rated capacity. With dampers and ash-pit door open and fires nearly burnt out on a clear day, with outside temperature 32 degrees Fahr., it was found by use of a water gauge that the draft at the base of the chimney was forty-eight hundredths of one inch of water.

Figs. 1 and 2, pages 62 and 63, show the details of the construction. The stack was erected in Peru, Ill. The specifications by which the chimney was constructed follow.

SPECIFICATIONS.

The contractor shall furnish a good and sufficient surety company's bond, to the approval of the owner. Bond to be for the use and benefit of the owner and shall be in force until eighteen (18) months after completion of the contract. The contractor shall be responsible for each and every violation of the public ordinances, caused by obstructing streets, sidewalks, etc., and shall hold the owner harmless for any damage arising therefrom. The contractor shall pay for the building permit.

The contractor shall give his personal superintendence to the work, or have some competent person on the work at all times to act for him; and shall furnish all material, labor, apparatus, scaffolding, etc., necessary for performing the work in the best possible manner, according to the accompanying drawings and these specifications. All material and labor to be the best of their respective kinds.

The drawings to be accurately followed, preference being given to figure dimensions over scale.

The drawings and specifications are the property of the owner to whom they must be returned on completion of the work. All work to be executed to the true intent and meaning of the drawings and these specifications, which are intended to include everything requisite and necessary for the proper and entire finish of the work, notwithstanding each and every item

necessarily involved in this work is not specifically mentioned. The work, when completed, to be delivered up in a perfect and undamaged condition without exception.

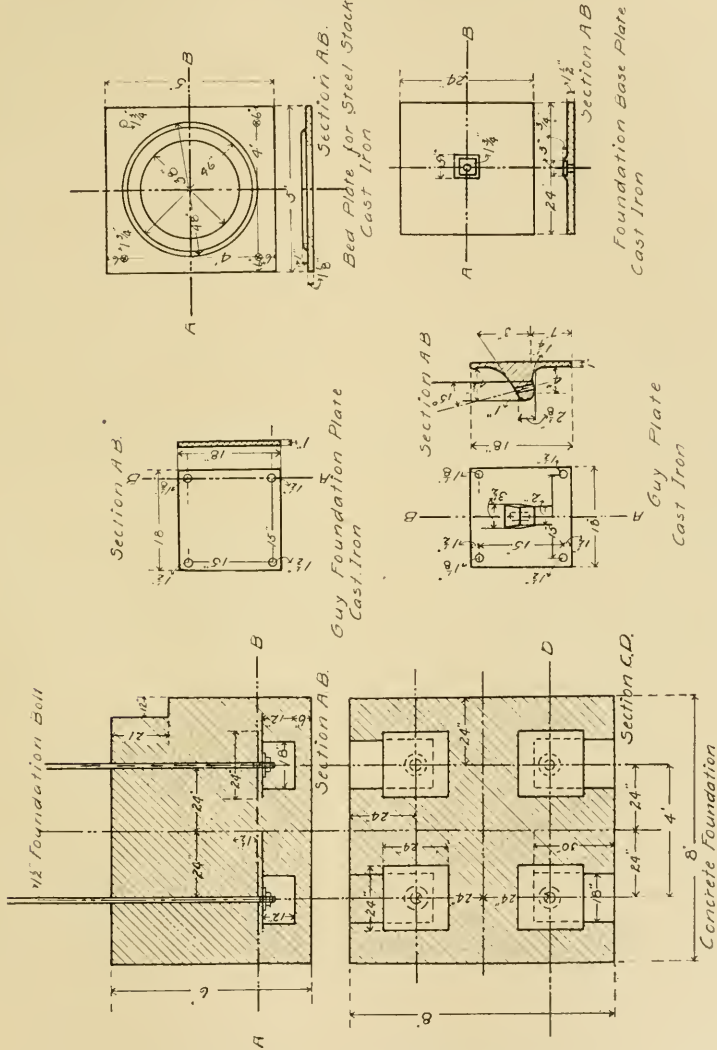


FIG. 2. DETAILS OF FOUNDATIONS.

The drawings and these specifications are intended to be co-operative, and work and material called for by the drawings and not mentioned in the specifications, or vice versa. is to be

furnished or done in as faithful and thorough a manner as though fully treated by both.

Concrete Foundation. See drawings for dimensions, etc. The concrete for the foundation of this chimney shall be composed of 1 part (by volume) of first quality, fresh Portland cement, 3 parts clean sharp sand, and 4 parts stone, broken small enough to pass through a 2-inch mesh. All shall be measured dry, and be *thoroughly* mixed before water is added, and again thoroughly mixed after. As soon as the concrete is mixed it should be taken to the trench, and should be gently dumped in, in layers about 6 inches thick, and immediately rammed until water flushes to the top. The next layer must be put on before the preceding one gets dry, and the top shall be well wetted before putting on the new layer. The concrete must not be dumped from a height of more than two feet, and if such should be the case it should be thoroughly mixed again in the trench.

The contractor will put in place the necessary foundation plates, bolts, etc., as shown by foundation plan and as directed by the owner. The iron parts will be furnished by the owner.

Brick Work. The brick work, excepting the inside lining, is to be laid up, to dimensions shown, with sound, hard, uniform, well burned, merchantable brick, in cement mortar with joints neatly struck. Brick to be laid wet, in warm dry weather; and dry, in damp and freezing weather. All brick work to be well bedded and laid compactly, tied and bonded in the proper manner. Utica cement mortar will be used in the proportion of 1 of fresh cement to $1\frac{1}{2}$ of clear sharp sand.

The contractor will line inside of chimney from foundation to top of ordinary brick work and including first thirty feet of steel stack, with at least 4 inches of a good quality fire-brick, properly dipped in fire-clay, laid compactly and properly bonded with the other wall where it comes in contact with same. The remaining 40 feet of steel stack is to be lined with a good quality of hard burned common brick dipped in fire clay and laid in position very compactly.

The top of the brick work must be brought to a level and finished smooth, with a thin layer of cement mortar, forming the bed for a cast iron plate on which the steel stack rests, and is fastened.

All necessary iron work as furnished by the owner must be set and properly masoned in.

Steel Stack. The steel chimney is to be seventy feet high. The diameter in the clear, or inside diameter, of stack must be thirty-eight inches. The stack is to have a suitable base plate made of wrought or cast-iron five feet square, having holes for four one and one-half inch wrought-iron or machinery-steel bolts, spaced as shown in drawings. The length of each of these four foundation bolts is to be about twenty-one feet, and all are to be threaded on both ends and supplied with two suitable nuts each, and the necessary washers and four cast iron plates one and one-half inches thick by two feet square. These plates must have an opening in center large enough to admit foundation bolt.

The steel plates used in this chimney must be one-fourth inch thick to a height of twenty feet above base plate, three-sixteenth inches thick for the next thirty feet, and balance one-eighth inch thick. The plates used shall be of tank steel, a test strip taken lengthwise of each plate of one-eighth inch thick and over, without annealing, shall have a tensile strength of sixty thousand pounds per square inch, and an elongation of 25 per cent in a section originally two inches long. Sheets will not be accepted if test shows the tensile strength less than fifty-five thousand pounds, or greater than seventy thousand pounds per square inch, nor if the elongation falls below 20 per cent. The plates must bend cold through an angle of one hundred eighty degrees with a radius equal to the thickness of the plate without showing cracks or flaws of any kind.

The joints will be riveted with steel rivets which shall have a tensile strength of from fifty-five thousand to sixty thousand pounds per square inch. They shall be capable of being flattened out cold under a hammer to a thickness of one-half of the diameter, and of being flattened out hot to a thickness of one-third of the diameter of the rivet, without showing cracks or flaws.

Means must be provided for getting to the top of the stack by means of a steel ladder or steel rungs securely rivited to outside of stack. Steel for these must have a tensile strength same as plates but must be capable of being bent (both hot and cold) through one hundred eighty degrees, flat upon itself with-

out showing cracks or flaws of any kind. Elongation 25 per cent in eight inches.

Instead of the ladder as above the following construction may be substituted. Stack to have six-inch iron pulley block large enough to receive rope $\frac{3}{4}$ -inch diameter, riveted to top with $\frac{1}{4}$ -inch wire tiller rope halyard rove through same and extending to roof or base of stack proper.

The stack must be securely guyed by four $\frac{5}{8}$ -inch galvanized-iron wire cables, each having the breaking strength of *at least* thirty thousand pounds. Each guy to be provided with a heavy wrought turn buckle for tightening, and with thimble for rope connection. The guys will be attached to the stack at about three-fourths of the height from top of concrete foundation as shown in drawings. They must not be attached or riveted directly to the stack, but must be attached to an angle-iron ring of suitable strength, which also must not be riveted to the stack, but must snugly fit the stack, and which in turn rests upon a suitable angle-iron ring securely riveted to the stack. The lower ends of the guys shall be fastened to suitable cast-iron plates used for such purposes and which must be included in the bid. Also four wrought-iron or machinery bolts 1-inch \times 48 inches with necessary nuts and washers must be furnished with each foundation guy plate. Guy fastenings will be about seventy feet from base of stack (horizontal distance).

The foundation for stack and for securing guy plates, and also brick work from foundation to cast-iron plate for base of steel work, will be furnished by the owner.

Stack, base, guys, bolts, etc., to be painted with two coats of an approved brand of paint.

COST.

| | |
|---|---------------|
| Concrete foundation with 16 ft. of brick work, interior lined with fire brick..... | \$300.00 |
| Two guy foundations 4 \times 4 \times 4 ft. concrete and 2 holes in building... | 28.00 |
| Fire and common brick lining of iron stack..... | 95.00 |
| Steel, cost of..... | 350.00 |
| Erecting steel work..... | <u>250.00</u> |
| Total..... | \$1 023.00 |
| Total weight of cast iron, sheet-steel, rivets, etc..... | 11 500 lbs. |
| Cost of iron work per pound ready for erection, about..... | 3.00 cents |
| Cost of erecting iron work per pound, about..... | 2.18 cents |
| Total cost of iron work erected per pound..... | 5.18 cents |
| Total cost of complete chimney per pound of iron work..... | 8.9 cents |

AN INEXPENSIVE MIRROR GALVANOMETER.

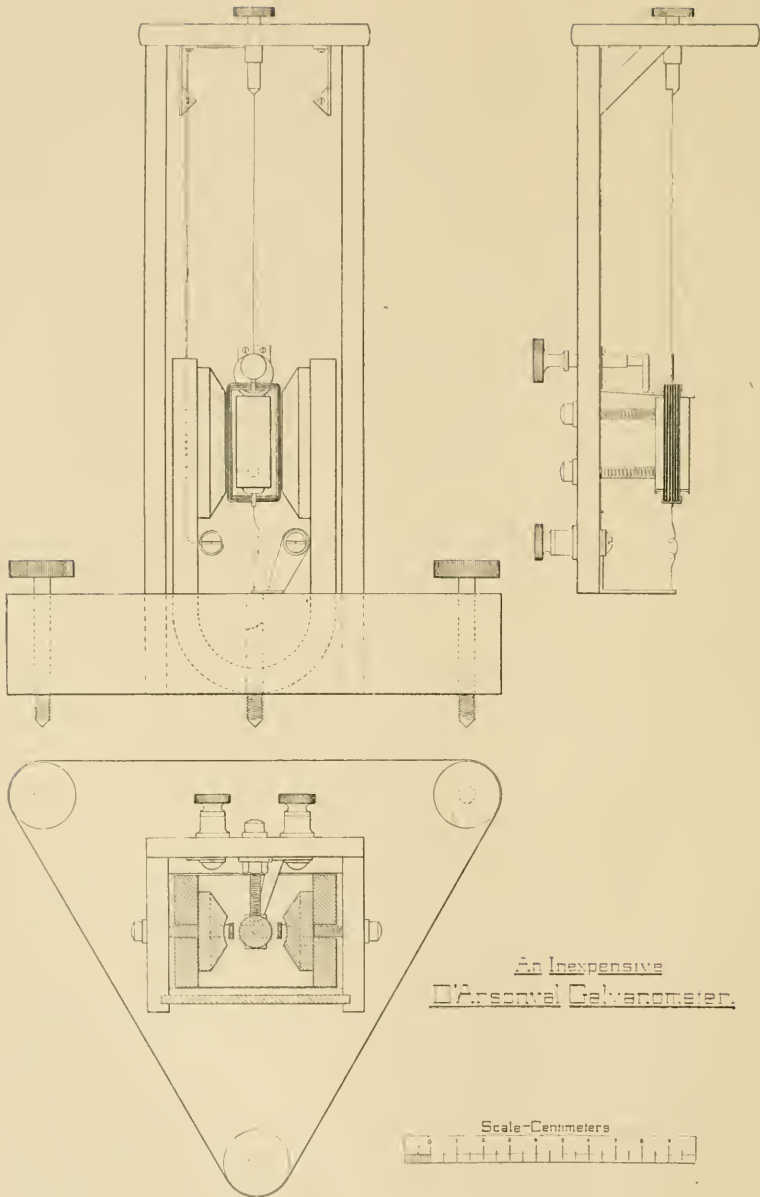
BY A. P. CARMAN, PROFESSOR OF PHYSICS.

Within a few years there has been an increased demand for mirror galvanometers which are sensitive, convenient to use, and inexpensive. This demand has come largely from the teaching of physics to elementary students by laboratory methods. The number of classes needing finer apparatus is thus increased, and at the same time the size of these classes has been growing, especially in engineering.

The purpose of this article is to describe the details of construction, the cost, and the performance of a galvanometer which was recently made in the physics workshop of the University for the purpose of finding out how inexpensive an instrument could be made to meet the above demand. The instrument as finally designed and constructed is the result of the suggestions of several persons, but chiefly of Mr. H. V. Carpenter, instructor, and Mr. E. D. Gagnier, mechanician of the department. The aim was to keep all the essential features of the finer instruments and to simplify the construction and to lessen the cost as far as possible.

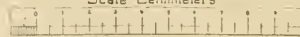
It is believed that this design puts it within the ability of almost any one to have a good working mirror galvanometer. Most of it can be made by a person with fair mechanical skill and with the tools ordinarily at hand. The parts requiring a machinist's skill had better be bought, but as will be seen these are few.

The design of the instrument is shown by the accompanying drawing. It is of the d'Arsonval type. This type has many advantages for general laboratory work. It is free from external magnetic disturbances, and hence can be used anywhere; it has a constant sensitiveness, the needle can be brought to rest quickly, and its sensitiveness is high enough for practically all measurement work. The essential parts are the permanent magnetic system and the movable coil. The magnets used were



An Inexpensive
D'Arsonval Galvanometer.

Scale-Centimeters



two U shaped magnets, such as made for telephone magnetos. These magnets can be purchased for ten cents each. They are strong and keep their magnetism very satisfactorily. The poles are two pieces of soft Swedish iron, shaped in a milling machine. The magnets are set in a depression cut in the thick cherry base, and the pole pieces are held in place against them by machine screws which go through the sides of the case into these pole pieces. Thus the base and sides of the case are the holders of the magnetic system; the back and top of the case become in a similar way the holder of the movable coil system and the iron core. A piece of plane glass for the front then completes the case. By this arrangement the coil is easily accessible by taking out the two or three screws which fasten the back and top to the sides. The connections are by means of two binding posts on the back of the case. The suspended system has all the ordinary adjustments. It can be raised and lowered and turned around, and it can also be taken off of its suspension. The device for lifting it free for its suspension, is a flat spring fixed to the iron core, which lifts the coil when the eccentric disk is turned from the back. Turning the eccentric further again depresses the spring and releases the coil. This device is new as far as we know. It works most satisfactorily and is not difficult to make.

The coil is wound on a wooden form and with No. 36 B. & S. silk-covered copper wire. The resistance in this particular instrument is only 25.6 ohms. Other coils wound with No. 40 B. & S. wire had a resistance of over 300 ohms. A low resistance was desired in this particular instrument.

The cost of the galvanometer may now be given:

| | |
|---|----------------|
| Base and case of cherry | \$1.00 |
| Materials: brass, iron, wire, suspension strips, screws, mirrors, etc., | 1.25 |
| Machinist's work: 2 binding posts, 3 leveling screws, 2 pole pieces, iron core, eccentric and spring, suspension head | 3.50 |
| Assembling parts and winding coil (if hired) | 3.25 |
| | <u>\$ 9.00</u> |

The galvanometer as made presents a very neat appearance and it has every convenience as far as working parts are concerned. Its figure of merit is 2.4×10^{-8} , with the scale at a distance of one meter and with millimeter scale divisions, or about 48 divisions per micro-ampere (10^{-6} amperes).

When we compare this with d'Arsonval galvanometer from standard makers, we find that it is as sensitive as the ordinary instrument of this type as sold. Thus, taking two instruments of about the same resistance from a list given in the Philosophical Magazine for October, 1898, we find a Nalder Bros. instrument of 29.5 ohms giving 3.62 scale divisions per micro ampere, and a Holden d'Arsonval galvanometer of 26.7 ohms resistance giving 0.54 scale divisions per micro-ampere. It would seem from the above that it should be possible for any one needing a mirror galvanometer to make one at little cost and also one capable of the best work.

TEST OF A 65 H. P. BATES CORLISS ENGINE.

BY CHARLES A. HOPPIN, '01, MECHANICAL ENGINEERING.

The material for this article has been derived mainly from an extensive, though by no means exhaustive, series of tests made at the plant of the Twin City Water Works, Urbana, Ill. While it is intended to consider these tests as applying more particularly to the Corliss engine furnishing the motive power, a brief description of the plant, together with summaries of the pump and boiler tests, are included, in the belief that they will not only furnish information of value, but will also give a clear idea of the conditions under which the engine was working.

Neither the plant nor the engine can claim distinction on the ground of unusual efficiency or economy of operation. The engine and pumps are, however, of good design, recent installation, and the results obtained would seem to indicate that the plant is fully up to what is now considered good practice in installations of its character and capacity. No attempt was made to determine the maximum efficiency of the plant—on the contrary, the idea was to test the equipments ordinarily operated.

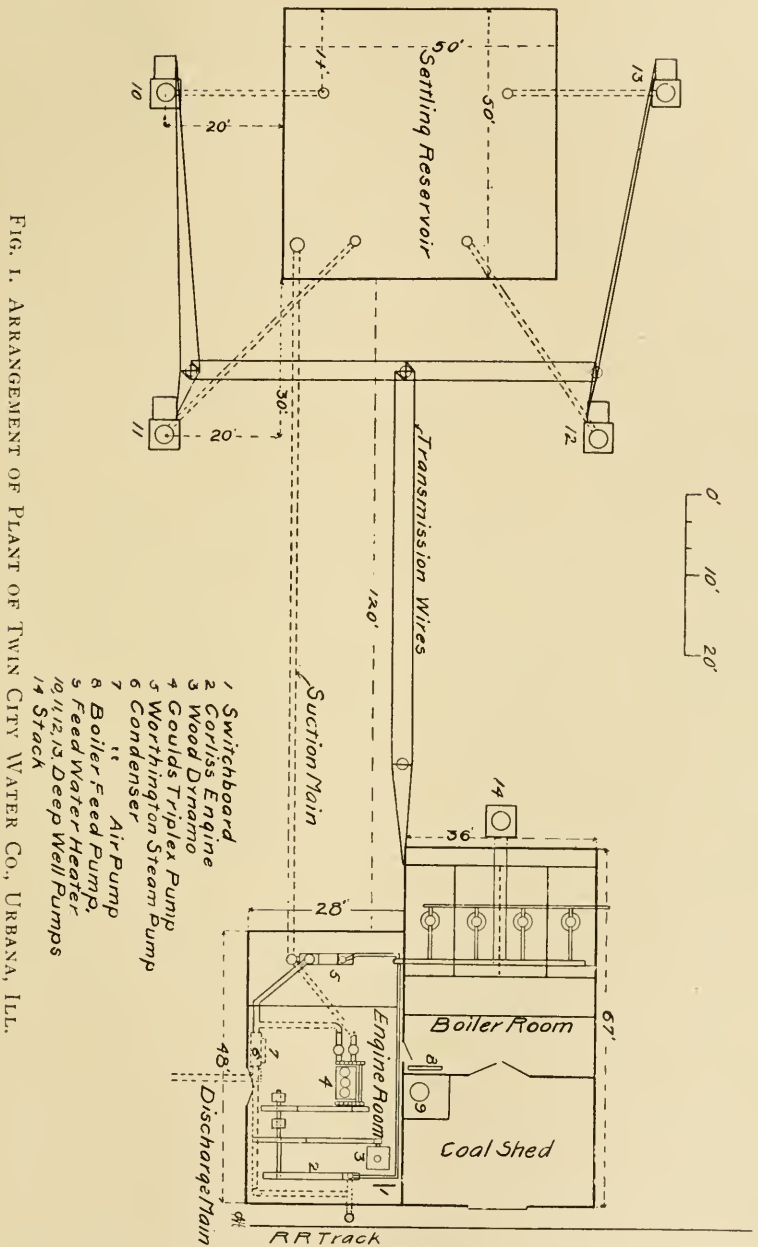


FIG. 1. ARRANGEMENT OF PLANT OF TWIN CITY WATER CO., URBANA, ILL.

