VOLUME XXV NUMBER 2/SECOND QUARTER 1985

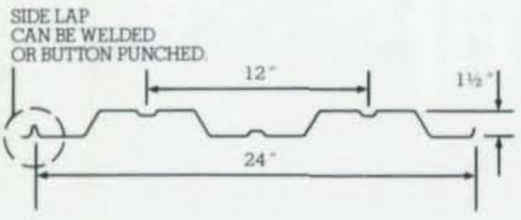
MODERN STEEL CONSTRUCTION

A Hospital's Orderly Plan for Growth
The New Reflects the Old
A Distinctive, Revitalizing Force
Low-rise Offices in Fast-rising Growth
Steel Framing Offers Maximum Flexibility

DECK DESIGN DATA SHEET

NO. 6

ALL ABOUT 1½" LOK FLOOR COMPOSITE DECK



w/h=3.85 (For stud design.)
Cv=0.0625
Concrete volume on undeflected deck in cubic ft. per square ft. is equal to the concrete thickness (inches) *Above* the flutes divided by 12 plus Cv.
V=t/12+Cv

SECTION PROPERTIES PER FOOT OF WIDTH

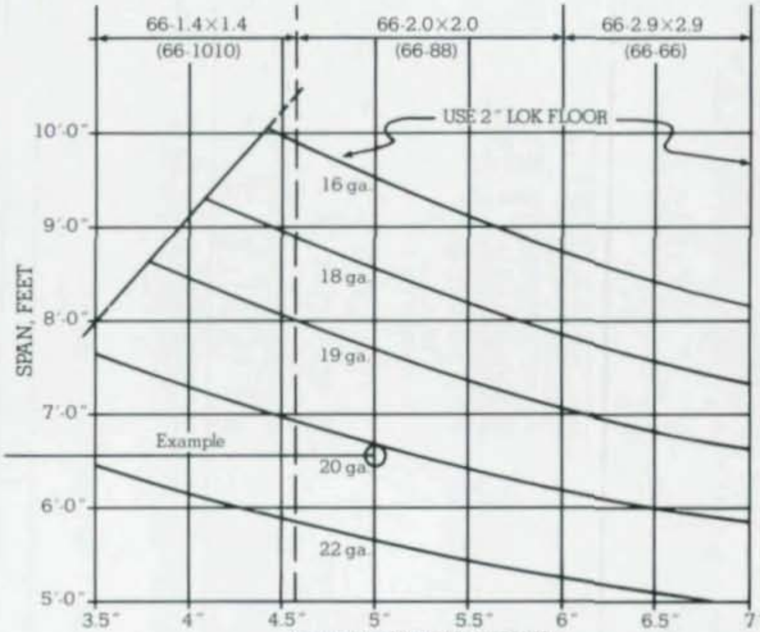
METAL THICKNESS		I	SP	SN.	R, INT.	R, EXT.	WT.
GA.,	INCHES	IN^4	IN^3	IN^3	LBS./FT.	LBS./FT.	PSF
22	0.0295	0.188	0.202	0.219	840	240	1.7
20	0.0358	0.236	0.260	0.281	1,140	380	2.0
19	0.0418	0.276	0.320	0.332	1,460	550	2.3
18	0.0474	0.316	0.381	0.381	1,820	750	2.6
16	0.0598	0.396	0.474	0.474	2,620	1,220	3.3

R int. is allowable interior reaction based on 5" of bearing. R ext. is allowable exterior reaction based on 2½" of bearing Properties and reactions based on American Iron and Steel Institute (AISI). *Specification For The Design Of Cold Formed Steel Structural Members;* 1980 edition. Steel conforms to ASTM A611. Grade C. or ASTM A446 Grade A (33 ksi Yield.)

RECOMMENDED GAGE CHART—NO SHORING

Chart based on Steel Deck Institute (SDI) Loading criteria for three (or more) span deck. Bending stress is limited to 20ksi and deflection (of deck) to L/180. 150 PCF concrete. Live load capacity of the deck/slab combinations covered by the chart is usually over 200 PSF.

Example: 6½' span with 5" slab. Intersection is in 20 Ga. area welded wire fabric is 66-2.0×2.0. No shoring req'd.



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George E. Harper, Editor of Publications
Amy Kragnes, Editorial Assistant
James Herman, Business

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CONTENTS

1985 FELLOWSHIP AWARD WINNERS NAMED

Eight winners of AISC's 1985 Fellowship Awards competition have recently been named. Each winner receives a $4,250 study fellowship, with another $750 going to the academic department heads for administering the awards. Students are judged by an outstanding award jury on the basis of grade point averages, faculty recommendations and contributions their expected programs will make to the engineering profession and the structural steel industry as a whole. The 1985 winners are:

Douglas J. Ammerman, *University of Minnesota*
Michael A. Avellano, *University of Cincinnati*
Deryl L. Easom, *Washington University*
Michael D. Engelhardt, *University of California - Berkeley*
Marvin W. Halling, *Utah State University*
James M. Ricles, *University of California - Berkeley*
David H. Sanders, *University of Texas - Austin*
Kay E. Vierk, *Illinois Institute of Technology*

PROFESSOR W. F. CHEN RECEIVES 1985 T. R. HIGGINS AWARD

Prof. Wai-Fah Chen of Purdue University, Lafayette, Ind. received AISC's prestigious 1985 T.R. Higgins Lectureship Award at the Structural Stability Research Council's annual meeting in Cleveland on April 16 in Cleveland, O. His award-winning lecture is "Columns with End Restraint and Bending in Load and Resistance Factor Design."

His award, an engraved citation and a check for $3,000, was presented by Robert P. Stupp, executive vice president of Stupp Bros. Bridge & Iron Company, St. Louis, Mo. Chen will present the paper at five additional cities and events during the year.

OUR APOLOGIES

In the last issue of Modern Steel Construction, *in the special Prize Bridge Awards section, we inadvertently listed the address of Atlas Machine and Iron Works, Inc. as Gainesville, Ga. It should have read Gainesville, Virginia. Atlas was the steel fabricator on the prize-winning Liberty Bridge in Pittsburgh, Pa.*

The University of Michigan Hospitals: Orderly Patterns for Growth

by Stephen Q. Whitney and Charles T. Robinson

Stephen Q. Whitney, AIA, is project architect, senior associate and assistant chief of architectural development, Albert Kahn Associates, Inc., Detroit, Michigan.

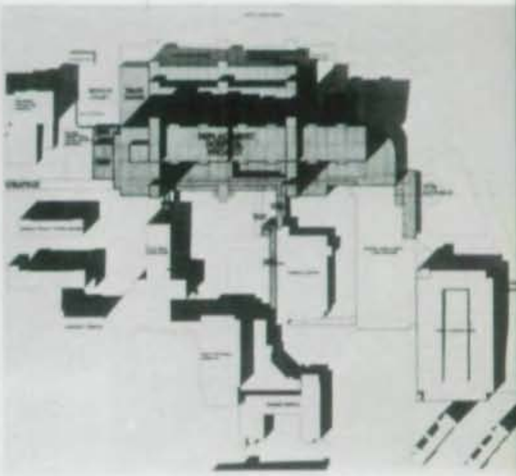
Charles T. Robinson, PE, is project engineer, senior associate and assistant chief of structural/civil engineering department, Albert Kahn Associates, Inc., Detroit, Michigan.

Organized in 1869, the University of Michigan Hospital system, Ann Arbor, is one of the largest university-owned hospital systems in the U.S. The hospitals also support one of the three largest educational programs for health professionals in the nation. Each year, 4,000 students, including doctors and other health care professionals, receive training at U-M Hospitals.

The original University Hospital (Old Main, as the existing hospital is called) was among the finest health care facilities in the country when opened in 1927. Designed by the renowned Architect Albert Kahn, it housed the most up-to-date systems and equipment in an elegant, decorative brick and limestone structure incorporating the latest planning innovations of the era.

The last 58 years have seen dramatic changes in the practice of medicine. Who, in 1927, could have anticipated the development of open heart surgery, organ transplants, computerized diagnostic procedures or environmental control systems? Once the premiere teaching hospital in the country, Old Main has regretfully become an antiquated facility unable to adapt to present requirements. Patients and staff expected more from such a well-known hospital. They wanted central air conditioning and were not satisfied with 16-bed ward rooms. Because the facility was outdated, it also became difficult for the university to recruit people for research.

Over the years, inspections of Old Main by the Michigan Department of Public Health and the state fire marshal resulted in an ever-increasing list of deficiencies. In 1970, the State of Michigan agreed with the results of a study prepared by the University of Michigan, which indicated it was no longer practical to attempt correction of cited deficiencies in Old Main. The study concluded with a recommendation for replacement of Old Main and upgrading of other facilities on the U. of M. Medical Center.