- 1 Switchboard
- 2 Corliss Engine
- 3 Wood Dynamo
- 4 Goulds Triplex Pump
- 5 Worthington Steam Pump
- 6 Condenser
- 7 Air Pump
- 8 Boiler Feed Pump,
- 9 Feed Water Heater
- 10, 11, 12, 13 Deep Well Pumps
- 14 Stack

For these reasons it is felt that the results obtained may be of interest to others than those immediately concerned.

DESCRIPTION OF PLANT.

Four double-piston deep-well pumps, each belt-connected to a small D. C. motor, and having an average total capacity of 600 gallons per minute, deliver the water from as many wells to an open concrete settling reservoir $50 \times 50 \times 15$ ft. From the settling reservoir the water is forced into the supply mains by a Goulds triplex pump rated at 750 000 gallons per twenty-four hours and belted to a pulley on the shaft of a 65 H. P. Bates Corliss engine. The fly-wheel of the engine is utilized as a belt pulley to drive a 60 KW Wood dynamo, generating current for the deep well motors referred to, and for the few lights needed about the plant.

The steam equipment of the works comprises four Chandler and Taylor fire tube boilers. Only two of these boilers (65-70 H. P.) are in use at any one time and this was the number included in the tests. All the boilers discharge into a common eight-inch main, extending entirely across and a little above the front end of the battery. Immediately over the center line of each boiler two feet of six-inch pipe extends down vertically from the main, whence connection is made with a tee fitted to dome of boiler through a horizontal section of six-inch pipe six feet long. The remaining opening of the tee on the dome is connected directly with the boiler safety valve. All the safety valves are set to blow off at 90 pounds and are arranged to exhaust through a six-inch pipe into the outer air.

The eight-inch steam main passes through the wall of the boiler room into the engine room where it immediately divides into two branches. One leads to a Worthington steam pump, the other a six-inch pipe rises vertically three feet, runs horizontally along wall of engine room for a distance of about thirty feet, and then descends to within four feet of the floor. At a point three feet above end of this pipe, connection is made with a six-inch pipe running out into engine room and terminating in steam chest of the engine. The extra length of vertical pipe on the wall serves as a separator, thus insuring a supply of almost perfectly dry steam in the engine. The exhaust passes into the condenser placed in the discharge main of the pump

plant, whence it is pumped outside the building, being too oily to be used in the boilers.

The auxiliary apparatus of the plant comprises: 1. One Worthington compound horizontal duplex steam pump $10 \times 16 \times 10\frac{1}{2} \times 10$, formerly used for main supply but now for the small amount of water occasionally needed above that supplied by the Goulds pump. 2. The Worthington surface condenser, placed in supply main and provided with a small automatic air pump. 3. One feed water heater, supplied with exhaust steam from the Worthington steam pump, the condenser air pump and boiler feed pump. 4. One Worthington duplex boiler feed pump $5\frac{1}{4} \times 3\frac{1}{2} \times 5$ inches

THE TESTS.

The tests made were three in number, namely: Two of ten, and one of twenty-four hour's duration. The apparatus used was in good condition and the tests were of sufficient length to provide for non-uniformity in conditions of operation.

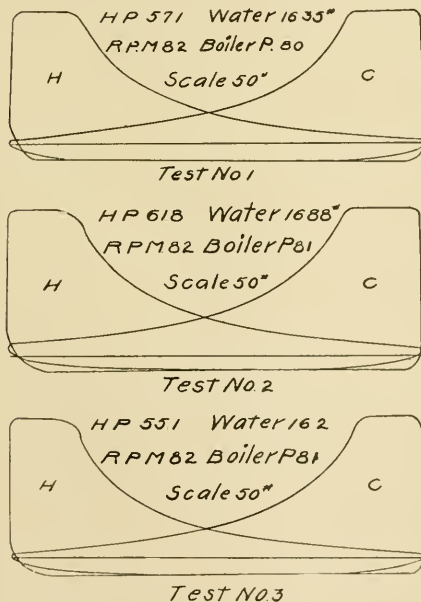


FIG. 2. INDICATOR CARDS.

The feed water was measured by allowing it to run into a specially constructed tank holding exactly 700 pounds, and emptying into a lower tank connected with the suction pipe of the feed pump. The exhaust of the engine from the condenser was caught outside the building in tanks placed on scales, and was carefully weighed. Coal and ash were weighed by the barrowfull on a platform scales. The coal used was a rather poor quality of slack from Vermillion County, Ill., and cost 90 cents per ton delivered at the plant.

Following are some of the more important dimensions, together with data and results obtained from boiler and engine trials.

BOILER TEST.

Dimension of Boilers.

| | | |
|---------------------------------|-----------------|-----------------|
| Length..... | No. 1, 19 feet. | No. 2, 20 feet. |
| Diameter..... | .60 inches. | |
| No. tubes..... | 46 | |
| Outside diameter of tubes..... | 4 inches. | |
| Size of grates..... | 4.5 × 5 feet. | |
| Grate surface, each boiler..... | 22.5 sq. ft. | |
| Grate surface total in use..... | 45 sq. ft. | |

Heating Surface.

| | |
|---|-------------------|
| Boiler No. 1, 46-4-inch tubes 19 feet long..... | 908.9 sq. ft. |
| ½ shell..... | 149.2 sq. ft. |
| Total..... | 1058.1 sq. ft. |
| Boiler No. 2, 46-4-inch tubes 20 feet long..... | 956.8 sq. ft. |
| ½ of shell..... | 157. sq. ft. |
| Total..... | 1113.8 sq. ft. |
| Total heating surface in use..... | 2171.9 sq. ft. |
| Ratio of grate surface to heating surface..... | $\frac{1}{48.25}$ |

Temperatures.

| Items | Trial No. 1 Duration, 10 hrs. | Trial No. 2 Duration, 24 hrs. | Trial No. 3 Duration, 10 hrs. |
|--|----------------------------------|----------------------------------|----------------------------------|
| 1. Average temperature feed water entering boiler, degrees Fahr. | 151.2 | 160.5 | 155.9 |
| 2. Average temp., outer air..... | 40.9 | 34.1 | 29.8 |
| 3. Average temp., fire room..... | 49.8 | 63.6 | 40.9 |

Pressures.

| | | | |
|------------------------------------|------|------|------|
| 4. Of steam in boiler by gauge.... | 79.7 | 79.2 | 79.2 |
| 5. Draft in inches of water..... | .35 | .31 | .31 |

Fuel.

| | | | |
|------------------------------------|---------|----------|-------|
| 6. Total coal consumed (pounds) .. | 4 987 | 12 368 | 4 600 |
| 7. Moisture in coal—percent..... | 6 | 6 | 6 |
| 8. Dry coal consumed—pounds... .. | 4 687.8 | 11 625.9 | 4 324 |
| 9. Total dry ash—pounds..... | 1 060 | 3 494 | 929 |
| 10. Total dry ash—per cent..... | 22.6 | 28.2 | 20.2 |
| 11. Total combustible—pounds.... | 3 627.8 | 8 131.9 | 3 395 |
| 12. Combustible consumed per hr.. | 362.8 | 338.8 | 339.5 |
| 13. Dry coal per hr.—pounds..... | 468.7 | 484.4 | 432.4 |

Water.

| | | | |
|--|----------|----------|----------|
| 14. Total weight pumped to boiler (pounds)..... | 22 659 | 53 677 | 21 840 |
| 15. Quality of steam—per cent.... | 98 | 98 | 68 |
| 16. Water evaporated—corrected for quality of steam..... | 22 206.4 | 53 603.5 | 21 403.2 |

Water.

| | | | |
|--|----------|----------|----------|
| 17. Ditto, per hr..... | 2 220.6 | 2 233.4 | 2 140.3 |
| 18. Total equivalent evaporated from and at 212 Fahr..... | 23 538.8 | 54 564.3 | 22 961.1 |
| 19. Ditto, per hour..... | 2 353.8 | 2 273.5 | 2 269.1 |
| 20. Water evaporated per lb. of dry coal..... | 4.73 | 4.25 | 4.65 |
| 21. Ditto, from and at 212°..... | 5.02 | 4.41 | 4.93 |
| 22. Water evaporated per lb. of com- bustible..... | 6.12 | 5.92 | 5.83 |
| 23. Ditto, from and at 212°..... | 6.48 | 6.14 | 6.18 |

Rate of Combustion.

| | | | |
|--|-------|-------|------|
| 24. Dry coal per sq. ft. of grate sur- face per hr..... | 10.41 | 10.76 | 9.60 |
|--|-------|-------|------|

Rate of Evaporation.

| | | | |
|---|-------|-------|-------|
| 25. Water per hour from and at 212° per sq. ft. of grate surface ... | 52.3 | 50.5 | 50.4 |
| 26. Commercial horse power (34½ lbs. water from and at 212°).. | 68.2 | 65.8 | 65.7 |
| 27. Sq. ft. of heating surface per horse power..... | 31.8 | 32.9 | 33.0 |
| 28. Horse power per sq. ft. of grate surface..... | 1.515 | 1.464 | 1.461 |

TEST OF DYNAMO.

| | | | |
|--|------|------|------|
| 29. Efficiency—per cent..... | 90 | 90 | 90 |
| 30. Average electric horse power de- livered..... | 33.1 | 34.8 | 32.0 |
| 31. Average electric horse power supplied..... | 36.4 | 38.3 | 35.2 |

TEST OF GOULDS TRIPLEX PUMP.

| | | | |
|--|----------|---------|----------|
| 32. Total No. of revolutions..... | 16 182 | 35 845 | 16 617 |
| 33. No. of gallons pumped per revo- lution (slip 3%)..... | 19.2 | 19.2 | 19.2 |
| 34. Total water pumped, gallons.... | 310 694 | 688 224 | 319 046 |
| 35. Water pumped per hr., gallons.. | 31 069.4 | 28 676 | 31 904.6 |
| 36. Average pressure in mains, lbs.. | 40.5 | 40.4 | 40.4 |
| 37. Horse power exerted by pump.. | 12.6 | 11.2 | 12.9 |
| 38. Horse power supplied to pump. | 15.1 | 13.6 | 15.5 |

TEST OF BATES CORLISS ENGINE.

Dimensions.

| | |
|----------------------------|-----------------|
| Stroke..... | 36 inches. |
| Diameter of Cylinder..... | 12 inches. |
| Clearance..... | 4 $\frac{1}{8}$ |
| Diameter of fly-wheel..... | 10 feet. |
| Face of fly-wheel..... | 15 inches. |

Data and Results.

| | | | |
|--|----------|---------|----------|
| 39. Net horse power of engine (item 30 + item 37.) | 51.5 | 51.9 | 50.7 |
| 40. Average M. E. P. head end | 34.3 | 35.5 | 34.8 |
| 41. Average M. E. P. crank end.... | 37.6 | 36.4 | 35.4 |
| 42. Average indicated horse power —head end..... | 28.9 | 29.9 | 29.0 |
| 43. Average indicated horse power —crank end..... | 28.2 | 29.6 | 28.7 |
| 44. Average total indicated horse power..... | 57.1 | 59.5 | 57.7 |
| 45. Efficiency of engine—per cent.. | 91 | 87 | 87 |
| 46. Total water used by engine—lbs. | 13 144.5 | 31 988 | 13 040.2 |
| 47. Water used per hour..... | 1 314.4 | 1 332.8 | 1 304.0 |
| 48. Water per net horse power per hour .. | 27.4 | 25.6 | 25.7 |
| 49. Water per indicated horse power per hour | 23.02 | 22.40 | 22.60 |
| 50. Coal per net horse power per hr. | 9.1 | 9.3 | 8.5 |
| 51. Coal per indicated horse power per hour | 8.2 | 8.1 | 7.5 |

Indicator Card Data.

| | | | |
|--|-------|-------|-------|
| 52. Maximum cut off—head end, per cent..... | 23.6 | 39.5 | 26 |
| 53. Ditto crank end..... | 24.9 | 39.5 | 26 |
| 54. Minimum cut off—head end.... | 2.6 | 0.27 | 4 |
| 55. Minimum cut off—crank end.... | 2.6 | 0.38 | 4 |
| 56. Average cut off—head end..... | 17.4 | 17.7 | 17.3 |
| 57. Average cut off—cranks end.... | 18.5 | 18.8 | 17.2 |
| 58. Water accounted for by cards (mean of ten cards)—lbs..... | 16.35 | 16.40 | 15.81 |
| 59. Ratio to condensed water—per cent..... | 71.0 | 70.3 | 70.0 |
| 60. Cylinder condensation—per cent | 8 | 7 | 7 |
| 61. Total steam entering cylinder .. | 17.65 | 17.58 | 16.81 |
| 62. Quality of steam—per cent | 99.5 | 99.5 | 99.5 |
| 63. Total steam and water entering cylinder..... | 17.73 | 17.66 | 16.89 |
| 64. Waste steam—per cent..... | 23 | 25 | 25 |
| 65. Dry steam used per hour..... | 23.01 | 22.3 | 22.5 |
| 66. Average vacuum—inches of mer- cury | 23.1 | 21.2 | 23.3 |

INITIAL TENSION IN ADJUSTABLE BRIDGE MEMBERS.

BY A. L. KUEHN, INSTRUCTOR IN CIVIL ENGINEERING.

Bridge specifications generally contain a clause which states a certain amount of stress to be allowed for initial tension in adjustable members, particularly lateral rods. In some specifications a fixed amount per member is stated, usually 10 000 pounds; in others a certain stress per sq. in. is given, also usually 10 000 pounds. Both these amounts are much smaller than those determined theoretically by considering the usual length of lever used in screwing up turnbuckles. This fact led the author to experimentally investigate the stresses produced by tightening up an adjustable member. The conditions under which the investigation was made were not those of bridge erection, yet it is possible to draw some conclusion from the results obtained.

The laboratory of the University having been destroyed by fire, the author was unable to make the tests at the University of Illinois. Through the courtesy of Prof. C. V. Kerr and Mr. Hurd of Armour Institute, Chicago, the work was done in the laboratory of that institution.

Tests were made on turnbuckles provided with stub ends placed in a testing machine. These turnbuckles were tightened up by means of levers about four and five feet long. The turning effort was that which could easily be produced by one man; it amounted to about 100 pounds, as was measured crudely later on. The conditions of the tests were such as would probably produce results smaller than those obtained in practice. The lever was horizontal and was somewhat interfered with by the standard of the testing machine so that the pulling was done at a disadvantage.

Four turnbuckles were used; two $1\frac{1}{4}$ -inch, one $1\frac{1}{2}$ -inch, and one 2-inch. All threads were well oiled. The results are shown in the following table:

| Diameter of Screw | Threads per Inch | Area of Body of Bar | Length of Lever Arm | Stress Produced | Stress per Sq. In. | Theor. Stress, no Friction | Coeff. of Friction |
|-------------------|------------------|---------------------|---------------------|-----------------|--------------------|----------------------------|--------------------|
| 1¼" | 7 | 0.601 | 3.5 ft. | 18500 lbs. | 80800 lbs. | 79100 lbs. | 0.34 |
| 1¼" | 7 | 0.601 | 4 ft. | 23300 lbs. | 38800 lbs. | 105700 lbs. | 0.36 |
| 1½" | 6 | 0.994 | 4 ft. | 30000 lbs. | 30200 lbs. | 90600 lbs. | 0.26 |
| 2" | 4½ | 1.767 | 4 ft. | 25000 lbs. | 14100 lbs. | 67900 lbs. | 0.23 |

The first three columns give the dimensions of the turnbuckles; the fourth column gives the average length of lever arms to which the force of 100 pounds was applied; the fifth column gives the stresses produced by turning up the turnbuckles; the sixth column gives the corresponding stresses per square inch produced in the bodies of the bars; the seventh column gives the stresses which could be produced if there were no friction. The results in this column were computed by the formula $2\pi r \times n \times 100$, in which r is the lever arm in inches and n is the number of threads per inch on the screw. The eighth column gives the coefficient of friction on the threads as determined from column five by the following formula: $\frac{100 \times r}{P \times m}$,

in which r is the the lever arm in inches, P is the stress produced in the turnbuckle, and m is the radius at which the friction acts (assumed at the middle of the thread).

It is to be noted from these tests that 10 000 pounds per rod or 10 000 pounds per square inch can easily be produced in screwing up turnbuckles, and it is very likely that several times these amounts are usually obtained. The object of initial stress is to give the members a firm bracing, and its amount is usually stated in the case of lateral rods so that struts of sufficient stiffness may be determined. Ten thousand pounds will surely fulfill these conditions. Allowing a certain initial stress per square inch is equivalent to reducing the working stress by that amount. This will not occur, since large rods will have smaller initial stress than small ones. It is best, therefore, to specify a fixed amount of initial stress for all adjustable members. Ten thousand pounds is sufficient. In order that stresses produced by screwing up the turnbuckles shall be somewhere near this amount, the levers should not be larger than two feet for turnbuckles up to two inches; for turnbuckles from two to three inches, a two and one half foot lever should be used; and for

three to four inch turnbuckles, a three and one half foot lever is of proper length. It is probable that with these lengths of levers, the stress will sometimes be over 10 000 pounds, but not enough so to produce any serious effect.

CHANCES FOR YOUNG ENGINEERS IN MEXICO.

BY J. M. ALARCO, '00, MANAGER LA LUZ ELECTRICA DE AGUASCALIENTES.

The subject is not new but deserves attention, especially of young engineers just out of school looking for work and for a field of action. From my personal experience and constant intercourse with engineers in this country, my opinion is that the chances here are good, but although it may seem presumptuous, let me name some of the requisites to success in this country.

In the first place, that which is necessary for success in all countries, and under all circumstances: Don't be afraid of work. Not only that, but show your employer you are willing and eager to do work. Next learn to speak and understand the Spanish language which is worth one hundred per cent of your salary at the start and a thousand per cent later on. It has been my experience, I am sorry to say, that about one in every fifty of the Americans in this country know Spanish only well enough to make themselves understood. Few take the trouble to learn Spanish thoroughly, consequently they fill only the lower positions in an office; and those that know it well, although probably not as efficient in their work, step above them and advance rapidly. Choose your employer if possible, above all select a gentleman and one who is willing to teach you. Another mistake of the Americans is that as soon as they are one month in Mexico, alcohol and other things not to be mentioned get the best of them. They burn the candle at both ends and do not last long.

But outside of this general advice, it is best when coming here to be in the employ of a foreign firm, or come to fill a position secured before hand—unless you have some capital to start for yourself. Mexicans as a general rule are not enterprising, and those that are and have money will award the contract for any enterprise they may undertake to a foreign firm and will employ foreign skill.

Opportunities there are galore. Every town of importance has an electric light system or is thinking of putting one in. All of them need a sewer system and public water supply. The matter is just waiting for some enterprising American firm to hustle it through. Although as a general rule the treasury of most cities is empty, they have the advantage of not being bonded, leaving therefore an untouched source of revenue and a way of raising money for future enterprises.

There are ranches of from 1 to 50 square milles in area, and whole sections of the country practically worthless for the lack of water. In many instances a dam can be built on the property at a very small cost, since material is handy and labor is cheap. A common laborer on the ranches gets twelve cents per day in Mexican money and enough corn to make a meal.

As for mining, there is a constant demand for a man willing to begin at the bottom with the probabilities of taking a claim for one's self. The mining laws of Mexico are excellent and claim jumpers do not exist. They died long ago of an indigestion of lead.

Labor, as I have already pointed out, is both cheap and efficient. The Guggenheim Smelting Company imported 200 chinamen, but it didn't pay, as one Mexican, when he is willing to work, will do as much as two chinamen for the same money. The regular price of unskilled labor in and around cities is from thirty-five to fifty cents in silver per day, and that of the best skilled labor from \$2 to \$3 silver per day.