University of Michigan Hospitals (l.), Ann Arbor, Mich. and replacement project (seen from NE). Site plan of adult general hospital above. Photo courtesy office of RHP-U. of Mich.

The Functional Planning—Orderly Patterns for Growth

Albert Kahn Associates, Inc. (AKA) was retained to plan and design the Adult General Hospital and associated facilities, the largest component of the $285-million Replacement Hospital Program. An early task was to develop a facilities master plan which, in concert with the site master plan, established orderly patterns of growth for the campus. In accordance with these plans, the Replacement Hospital Program was sited just north of the existing multi-building medical center, overlooking the Huron River Valley. This placed the new Adult General Hospital close to the original patient care facilities and the medical education and research center. The new facility will replace Old Main and the Adult Psychiatric Hospital constructed in 1938.

A functional and space program for the Replacement Hospital Program was initially completed in July 1978. It described the functional elements of the Replacement Hospital Program, including Nursing Units, Radiology, Surgery Suites and Specialty Clinics on a room-by-room basis. Input to the project design came from many sources. To ensure the new hospital would meet the needs of staff members, they participated in the building design through a process of "gaming." In gaming, colored squares representing rooms scaled to size were arranged by AKA and the various interested user groups to produce optimal relationships. From these diagrams, schematic plans were developed. A total of 32 hospital staff user groups reviewed the architects' design to ensure that various areas or systems would be designed based upon appropriate criteria. Additional input came from surveys conducted by Replacement Hospital Program staff among visitors and patients to consider their concerns related to the new hospital.

Extensive use was made of full size mockups of both single and double patient bedrooms, intensive care units and nursing stations to test the design of these highly critical areas. The Office of the Replacement Hospital Program, in cooperation with the University Architectural Research Lab, conducted studies that evaluated such features as size, layout, equipment organization, traffic flow and accessibility for handicapped and elderly.

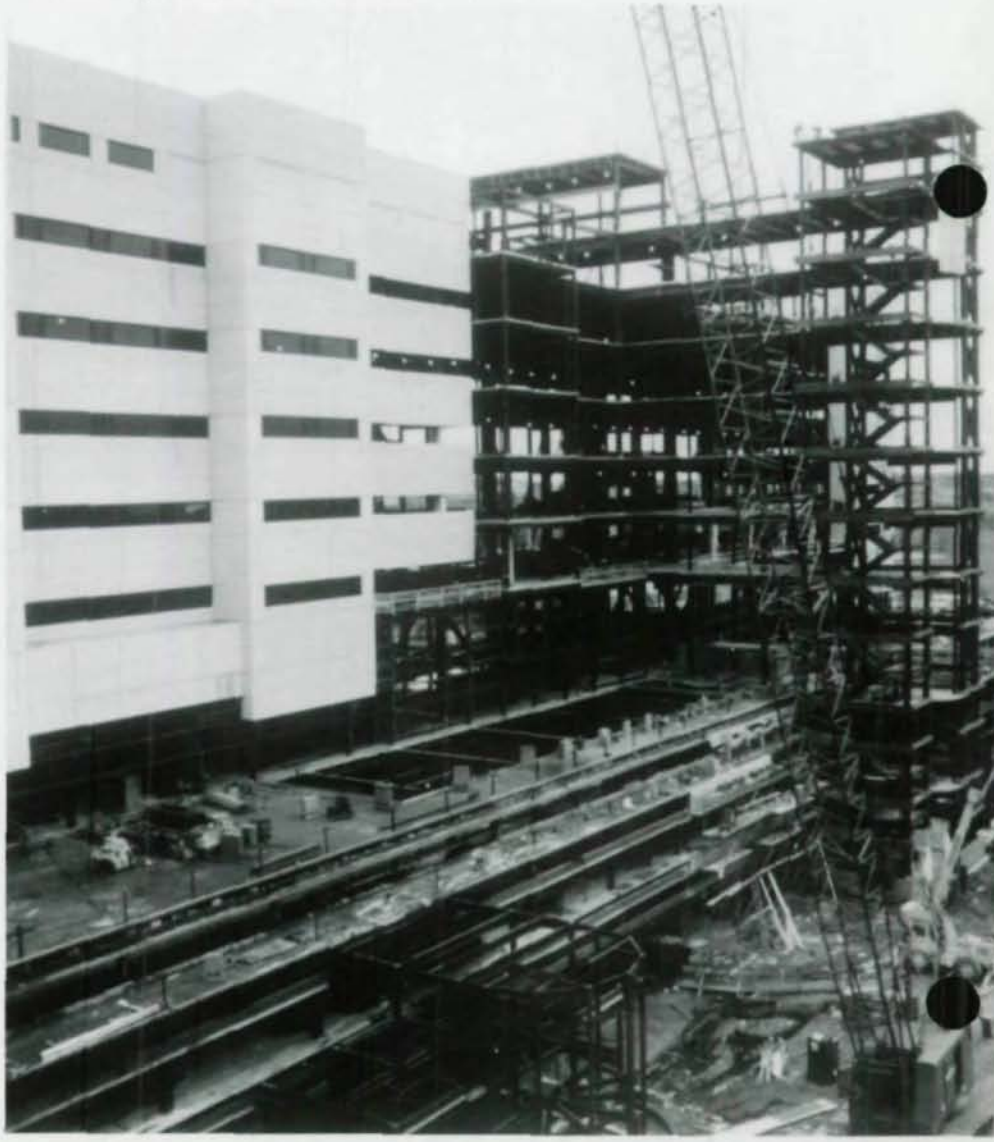
Systems Analysis Process—Minimize Obsolescence

Concurrent with the functional planning process just described, an analysis of various construction and engineering systems was undertaken by AKA. This analysis included research findings and recommendations regarding state-of-the-art planning for departmental areas as well as innovative design alternatives related to communications, movement, environmental and other engineering and architectural building systems. Included in this analysis was a study to determine the best methods to minimize facility obsolescence in the face of ever faster advancing technology. Hospital complexity has increased more in the past 30 years than in the previous 200. This not only has dramatically increased construction, operation and maintenance costs, but also has reduced the ability of hospitals to respond to continuing changes in health services, medical education and research.

During the 60's, special spaces to accommodate mechanical and electrical systems began to be used more frequently. The first implementation of a walkway space concept, begun in England in 1962 at Greenwich District Hospital, consisted of a 6-ft high horizontal mechanical/electrical distribution space between floors, now known as interstitial space. The interstitial space concept received careful consideration by AKA because:

- The anticipated useful life of a major health care facility such as this must be well in excess of 50 years.
- Effective functional planning recognizes the inevitability of future change.
- Conventional construction usually involves mechanical and electrical services designed and sized for a specific

Erection of steel-framed exterior wall of adult hospital (from SW). Photo courtesy Barton/Malow. Section view at r.



function. Typical ceiling spaces which house these services are often difficult to access, thus resulting in costly maintenance, as well as significantly limited flexibility to accommodate growth or change.

- Initial capital expenditures for a major health care facility are likely to be exceeded by operational costs in less than two years.
- Interstitial space permits renovation to occur with minimal disruption to occupied spaces below. This is especially important for functions adjacent to the area to be renovated, which would require no disruption except for revision to services above.