Mexican peones have to be treated in a special way. They are like children, need to be praised and patted on the back every now and then, and must have a regular day off on their feast days. They need to be "called down", but without any cursing, for although they do not understand English, they know you are swearing at them and will tell you: "I do not have to work. There are tunas in the mountains." Tunas are

a fruit that grow on the wild cactus and which furnishes the peones with all the nourishment they need, during the three months that the tunas last; consequently when the peones do not want to work, they will camp out and live on tunas as long as they last.

If the engineer, after graduating, stays in the States a couple of years, and gains the practical knowledge necessary to supplement the theory he has learned in college, then he can command a situation here in any branch of the profession. But do not let him come with the idea that he will find an up-to-date machine shop in the whole country, or that any of the standard size materials can be bought in the open markets as in the States. When erecting a plant of any kind he must learn to use the material at hand, and operations that are done in the States with lathe or shaper must frequently be done here with hammer, chisel, hack-saw, and file. If the specifications call for brick and cement, he must most of the time content himself with adobes, mud, and lime.

Economy in the use of fuel, is of the utmost importance here, for coal costs from \$8 to \$10 gold per ton; and fuel saving devices such as condensers, heaters, and economizers, if not already attached to the engine, must be bought or contrived by the engineer or manager.

Any good engineer will get from \$90 to \$150 gold per month. As his living expenses are more than 50 per cent lower than in the States, it follows that more money can be saved. The field is not crowded by any means, and all it needs is to get down here and hustle, and success will follow.

Last but not least be polite to the Mexicans. Do not look upon them as "greasers" and an inferior race; a smile, the lifting of your hat, or an inquiry about their health, will do more to help you in some cases than any amount of hard work.

THE MECHANICS OF A ROLLING DISC.

G. A. GOODENOUGH, ASSISTANT PROFESSOR OF MECHANICAL
ENGINEERING.

A problem of theoretical interest and of some practical importance is the following: A flat circular disc, Fig. 1. rolls on a circular track, the center of the disc having uniform velocity; required the acceleration of any point in the disc.

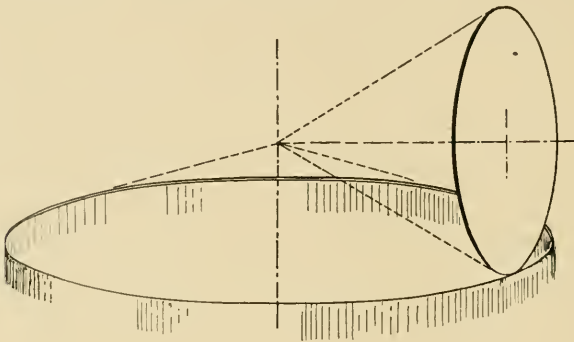


FIG. 1.

Evidently this is a case of spheric motion, and the rolling of the disc on the track may be represented by the rolling of a circular cone with the disc as a base upon another circular cone with the same point as vertex. The problem may therefore be stated thus: Required the acceleration of any point in the base of a cone that rolls with uniform velocity upon a stationary cone.

To solve this problem we use the following theorem, the proof of which may be found in standard works on mechanics: Infinitesimal rotations about two intersecting axes may be combined into a single infinitesimal rotation about a third axis concurrent with the first two and lying in their plane. Conversely, an infinitesimal rotation about an axis may be resolved into infinitesimal rotations about two axes meeting the original axis in the same point. Thus simultaneous infinitesimal rotations about the intersecting axes OA and OB , Fig. 2, may be combined into a single rotation about the axis OC , or vice versa.

If α and β denote respectively the angular velocities of the rotations about OA and OB , then

$$\alpha \sin AOC = \beta \sin BOC,$$

or
$$\frac{\alpha}{\beta} = \frac{\sin BOC}{\sin AOC}$$

Evidently the position of the axis OC and the magnitude of the resultant angular velocity r of the rotations about OC may be

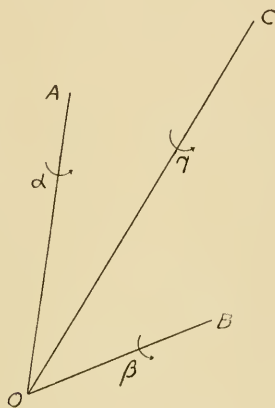


FIG. 2.

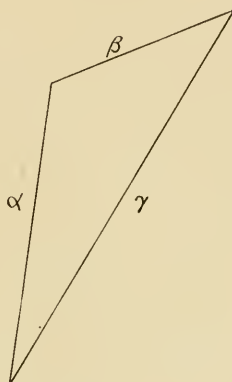


FIG. 3.

obtained by the ordinary triangle construction. We lay off one side of a triangle parallel to OA and proportional to α , the second side parallel to OB and proportional to β ; then the closing side is parallel to the axis OC and its length is proportional to the resultant angular velocity γ . See Fig. 3. In general, we may apply to angular velocities the laws of the composition and resolution of forces, assuming that the directions of the forces coincide with the axes of rotation and that the magnitudes are proportional to the angular velocities.

This principle we apply to the case of the rolling cone, Fig. 1. Evidently the moving cone is at any instant rotating about the line of contact in the common element of the two cones. In Fig. 5, which shows three views of the two cones, OA is this common element. After the cone has turned slightly, it will be in contact with the stationary cone along a second common element passing of course through the vertex O , and the

motion of the rolling cone during this second instant will be a rotation about this new common element. Suppose that OA and OB , Fig. 4, are respectively the original axis of rotation and the new axis of rotation. Let the angular velocity of the rotation of the cone about the axis or common element OA be denoted by ω ; then since the motion is uniform, the angular velocity of the

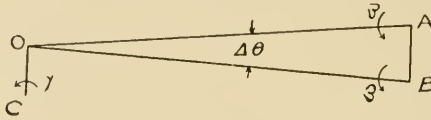


FIG. 4.

rotation of the cone about its new axis OB will also be ω . Now according to the principle just stated, the rotation about the axis OB can be resolved into a rotation of equal angular velocity ω about the axis OA and a rotation of angular velocity γ about a third axis OC . Treating the angular velocities like forces, the two equal sides OA and OB of the triangle OAB may be taken to represent the equal angular velocities ω ; then the third side AB represent in magnitude the angular velocity γ and the direction of AB gives the direction of the axis OC . The sense of γ is the same as that of ω —counter-clockwise looking along the axis from C to O . The limiting position of OC , when OB is made to approach OA is the perpendicular to OA , lying in the tangent plane of the cone passing through OA .

Consider now the motion of any point in the base of the rolling cone, as P , Fig. 5. When the axis of rotation is OA the point P has some definite velocity. The direction of this velocity is perpendicular to the plane through OA containing P , and the magnitude, which we will denote by v' , is proportional to the distance of P from the axis OA . When OB is the axis of rotation, the velocity of P is perpendicular to the plane through P and OB , and the magnitude has a new value v'' . Thus during the motion of the cone the velocity of P has changed both in magnitude and direction. If Δv denotes the change in velocity, that is, if Δv is the velocity that must be given the point P to change its velocity from the original v' to the new v'' , then by the definition of acceleration, the acceleration of P is the limiting value of the quotient obtained by divid-

ing the increment Δv by the time occupied in the change; thus denoting the acceleration of P by f ,

$$f = \lim. \left(\frac{\Delta v}{\Delta t} \right) \text{ as } \Delta t \text{ approaches zero.}$$

By the resolution of the rotation of the cone about OB into rotations about OA and OC , we have at the same time resolved

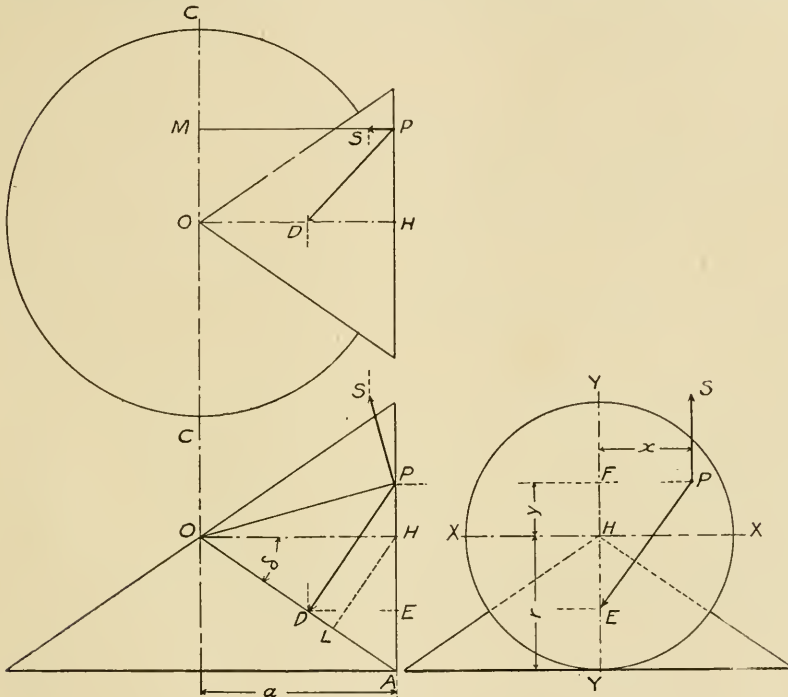


FIG. 5.

the increment of velocity Δv into two components. Leaving out of consideration the rotation about OC , the cone rotates during two consecutive intervals of time about the axis OA , and the point P therefore moves with uniform angular velocity ω in a circle whose radius is PD , Fig. 5, and whose plane is perpendicular to OA . It is well known that in such a motion the acceleration of the point P is $PD \cdot \omega^2$ directed towards the center of the circle, that is, towards the point D . This acceleration is the limiting value of the quotient of *one* component of Δv divided by Δt . The *other* component of Δv is due to the rotation about

OC of angular velocity γ . If we denote by l the perpendicular distance of the point P from the axis OC , then the velocity of P due to the rotation about OC is $l\gamma$, and this $l\gamma$ is the second component of $\mathcal{J}v$. The first component of $\mathcal{J}v$ gave P the acceleration

$$f_1 = PD \cdot \omega^2$$

directed along PD . The component increment $l\gamma$ gives P an acceleration at right angles to the line PM , Fig. 5, joining P to the axis OC , and of magnitude

$$f_2 = \text{limit} \left[\frac{l\gamma}{\mathcal{J}t} \right], \text{ as } \mathcal{J}t \text{ approaches zero.}$$

To evaluate this expression we have from Fig. 4

$$AB = 2 OA \sin \frac{1}{2} \mathcal{J}\theta,$$

$$\text{or} \quad \gamma = 2 \omega \sin \frac{1}{2} \mathcal{J}\theta.$$

$$\text{Therefore} \quad \frac{l\gamma}{\mathcal{J}t} = 2 l \omega \sin \frac{\frac{1}{2} \mathcal{J}\theta}{\frac{1}{2} \mathcal{J}t},$$

and

$$\text{lim.} \left[\frac{l\gamma}{\mathcal{J}t} \right] = l \omega \cdot \text{lim.} \left[\frac{\sin \frac{1}{2} \mathcal{J}\theta}{\frac{1}{2} \mathcal{J}t} \right] = l \omega \cdot \text{lim.} \left[\frac{\mathcal{J}\theta}{\mathcal{J}t} \right] = l \omega \cdot \frac{d\theta}{dt}$$

We have used $\mathcal{J}\theta$ to denote the angle between consecutive axes of rotation OA and OB ; hence $\frac{d\theta}{dt}$ is evidently the angular velocity of the instantaneous axis or common element OA . Referring to Fig. 5, let v denote the linear velocity of the center H of the base. Since H is for the instant rotating about the point L ,

$$v = HL \cdot \omega = \omega r \cos \delta.$$

The end A of the axis OA has also the velocity v ; hence the angular velocity of OA is

$$\frac{v}{OA} = \frac{v}{\cos \delta} = \frac{v}{r} \sin \delta;$$

$$\text{hence,} \quad \frac{d\theta}{dt} = \frac{v}{r} \sin \delta = \frac{\omega r \cos \delta}{r} \sin \delta = \omega \sin \delta \cos \delta.$$

$$\text{Finally,} \quad f_2 = \text{limit} \left[\frac{l\gamma}{\mathcal{J}t} \right] = l \omega \cdot \frac{d\theta}{dt} = l \omega^2 \sin \delta \cos \delta.$$

We have now determined the two components of the acceleration of the point P . The centripetal component $f_1 = PD \cdot \omega^2$

directed along PD may be represented by the vector PD to some scale. The other component $f_2 = PM \cdot \omega^2 \sin \delta \cos \delta$ is represented by the vector PS drawn through P at right angles to PM . The axis OC , Fig. 5, lies in a horizontal plane and is perpendicular to both OA and OH , and therefore to the vertical plane OAH ; the acceleration PS must lie in a parallel vertical plane through P .

The total acceleration of the point P is evidently the resultant of the accelerations f_1 and f_2 .

It is convenient to resolve f_1 and f_2 into components parallel to three rectangular axes; for these axes we naturally choose the axis OH of the rolling cone and the horizontal and vertical axes XX and YY of the base of the cone. It will be observed that PD is the diagonal of a rectangular parallelepiped, of which the edges parallel to the axes mentioned are:

$DE = (r + y) \sin \delta \cos \delta$; $FP = x$; and $FE = (r + y) \cos^2 \delta$;
hence the components of $PD \cdot \omega^2$ are:

$$PD \cdot \omega^2 \frac{DE}{PD} = \omega^2 \cdot DE = \omega^2 (r + y) \sin \delta \cos \delta, \text{ parallel to } OH;$$

$$PD \cdot \omega^2 \frac{EP}{PD} = \omega^2 \cdot FP = \omega^2 x, \text{ parallel to } XX;$$

$$PD \cdot \omega^2 \frac{FE}{PD} = \omega^2 \cdot FE = \omega^2 (r + y) \cos^2 \delta, \text{ parallel to } YY.$$

The components of the acceleration represented by PS are:

$$PM \cdot \omega^2 \sin \delta \cos \delta \frac{HF}{OF} = y \omega^2 \sin \delta \cos \delta, \text{ parallel to } OH;$$

$$PM \cdot \omega^2 \sin \delta \cos \delta \frac{OH}{OF} = r \omega^2 \sin \delta \cos \delta = r \omega^2 \cos^2 \delta, \text{ parallel to } YY.$$

As PS lies in a plane perpendicular to XX , it has no component parallel to XX .

The total acceleration parallel to OH , which we may denote by f_z , is

$$\begin{aligned} f_z &= \omega^2 y \sin \delta \cos \delta + \omega^2 (r + y) \sin \delta \cos \delta \\ &= \omega^2 (r + 2y) \sin \delta \cos \delta. \dots \dots \dots (1) \end{aligned}$$

This equation shows that the acceleration component in question depends upon the distance of the point from the horizontal

diameter of the base. All points in any line parallel to this diameter have the same acceleration perpendicular to the base. For $r + 2y = 0$, or $y = -\frac{1}{2}r$, $f_z = 0$; that is the points lying on a horizontal line of the base midway between A and H , have no acceleration perpendicular to the base. For points above this line, $r + 2y$ is positive and the points have perpendicular accelerations directed toward that side of the base facing the vertex O . Points below this line have accelerations with the opposite sense, $r + 2y$ being negative.

Of the two vertical components that of PD is directed downwards and that of PS upwards. Subtracting the latter from the former, the resultant vertical component is

$$f_y = \omega^2 (r \times y) \cos^2 \delta - \omega^2 r \cos^2 \delta = \omega^2 y \cos^2 \delta \dots \dots (2)$$

This component vanishes when $y = 0$, that is for all points on the horizontal diameter of the base. For all points above this diameter (*i. e.* for $+y$), it is directed downwards, and for all points below it (*i. e.* for $-y$) it is directed upwards. In other words, the vertical acceleration of any point in the base is directed towards the horizontal diameter XX .

The component parallel to XX , $f_x = \omega^2 x$, is directed towards the vertical diameter of the base, and vanishes for all points on that diameter.

Let Ω denote the angular velocity of the axis OH of the rolling cone about the point O ; then since v is the velocity of the point H ,

$$\Omega = \frac{v}{OH} = \frac{v}{a}.$$

Substituting for v its value $\omega r \cos \delta$,

$$\Omega = \frac{\omega r \cos \delta}{a} = \frac{\omega r \cos \delta}{r \cot \delta} = \omega \sin \delta,$$

and $\omega^2 = \Omega^2 \cos^2 \delta$.

Substituting this value of ω^2 in the preceding equations, we obtain

$$\left. \begin{aligned} f_z &= \Omega^2 (r + 2y) \cot \delta, \\ f_y &= \Omega^2 y \cot^2 \delta, \\ f_x &= \Omega^2 x \cos^2 \delta. \end{aligned} \right\} \dots \dots \dots (3)$$

The functions of δ may be expressed in terms of r and a ; then the equations become

$$\left. \begin{aligned} f_z &= \frac{a}{r} \Omega^2 (r + 2y), \\ f_y &= \frac{a^2}{r^2} \Omega^2 y, \\ f_x &= \left(\frac{a^2}{r^2} + 1 \right) \Omega^2 x. \end{aligned} \right\} \dots\dots\dots (4)$$

Having obtained the acceleration components of any point of the base of the cone (or flat disc), we are enabled to study the action of one or more concentrated masses assumed to be attached to the disc. Two cases are of special interest: (1) when there are two equal masses attached at diametrically opposite points, as shown in Fig. 6; (2) when there are three equal masses 120° apart and at the same distance from the center, Fig. 7. If m denote the mass of one of these attached weights, the forces of inertia parallel to the three axes previously assumed are, respectively:

$$\left. \begin{aligned} Z &= m f_z = \frac{a}{r} m \Omega^2 (r + 2y), \\ Y &= m f_y = \frac{a^2}{r^2} m \Omega^2 y, \\ X &= m f_x = \left(\frac{a^2}{r^2} + 1 \right) m \Omega^2 x. \end{aligned} \right\} \dots\dots\dots (5)$$

Each of these forces acts in a sense opposite to that of the corresponding acceleration.

Consider now the case of the equal and opposite masses, Fig. 6. The forces perpendicular to the disc are, since $y = c \sin \theta$,

$$\begin{aligned} Z_1 &= \frac{a}{r} m \Omega^2 (r + 2c \sin \theta_1); \\ Z_2 &= \frac{a}{r} m \Omega^2 (r + 2c \sin \theta_2) = \frac{a}{r} m \Omega^2 (r - 2c \sin \theta_1). \end{aligned}$$

The resultant of these parallel forces is

$$Z_1 + Z_2 = 2 am \Omega^2.$$

To find the distance ρ of the point of application of this resultant from the center O of the disc, we have

$$\rho (Z_1 + Z_2) = (Z_1 - Z_2) c = \frac{4ac^2}{r} m \Omega^2 \sin \theta_1,$$

whence
$$\rho = \frac{2c^2}{r} \sin \theta_1.$$

This is the polar equation of a circle, tangent to the horizontal diameter of the disc and with its center G , Fig. 6, on the vertical diameter at a distance $\frac{c^2}{r}$ above the center O of the disc.

The intersection D of this circle with the line joining the two masses is the point of application of the resultant $Z_1 + Z_2$. The distance of this point of application above the horizontal diameter of the disc is

$$e = \rho \sin \theta_1 = \frac{2c^2}{r} \sin^2 \theta_1.$$

If we denote by R the pressure between the disc and track due

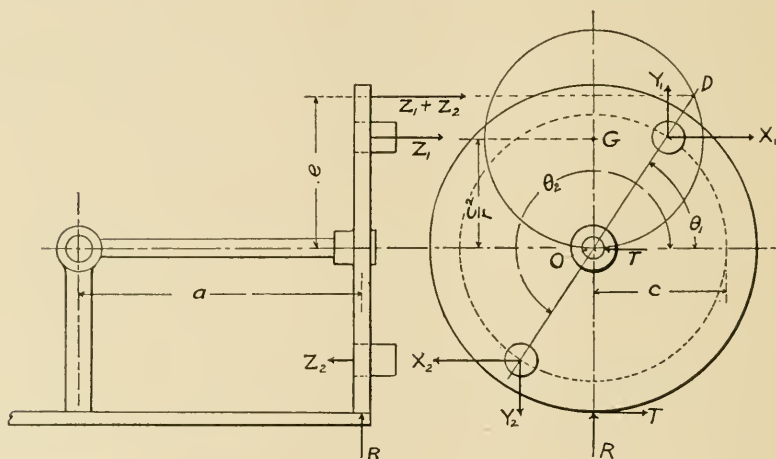


FIG. 6.

to the forces of inertia, then taking moments about the axis CC , Fig. 5,

$$Ra = (Z_1 + Z_2)e = \frac{4ac^2}{r} m\Omega^2 \sin^2 \theta_1;$$

or,

$$R = \frac{4c^2}{r} m\Omega^2 \sin^2 \theta_1.$$

For $\theta = 0$, $R = 0$, for $\theta = 90^\circ$, $R = 4\frac{c^2}{r}m\Omega^2$, its maximum value.