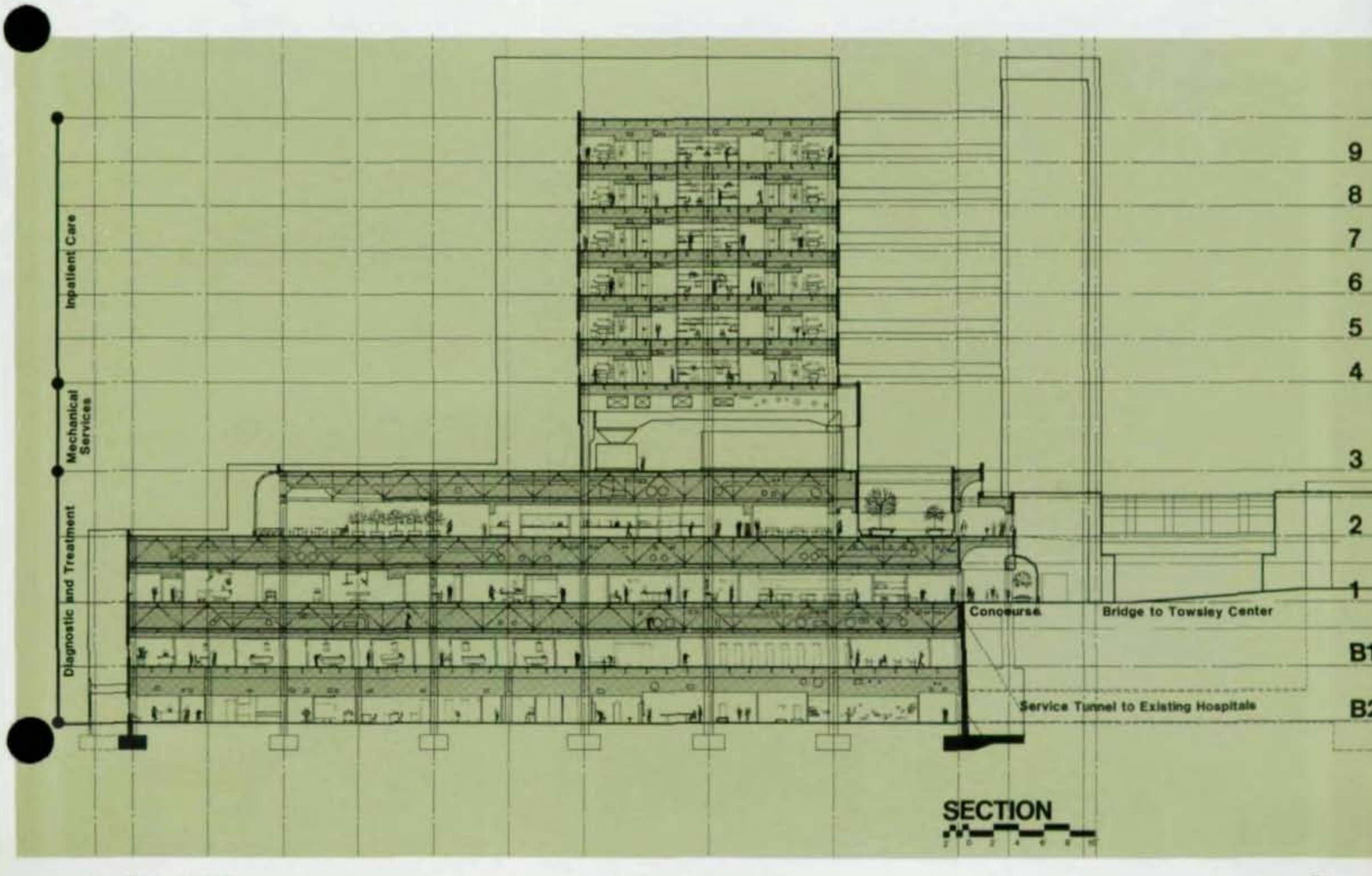
AKA prepared a special study of 16 existing major healthcare facilities using the interstitial space concept. Of these facilities, 13 had interstitial construction associated with all parts of the building, and in general, the inpatient bed units were linked horizontally with the diagnostic and treatment functions. The remaining three included interstitial construction in selected areas only. In these facilities, the inpatient bed units had not been integrated into the diagnostic and treatment block. The decision to not provide interstitial construction in the inpatient bed units was based primarily on the infrequency of change requirements.

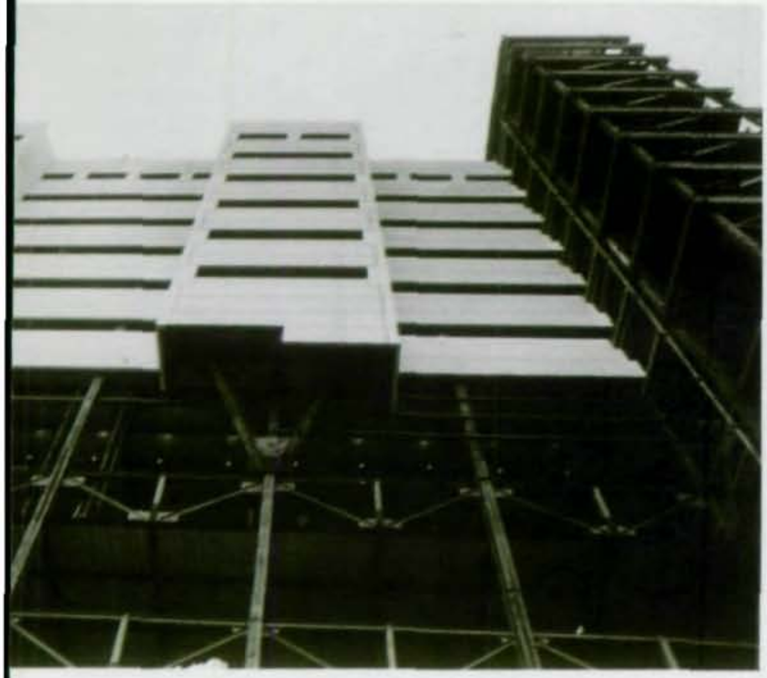
Major deterrents to the use of interstitial construction were first-cost factors, including additional deck, framing or catwalk systems, elevator service (if applicable), lighting, power, fire protection systems (if applicable) and exiting systems. In addition, the building became taller, increasing construction costs related to columns, exterior walls, elevators, stairs, as well as electrical and mechanical risers. These extra material costs were somewhat offset by savings in labor costs because various trades can work simultaneously, one above another rather than sequentially as necessary in conventional construction. In the final analysis, first-cost increases were determined to be insignificant when compared to the potential operational cost savings over the life of the facility, due to greater flexibility and decreased down time.

Structural Criteria

The primary objective of a structural system is to support all of the loads which may occur on or in the building without excessive deflection or excessive material stresses. Construction loads, wind and seismic loads, weights of the various building materials, equipment and personnel must all be considered in designing the systems. Structural systems should not interfere with the installation of the building electrical and mechanical systems, and should not impose severe restrictions to changes in the hospital layout or to department function changes. The system should be simple to construct and not require a great deal of maintenance. It also should reduce noise transmission and isolate vibrations originating from mechanical equipment.

To respond to the changing demands of health care in a large medical facility, the structural system must have qualities that permit frequent changes in department layouts and associated mechanical and electrical services. However, when these functional changes induce loads which exceed design capacity, the systems must be reinforced. There is a clear difference between structural steel framing and reinforced concrete when structural modifications are needed. Structural steel frames can be readily reinforced in the field to allow increased loading, or to provide new clearances when required.





View of interstitial framing and extended 2-bed patient rooms (l.). Closeup (above) of interstitial space before deck pouring. Photos courtesy Albert Kahn Associates. Below, r.: interstitial truss swings into place. Inpatient bed floors beyond. Photo courtesy Barton/Malow.

Reinforced concrete frames are more difficult to strengthen or structurally modify. Once the concrete frame is completed, it is often not practical to modify the construction without adding new support systems which generally interfere with spaces dedicated to mechanical and electrical services. The interferences which are produced severely limit the facility's flexibility for all future changes. For this reason, reinforced concrete systems may not be appropriate where facility changes are frequent. For this facility, most of the actual loading requirements were satisfied by systems designed in accordance with minimum code standards. In evaluating structural loading conditions, the weights of partition systems were treated as live load (i.e., movable systems). Architectural plan flexibility was a basic assumption, and the structural systems were designed to be as independent of the room and department layouts as possible.

To obtain the economy associated with repetition of structural members and the advantages of prefabrication, the structure was designed for loads that met the requirement of most or all departments associated with a given building type (e.g., diagnostic and treatment or nursing units). This also allowed the hospital plan to develop and change without modifications to the structural system.

Structural Studies

During the system analysis process, structural materials and construction techniques were studied with the goal to select the best system for the project. Initial costs, flexibility for change, construction time, site constraints and the effects of a severe winter climate on construction were all factors in making the selection.

The evaluation of structural steel and reinforced concrete framing systems was divided into loading groups and span categories. The loading groups were light loading with a total live load of 40 to 60 psf; medium loading with a live load of 100 psf; and heavy loading with a live load of 150 psf. These loading conditions satisfied the necessary code minimums for the various hospital areas, as well as the special loading requirements of mechanical rooms and areas with special equipment. Two span categories were established—medium spans of 24 to 35 ft, and long spans of 35 to 75 ft. Short spans, those less than 24 ft, were found to impose severe planning restrictions and were eliminated early in the study.

The various building types and functions each presented different criteria for the design of the structural systems. This could have resulted in the selection of different structural systems for each major building area. The selection of completely different types of systems, such as the use of a steel frame for interstitial type construction and a reinforced concrete frame for some other building type, was entirely possible. The original structural studies for the hospital considered 594 structural steel non-composite designs, 108 structural steel composite floor designs, and 1,168 reinforced concrete schemes. Several computer programs were developed to provide the analysis, design and cost determinations needed to evaluate changes to loadings, bay sizes, forming systems and construction types.

In addition to the characteristics of the various structural systems already described, the construction time, coordination with other building trades and site requirements were considered in evaluating and selecting the primary building material and framing system. Because structural steel sections are prefabricated and delivered to the site ready for final assembly, the field construction time and space requirements for on-site storage are reduced. Prefabrication does require early design effort and selection of contractors to take advantage of the field time savings. In this way, the building structure could be ready for work by other building trades months earlier than with on-site construction methods usually associated with cast-in-place reinforced concrete. The use of such a fast-track design and construction approach requires that the structural system be designed to afford flexibility for changes which result from the final development of the architectural hospital layout, and mechanical and electrical building services which follow.

Another advantage of structural steel framing is that it allows early access by other building trades to floor levels below.

With cast-in-place construction, workmen of other building trades may not have early access to the completed floors due to reshoring. The formwork for each new floor would probably require that two lower completed floors be used for support, with the resulting forest of shores. In addition to limiting access by workmen, this aspect of concrete construction creates a fire hazard during construction, particularly with the need for temporary heat.

Building Design and Organization

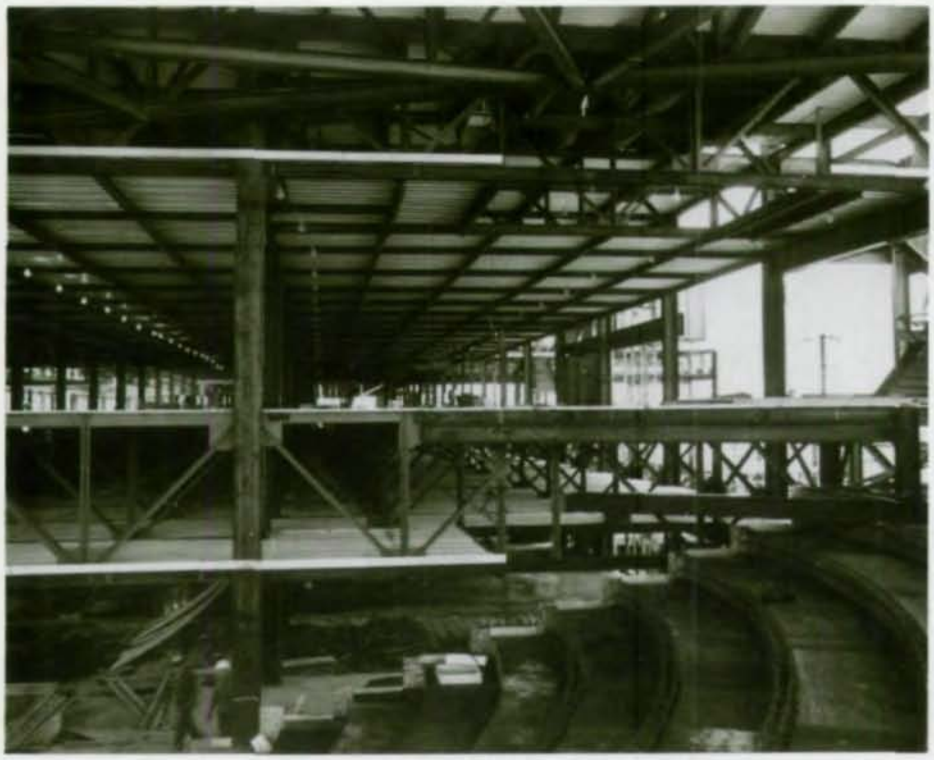
The Adult General Hospital, in excess of 1,000,000 sq ft, is organized into two major elements; a stepped 4-level base with provisions for future horizontal expansion, and a 6-level inpatient tower located above, with the capability for vertical expansion. The 660,000 sq ft base contains diagnostic and treatment (D&T) functions such as Radiology, Emergency, Surgery and Laboratories, plus support spaces such as Public, Admitting, Dietary, Pharmacy and Material Handling areas necessary to a major teaching medical center.

The inpatient tower (IPU) houses 586 patients, including 70 intensive care rooms equipped with highly sophisticated monitors and medical services. Separating the D&T base and IPU tower is a 27-ft high mechanical floor containing 17 air handling systems and three electrical substations.

In 1930, less than 30 effective drugs existed for patient treatment. Bed rest was the only known treatment for many ailments. Today a broad range of medication and treatments is available to the physician, and the Adult General Hospital as a state-of-the-art facility is equipped to provide all resources possible, including the following:

- In the Diagnostic and Treatment base, the main Pharmacy Dept. serves five satellite pharmacies on the inpatient floors.
- Three linear accelerators for cancer treatment are located in a specially designed and protected area in Therapeutic Radiology on the lowest level.
- Planning for Diagnostic Radiology included such systems as computerized (C.T.) body scanners, ultrasound and the latest Magnetic Resonance Imaging.
- The new surgical suite contains 17 highly specialized operating rooms, including one dedicated to new or experimental procedures and another equipped to facilitate organ transplants.
- Multiple workstations have been provided in the Clinical Labs in anticipation of over 750,000 medical tests per year.
- The rapid development of the computer has caused a revolution in medical information processing. In the Adult General Hospital, an extensive communication system allows computer access at over 3,600 points in the hospital.

The IPU has been designed for a continuum of care. Each floor has intensive care, stepdown and acute care beds. Only the most critically ill patients will be treated in the intensive care unit. The linear arrangement of nursing units will allow patient care disciplines to use beds and allocate staff as necessary. Of the 586 beds in the Adult General Hospital, 324 will be single-bed rooms, the remainder two-bed. Personal comfort of the patient was a major concern during the design of the patient bedrooms. Each room will have its own bathroom with tiled shower. Large windows with low sills allow bed-ridden patients a panoramic view of the wooded, rolling Huron Valley to the north or to the



Interstitial steel framing system and use areas adjacent to stepped amphitheater. Photo courtesy Albert Kahn.

sunny landscaped courtyard of the Medical Campus and University skyline to the south.

Because it is a teaching hospital, the Adult General Hospital has a number of special educational spaces. An amphitheater seating 220, opening off the upper lobby, is equipped with the latest in audiovisual equipment, including video projection and provisions to accommodate headsets for simultaneous translation. Conference rooms and classrooms have been located throughout the facility. Patient rooms, which also reflect the need for student involvement in patient care, are sized to accommodate teams making their rounds.

In the Adult General Hospital, "way-finding" was a critical design consideration. Horizontal traffic is routed through a 2-level main concourse system, which interconnects the main lobby on Level 1 with major public elevator and escalator lobbies. The Level 2 concourse is connected to adjoining buildings in the Medical Center by enclosed pedestrian bridges, completing a major interior pedestrian street system within the Center.

Orientation is an important design criteria which was accommodated by locating the main concourse on each level adjacent to the south exterior wall. Using natural light through clerestory and barrel vault glazing systems, the concourse and bridge system will provide pleasant lounge areas for visitors, patients, staff and students as they overlook a landscaped pedestrian courtyard. Traffic to other floors is first routed horizontally to the east or west portions of the Adult General Hospital. Visitor or outpatient traffic is directed to two public elevator lobbies, which each access three elevators connecting all 10 public floors. To reduce the elevator traffic, staff or student traffic to the three primary D&T floors is encouraged to utilize the eight escalators, divided into the two locations. Staff or inpatient traffic between any of the 10 floors is facilitated by six patient-sized elevators, located in two clusters, north of the main concourses.

Material transport systems have been designed to make scheduled deliveries automatically to all Adult General Hospital floors, as well as to other new and existing patient care facilities in the Medical Center. This is accomplished via an automated floor guidance system, a computer-based system of automated vehicles. These vehicles deliver patient meals and departmental supplies to predetermined areas by following designated pathways to six dedicated elevators. Two additional elevators provide necessary supplies to the Surgery Department and a third has been dedicated to transport dietary supplies from the Main Kitchen to the Cafeteria on Level 2. In addition, a new 6-in. dia. 62-station pneumatic tube system provides for the transport of laboratory specimens, pharmaceuticals and other urgently needed materials.

The Results

Construction began first on a 1,000-car parking structure in June 1981, to provide space for construction vehicles. In October 1981, ground was broken for the new Adult General Hospital. Fast-track construction was determined to be the most appropriate method for completing construction in the minimum time frame. The construction sequence called for the building to be completed in a series of vertical segments—steel erected, deck placed, studs welded and concrete placed. The exterior wall was then erected and interior work started.

Because the hospital is on a sloping site, more than 300,000 cu. yd. of material was cut out of the hillside. A former dump site, earth at this location was mixed with large quantities of nonusable material. A 600-ft long, 45-ft high, temporary earth retaining wall was erected along the north face of the existing Medical Center. Following the installation of the temporary retaining wall and mass excavation, approximately 1,000 ft of 50-ft high counterforted retaining wall was constructed. About 400 ft of conventional retaining walls, averaging 20 ft to 30 ft high, completed enclosure of the hospital below grade.