We arrive thus at the interesting conclusion that if a disc carrying two equal and opposite weights rolls on a circular track, there is a periodical variation of the pressure between the disc and track. Evidently this variation grows smaller as we

increase the radius of the track and thus decrease the angular velocity Ω . For a straight track $\Omega = 0$, and the variation in pressure vanishes.

The two vertical forces

$$Y_1 = \frac{a^2}{r^2} m \Omega^2 y_1$$

$$Y_2 = \frac{a^2}{r^2} m \Omega^2 y_2 = -\frac{a^2}{r^2} m \Omega^2 y_1$$

are parallel and of the same magnitude and form a couple whose moment is

$$2 \frac{a^2}{r^2} m \Omega^2 y_1 x_1 = 2 \frac{a^2 c^2}{r^2} m \Omega^2 \sin \theta_1 \cos \theta_1.$$

Likewise the forces X_1 and X_2 form a couple whose moment is

$$2 \left(\frac{a^2}{r^2} + 1 \right) m \Omega^2 x_1 y_1 = 2 c^2 \left(\frac{a^2}{r^2} + 1 \right) m \Omega^2 \sin \theta_1 \cos \theta_1.$$

These two couples have opposite senses; combining them we obtain a single couple of moment,

$$2 c^2 m \Omega^2 \sin \theta_1 \cos \theta_1 = c^2 m \Omega^2 \sin 2 \theta_1.$$

This couple is balanced by a couple of the same moment and opposite sense composed of the forces T , T , Fig. 6, the tangential resistance between the disc and track and the pressure between the pin at the center of the disc and its bearing. The equality of the moments gives the equation

$$Tr = c^2 m \Omega^2 \sin 2 \theta_1,$$

or

$$T = \frac{c^2}{r} m \Omega^2 \sin 2 \theta_1.$$

For $\theta = 0^\circ, 90^\circ, 180^\circ$, etc.; $T = 0$; while for $\theta_1 = 45^\circ, 135^\circ$, etc., T reaches its maximum value $+\frac{c^2}{r} m \Omega^2$. Evidently T

changes its sense whenever θ_1 changes from one quadrant into the next. As in the case of the pressure R , the variation in T vanishes for $\Omega = 0$, that is, when the track is straight.

Let us consider now the case of three equal masses evenly

spaced around a circumference of radius c , as shown in Fig. 7. The three angles, θ_1 , θ_2 , and θ_3 are connected by the relations

$$\begin{aligned}\theta_2 &= \theta_1 + 120^\circ \\ \theta_3 &= \theta_2 + 120^\circ = \theta_1 + 240^\circ.\end{aligned}$$

When these relations exist it may be readily proved that

$$\begin{aligned}\sum \sin \theta &= 0; \\ \sum \cos \theta &= 0; \\ \sum \sin \theta \cos \theta &= 0; \\ \sum \sin^2 \theta &= \frac{3}{2}; \\ \sum \cos^2 \theta &= \frac{3}{2}.\end{aligned}$$

The resultant of the forces of inertia perpendicular to the disc has a magnitude

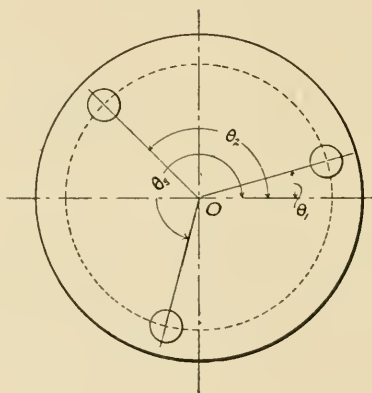


FIG. 7.

$$\begin{aligned}Z_1 + Z_2 + Z_3 &= \frac{a}{r} m \Omega^2 \left[(r + 2y_1) + (r + 2y_2) + (r + 2y_3) \right] \\ &= 3 a m \Omega^2 + 2 \frac{a}{r} m \Omega^2 c \sum \sin \theta \\ &= 3 a m \Omega^2,\end{aligned}$$

since $\sum \sin \theta = 0$.

To find the coordinates of the point of application of this resultant, we take moments about the horizontal and vertical axes of disc respectively.

$$\begin{aligned} \bar{y} &= \frac{Z_1 y_1 + Z_2 y_2 + Z_3 y_3}{Z_1 + Z_2 + Z_3} \\ &= \frac{a c m \Omega^2 \Sigma \sin \theta + 2 \frac{a c^2}{r} m \Omega^2 \Sigma \sin^2 \theta}{3 a m \Omega^2} \\ &= \frac{c^2}{r} \quad (\text{since } \Sigma \sin \theta = 0, \text{ and } \Sigma \sin^2 \theta = \frac{3}{2}). \\ \bar{x} &= \frac{Z_1 x_1 + Z_2 x_2 + Z_3 x_3}{Z_1 + Z_2 + Z_3} \\ &= \frac{a c m \Omega^2 \Sigma \cos \theta + 2 \frac{a c^2}{r} m \Omega^2 \Sigma \sin \theta \cos \theta}{3 a m \Omega^2} = 0. \end{aligned}$$

It appears therefore that the resultant of the three forces has the same magnitude and the same point of application for all positions of the disc; and this point of application is the center G of the circle shown in Fig. 6. It follows that the moment of this resultant is constant and that the pressure between the disc and track is also constant.

For the vertical forces of inertia we have

$$\begin{aligned} Y_1 + Y_2 + Y_3 &= \frac{a^2}{r^2} m \Omega^2 (y_1 + y_2 + y_3) \\ &= \frac{a^2}{r^2} m \Omega^2 c \Sigma \sin \theta = 0. \end{aligned}$$

The summation of the moments of these forces about the center of the disk gives

$$\begin{aligned} Y_1 x_1 + Y_2 x_2 + Y_3 x_3 &= \frac{a^2}{r^2} m \Omega^2 (y_1 x_1 + y_2 x_2 + y_3 x_3) \\ &= \frac{a^2}{r^2} m \Omega^2 c^2 \Sigma \sin \theta \cos \theta = 0. \end{aligned}$$

Likewise for the horizontal forces X_1 , X_2 and X_3 ,

$$X_1 + X_2 + X_3 = \left(\frac{a^2}{r^2} + 1 \right) m \Omega^2 c \Sigma \cos \theta = 0.$$

$$X_1 y_1 + X_2 y_2 + X_3 y_3 = \left(\frac{a^2}{r^2} + 1 \right) m \Omega^2 c^2 \Sigma \cos \theta \sin \theta = 0.$$

The preceding analysis lead to the following conclusions: When a wheel or disc rolls on a curved track an eccentric mass, as a crank or crank pin, can not be perfectly balanced by an equal mass placed diametrically opposite. The forces of iner-

tia of the two masses will cause variations in the track pressure and in the tangential force between track and wheel, and these variations will be more marked the sharper the curvature of the track. If the eccentric mass be balanced by two equal masses spaced 120° from the original mass there will be no disturbances of this character. The pressure on the track and the tangential force between track and wheel will remain constant.

Attention was first drawn to this subject by the efforts of a Philadelphia engineer to devise an improved method of counterbalancing locomotive driving wheels. This gentleman had a theory that the translation of the wheel along the track has an important bearing on the action of the inertia forces of the rotating parts. To substantiate his views he built a testing machine and experimented with discs counterweighted in different ways. As it would have been difficult to make a straight track of sufficient length, the testing machine was constructed with a circular track; the experimenter presumedly supposing that the character of the track could have no influence on the validity of the experiment. The experiments naturally showed a variation in track pressure when the disc carried two equal and opposite masses and no variation when it carried three masses 120° apart. On the strength of these experiments the gentleman in question was granted patents for an improvement in counterbalancing locomotive driving wheels, and began to advertise his invention. A committee of the Franklin Institute, appointed to investigate the alleged invention, quickly showed the would-be inventor the true interpretation of his experiments and convinced him of the worthlessness of his patents. A full account of this investigation may be found in "The Journal of the Franklin Institute," August, 1898, p. 105.

It may be worth while to see what the variation in track pressure will be in the case of a locomotive on a sharp curve. As an extreme case, let the radius of the curve be 500 feet, and the speed of the locomotive 90 feet per second. Further, let the mass $m=10$ be concentrated at the crank pin, 1 foot from the center of driver, and let the radius of driver be $2\frac{1}{2}$ feet; then

$$R = 4 \frac{c^2}{r} m \Omega^2 = 4 \times \frac{1}{2\frac{1}{2}} \times 10 \times \left(\frac{90}{500}\right)^2 = .52 \text{ lb.},$$

a variation quite insignificant.

REGULATION OF ALTERNATORS UNDER VARIABLE REACTIVE LOADS.

BY GEO. W. REDFIELD, ELECTRICAL ENGINEER '01.

One of the most important questions confronting the electrical engineer of to-day is that of the regulation of alternating-current generators under variable reactive loads. By reactive loads we mean those which have lagging or leading wattless components of the current; that is, the current is not in phase with its impressed E. M. F. By the use of single and polyphase induction motors on lighting circuits it was found that ordinary alternators, however satisfactory in regulation on such non-inductive loads, were almost worthless when used on mixed and inductive circuits. Designers were surprised to find so large a drop of voltage under these conditions, that by no method of regulation of excitation could the voltage at the terminals of the machine be maintained at its correct value. This problem of alternator regulation is at once technical and commercial.

ELEMENTS DETERMINING SATISFACTORY PERFORMANCE.—The ultimate success of any electrical supply for light or power, or both, depends upon the degree of regulation attainable at the generator. The normal voltage of the generator is to be taken as the voltage at its terminals at no load or on open circuit. The drop at the machine with any character of load will then be the difference between this normal voltage and the voltage at the same terminals for any given load. At full load this difference gives the maximum drop for any kind of load in question. Line drop, so called, is the difference of pressure between the generator and receiver terminals of the line for any given kind and amount of load. Line drop is entirely distinct from generator drop. To give satisfactory service on power circuits, and to some extent on lighting circuits, the performance of generators is characterized and determined by the permissible maximum drop of the generator for the kind of load in question.

ESSENTIAL FEATURES IN THE DESIGN OF ALTERNATORS.—The design of alternators has now settled into quite well-defined

lines. For instance, for each kind of service certain limits are prescribed for the flux densities and air-gap. Also, definite maximum drop is usually determined upon. General principles have been established by research and the exacting requirements of commercial service; for instance, good regulation is required up to 50 per cent. overload even during rapid fluctuations, and also for continuity of electrical supply under any conditions of service that may arise. These principles are followed by the most successful designers of alternators. Almost all machines of this type, especially those of larger sizes, are now separately excited. Hence, their successful operation depends entirely upon their inherent regulation. We understand this term to refer to the characteristic behavior of the machine as a maintainer of its normal voltage at different loads, with variable reactance in the external circuit as well as with non-inductive loads, the speed and excitation remaining constant for any given case.

A number of features in the design of alternators involve regulation as a function. Almost all of them however can be considered under the following heads:* (1) Ohmic armature resistance. (2) Eddy currents set up by leakage fields, due to armature or field current, or both. (3) Increase in the field leakage between no load and full load. (4) Self-inductance of the armature. (5) The presence of leading or of lagging currents in the armature which depend upon the kind of reactive loads on the machine. Lagging armature currents have the effect of weakening the generator field, and leading currents the effect of strengthening the field.

In regard to the above items the first requires no comment. The second feature has quite a demagnetising effect upon the field but can be greatly reduced by careful design. The third point considers the cross-magnetising effect due to the increase with the load of the cross-magnetising ampere-turns of the armature. This has the effect, furthermore, of increasing the reluctance of the magnetic circuit. Hence the leakage is increased and the useful flux decreased. All of these undesirable features can be minimized by careful design. The fourth item takes account of the self-inductance of the armature which causes a

*Design of Alternators. V. A. Fynn. Elec. Rev. London. Vol. 48: p. 55. Jan. 11, 1901.

phase displacement of its current resulting in its lagging behind the generated E. M. F. As the load increases this effect also increases, and the resulting drop is one of the main causes of bad regulation. In referenee to the fifth item, the presence of a lagging current in the armature circuit, either due to high armature self-inductance or an external inductive load, exerts upon the generator field a very marked demagnetising effect, which increases with the load and also with the lagging wattless component for any given load. The result is a decrease in the useful flux and hence a greater terminal drop at the generator. The presence of leading currents in the armature circuit due to external loads whose wattless components are leading produces an opposite effect to that described above for lagging currents. The last two cases are closely related and will be discussed more fully further on.

DESCRIPTION OF THE ALTERNATOR.—The curves in this article are from data taken by the author in the Electrical Engineering Laboratory of the University of Illinois, from a 10-kilowatt, 4-pole machine made by the Westinghouse Electric and Manufacturing Co. The machine was constructed for single and polyphase work, as generator, synchronous motor, or converter. The armature has a distributed winding and was here tapped off as a three-phase, delta combination. The resistance of one phase was 0.92 ohms (hot). The field cores are laminated; they have no pole-shoes, but a heavy copper shoe of the form of an ordinary pole-shoe in place of the latter. These copper shoes are placed around and slightly under the pole tips and evidently suppress hunting when the machine is to be operated as a synchronous motor or converter.

DIMENSIONS AND MEASUREMRNTS OF ALTERNATOR.

| | |
|---|---------------------|
| Type..... | Polyphase Converter |
| Serial number..... | 135 751 |
| Capacity..... | 10 Kilowatts |
| Number of poles..... | 4 |
| R. P. M..... | 1 800 |
| Frequency..... | 60 Cycles |
| Normal Volts (three-phase)..... | 410 |
| Full Load Current per branch (three-phase)..... | 14 Amperes |
| Resistance of Field (hot)..... | 685 Ohms |
| Resistance of Armature per Phase (hot)..... | 0.92 Ohms |
| Diameter of Armature..... | 9.50 Inches |
| Diameter of Armature Bore..... | 9.71 Inches |
| Length of Air-Gap..... | 0.105 Inches |
| Length of Poles (axial)..... | 5.25 Inches |
| Breadth of Poles..... | 4.45 Inches |

CONSIDERATION OF CHARACTERISTICS.—Referring to Fig. 1, page 99, curve *c* is the average no-load or so-called “static characteristic” for one phase *A-B* of the armature three-phase delta circuit. This characteristic was obtained experimentally by running the machine under no load, at constant speed and variable excitation, and measuring the terminal voltages for the respective excitations.

Curve *d* is the corresponding dynamic characteristic. This was obtained by reading the terminal voltages at the generator for the corresponding excitations while the speed and power factor were maintained constant during the time these points were being taken. The current in each of the branches was kept constant at its full load value of 14 amperes. The output of the generator was absorbed by water rheostats. At each point the field current for the respective excitations was reversed and the average taken of the two readings. The plotted curve was from these averages. The external circuit power factor was maintained at unity as noted, while the power factor of the inductive armature circuit itself will be something less than unity.

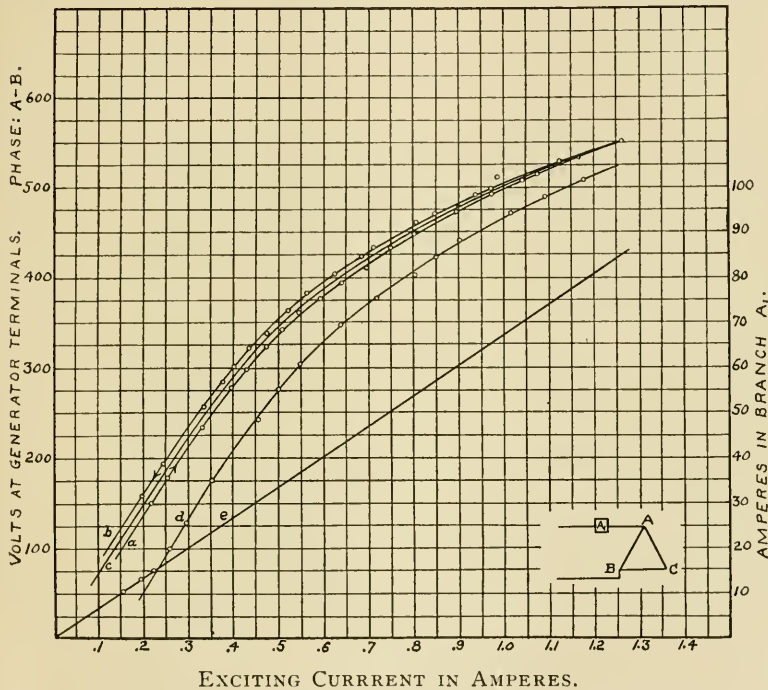
The distance between curves *c* and *d* at any given excitation represents the effective volts lost or the drop of the machine at that excitation with full load current in the armature. It will be seen that the drop above noted decreases as the excitation increases. This decrease is more rapid after the knee of the static characteristic has been passed, being due chiefly to the fact that the iron in the magnetic circuit is nearing saturation. At such a point the field is less susceptible to the demagnetising influence of the lagging current in the armature.

Several dynamic characteristics might also have been taken with other external circuit-power factors (lagging or leading). Such power factors, however, would require to be maintained constant throughout the entire range of load for their assigned values. The curves for all lagging power factors will be found below that of curve *d*, for unity power factor. The curves for leading power factors will lie above the curve *d*. However, all of such curves would approximate to the curve *d* as shown for unity power factor.*

*The Factors which Determine the Design of Monophase and Polyphase Generators. B. A. Behrend. Electrical World and Engineer. Vol. 35, p. 125. Jan. 27, 1900.

The points for the short-circuit characteristic *e* were obtained by using an ammeter for the external circuit, resulting in practically unity power factor. Through such points we may draw a right line to the origin.

“The terminal voltage of an alternator under short circuit is, of course, zero, and on account of the low resistance of the armature windings, the pressure required to drive the full load current through the short-circuited armature against its ohmic



R. P. M. 1800. Frequency 60. $\cos \phi$ (External Circuit) 1.00.

Curves *a* and *b*, no load (or static) characteristics going up and down, curve *c*, average of *a* and *b*; curve *d*, dynamic characteristic with full load current in branch *A*, constant; curve *e*, short-circuit characteristic.

FIG. 1—CHARACTERISTICS OF WESTINGHOUSE 10 K. W. ALTERNATOR AS THREE-PHASE GENERATOR.

resistance is insignificant. Consequently the current circulating in the windings is practically wattless, and with a given field excitation, it attains such a value as to produce an equivalent

(and opposing) armature flux, which balances the flux of the field system produced by the exciting ampere-turns. The resultant of the impressed flux (due to the ampere-turns on the field system), and of the opposing flux (due to the reactive ampere-turns of the armature), is the actual flux existing in the armature iron corresponding to the short-circuit current, and is, of course, of small value. It may be regarded as being made up of two fluxes in quadrature, one (quite insignificant) corresponding to the small pressure required to drive the short-circuit current against the ohmic resistance of the windings; the other, a larger flux corresponding to the induced E. M. F., and this latter flux is the true leakage flux of the armature. A little consideration will therefore show that the short-circuit current gives the relation between the ampere-turns on the field magnets and those on the armature, or what is the same thing, it expresses the relation between the field current and the armature current. It is, therefore, a straight line, which represents the actual short-circuit current curve."*

An inspection of the short-circuit characteristic will show that the corresponding armature current can be obtained for any given excitation. By a further reference to curve *c* the corresponding open-circuit voltage may be determined.

"If we take an ordinate of the static characteristic, and divide it by the short-circuit current belonging to the same excitation, we immediately get the reactance of the armature; or as we may assume this reactance equal to the combined effect of armature reaction and armature leakage, this result will give us the apparant reactance of the armature. The term apparant reactance is used here as the real reactance may be of a different value."† This refers to a nearly wattless load. The ohmic drop also enters into the quotient above referred to but is so small compared with the apparant reactance drop that it may be neglected.