In addition to the 1,000,000 sq ft of hospital floor space, there is 320,000 sq ft of interstitial floor area, all under 116,000 sq ft of roof. The structure is of AISC Type-2 construction, with connections specified as shop-welded and field-bolted. The D&T areas were constructed of trusses and shallow composite beams, while the IPU was framed with simple composite beam-and-girder construction. Nearly 9,850 tons of mostly high-strength, A572 Gr.50 steel was used, including 1,700 tons in truss material.

AKA investigated five types of interstitial space construction. All of the types assumed fire protection requirements of three hours for columns and two hours for floors, trusses, girders and beams. The interstitial system selected had a 2-hr. fire-rated interstitial deck. With this system, only the columns and the exterior frame required fireproofing within the interstice; 2-hr. rated, 1-hr. rated and smoke barrier partitions terminated at the underside of the interstitial deck. Only stairs and shafts extended through the interstice. An automatic fire suppression system was provided in the interstitial space to assure a consistent level of safety throughout the entire Adult General Hospital. Normal fire dampers were required for mechanical ducts penetrating stairs or shafts. The number and size of duct penetrations in the interstitial deck were unlimited.

The interstitial trusses typically have tee-section top chords and wide-flange bottom chords with conventional double-angle web members. They are 8 ft, 6 in. deep, providing a clear distance from interstitial floor to underside of steel of 6 ft, 10 in. Bay sizes are 24 ft × 48 ft and 24 ft × 40 ft, with a floor-to-floor height of 14 ft in the patient tower and 20 ft, 8 in. in the diagnostic and treatment base.

Exterior materials were chosen to relate to adjoining buildings on the medical campus. The building base and stairtowers are clad in bands of smooth and rough-faced tan brick to provide visual continuity of color and material to the existing medical campus. The use of panels of light beige precast concrete on the tower eliminated the need for scaffolding that masonry would have required, accelerated the enclosure of the top floors and provided a durable, low maintenance facade that gives a visual focal point to the northeast corner of the campus.

Another major element in the Adult General Hospital design is a 2-million gallon, underground, thermal storage basin (TSB). Filled with chilled water, the basin acts like a liquid storage tank for cooling or heating energy. The TSB has allowed the size of the refrigeration plant to be reduced from a peak capacity of 4,500 tons to an average load capacity of 3,000 tons, thereby saving on capital equipment costs. The TSB serves as a heat sink in the winter, through operation of the refrigeration plant in a heat pump mode. During the summer, it will also provide backup cooling capacity in the event of equipment failure, permitting the hospital to continue to air condition critical areas in the event of a power failure. The TSB will be used to decrease facility energy requirements during high energy demand/high cost periods and will be replenished when conditions of lower energy demand/lower costs prevail.

The Future

In January 1986, Old Main will be retired from service as the Adult General Hospital is occupied. Occupancy of the Adult General Hospital will not mark the completion of the facility, however. Current planning efforts are underway for a new Burn Treatment Unit on Level 1 of the D&T, immediately east of the new Surgery Suite. In addition, a Solid Waste Disposal/Waste Heat Recovery facility is to be located in the D&T expansion zone. These areas will not be completed by the occupancy date, but rather represent the first of many facility modification projects to be undertaken over the years. As designed, the Adult General Hospital will expedite these changes with a minimum of disruption.

Occupancy of the Adult General Hospital will mark the beginning of a second century of medical care and training at the University of Michigan. It opens with the promise that the University of Michigan has a medical facility that will remain functional and attractive for many years to come. ☐

Architect/Structural Engineer
Albert Kahn Associates, Inc.
Detroit, Michigan

Construction Manager
Barton-Malow/CM, Inc.
An Association of Construction Managers
Ann Arbor, Michigan

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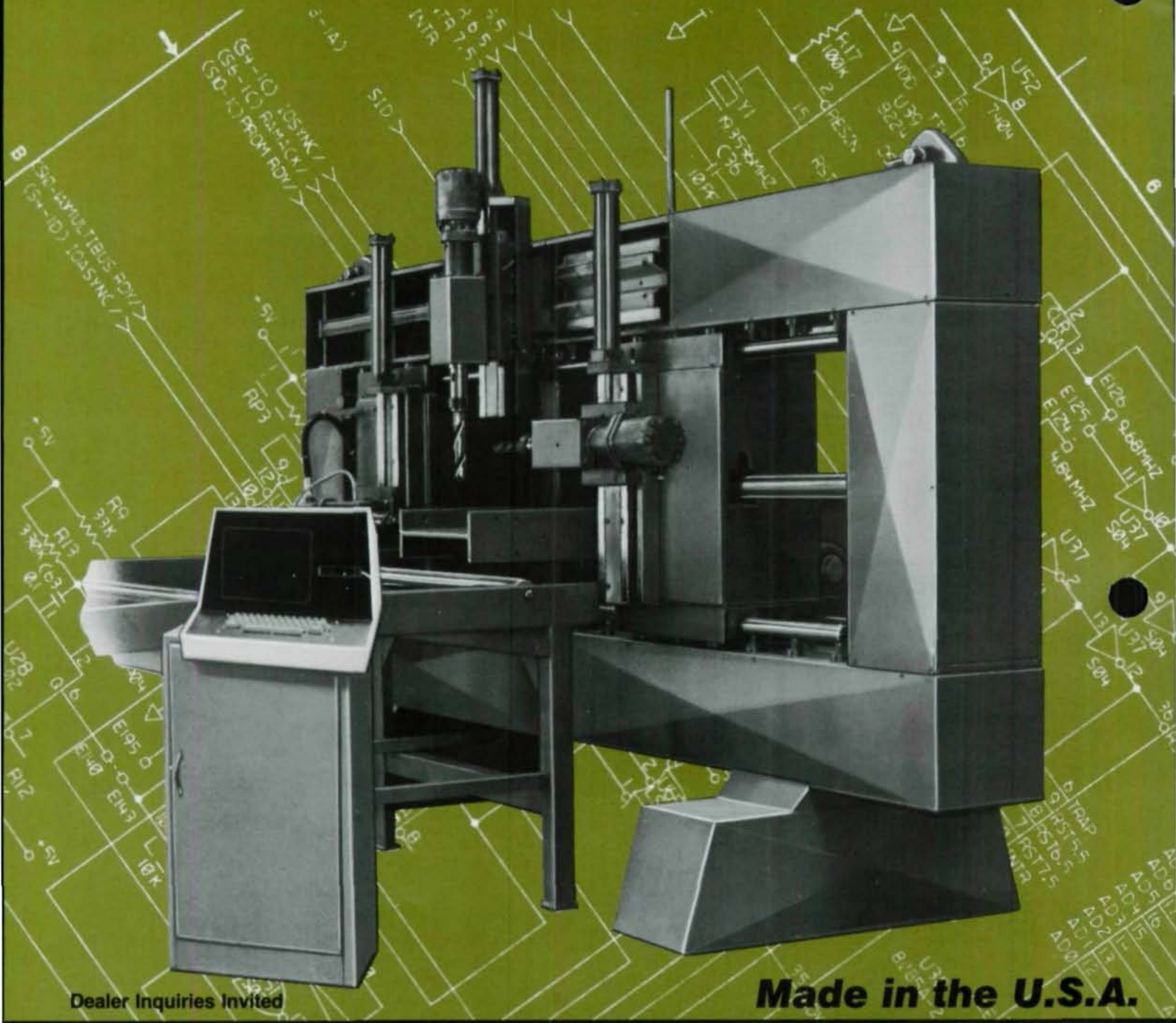

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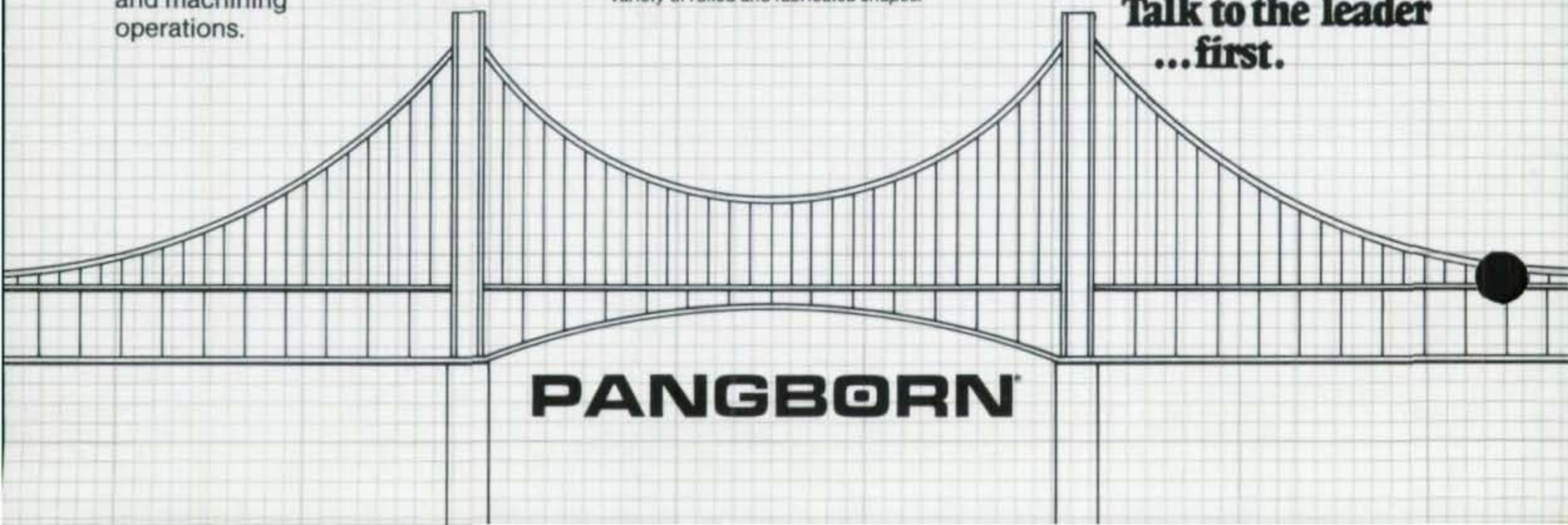


PANGBORN

1999 Broadway:
The New Reflects the Old

"So he came to me with a sketch of a triangular site with a church on it, and he said, 'I want you to design an office building on this site and keep the church as part of the development. I'll be back in a fortnight.' *The first thing I had to do was* find out what a fortnight was."

That conversation between developer and Architect Curtis W. Fentress set the first restrictions on the design for 1999 Broadway, the $135-million, 43-story office tower built around Holy Ghost Catholic Church in downtown Denver.

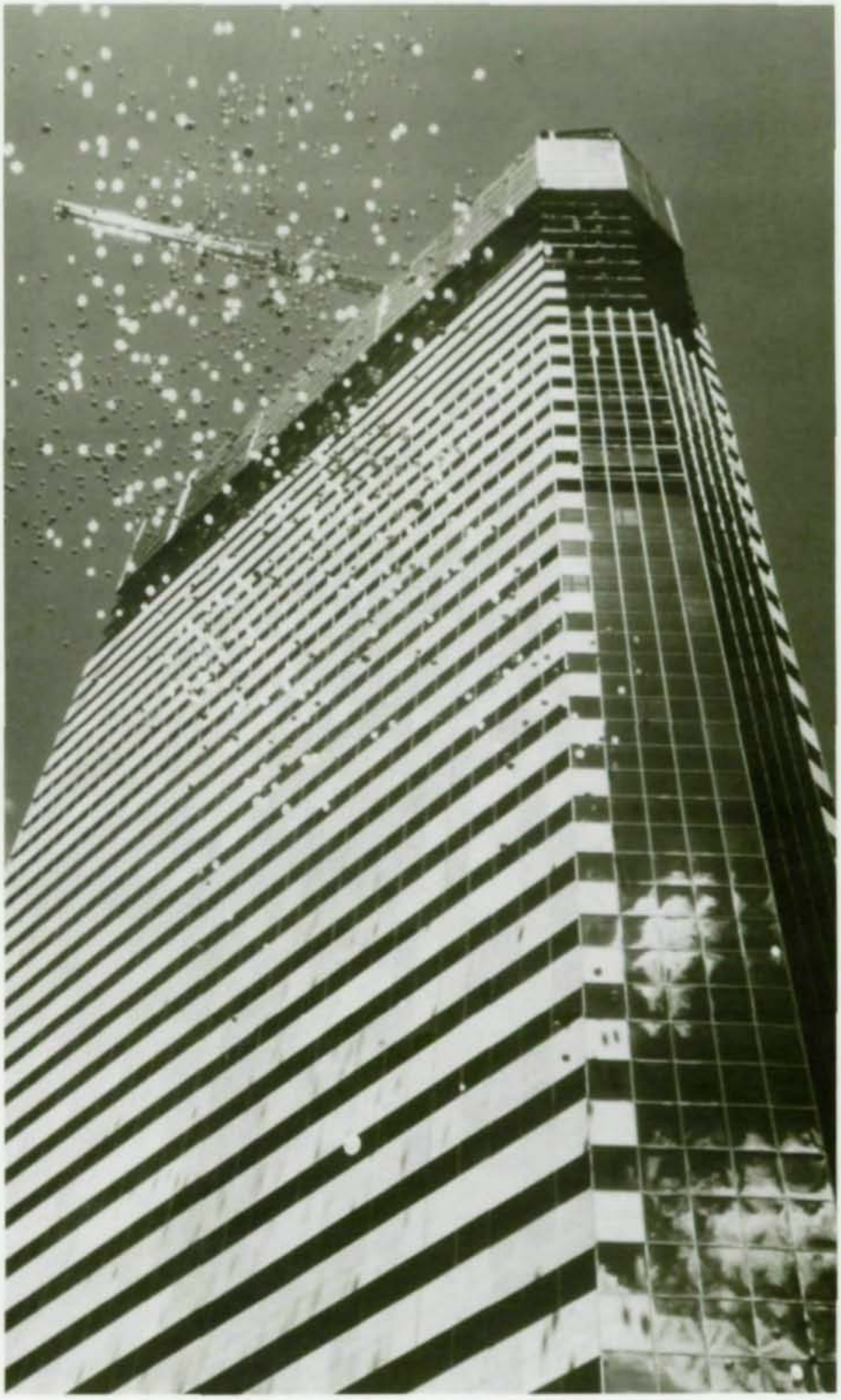
Next, the architect developed four possible design schemes, and eliminated all but one—the one that radiated from the epicenter of the church and spiraled around its cruciform shape, wrapping the envisioned office building around three sides of the existing structure.

In designing 1999 Broadway, the architect considered a variety of factors that would affect its shape, height and mass. He took into consideration the physical restrictions of the triangular site, "and what was appropriate for new construction around a pre-existing structure, for downtown Denver and for building around a historic church.

"The object was to design a significant high-rise that would complement the church's style and location, and build it without causing the church to miss any of its services."

In addition, the building's location within the B-5 district in Denver's downtown core permitted a floor-area-ratio of 10 for the 47,434-sq ft site. Zoning premiums for plaza, arcade and low-level buildings—for which the church qualified—increased permissible gross square footage to 760,000 sq ft.

The architect deliberately contrasted and complemented the two buildings by lifting up 1999 Broadway and setting it apart from the church with a 50-ft arcade beneath the office tower. Clear glass on its first and second floors was selected to create a sense of transparency at pedestrian level, a feeling enhanced by views of the rear facade of the church from inside the office building. The plaza around the church was designed as an urban resting place much like an English garden grove, with sodded and shaded seating areas where parishioners and passersby could enjoy city views.



1999 balloons were released to celebrate topping out of 1999 Broadway Building, Denver, Colo. The 43-story office tower, built around a church, faces business district and famed Pike's Peak.

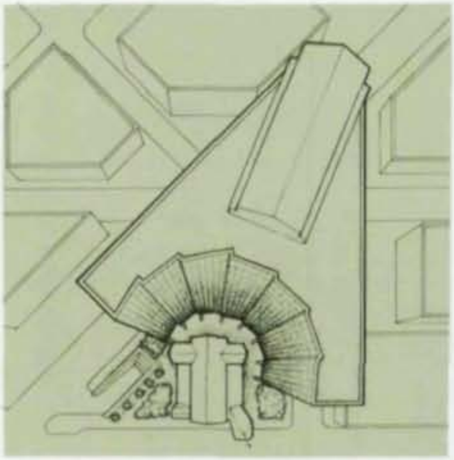
A Marriage of Materials

The next consideration was to select building materials to marry the high-rise with the church, using to the project's advantage the way new materials of the skyscraper would harmonize with weathered counterparts on the church. 1999 Broadway's limestone—140,000 sq ft quarried from the same vein in Indiana that provided the exterior for Rockefeller Center—was chosen to match the buff brick exterior and terra-cotta trim of the church. The building's 230,000 sq ft of sea-green reflective glass was picked to blend with the church's green clay tile roof, replaced as part of its $1.6-million renovation. The framing of highly polished, stainless-steel mullions that supports the exterior cladding enhances the reflective quality of the building's Broadway apex and its faceted, glass curtain wall embracing the church.