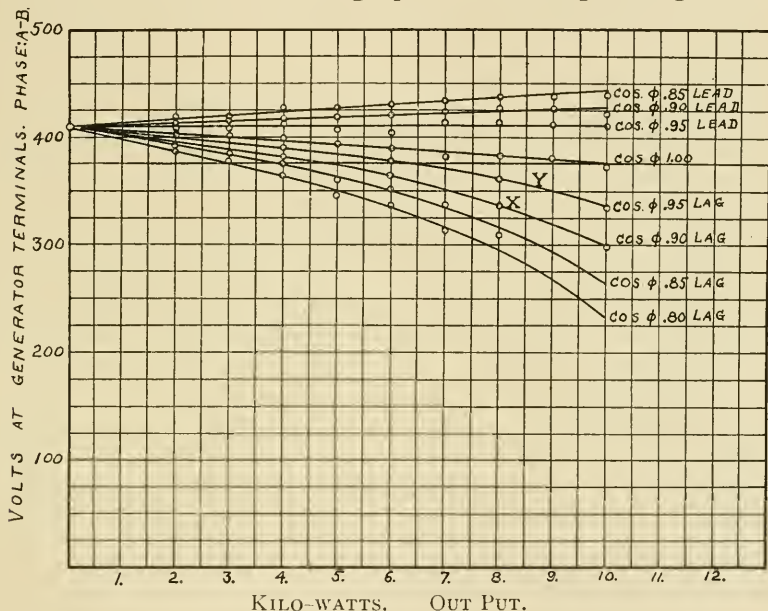
CONSIDERATION OF EXTERNAL CHARACTERISTICS.—External characteristics were also taken of this machine with various lagging and leading reactive loads. The results are shown in Fig. 2, page 101. In obtaining each of these curves the true

*Some Notes on the Design of Large Alternators. A. Heyland. Elec. Rev. London. Vol. 47, p. 896. Dec. 7, 1900.

†Ibid. B. A. Behrend.

power was measured by the two-wattmeter method. The power factor of the external circuit was kept constant throughout the whole range of load by maintaining constant the ratio of two-wattmeter readings.*

These curves show some interesting points. The lower four curves were taken with external loads producing lagging currents, varying from 0.80 to 0.95 power factor. They also illustrate the bad effect upon regulation of induction motors, under-excited synchronous motors, and arc-lighting circuits. Such external circuit loads reacting upon and through the generator



R. P. M., 1800. Frequency 60. Field Excitation 0.650 Amperes. Open-circuit E. M. F. 410 volts.

FIG. 2.—EXTERNAL CHARACTERISTICS OF WESTINGHOUSE 10 K. W. ALTERNATOR AS THREE-PHASE GENERATOR, SHOWING THE EFFECT OF VARIABLE REACTIVE LOADS ON REGULATION.

armature reduce the pressure at the terminals of the machine by their marked demagnetising effect upon the field, as earlier noted. As the power factor increases the regulation is much improved. Nevertheless all of the curves below that for unity

*Power factor Measurements. B. Frankfield. Electrical World and Engineer. Vol. 35; p 178. Feb. 3, 1900.

power factor show drooping characteristics, features which are certainly undesirable in a separately-excited machine of this type.

The characteristic for unity power factor in the external circuit is such as would be obtained with incandescent lamps and other non-inductive loads. It is an improvement on the others, with a maximum drop at the machine of about $8\frac{1}{2}$ per cent. This is a good showing under such conditions for a machine of this capacity.

If we maintain in the external circuit a leading power factor at 0.95, it will be seen that practically perfect regulation is secured. There is no drop at any load. Such regulation can be obtained in the given machine only under this condition. In this case, therefore, the resultant boosting (or compounding) effect exactly compensates for what would be otherwise an alternator drop. Hence the external characteristic is, as shown, a horizontal line through the initial voltage.

Increasing the wattless leading component of the external circuit we obtain still greater boosting effects, practically over-compounding the machine. The voltage at its terminals increases almost directly with the load under these conditions for leading power factors of 0.90 and 0.85.

EXPLANATION OF INTERPOLATION CURVES.—The question arises: How can the voltage be obtained for given loads and other power factors than those experimentally determined as shown in Fig. 2? Fig. 3, page 103, illustrates the method of obtaining a sufficient number of points for any other complete characteristic curve, at any power factor within the range of the curves shown in Fig. 2, page 101.

Curves *X* and *Z* in Fig. 2 were obtained by this method of interpolation as shown in Fig. 3. Only representative cases suited to the conditions usually found in practice have been covered in this experiment.

In Fig. 3 all of the curves pass through the same point, namely that of the voltage for 0.95 leading power factor, for all loads. Under these conditions, it will be recalled, perfect regulation was obtained, equivalent to compounding.

EFFECTS OF WATTLISS CURRENTS UPON GENERATOR VOLTAGE —The curves in Fig. 4, page 104, shows the rate of change of generator terminal voltage with varying wattless (lagging or

leading) currents for the respective loads there indicated. At the given constant excitation of 0.650 amperes, the machine was worked just beyond the knee of its no-load (or static) characteristic as may be seen by referring to Fig 1, page 99.

DIAGRAMS OF CONNECTIONS AND LOADS.—The several characteristics were determined with the connections as shown in Fig. 5, page 105. In obtaining the external characteristics, Fig. 2, page 101, the load was furnished by a $7\frac{1}{2}$ kilowatt, 110-volt, polyphase synchronous converter made by the General Electric Co. It was operated, as shown in Fig. 5, as a three-phase synchronous motor from step-down transformers. This

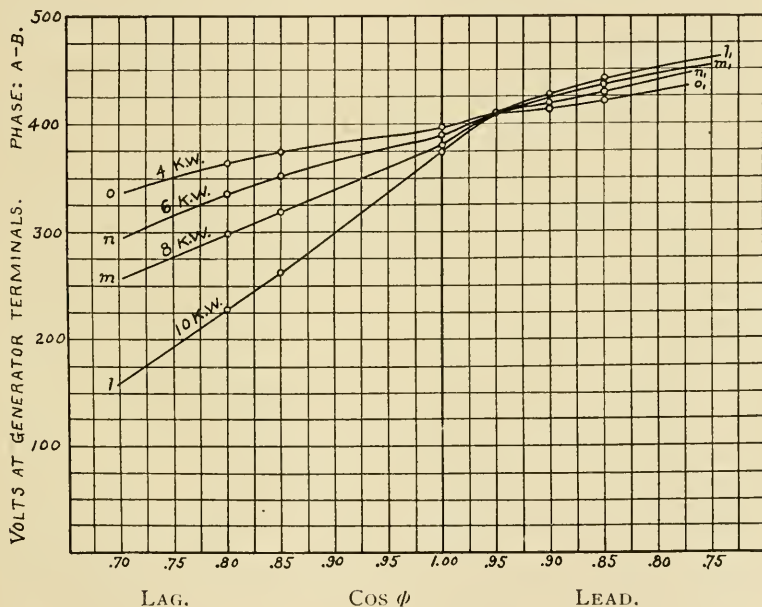


FIG. 3.—INTERPOLATION CURVES SHOWING METHOD OF GETTING POINTS FOR CURVES OF POWER FACTORS NOT GIVEN IN FIG. 2. THE VOLTAGE FOR THE GIVEN LOADS AND ANY POWER FACTOR CAN BE READ DIRECT FROM THE ABOVE CURVES.

synchronous motor was belted to a similar machine used as a generator. The external load of this machine was arranged so that it could be very closely adjusted for any desired condition. The field excitation of the three-phase synchronous motor was

varied in such manner as to keep the ratio of the two-wattmeter readings constant throughout the whole range of load on the alternator under test. In this way the power factor was maintained constant, as formerly described.* All results here given were determined for one phase only of the three-phase performance of the alternator, as the phases were fairly well balanced.

TO EFFECT GOOD REGULATION UNDER GIVEN CONDITIONS.—The work here outlined illustrates the evil effects of inductive loads upon the regulation of an alternator that otherwise may possess excellent regulation with reactive loads which are lead-

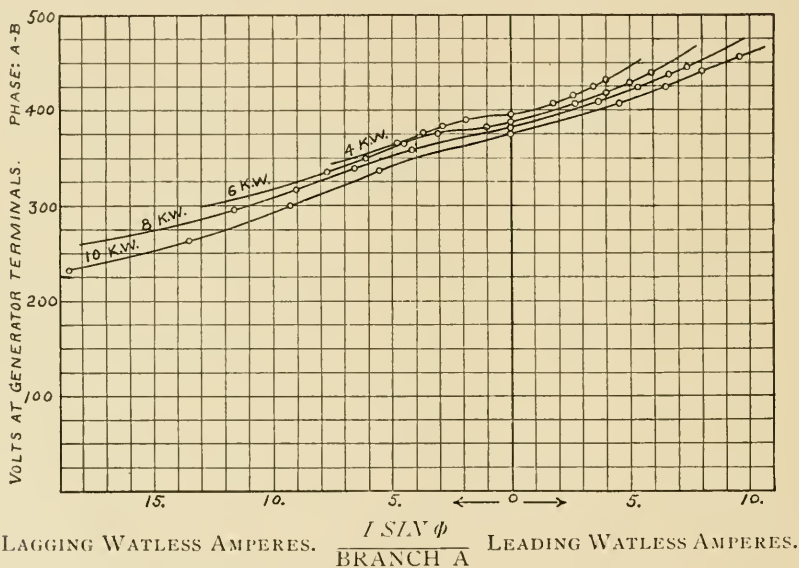


FIG. 4.—CURVES SHOWING THE DEPENDENCE OF THE GENERATOR TERMINAL VOLTAGE UPON THE VALUE OF $I \sin \phi$ (LAGGING OR LEADING) FOR THE ABOVE RESPECTIVE LOADS. AS THE POINTS ON EACH CURVE RECEDE EACH WAY FROM THE ZERO VALUE OF $I \sin \phi$ THEY REPRESENT A SUCCESSIVE DECREASE IN VALUE OF $\cos \phi$, FROM UNITY BY INCREMENTS OF 0.05.

ing. The characteristic drop under inductive loads increases much more rapidly than the load. Lagging wattless currents are not to be tolerated under any consideration where it is at all

*Ibid. B. F. Frankenfield.

possible to neutralize them by leading wattless currents. There are very few cases of electric power transmission where such neutralization can not be satisfactorily accomplished by the installation and intelligent use of at least one synchronous motor.

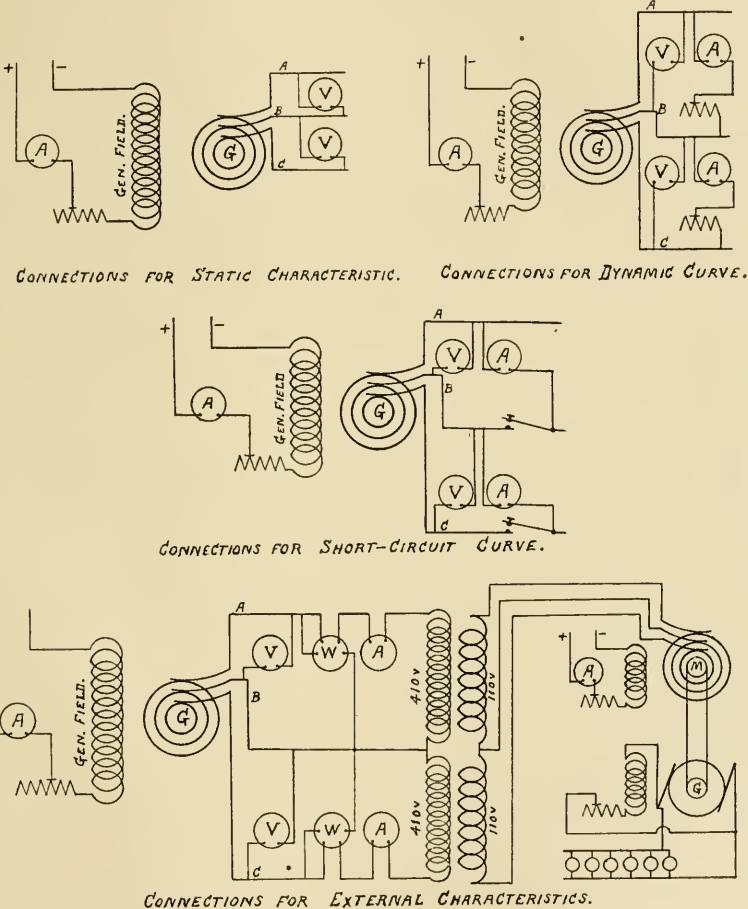


FIG. 5.—DIAGRAMS OF CONNECTIONS AS USED FOR DETERMINING VARIOUS CHARACTERISTIC CURVES.

It can not much longer remain the custom to praise the performance and regulation of an alternator as ideal on non-induct-

ive loads. Such a load, however, is easily to be obtained for commercial testing and probably forms as satisfactory a basis for comparison as any other standard that might be selected.

The increasing use of synchronous motors and converters in parallel with various inductive loads make it entirely practicable to secure from the former sufficient leading wattless current to entirely neutralize the lagging wattless current of the latter. In ordinary cases the distance of transmission is not so great as to introduce to any appreciable extent the capacity of the line. Hence, over-excitation of the synchronous motor or converter is not only practicable but desirable. The regulation characteristics of Fig. 2, page 101, with decidedly leading wattless components of current show how easily the generator voltage may thus be maintained constant, throughout all ranges of load. Furthermore, a slight increase of such leading wattless components will cause the generator voltage to rise with the load to any desirable extent; resulting practically in an "over-compounding" effect.

The chief modern requisite for best electrical supply service is good regulation. Concrete cases may be found almost anywhere in current practice. As an instance, consider an alternating current power transmission for a manufacturing establishment. Many induction motors will probably be found in use for various purposes scattered throughout the works. Such motors with their inherent and variable lagging currents will materially interfere with the voltage regulation at the generating plant. The practical remedy is to install at least one synchronous motor or converter. It should be of sufficient but quite moderate size. By a definite amount of over-excitation, predetermined or by trial, its leading wattless component of current ($I \sin \phi$) may easily be made equal to and therefore neutralizing the sum of all of the lagging wattless components ($\sum I \sin \phi$) of the inductive loads. The whole system is therefore reduced at once to an electric transmission with an equivalent ohmic line. The evil effects of the inductive loads are entirely overcome. Further over-excitation of such synchronous motor or converter results in the so-called "boosting" of voltage at the generator with each increasing load. Many similar instances might be cited in which the use of synchronous machines has brought about most satisfactory regulation, where formerly it

had been practically impossible under necessary and existing conditions of inductive loads.

Another illustration of this method is the installation of the Montana Power Transmission Co., where power is transmitted over 20 miles to Butte, Mont. "Here the average power factor is 0.87. Few plants of this kind have an accurate record of what their power factor is, and as this figure is not a guess but is the result of actual tests by an interesting method, it is of value. The method of determining the power factor is this: The plant is operated in the ordinary way, and the ammeter and voltmeter readings are taken to give the apparent watts. Then one of the generators at the power house is started up and run as a synchronous motor. The field of this motor is over-excited so as to give a leading current. The effect of this is to overcome induction and bring the power factor up towards unity. The excitation is increased until the power factor is unity, which is indicated by the ammeter reaching its lowest position, on a given load. The observed watts will then be the true watts, and can be compared with the previous reading."*

*Notes on Electric Light and Power Work at Butte, Mont. J. R. Cravath. Electrical World and Engineer. Vol. 37; p. 149. Jan. 26, 1901.

EFFECT OF DIFFERENT METHODS OF MOLDING UPON THE STRENGTH OF CEMENT.

BY IRA O. BAKER, PROFESSOR OF CIVIL ENGINEERING.

It is well known that there is a considerable variation in the tensile strength of any particular cement mortar as obtained by different observers. Part of this variation is inevitable. The strength of hydraulic cement depends so largely upon the details of the method of testing that undetected variations in manipulation will make an appreciable difference in the results. Therefore it is important to eliminate as far as possible any variation in the method of testing the cement.

The amount of water used in mixing the test specimen materially affects the strength obtained; but recently it has become the practice in reporting results of experiments to state the per cent of water used, which practically eliminates this source of error. Of course different cements require different amounts of water according to the variation in composition, fineness, freshness, etc.; but a statement of the amount of water employed shows the condition under which the particular cement was tested.

The quality of the sand employed has a very marked influence upon the strength, but for some time it has been the custom of careful experimenters to employ only standard sand,—either German natural sand or artificially crushed quartz having a standard degree of fineness.

The amount of force employed in pressing the mortar into the molds also has a very marked influence. Ordinarily the mortar is pressed in by hands and it is impossible to describe the intensity of the force employed. To eliminate this source of error, it has long been the practice in Continental Europe, particularly in Germany, to use an automatic machine in compacting the mortar in the briquette mold. In this country another machine for the same purpose has been lately put

upon the market. The writer has recently made a series of experiments to compare these three methods of filling the molds. The results are stated in Table I, page 110.

All the tests were made by Mr. O. L. Gearhart, a former student of the author, who spent practically all of his time during the three past working seasons testing cement. He is a careful, methodical, observing, conscientious experimenter. In several cases results obtained by him by hand molding in the ordinary course of business have been compared with those obtained by other operators, and apparently his results are fairly representative of the usual methods of hand molding.

The Böhme hammer is the standard German machine, and consists of an arrangement by which the mortar is compacted by 150 blows of a hammer weighing 2 kilogrammes (2.2 pounds) upon a plunger sliding in a guide placed upon the mold.

The Olsen press consists of a plunger, driven by a screw and a hand wheel, working in a guide below the mold. The power applied is measured by a finger revolving in front of a graduated dial. The briquettes were molded under a pressure of 4000 pounds applied to the broad side of the American Society of Civil Engineers form of briquette. The pressure was applied gradually to permit the air to escape, and was maintained at the maximum pressure, say, half a minute after the air ceased to escape. The escape of air is indicated by a gradual decrease of the pressure. The immediate purpose of the tests was to standardize this press. A pressure of 4000 pounds was adopted as being a convenient number (equal to one revolution of the finger on the dial) and as being about as much as the machine would safely bear.

The cement was one that had been in the laboratory some months, and was supposed to be a representative Portland. The sand needs no description farther than stated in the table. The per cent of water employed for neat cement was that adopted by the operator as giving the plasticity usually employed by him, and is about an average of the quantity ordinarily used by him with other cements. The resulting mortar is not at all jelly-like, and water, or rather moisture, flushes to the surface only after vigorous troweling. The per cent of water for the mixture of sand and cement was chosen as giving

TABLE I.
EFFECT OF DIFFERENT METHODS OF MOLDING ON THE TENSILE STRENGTH OF CEMENT MORTAR.

| Ref. No. | Method of Molding | Neat Mortar with 16 $\frac{2}{3}$ % of Water | | | 1 Part Cement to 3 Parts Standard German Sand with 6 $\frac{1}{2}$ % of Water | | | 1 Part Cement to 3 Parts Standard Crushed Quartz with 6 $\frac{1}{2}$ % of Water. | | |
|----------|--------------------|--|--------|---------|---|--------|---------|---|--------|---------|
| | | 1 day | 7 days | 30 days | 1 day | 7 days | 30 days | 1 day | 7 days | 30 days |
| 1 | Hand | 258 | 342 | 470 | 74 | 104 | 225 | 63 | 92 | 213 |
| 2 | Böhme Hammer | 388 | 514 | 575 | 84 | 162 | 194 | 86 | 168 | 324 |
| 3 | Olsen Press | 232 | 312 | 563 | 33 | 68 | 90 | 50 | 92 | 132 |
| | | | | | Pounds per Square Inch | | | | | |
| 4 | Hand | 67 | 67 | 82 | Relative Strengths in per cents | | | | | |
| 5 | Böhme Hammer | 100 | 100 | 100 | 89 | 64 | 116 | 73 | 55 | 66 |
| 6 | Olsen Press | 61 | 61 | 98 | 100 | 100 | 100 | 100 | 100 | 100 |
| | | | | | 39 | 42 | 47 | 58 | 55 | 42 |

apparently the same plasticity for the mixture as for the neat mortar.

Lines 4, 5 and 6 of the table are given to aid in studying the relative effects of the different methods of molding. The mean of the per cents in lines 4 and 6 for all ages, is shown in Table II.

TABLE II.