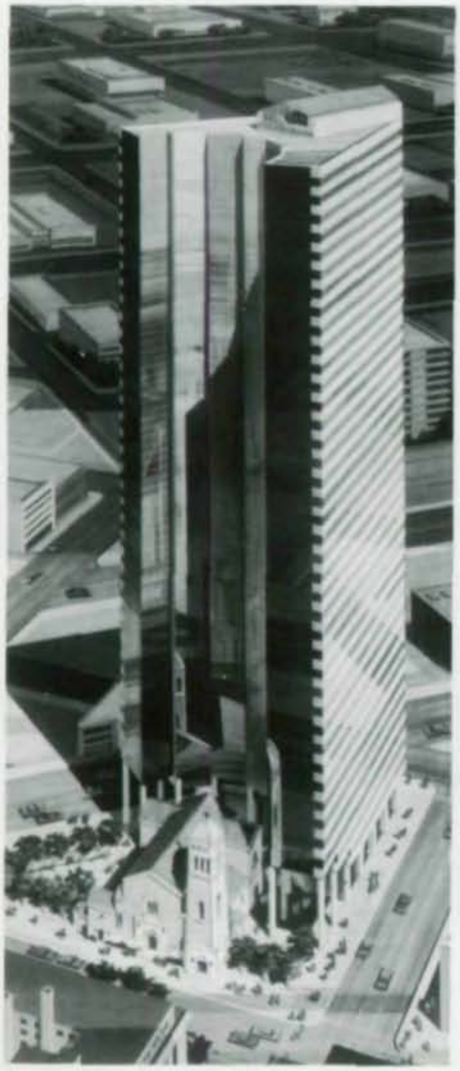
Because it blended with the slate already used on the front steps into the church, an olive slate from northern England was selected to pave the remaining church entries and to border the house of worship, separating it from the acre of African green granite paving its landscaped plaza.

Form elements of the church were incorporated into the design of the high-rise. The gabled roof of the church became the shape for 1999 Broadway's mechanical penthouse, as well as the cathedral ceilings in its lavatories, elevator cabs and elevator lobby. The keystone integral to the church's Italianate renaissance architecture is repeated in the wood trim above the skyscraper elevators. The marble interior of the church—300 tons of travertine quarried in Colorado—is reiterated in the high-rise through 12,000 sq ft of green marble from Vermont installed on 1999 Broadway's interior public spaces.

Next, the architect turned attention to creating the office building entrance on Broadway, the main thoroughfare at the opposite side from the church. The two faces of 1999 Broadway's corporate and ecclesiastical sides now evolved. To strengthen the skyscraper's corporate image, its two sides of limestone and glass touch ground and act as giant gateposts. Then, lifting the reflective-glass spine ascending to the peak of the penthouse, the architect placed a solitary stainless steel column at the nose of the building to mark its entry as prominently as the church spire at the opposing side.



Unusual footprint of tower and church presented many challenges.



Rendering (l.) shows relationship between tower and church. Structural steel frame at mid-point (above). Three levels are enclosed by environmental screen. Self-climbing jump-form system, here 8 stories above steel, formed core.

Church Renovation Complements 1999 Broadway

Catholic church, cradled by tower, undergoes $1.6-million renovation as part of 1999 Broadway development.

Holy Ghost Catholic Church, the renaissance-style church built in downtown Denver in 1943, underwent a $1.6-million renovation as part of the development of 1999 Broadway.

Most of the improvements are necessary because of a growing ministry, the age of the church, the dilapidated state of the rectory and the requirement to bring the church up-to-date with building and fire codes. Priorities were to upgrade the church and continue parish activities throughout renovation and new construction. All public utilities were rerouted to assure the church's day-to-day operations continued throughout development. Space within the structure has been shifted as well to keep the church operational during renovation. And two temporary walkways for parishioners were attached to the emergency side exits of the building above excavation level to provide unobstructed exits to the street.

As part of the renovation effort, the church's green clay tile roof was replaced and its rear facade rebuilt to restore an exterior cruciform shape that expresses the interior sanctuary and side chapels. The rear elevation is reflected in the curtain wall of the completed office building and is visible at street level through the glass walls of the tower's lower two levels.

New life-safety and mechanical systems bring the church into compliance with fire and building codes. The pre-action sprinkler system installed in the attic and basement is supplemented by an attic smoke exhaust fan and a fire standpipe system installed in the belltower to provide fire department hookups.

In February 1982, the church building was sold by the Denver Archdiocese to the developer, and leased back for 1,000 years. The leaseback agreement made Colorado history as the first in the 168-parish archdiocese. ☐

Last summer, when the last structural steel beam was hoisted into place, the topping-out milestone marked more than the completion of erection of 13-million tons of structural and reinforcing steel on the arrowhead-shaped building. It signified the reasons steel was chosen by the developer for the framing of 1999 Broadway in the first place.

Steel's Flexibility Paramount

Steel was viewed as a more reliable manufactured product than concrete. And, by using steel, the odd shape of the building was significantly easier to design and execute, and future tenant remodeling would be simpler. Also, it would be easier to cut holes in floors to add internal office stairs or a private elevator, or to weld steel plates to beams and columns to create the floor capacity to bear the additional loads of law libraries or file rooms.

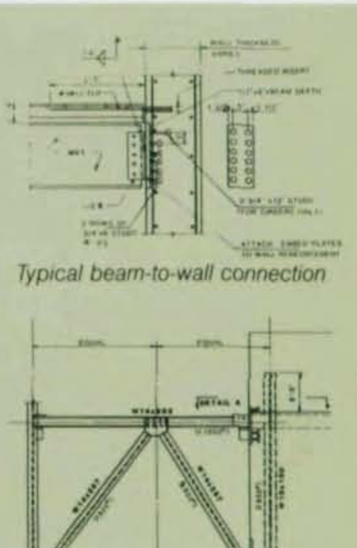
A non-structural consideration also weighed heavily in favor of steel erection—1999 Broadway could be built in 18 months, as opposed to 24 months with concrete. The faster the high-rise could be built, the sooner the developer could switch from a construction loan, which caries higher interest rates, to permanent financing—a particularly important consideration in today's tight real estate market.

Unusual Footprint a Challenge

The unusual shape of 1999 Broadway and its footprint presented a challenge to the structural engineering solution, according to consulting engineer Edward Messina. Also, the high aspect ratio and the presence of the church structure in close proximity to the tower strongly suggested a wind study. Various wind resisting systems were studied and analyzed using in-house computer developed programs to determine the most economic method to resist the wind forces resulting from a wind load test conducted at Fluid Dynamics and Diffusion Laboratory, Fort Collins, Colo.

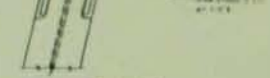
The test predicted the extreme loads at different angles from 0 to 360°. The final system chosen was a mixed system of structural steel frame and a reinforced concrete triangular core. In the north-south direction, the long direction of the triangle, the concrete core resists all the lateral forces within the recommended deflection limits. In the east-west direction, the narrow width of the core, two two-story high trusses at the mechanical levels 3 and 5 and 29 and 31 were introduced to reduce expected drift.

A typical floor construction consists of 5¼-in. thick composite metal deck slab construction (3¼-in. lightweight concrete on 2-in. metal deck). The deck spans were



Typical beam-to-wall connection

Truss T-2 at 29-31st floors



Detail A

typically 11 ft, and were supported by 16-in. and 18-in. rolled sections. The beams were designed to act compositely with the slab through shear studs, field installed through the metal deck.

Due to deck and beam deflections the slab thickness varied. This additional load was introduced into the design of the beams, and deck selection. Girders spanning 33 ft from the perimeter columns to the concrete core were also designed to act compositely with the slab. The girders were connected to the concrete core by shear plates which were field-welded to steel embedment plate connected to the concrete walls with a series of shear studs. The floor slabs act as a shear diaphragm connecting the exterior steel system with the core. The shear connection of the slab to the wall is through steel dowels at each slab level. These dowels transmitted the tension and shear forces to the reinforced concrete core walls. Gravity load is transmitted through shelf angles connected with expansion bolts to the core wall.

Moment-Resisting Frame

The exterior steel frame was designed as a moment-resisting portal frame to resist a part of the lateral forces and any eccentric forces. The spandrel beams were connected to the concrete floor with shear studs.

The foundation system consisted of cast-in-place caissons founded on claystone and sandstone bedrock approximately 50 ft below grade. The caisson foundation provided a single high-capacity support for each column to transfer the building load to the bedrock. The maximum bearing pressure of 70,000 psf and a skin friction of 7,000 psf for the portion in the bedrock was used. Core walls below the parking level bear on continuous concrete grade beams transferring the load to spaced caissons located around the perimeter of the triangular core. In order not to reduce the capacity of a single caisson, a minimum distance between caissons of three diameters was used.