STRENGTH OF HAND-MOLDED AND PRESS-MOLDED BRIQUETTES IN PERCENTS OF THE STRENGTH OF HAMMER-MOLDED BRIQUETTES.

| Method | Neat | Sand | Quartz | All |
|--------|------|------|--------|-----|
| Hand | 73 | 90 | 65 | 76 |
| Press | 73 | 43 | 25 | 73 |

From Table II it appears that hand-molded and also press-molded briquettes are only about three fourths as strong as hammer-molded briquettes. Table II also shows that for this operator hand molding was substantially the same as press molding with a pressure of 4000 pounds. Three months after making the above tests, the same operator with another cement made a series of briquettes in which the strength of the hand-molded specimens were 78 per cent as strong as those molded with the Böhmé hammer apparatus. Apparently then this operator's personal equation with reference to the Böhmé apparatus is 77 per cent, or in round numbers, three fourths; and with reference to the Olsen press is $76 \div 73 = 104$ per cent, or in round numbers unity.

The hammer apparatus gives the greater strength, but it requires a longer time to mold a briquette than by hand or with the press. About 35 minutes are required to mold 6 briquettes with the Böhmé hammer, 20 minutes with the Olsen press, and 15 minutes by hand. The hand-made specimens were finished with the trowel on both sides; those from the press and the hammer were finished with the trowel only on the top. With a quick-setting cement there is danger with the hammer apparatus and also with the press, of encroaching upon the time of the initial set, before completing the last briquette of a set. The amount of skill required is practically the same in all three methods. There was not much, if any, difference in the uniformity of the results. This particular cement was rather

quick-setting, and hence part of the variation with the hammer apparatus may have been due to an encroachment upon the time of initial set. However, in a later series with a slow-setting cement, the three methods of molding gave about equal variations.

If others should make similar experiments with either or both machines, it might result in greater uniformity in hand molding, and also give data of value in comparing results obtained by different observers.

AN AUTOMATIC RECORDING MACHINE.

BY E. C. OLIVER, INSTRUCTOR IN MECHANICAL ENGINEERING.

In conducting tests of steam, gas, or other engines or machines it is the usual custom to employ a number of observers, who at stated intervals or at a predetermined signal take simultaneous readings of various instruments, the interval between these readings being from one to fifteen minutes, varying with the nature of the test. The data obtained in this manner are afterwards averaged or otherwise "worked up," and the results are accepted as indicative of the average performance of the engine throughout the test.

If the conditions are fairly uniform during the test or if the changes are gradual, this method may give results sufficiently accurate for any practical purpose; if however the changes are frequent and considerable in amount, the simultaneous readings may or may not represent the average conditions since the previous observation and a factor of uncertainty is introduced in the final results. The question of the accuracy or reliability of such tests has been the subject of a number of discussions from time to time in the technical journals.

The machine described in this article was designed and built by the writer for the purpose of overcoming these uncertainties by recording on a continuous strip of paper the momentary changes of conditions throughout the test, thus producing in the end a sort of extended graphical log to be used as a basis of calculations for the final results.

The machine shown in the accompanying illustrations consists essentially of two parts; the paper-feeding mechanism and the recording mechanism. A supply of paper is carried on a roll supported by shaft A Fig. 1. The sheet is led upward over a horizontal to a pair of rolls G and F, over which it passes in an ∞ shape to give the necessary friction for feeding; from these rolls it passes to a receiving spool on shaft I. The paper

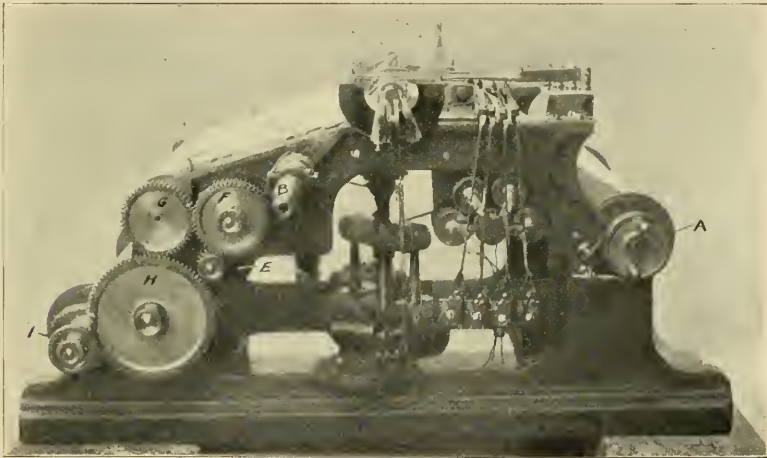


FIG. 1.

is fed forward by the motion of the engine or machine under test. connection being made between the engine shaft and driving shaft B of the machine by a light steel rod. The driving shaft B extends to the opposite side of the machine where its motion is reduced through a worm and gear in a ratio of 100 to 1. A pinion E on the shaft with this worm gear but on the front of the machine engages a gear on the feed roll F; the paper therefore travels forward with a speed proportioned to the

speed of the driving shaft. This speed may be varied as necessary by using gears of different ratios between E and F.

The two feed rolls are also driven together by gears G and F, and the receiving roll I is driven from gear G through an idler H, a friction device between the gear on I and its shaft accomodating the speed of rotation to the increasing diameter of the roll: The tension on the paper in front of the feed rolls is adjusted by means of the thumb nuts on the shaft I, and the tension behind the feed rolls is adjusted by means of a band-brake on the shaft A. A clutch interposed between two sections of the shaft B allows the feeding mechanism to be stopped and started at will.

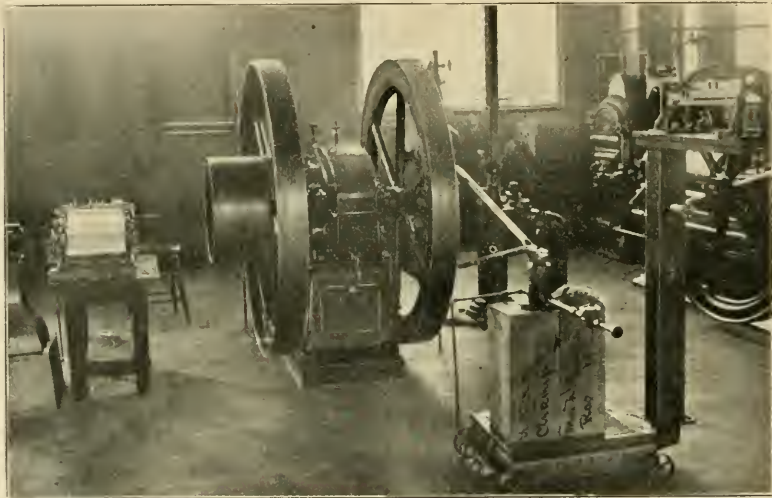


FIG. 2.

The record is made as the strip of paper passes under a number of glass pens on top of the machine, Fig. 3. There are twelve of these pens available for taking eight readings; the four pens seen on the rear bar are for tracing the base lines for the movable pens in front. The four pens to the right are connected through a system of levers to the armatures of electromagnets so that the closing of circuit by any means will cause one of these pens to shift, thus indicating some movement, a record of which is desired. The pens to the left are held in

runners which slide on a circular bar. They are actuated by light cords attached to the underside and led over pulleys on either side of the machine to a moving part of an engine or instrument, the extent of whose movement it is desired to record.

The method of connecting the machine for taking a record is best understood by considering the records Figs. 4 and 5. These records are as taken except that they have been made somewhat narrower to save space; the original width of the paper was ten inches.

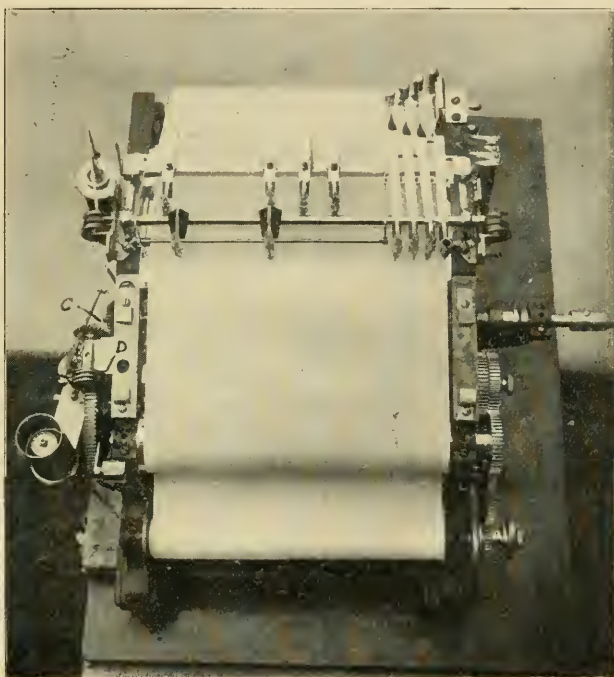


FIG. 3.

Fig. 4 is a record for a 10-horsepower "Otto" gasoline engine in the Mechanical Engineering Laboratory. The upper line is made by connecting the terminals of one electro-magnet to a clock which makes contact at stated intervals. The second line is made by attaching a brass contact piece to the engine in such a manner that the lever which injects the gaso

line charge will strike it at each injection thus making contact and causing the pen connected to it to move, thus indicating an explosion. The third line represents revolutions, contact being made at each revolution of the side shaft; thus each mark represents one cycle or two revolutions of the engine. To make the fourth line a push button is attached to the indicator in such a way that when the pencil is pressed on the paper, electric contact is made and the recording pen pushed out, in which position it remains until the pencil is withdrawn from the paper the effect is shown at A, the diagram covering six explosions.

The speed curve is obtained by connecting one end of a cord to an arm actuated by a centrifugal governor. This cord extends upward over a light pulley and downward; a light spring connected to this end of the cord effects its return motion when drawn in the opposite direction by the action of the governor. Near the center of this cord is attached the runner carrying the speed pen; any movement of the governor below due to a change of speed will thus give a corresponding movement to the pen above.

The method of obtaining the line representing horse power may be seen by reference to Fig. 2. The brake arm is shown resting directly on the piston of an hydraulic cylinder, the area of which is one-half of a square inch. A small pipe connects this cylinder with the cylinder of a steam engine indicator attached to the side of the recording machine, the system being filled with oil by means of the pump shown. Any pressure imposed by the brake due to friction will be transmitted to the under side of the indicator piston, raising it against the resistance of the usual spring. The upward movement of the arm is thus a measure of the pressure at the end of the brake arm and consequently of the horse power. This movement is transmitted by means of a cord to the pen above in the same manner as for the speed.

At the point marked *B* the load was considerably increased by tightening the brake; the effect on the speed and the number of explosions is apparent.

Fig. 5 shows a record taken from a Corliss engine in the power plant of the Champaign Electric Light and Power Co.; the engine furnishes power for a street railway.

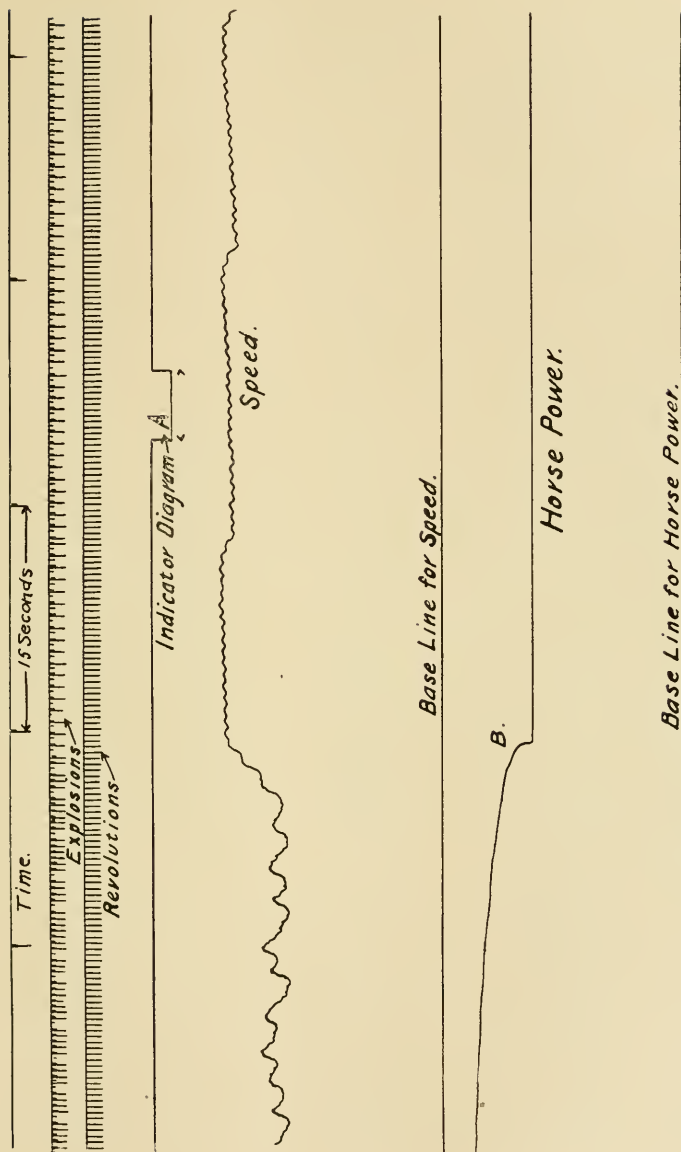


FIG. 4.—TEST OF AN OTTO GASOLINE ENGINE.

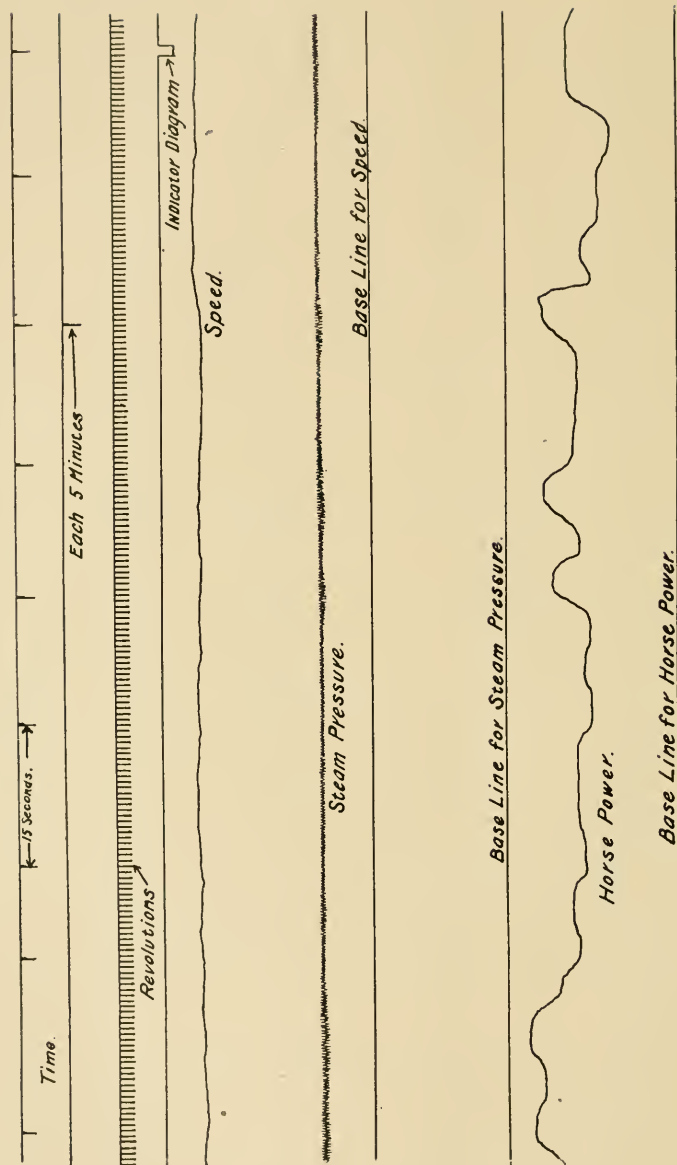


FIG. 5.—TEST OF A CORLISS STEAM ENGINE.

The first five lines were made by methods similar to those used in the gasoline engine test, except that a time record for each five minutes was substituted for the record of explosions. The steam pressure line was obtained by connecting the steam pipe just above the throttle with the indicator used in the previous test to record horse power. The line denoting horse power was obtained through the motion of the governor by connecting a cord to a vertically moving arm. This cord was led by means of pulleys to a pen on the machine in a manner similar to that already explained; thus any movement of the governor up or down was instantly shown by a movement of the pen on the paper. This line, then, really gives a record of governor positions; yet, as the cut-off is affected directly by the position of the governor and as the mean effective pressure is dependent, on the cut-off, providing the initial pressure is constant, the same position of the governor will give at any time practically the same mean effective pressure. The curve is calibrated by taking a number of indicator cards throughout the test, not necessarily at stated intervals but at times which will give as great a variety of cut-offs as possible. When a card is taken a mark is made on the record, as shown, and by drawing a vertical line through this point we obtain on the line below the position of the governor for this diagram; the horse power is then known for this position. In like manner as many other points as possible are calibrated and a scale is made which, when moved along this line will give the horse power for each revolution if necessary. While subject to some slight errors, this method greatly assists in studying the performance of such engines.

The machine has also been used very successfully on the University's dynamometer car. In these tests the following readings were taken: time, mile posts, stations, crossings, draw-bar pull, speed of train, and location of curves. The first reading is taken by means of an electric clock; the next three by means of push buttons pressed by observers; the fifth by connecting the recording indicator with the pressure side of the hydraulic indicator against which the locomotive pulls; the sixth by connecting with a Boyer speed recorder and the seventh by means of a specially constructed mercury level placed across the car.

The records are in this manner all traced to the same scale

and collected on one sheet, thus greatly facilitating the process of working up and at the same time decreasing the possibility of errors due to incorrectly marking the several individual records.

The records shown have many very interesting details which a slight observation will disclose. Numerous other experiments or operations may be suggested in which a machine of this sort can be utilized for the purpose of obtaining useful information.

TABLES FOR ESTIMATING AMOUNT AND COST OF MATERIALS AND LABOR FOR BUILDINGS.

BY LOUIS F. BRAYTON, ARCHITECTURAL ENGINEER, '01.

The following is a abstract from a thesis presented by the author for the degree of Bachelor of Science in Architectural Engineering. It is hoped that the method of presentation may be useful to architects.

QUANTITIES FOR BRICK WALLS.

Plate I, facing page 120, gives the quantities of brick, mortar, and labor required in the construction of 100 square feet of brick wall varying from 4 inches to 24 inches, for different sizes of brick, various thickness of joints, several proportions of mortar, different quality of work, various prices of materials and labor, etc. The chart is based on data from Baker's Masonry Construction, Trautwine's Pocket-book, and contractor's notes. One quarter of an inch mortar joint has been included for each 4 inches of thickness of wall. Five per cent has been allowed for breakage of brick. Prices for material delivered; and no allowance has been made for scaffolding or profit.

Directions for using the chart: Brick.—To find the number and cost of brick, start with the thickness of the wall to be esti-

mated, (see the upper left-hand corner of chart) follow upward along a vertical line to its intersection with the diagonal line giving the thickness of the joint, then follow the horizontal line to the right to the intersection with the line giving the contents of one brick in cubic inches, then follow down the vertical line to the horizontal scale giving the number of brick required for 100 superficial feet of wall. Write this number in the proposed bill of materials. Continue down the vertical line to its intersection with the line giving the cost of the brick per thousand, and then follow a horizontal line to the left and read on the vertical scale the cost of the required number of brick.

Labor.—To find the labor required, return to the point on the horizontal scale corresponding to the number of brick required, and follow a vertical line down to the number of brick a mason will lay in an hour, and from thence follow a horizontal line to the left and read from the vertical scale the number of hours of labor required in laying the wall. One tender will conveniently make mortar and tend two masons; consequently the total price per hour for labor is equal to one half the price paid for the tender plus the price paid for one mason. Thus to find the cost of the above labor, continue the horizontal line to the left from the hours of labor required, to the price of the mason and tender, and from thence proceed vertically upward and read the amount of the cost of the labor.

Mortar.—To determine the amount of mortar required, start at the upper part of the center of the chart with the thickness of the wall; proceed vertically to the diagonal line giving the thickness of the joint to be used, and thence horizontally to the right and read on the vertical scale the amount of mortar.

Sand.—If lime mortar is to be used, continue the horizontal line through the point on the scale giving the amount of mortar required to the diagonal line marked "lime," and thence proceed vertically down to the horizontal scale and read the number of cubic yards of sand required; continue the vertical line through the number of yards of sand just found, down to the diagonal line giving the cost of sand per yard, and thence follow a horizontal line to the left and read on the vertical scale the cost of the sand. If cement mortar is to be used, the sand is found in the same way, except the "cement" diagonal is used in place of the "lime" diagonal.

Lime.—To determine the amount of lime required, follow the horizontal line from the quantity of mortar required, to the “diagonal for lime,” and then proceed in the same way as in determining the amount and cost of the sand.

Cement.—To determine the amount and cost of the cement, follow the horizontal line from the amount of mortar required to the right to its intersection with the line giving kind and proportion of cement to be used (at the extreme right hand edge of the chart), and then proceed in the same way as in determining the quantity and cost of sand.

Weight.—The weight of 100 superficial feet of wall of different thicknesses and different kinds of brick, is given in the small table near the upper left-hand corner of the chart. This table is calculated on the basis of pressed brick masonry weighing 150 lbs. per cubic foot, common brick 125 lbs. per cubic foot, and soft brick 100 lbs.

DATA FOR LATH AND PLASTER.

Table I, page 123, gives the quantities of materials and the amount of labor required for different coats of different kinds of plaster with different lath. With this table it is easy to prepare an estimate for any kind of plastering except that involving patent plasters. The data for this table were obtained directly from plastering contractors.

No explanation is needed as to the method of using the table itself, but the following remarks may be useful in this connection. More plaster is required for metal lath than for wood, because of the heavier clinches and the greater waste; and the greater material requires a corresponding increase in the labor. In determining the quantity of materials required for plastering on brick, use the data for the brown and white coats, and double the sand in the former, as is explained in the note in the table. In determining the quantities for back plastering, use the data for scratch coat for “drawn” work.

In measuring areas, to determine materials and labor, one eighth is added to all circular work and the calculated areas of domes are doubled. Columns and pillars are measured double, whether circular or square; chimney breasts are added to the gross area of the walls. No surface (reveal, chimney breast, or panel) is to be considered less than one foot wide: Plasterers

at one time measured doors and windows as wall surface, but competition has become so close that it is now customary to deduct them.

TABLE I.—DATA CONCERNING LATHING AND PLASTERING.

| Coat | | Sand, cu.yds. | Lime, Barrels of | Water, of Hrs. | Hair | Water, Hours | Tender, Hours | Remarks. |
|---------|---------------------------|---------------------|------------------|----------------|------|--------------|---------------|--|
| Scratch | On L: expanded Metal | Drawn $\frac{2}{3}$ | $1\frac{1}{3}$ | | 13# | 6 | 4 | |
| | | Dry $\frac{2}{3}$ | $1\frac{1}{2}$ | | 15# | 6 | 4 | |
| | On Lath | Drawn $\frac{1}{2}$ | 1 | | 10# | 3 | 2 | |
| | | Dry $\frac{1}{2}$ | $1\frac{1}{4}$ | | 12# | 3 | 2 | |
| Brown | Grounds | 5" Drawn | 1 | $\frac{5}{8}$ | | 7 | 4 | If plastering on brick, double the amount of sand here given and use this for the first coat. |
| | | 0" Dry | $\frac{3}{8}$ | $\frac{3}{8}$ | | 10 | 7 | |
| | 8" | 7" Drawn | $\frac{1}{2}$ | $\frac{2}{3}$ | | 7 | 4 | |
| | | 0" Dry | $\frac{3}{4}$ | $\frac{3}{4}$ | | 10 | 7 | |
| White | Sand finish for frescoing | $\frac{1}{4}$ | $\frac{1}{4}$ | | | 9 | $\frac{1}{2}$ | Frescoe finish used in the Chanipoiagi Co. court-house. Putty finishes differ very much. Two good finishes are given here. |
| | Putty | 1 | $\frac{2}{3}$ | 100# | | 9 | $\frac{1}{2}$ | |
| | Finish | 2 | 1 | 50# | | 9 | $\frac{1}{2}$ | |

| Lath | Lath, nails. | Labor, hours. | Labor, Metal lath. | Furring strips. | Labor, Furring. | Furring nails. | Remarks. |
|-----------------------------|--------------|---------------|--------------------|-----------------|---------------------------|---------------------|---|
| Walls 1400 Ceilings 1300 | 16 studs 7# | 7.5 | 18 | 62.5fc B.M. | $\frac{1}{2}$ to 2 hours. | 13# 8d. or 12# 10d. | Estimates for furring strips, are on the basis of $\frac{1}{2}$ " x 1" strips, spaced 16" o.c. Lewis P. Brayton '01. |

Instead of using the table to determine the cost of the labor required for wood lathing, it would better be estimated at from two to two and one half cents per square yard. Metal lath will cost twice as much as wood lath for the labor of putting in place.

COMMERCIAL ELECTRIC METERS.

BY GUY RICHARDSON RADLEY, '00, METER DEPARTMENT OF THE MILWAUKEE ELECTRIC RAILWAY AND LIGHT COMPANY.

The desideratum of the central station manager is a meter which will be accurate at all loads, consumes no energy, may be installed by a boy, and after installation requires no attention. No meter on the market to-day fulfills all of these conditions, each one requiring intelligent handling and an occasional test and inspection to secure results which may be classed as better than guesses.

Commercial requirements as to accuracy are fulfilled if the meter will run on one light and is less than 2% in error on full load. Extreme accuracy can not be obtained on very small loads without undue expense in the construction and increased care and attention in the operation. In order that a meter may be sensitive on small loads a shunt field should be provided of sufficient strength to nearly overcome the friction of rest.

If the meter should be installed in a location subject to jar or vibration, the static friction is reduced and creeping will result. This has led to the furnishing of an adjustable friction compensator on some meters. This is a good thing, although the creeping is easily stopped in those styles having a retarding disc moving in the field of a permanent magnet. This is done by placing on the periphery of the disc a bit of steel wire like a "Niagara clip," at such a distance from the magnet that the attraction is enough to prevent creeping but is not enough to hold it when one lamp is turned on. The presence of the bit of wire in no wise affects the speed of the meter under loads, but it does effectually prevent rotation without a load.

Meters should be dust-proof. This is an important point. The length of time a meter will run without the necessity of inspection is proportional to the completeness of the provisions for the exclusion of dust. This is apparently a simple problem, but not all meters, even those of the latest type, are satisfactory in this respect. The principal difficulty is with the leading-in wires. Rubber diaphragms or soft rubber hollow cones soon harden and crack, and at the second installation afford no protection. Pieces of felt through which the wires must be placed have lately been tried, but without success. The glue does not hold this material firmly enough to prevent its coming off with the wire in removing a meter. Apparently the best plan to ensure dust-proof construction is to have the binding posts of the tube form with closed ends. This entirely prevents the entrance of dust, and eliminates the possibility of short-circuiting. This may occur whenever a bared wire touches the wrong one of two terminals. These are only an inch apart, and three inches from the hole in the base through which the wires are pushed. All of the old types of meters had the binding screws directly behind some part of the frame. This required the use of a long-blade screw-driver, used at an angle to the axis of the

screw, and always resulted in the mutilation of the slot, even if the screw itself did not break.

The device for adjusting the speed of the meter should be capable of easy and rapid manipulation. The use of putty or solder in this operation is an unnecessary evil.

Some meters are now furnished with cyclometer dials, giving the indication in plain figures. An advantage claimed is that the consumer may read the meter himself and thus keep a check upon his power consumption. Another is that inexperienced boys may read the meters. This latter argument also holds when dial books are used. In this case only the position of the hands is marked, the translation being made afterward by an experienced man. However, it is a debatable question whether the inevitable mistakes owing to the employment of small boys do not cause a lack of confidence on the part of the customer. This may cause a greater loss than the difference in the salaries.

It is a self-evident proposition that the energy consumed by the shunt circuit of the meter should be the least possible. This reduction, however, must be consistent with low first cost, substantial construction and permanency of calibration. If too much resistance is used the torque becomes small and the moving element necessarily very delicate. This is a disadvantage, since meters with a low torque are seriously affected by dust or vibration. With a high turning moment the proportion of work done against friction to that done against the retarding force is small. A change in the friction then affects the accuracy only to a slight extent.

Table I, page 126, gives the watts loss in meters as advertised by the manufacturers; also the loss for those meters in which it has been measured.

The relative cost for energy to a station using a meter having five watts loss and one taking but one watt may be stated this way: One watt continuously amounts to 8.7 kilowatt-hours per year, or at 10 cents per kilowatt-hour, equals \$0.87. The 5-watt meter in the same time will expend 43.5 kilowatt-hours, or \$4.35. The difference, \$3.48, is 6% interest on \$50.80. Other things then being equal the one-watt meter is the less expensive, even if the difference in first cost were fifty dollars.

In order to give a satisfactory lighting service the voltage

TABLE I.
SHUNT LOSSES OF VARIOUS METERS.

| Name of Meter. | Watts Loss. | |
|---|-------------|---------|
| | Claimed. | Tested. |
| Thomson, Low Eff. Type, 5 to 100 amperes, 100 volts..... | 10 | 10 |
| Thomson, High Eff. Type, 5 to 100 amperes, 100 volts..... | 4 | 5 |
| Thomson, Induction Type, 5 to 100 amperes, 100 volts..... | 2 | |
| Scheaffer, Old Style, 5 amperes, 100 volts, 130 cycles..... | | 2.6* |
| Scheaffer, New Style, (all sizes)..... | 1 | |
| Duncan (Fort Wayne) 15-100 amperes..... | | 1.1* |
| Fort Wayne, Type K..... | 1.0 | |

*From thesis of R. F. Schuchardt. University of Wisconsin. '07.

at the lamps must be kept constant, and every effort is made to secure this. In some meters the drop in pressure over the series coil amounts to two volts. This of course is only in the smallest size of meter. Such small meters are usually employed of a capacity equal to about one-half of the lights installed. Ordinarily this is sufficient. The time, however, always comes when every lamp is turned on at once, and then the drop becomes excessive. Under test a Thomson 3-ampere meter whose drop on full load was 2 volts, caused a drop of 4 volts when overloaded 100%. This was increased to 5 volts at the end of two hours, owing to the great temperature rise (about 85° C.) of the fields.

Table II, page 127, gives the effective total drop in voltage caused by the series field. In the case of three-wire meters the drop given is that over each field.

The weight of a meter is an important consideration. A light meter will be handled with more care than one which taxes the strength of the meterman. A cast iron case is not necessary if the meter is properly designed. Table III, page 128, gives the weights of several of the better known makes of meters. It shows the reduction in weight which has been accomplished by some manufacturers.

It is now an established principle that distribution by direct current is cheaper than by alternating current within a radius not exceeding one mile. For greater distances the alternating current is more economical. Because of this limitation many stations supply both kinds of current. When this is the case shall both alternating and direct-current types of meters be used,

TABLE II.
SERIES DROP IN INTEGRATING WATTMETERS.

| Name of Meter. | Drop. |
|--|------------|
| Thomson, 3 amperes..... | 1.9 volts |
| Thomson, 10 amperes..... | .5 volts |
| Thomson, 25 amperes..... | .25 volts |
| Thomson, 50 amperes..... | .16 volts |
| Thomson, 100 amperes..... | .10 volts |
| Scheeffer, Old Style, 5 amperes..... | .35 volts* |
| Scheeffer, New Round Type (claimed)..... | .10 volts |
| Shallenberger Wattmeter (old), 10 amperes..... | .45 volts* |
| Shallenberger Ampere-Hour, 10 amperes..... | .95 volts* |

*From thesis of R. F. Schuchardt. University of Wisconsin. '07.

or shall one kind be chosen which may be installed on either service? From Table I, on shunt losses, it will be seen that the alternating current meters of the induction type consume less energy than the only "universal" type now on the American market. Whether this saving is enough to pay the interest on the added investment of "stock" meters and also to compensate for the increased complication of record systems, must be decided in each case.

After a meter is installed it may usually be left to itself in the hope that it will remain correct, but this should not be depended upon. Almost all manufacturers recommend an inspection and test at least yearly. With the Thomson meter installed under adverse conditions, a few weeks only suffices to blacken considerably the silver commutator and thus slow down the meter. It was formerly advised in such a case to clean to its original degree of polish the commutator with narrow cotton tape. This restored its former light-load accuracy. The effect of the cleaning, however, could not last long. To overcome this defect an adjustable starting coil has been provided on the new type. With this device the added friction of the dirty brushes may be overcome and the light-load accuracy restored with the knowledge that it will not soon change again.

Induction meters, particularly those of the more recent types, being quite dust-proof, will not require much attention in the way of cleaning. A simple checking up as to accuracy is all that is required. This is most easily accomplished with a portable calibrated lamp board and a voltmeter. The board is connected as an only load to the meter.

TABLE III.
WEIGHTS OF INTEGRATING WATTMETERS.

| Name. | Size. | Wt., lbs. |
|------------------------------------|---------------------------|-----------|
| Thomson, Recording | 3 to 10 amp., 100 volts | 12½ |
| Thomson, Recording | 15 to 100 " 100 volts | 22½ |
| Thomson, Induction | 25 amp..... 220 volts | 17 |
| Thomson, Recording (New Type)..... | 10 amp..... 100 volts | 14 |
| Scheeffer, Old Style | 10 amp..... 50 volts | 21½ |
| Scheeffer, New Round Type | 10 amp..... 50 volts | 13 |
| Slatteny (Old Fort Wayne) | 25 amp..... 50 volts | 16 |
| Fort Wayne, New Type K | 25 amp..... 220 volts | 12½ |
| Westinghouse, New Type..... | 10 amp..... 100 volts | 17½ |
| Series Transformer for above..... | | 10 |
| Stunley | 25 to 100 amp., 220 volts | 37½ |

With a stop-watch the time for a given number of revolutions is taken, the voltmeter during the count being frequently observed. In the calibration table of the board are found the watts corresponding to the observed average voltage. The watts registered by a meter are given by the formula:

$$\frac{3600 \times \text{Rev.} \times \text{Constant.}}{\text{Seconds for above Rev.}} = \text{Watts.}$$

From these quantities the per cent. error of the meter may be obtained. A portable board of this kind will only serve for small meters, an ammeter being used to determine the current on direct current circuits and an indicating wattmeter for alternating currents.

Alternating-current meters should always be tested with the cover on as the influence of the closed secondary circuits of the hood materially affect the speed. An old-style Scheefer meter was found to be about 1 % slower with the cover off than when on. In this and the Duncan meter it is not easy to observe the revolutions without a mirror or special cover with window. All the new types of alternating-current meters, however, have such a window provided.

In tests of this kind on installed meters, approximate results only can be obtained. When greater accuracy is desired or the meter has been found in error it should be removed and set up on the testing board at the station.

An arrangement of testing board similar in many respects to that used in the testing department of the Milwaukee Electric Railway and Light Co. is shown in Fig. 1. The meter is supported above the bench at a convenient height by bolts whose

heads are in a T-slot in a heavy board. The outer ends of the bolts are slotted. After a meter has been placed over them thin brass wedges are slipped in, thus securing the meter in place. The oblong blocks shown serve to take the wear, preventing damage to the finish of the board.

The meter is connected up preferably with a flexible cord having a clip on one end and a solid wire tip on the other. Direct current is obtained from either set of direct-current terminals located under the ledge of the meter-supporting board. These are wired up through the circuit-breaker (9) having a

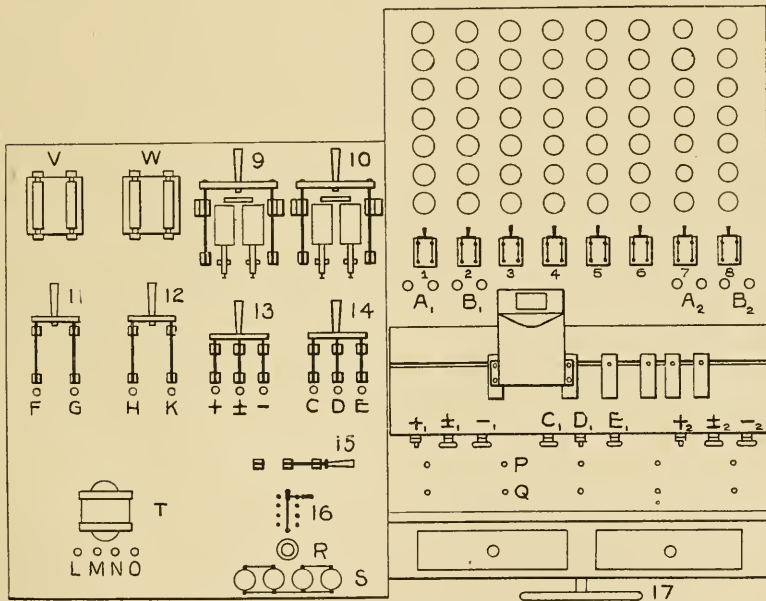


FIG. 1.—TESTING BOARD.

tripping coil in each leg, and the switch (13). An alternating current is supplied from a three-wire transformer through a similar circuit-breaker (10) and switch (14) to the binding posts C, D, E. The current is usually led from the positive terminal to an ammeter or the series coil of an indicating wattmeter lying on the shelf; thence, through the series coil of the wattmeter under test and to the lamp bank.

The lamp bank consists of a number of rows of lamps, each controlled by a baby knife switch. The odd-numbered switches

are connected to terminals A_1 and A_2 ; the even numbers to B_1 and B_2 . A link usually connects the inner posts of A_1 and B_1 , forming a three-wire system. Switch (15) connects the neutral of the lamp bank to the neutral of the direct-current system when thrown over to the left, and to the neutral of the three-wire transformer when thrown over to the right. With a two-wire meter on the board this switch completes the series circuit through meter and lamps. With a three-wire meter, after the two legs are nearly balanced, this switch is opened and the ammeter then indicates the current which is now equal in both sides.

The potential terminal of the meter is connected to a small flexible cord which is plugged into one of the upper holes marked P . These are spring jacks which are in parallel and are connected through a plug fuse R to the blade of an 8-pole switch (16). Positions to the left give direct-current voltages of 50, 100, 200 or 500 volts, and positions to the right give 50, 100 or 200 volts, alternating current.

In the 50-volt position the lamps shown at S are in series in the potential circuit and by the series-parallel arrangement of differently-rated lamps any desired drop may be obtained. One side of the voltmeter, or potential coil of an indicating wattmeter is also plugged into the upper row of spring jacks while the other side is connected to the series coil of the meter under test. Here the question arises as to which end of the coil is the proper place for this connection. Since the drop over the series coil may amount to two volts, it is seen that the calibration of a meter may vary 2 per cent. for the two positions. Our standard practice is to measure the voltage at the ends of the potential circuit of the meter under test.

A water rheostat whose plates are raised or lowered by hand-wheel (17) serves to adjust the current to the desired value. This makes it possible also to counteract the effect of a decrease of line voltage by an increase of current. It will be noticed that all potential connections to the meter are from the jacks. Since a one-ampere fuse plug is in that circuit very little damage results from a short-circuit. If these connections were made directly to the terminals, the instruments might be damaged before the circuit-breaker would open when wrong connections were made.

The 500-volt terminals are *H* and *K*, below the hinge of the switch (12). The cut-out *W* protects this circuit. Power meters are usually tested by obtaining the desired current for the series field from the 100-volt circuit, the higher potential being only applied to the armature.

Primary alternating current may be obtained from the binding posts *F* and *G* of switch (11). This switch also serves to energize the primary of the potential transformer *I*, the secondary of which may be connected for 50 or 100 volts for testing primary meters.

All meters are constructed so that one revolution of the moving element is equal to one watt second or some simple multiple of this. The standard formula for testing such meters is

$$\frac{3600 \times \text{Revolutions} \times K}{\text{Time}} = \text{Watts} \dots \dots \dots (a)$$

In which *K* is the constant marked on the dial. In some of the latest types this constant has been eliminated and the indications have been made direct reading by the use of an auxiliary gear having a ratio equal to the former constant. In such meters the value of *K* must be determined by inspection, if not already known.

Placing watts equal to volts and amperes, substituting in equation (a), and transposing, we obtain:

$$\frac{3600}{\text{Volts}} = \text{Time} \cdot \frac{\text{Amperes}}{\text{Rev.} \times K} \dots \dots \dots (b)$$

If now a number of revolutions is taken equal to the quotient of amperes divided by *K* the latter term of the second member of equation (b) reduces the unity, and the equation becomes:

$$\text{Time} = \frac{3600}{\text{Volts}} \dots \dots \dots (c)$$

From this it is seen that the time required to make a number of revolutions numerically equal to the current divided by the constant is equal to 3600 divided by the voltage at the meter. This is the true or theoretical time provided the meter is correct. Dividing the difference between this and the time actually observed by the theoretical time gives the error; by pointing off two decimal places gives the percentage error. For example, the constant of a 5-ampere 100-volt meter is 1/2. If a load of 5

amperes is put on the time will be taken by a stop-watch for a number of revolutions equal to $5 \div \frac{1}{2}$, or 10 revolutions. If the voltage during the time of observation were 118 the time according to formula (c) should be 30.51 seconds. If the observed time were 30.00 seconds the error would be

$$(30.51 - 30.00) \frac{1}{30.51} = 0.51 \times 0.0328 = 0.0167 = 1.67 \%$$

This would mean that the meter was 1.67% *fast* since the time actually taken was *less* than it should be.

In regard to the accuracy obtainable when using the above formula, it will be seen that the time of observation is relatively short, being 30 seconds at 120 volts and 40 seconds at 90 volts. The smallest division on a stop-watch has a value of $\frac{1}{5}$ second. An error of one of these divisions will then cause an error in the result of $\frac{0.2}{30} = 0.66 \%$ at 120 volts, and $\frac{0.2}{40} = 0.5 \%$ at 90 volts. If the voltmeter can be read only to single volts the error produced is $\frac{1}{120} = 0.83 \%$ or $\frac{1}{90} = 1.11 \%$ respectively for an error of one division in the observation.

It will be seen, therefore, that leaving the question of current measurement aside (the current is kept at a constant value by the continuous adjustment of a water rheostat), the result may be in error

$$0.5 + 1.11 = 1.61 \% \text{ at 90 volts; or}$$

$$0.66 + 0.83 = 1.49 \% \text{ at 120 volts.}$$

This would occur should a mistake be made of one division in reading both time and voltage. It indicates that errors of 1.5% may occur in practice.

To show what errors do occur, Table IV, page 133, is presented. The application of the principle of least squares there made shows the probable error of a single observation to be somewhat less than 0.5%. It may be remarked that this test was made on an alternating current circuit with quite a steady voltage. Similar tests made on direct current circuit whose voltage varied considerably, due to heavy motor loads on the system, show the probable error of a single observation to be about 0.9%, and of the average of 10 observations to be about 0.3%.

A point to be observed in testing meters, and which is not generally observed, is that care must be taken to leave the cur-

TABLE IV.

TEST OF THOMSON RECORDING WATTMETERS.

No. 154113—25—220. K = 2.

60 cycles A. C. Cover on meter. Full load, = 25 amperes.

Ammeter: Thomson No. 20809.

Current by Radley.

Voltmeter: Weston No. 1567.

Time by Burke.

| Volts. | Time. | % Error | Residual. | Residual ² |
|----------------------------|-------|-----------|-----------|-----------------------|
| 115 | 31.80 | 1.59 slow | .40 | .16 |
| 115 | 31.60 | .96 slow | 1.03 | 1.06 |
| 115 | 31.90 | 1.91 slow | .08 | .01 |
| 114.8 | 31.90 | 1.59 slow | .40 | .16 |
| 115 | 31.90 | 1.91 slow | .08 | .01 |
| 115.5 | 32.00 | 2.57 slow | .58 | .34 |
| 114.5 | 32.00 | 1.75 slow | .24 | .57 |
| 114.6 | 32.10 | 2.07 slow | .08 | .01 |
| 115.3 | 32.00 | 2.40 slow | .41 | .17 |
| 116 | 32.00 | 3.13 slow | 1.14 | 1.30 |
| Average error = 1.99 slow. | | | s = | 3.79 |

$$\text{Mean error of single observation} = \pm \sqrt{\frac{S}{n-1}} = 0.65$$

$$\text{Probable error of single observation} = \pm .6745 \sqrt{\frac{S}{n-1}} = 0.45$$

$$\text{Mean error of result} = \pm \sqrt{\frac{S}{n(n-1)}} = 0.21$$

$$\text{Probable error of result} = \pm .6745 \sqrt{\frac{S}{n(n-1)}} = 0.14$$

$$\text{Probable error of meter} \pm 1.99 \pm .14 \% \text{ slow.}$$

rent on a sufficient length of time. This ensures the temperature of the shunt circuit reaching nearly its constant value before observations are taken. Tests have shown a difference of some 4 % in the speed of a meter between that taken when first connected and after having been under load for fifteen minutes. For this reason several meters are usually connected up at one time. They are supplied with both potential and current for ten minutes before an observation is made, this time being utilized in cleaning them. The current so used is in no sense wasted. It is essential to get the meter into a condition similar to that existing when installed, which condition is a prime requisite to insure a correct test.

STABILITY OF A TALL CHIMNEY.

BY CARL HAYS, CIVIL ENGINEERING, '01.

The chimney under discussion was erected by the Big Four Railroad at the time of rebuilding the shops for the Peoria and Eastern Division, at Urbana, Illinois. Fig. 1, page 135, shows an elevation, a longitudinal section, and several cross sections. It is proposed to examine the stability of the chimney against overturning, and also to determine the maximum pressure on the masonry and on the soil.

The contents of the chimney were computed by the prismoidal formula, the volume of the air spaces being deducted. The results are as follows:

| | |
|--------------------------------------|--------------|
| Brick masonry in chimney proper..... | 7468 cu. ft. |
| Limestone rubble in foundation..... | 3803 cu. ft. |
| Concrete in foundation..... | 143 cu. ft. |

The brickwork is of a good quality, with thin joints, and was assumed to weigh 140 pounds per cubic foot. The stonework is coursed limestone rubble and was assumed to weigh 150 pounds per cubic foot. The concrete was figured at 140 pounds. A summary of the weights is as follows:

| | |
|---|-------------|
| Brick masonry, 7468 cu. ft. @ 140 lbs..... | 577.77 tons |
| Limestone rubble, 3803 cu. ft. @ 150 lbs..... | 285.22 tons |
| Concrete, 143.4 cu. ft. @ 140 lbs..... | 10.04 tons |
| Steel, 32 8-inch 32-lb. I beams, 26 ft. long..... | 9.00 tons |
| Total weight..... | 882.03 tons |

The chimney is located on comparatively high ground, and is exposed to strong winds. The wind pressure was assumed as 40 pounds per square foot of exposed surface, which is higher than common practice, but was so taken on account of the exposed site. The area of the exposed surface of one side is 1085 square feet. The center of pressure was assumed to be at the center of gravity of the surface, or 48.2 feet above the top of the stonework. The wind moment about the top of the stone masonry then is: $40 \times 1085 \times 48.2 = 1046.2$ foot-tons.

The stability against overturning will be considered only for the brick shaft about the top of the stone foundation. The

factor of safety against overturning is equal to the moment of the weight divided by the moment of the wind. For the top of the stone work this is $2888.75 \div 1046.2 = 2.76$

That is, the resisting moment is 2.76 times the overturning moment; or in other words, the factor of safety against overturning is 2.76. Obviously the factor of overturning about the edge of the foundation is much greater, and will not be computed.

The next step is to find the maximum and minimum pressure on the brick-work at the top of the stone masonry.

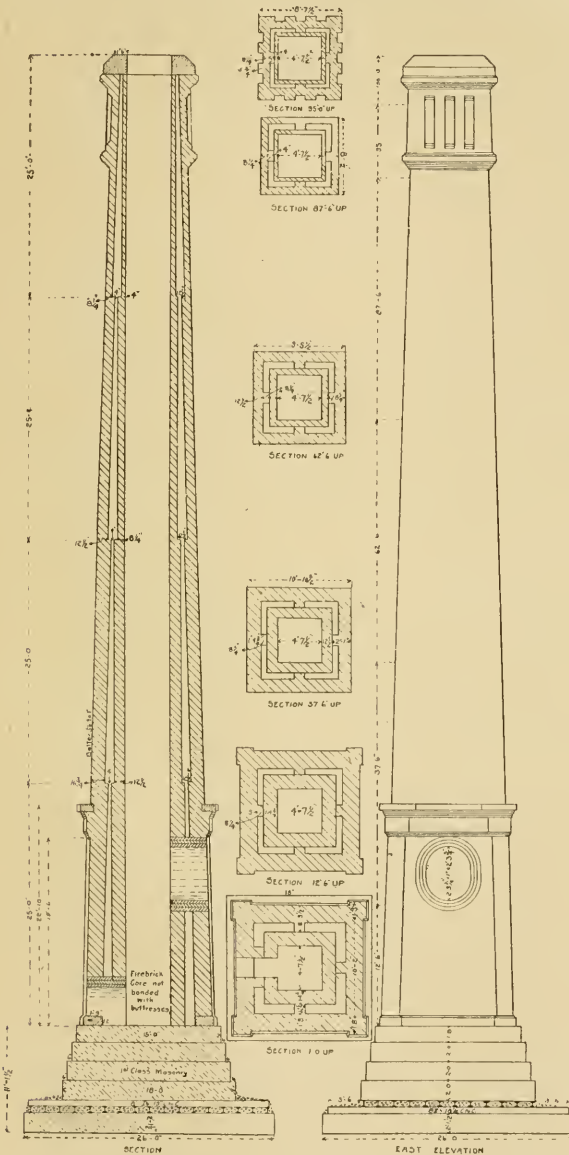


FIG. 1.—CHIMNEY C. C. C. & ST. L. R. R. AT URBANA, ILL.

- Let P = maximum pressure, tons per square foot.
 W = weight above the section considered, tons.
 S = area of section considered, square feet.
 M = overturning moment of the wind, foot-tons.
 I = moment of inertia of the section, feet.
 l = length of the section, feet.

The maximum pressure on any section is given by the formula*

$$P = \frac{W}{S} \pm \frac{M l}{2 I}$$

in which the plus sign gives the maximum pressure and the minus the minimum pressure. For the base of the brickwork the formula becomes: $P = 577.77 \div 135 \pm (1046.2 \times 13.66 \div 4793) = 4.28 \pm 2.98$ tons, making the maximum 7.26 tons per square foot or 108 pounds per square inch, and the minimum 1.3 tons per square foot or 18 pounds per square inch.

The maximum and the minimum pressures on the soil were found in a similar manner. There are two cases to be considered, viz.: (1) when the resisting moment of the earth on the projecting portion of the foundation is neglected, and (2) when this moment is included.

1. The uniform pressure on the soil was found to be 1.3 tons per square foot when the wind was not considered; and when the wind was taken into account the maximum was found by the above formula to be 1.41 tons and the minimum 1.19 tons.

2. The earth backfilling vertically above the outer edge of the foundation has the following dimensions:

| | |
|---|---------|
| Length over all..... | 26 feet |
| Depth on top the projecting concrete at the base..... | 8 feet |
| Width at the bottom..... | 4 feet |

The earth was assumed to weigh 100 pounds per cubic foot. The weight of the earth backfilling per linear foot of foundation is $\frac{1}{2} (6 + 4) 80 \times 100 = 2$ tons. The weight of the earth on the windward and the two adjacent sides is equal to 132 tons, and has an arm of 15.1 feet. The moment of the earth is: $132 \times 15.1 = 1992$ foot-tons. Then $\frac{M l}{2 I} = 0.0103$ tons. The maximum pressure, when the resisting moment of the earth is considered is then $1.41 - 0.0103 = 1.397$ tons per square foot; and the minimum pressure is 1.203 tons per square foot. These results show that the effect of the backfilling is not important.

*Baker's Masonry Construction, pages 205-6.

The preceding computation is on the assumption that the earth would rupture in a plane vertically above the edge of the foundation; but in reality it would shear along a line sloping outward from the base of the foundation. Taking account of this would decrease the above maximum and minimum by some unknown and unknowable amount.

The writer is of the opinion that the design of the chimney could have been improved in three particulars, as follows:

1. A circular cross section is more economical, since the round chimney is easier to build, and since it would require less material both in the body and in the foundation for the same flue space, and since the wind pressure is less on a cylindrical surface than upon a flat surface.

2. The maximum unit compression upon the brickwork seems needlessly low. Experiments show that reasonably good bricks laid in lime mortar have a strength of 100 tons per square foot. The maximum pressure on the chimney is 7.26 tons per square foot, a considerable portion of which is due to the action of the wind. It is the universal custom to allow a larger working stress when the effect of the wind is included, than for a uniform pressure. The pressure at the base of the tallest brick chimney in the world—the 468-foot chimney at Glasgow, Scotland—is 9 tons per square foot with no wind, and 15 tons under a maximum wind. It is believed that the wind pressure was assumed abundantly high in the above example, and therefore it seems that the unit working pressure is needlessly small.

3. Apparently the foundation is excessively large. If the chimney had been built without the lower course of stone masonry, the steel I beams, and the concrete, the maximum pressure on the soil, including the wind pressure, would have been only 2.72 tons per square foot, and the minimum 2.1 tons. Surely this would have been safe, since the soil at the bottom of the foundation is gravelly clay, and since the base of the foundation is well below the frost line. This pressure is excessively low, since well-drained gravelly clay of good consistency could easily hold from 8 to 10 tons per square foot. The site of the chimney has a very good surface drainage, and the subsoil could have been thoroughly drained by a few hundred feet of drain tile. The omission of the masonry, concrete, and steel I beams would have effected a saving of something like \$750.

REPAIRING THE SANGAMON COUNTY COURT HOUSE.

BY WILLIAM G. FOSTER, '00, ARCHITECT, URBANA.

The old state house served as a court house for Sangamon county for thirty years, when it became necessary either to erect a new building or to repair the old one. The historical interest centering around the building which had once been the "stamping ground" of such men as Lincoln and Douglas, made the people very much averse to parting with it; hence it was decided to remodel the old building. The building was raised eleven feet and a new story was built under it.

All of the inside of the building was removed, except the two main partition walls, so that all that remained of the old building were the outside walls, the two cross walls, and the two large stone porticoes over the entrances. The inside walls were of brick, two feet thick, and the outside walls were brick faced with stone, and four feet thick. All the building above the water table was to be raised, and it was necessary to do this in such a manner as to prevent cracking of the walls and otherwise damaging the structure. It was also necessary to support the walls so that the new walls could be built up underneath. To accomplish this, holes were cut through the walls at the height of the water table, through which steel I beams were passed. Under the windows 6-inch beams were used, and under the heavier parts 12-inch. The weight carried by each beam varied, of course, according to the location and spacing. Between the windows three or four 12-inch beams were placed side by side, and each carried approximately fifteen thousand pounds.

The I beams projected on each side of the wall, so that when the jack-screws were placed under the ends there was room enough for men to work on the new walls.

Two lines of 12 × 12-inch timbers on each side of the wall formed the foundation for the jack-screws and for the cribbing which was put in as the building was raised. This cribbing consisted of 6 × 6-inch pieces from two to six feet long. In all,

1700 jack-screws were required to support the building. The illustration on this page shows the building in process of being raised.

After the building had been lifted to the proper height, the old basement walls were torn down to the level of the ground on the outside, and new brick walls faced with stone were built on the old foundation up to the I beams supporting the building and as high as possible between them. Long thin oak wedges were then driven between the old and the new wall, and the I beams were removed. The spaces occupied by the I beams were then filled with brick masonry.



The building was raised at the rate of one foot per day, and required the services of one hundred men to operate the jack-screws. Each man had charge of eighteen or twenty jacks, and when all were ready, each man gave a specified number of turns to his screws.

The contract price of raising the building, and constructing the new walls and the new floors, was \$27,000. The cost of raising alone was \$6,800. The stone facing and other stonework cost \$6,500. The building is now a thoroughly substantial and fire-proof structure.

Obituary.

Halbert Lilly Chipps was born Oct. 13, 1879, at Sullivan, Ill. He graduated at the Sullivan High School in 1894 and entered the University of Illinois in 1895, graduating in civil engineering in 1899. After graduation he entered the service of the Chicago and Western Indiana Railway, but returned to the University in the same year as Assistant in Civil Engineering. In June, 1900, he entered the service of the Chicago Junction Railway, leaving in September to accept a position as assistant engineer with the Union Pacific Railway at Laramie, Wyoming. While there he contracted typhoid fever, which caused his death Nov. 3, 1900.

It is but so short a time since Mr. Chipps was at the University that he is well remembered by many. His pleasant, upright manner and his modesty made him strong friends. Thoroughness and attention to details were marked characteristics of his work, and this assured a bright future. The illness of which he died was due to exposure while in pursuance of his work. His life was given to his profession.

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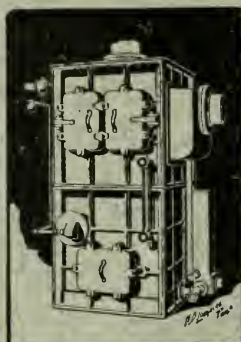
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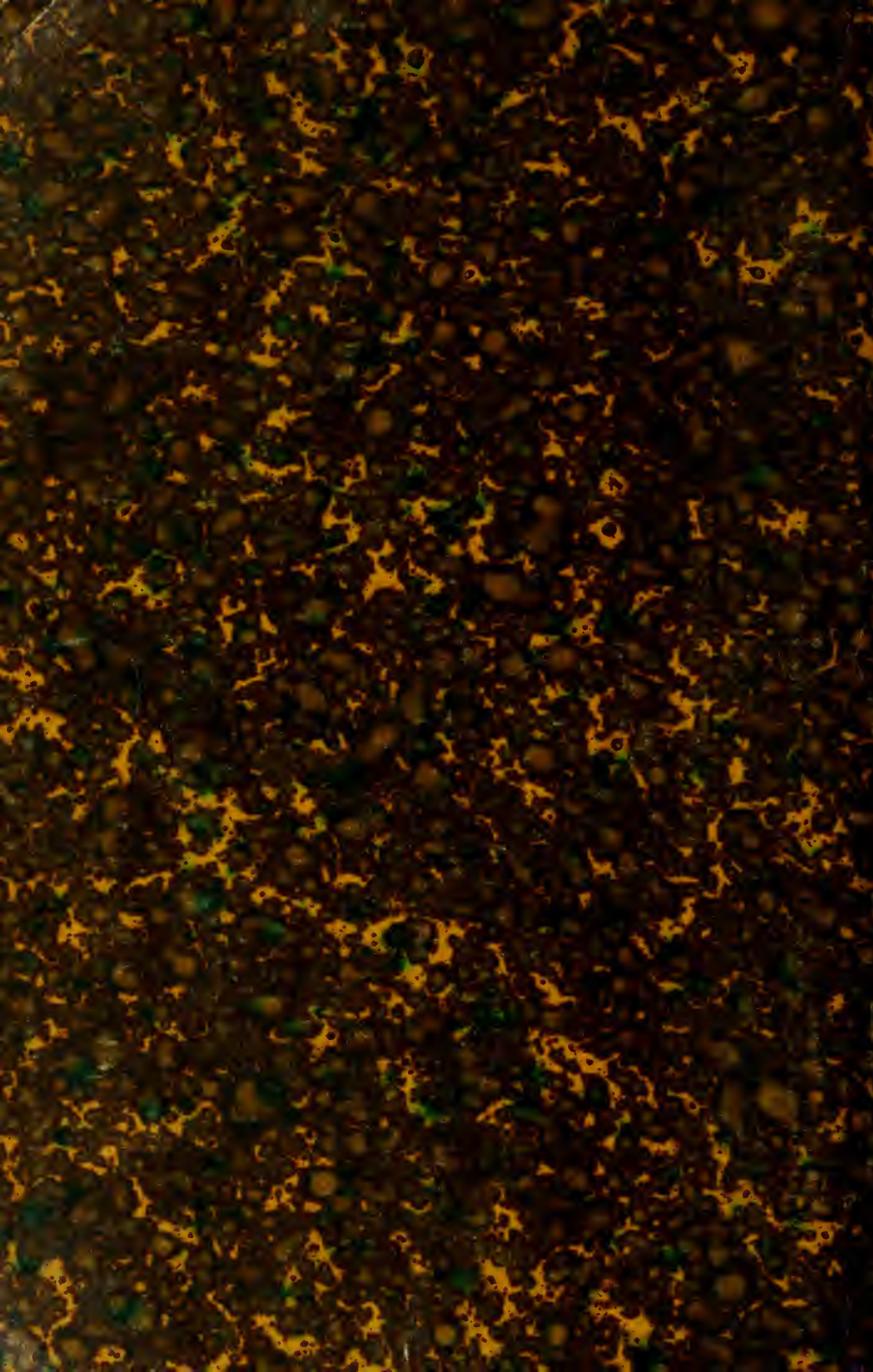
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