Facade Surrounds Church

The exterior facade, a combination of glass and limestone, surrounds the church, which has reflecting glass. The facade on the long legs of the triangle are glass and limestone panels. The prestressed panels, which act as beam spacing 30 ft between exterior steel columns, consist of six separate pieces of limestone 5-ft wide by 7 ft-6 in. high doweled together and prestressed using a 5/8-in. Gr.157 threaded bar tendon.

Load-bearing connections at each column support the prestressed limestone panels which in turn support continuous glass windows. One end of the panel is fixed, but the other end is free to move, permitting thermal expansion and anticipated movements between the structural frame and the exterior cladding. Wind connections are provided at third points below the floor line and at quarter points at the floor. ☐

Architect
C. W. Fentress and Associates P.C.
Denver, Colorado

General Contractor
Hensel Phelps Construction Co.
Greeley, Colorado

Structural Engineer
Severud Perrone Szegezdy Strum
New York City, New York

Steel Fabricator
AFCO Steel
Little Rock, Arkansas

Steel Erector
Derr and Gruenewald Construction Co.
Henderson, Colorado

Developer
Lawder Corporation
Denver, Colorado

The Sohio Building:
A Distinctive, Revitalizing Force

by Jerry Sincoff and William O'Neal

Jerry Sincoff is vice president, operations, for the architectural firm of Hellmuth, Obata & Kassabaum, Inc., St. Louis, Missouri.

William O'Neal is principal in charge of the structural engineering firm of KKBNA, Wheat Ridge, Colorado.

Architect's rendering of new skyscraper on Cleveland skyline, the 45-story Sohio Building.

Sohio's goals in the design of its new headquarters in downtown Cleveland were twofold: construction of a distinctive building to house corporate administrative operations which would successfully relate to the landmarks surrounding it; and creation of a positive force in the revitalization of the city's downtown core.

The site faces historic Public Square, the symbolic and functional center of Cleveland, and is situated near two landmark buildings, The Arcade and Terminal Tower. The Hanna Fountains Mall to the north is another significant nearby development.

The Sohio Headquarters has two components: the atrium, an 8-story enclosed garden surrounded by offices, shops and restaurants; and the 45-story high-rise tower containing Sohio's corporate offices. The $200-million complex of office and retail space will be Ohio's largest corporate office building. It will consolidate Sohio operations currently in nine locations, and bring nearly 3,000 corporate employees under one roof.

The atrium will have a dramatic presence on Public Square, while relating well to the height, mass and architecture of nearby buildings. It is designed as an inviting glass-covered space, filled with activity and light. It extends the pedestrian-scale environment of Public Square and Euclid Avenue into the corporate center and serves as a transitional element to the high-rise tower.

The office tower, set back from Public Square, is aligned with the north-south axis of the Hanna Fountains Mall and provides an important terminus at the Mall's southern edge. The building axis is bent midway into the site so as to be perpendicular with Euclid Avenue. The tower is angled to frame Public Square, and its apparent mass is reduced by a series of facets which ascend in steps to the top-most floor. In profile, this gives the building a distinctive shape which complements the form and height of Terminal Tower.

The Atrium Design Statement

The eight-story atrium will have shops and restaurants on its first two levels, a Sohio cafeteria and a conference center on the third level, a physical fitness center and employee training on the fourth level, and three levels of office space. Pedestrians enter at street level, then take escalators to the second floor, the main people distribution level.

The atrium is actually two separate buildings connected by the roof skylight and several walkway bridges that span open space. The skylight, roughly 170-ft long and up to 150-ft wide, is framed with curved pipe trusses 15 ft o.c., with a depth of 31 ft at the end supports and 6 ft at the center. Linear braces appear at quarter points on the trusses to connect the west wall of the atrium to the tower interface. The west wall is framed with three vertical pipe trusses that curve to meet the form of the skylight roof trusses.

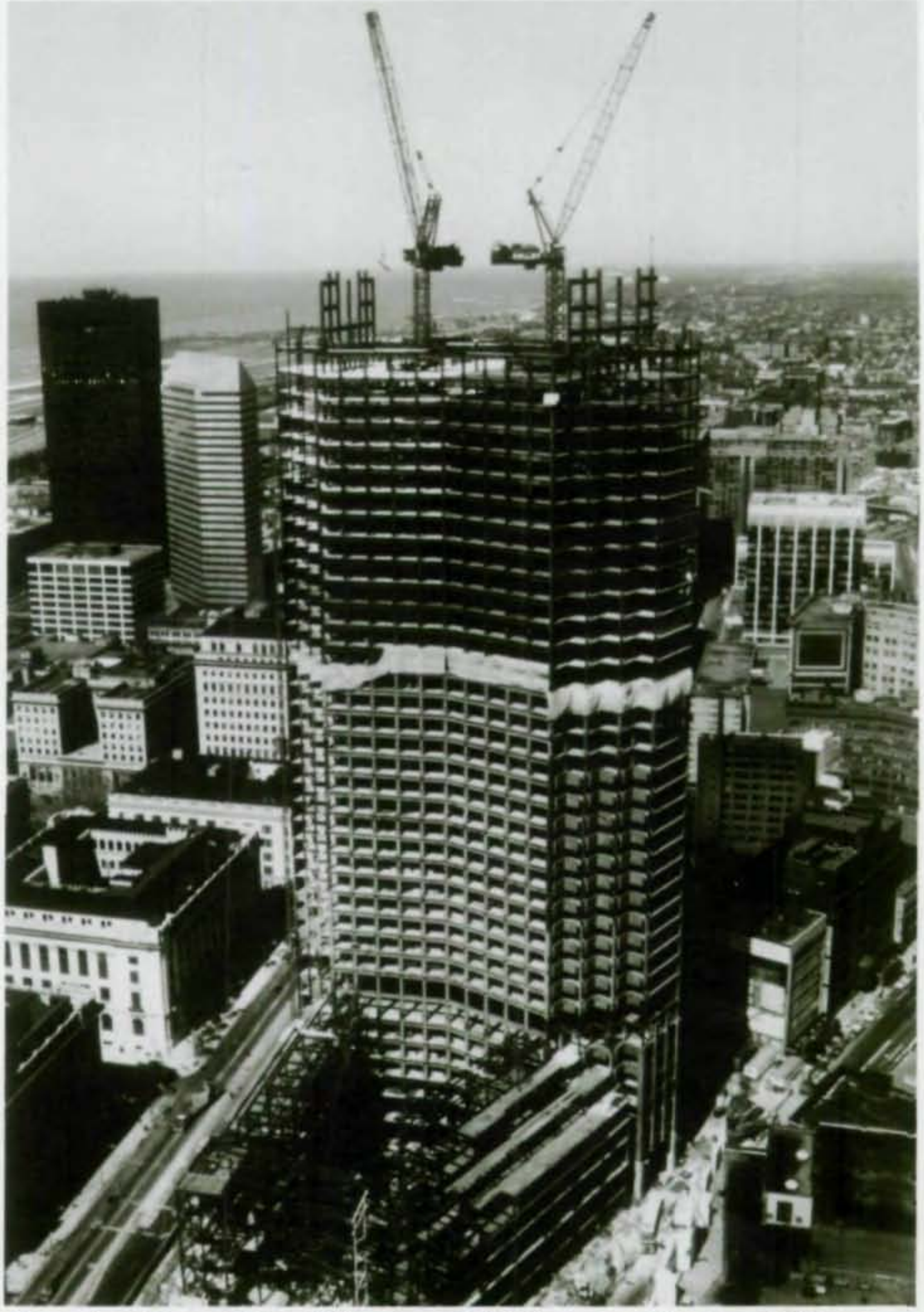
Three loading docks service the facility off Superior Ave. Three 9-ft deep, 55 to 60 ft long trusses span the dock ramp area. W14 × 730 members were used for chords, and some web members were of built-up sections. Diagonals were butt-welded. Each truss weighs over 50 tons.

The lateral system for the atrium building was dictated by open space requirements above and below the atrium floor. Drift criteria for each wing had to be stringent to prevent unacceptable loads being transmitted through the light atrium roof. Use of a series of moment frames in each wing was analyzed, but this resulted in an unacceptably high structural steel tonnage. Additional studies evolved into the unique solution of using only one rigid frame line in each wing at the west end only, linked together by the atrium bridges. This linkage minimized differential horizontal movement between the wings and permitted a relaxation of the drift criteria. Lateral loading in the north-south direction at the east end of the atrium is carried by the tower, as is the total atrium loading in the east-west direction. In addition to the gravity, wind and earthquake load conditions, loading applied to the atrium from tower drift was also checked. The atrium drift was also limited, reducing rotation to approximate the tower drift at the 9th floor.

The atrium space, created by the atrium building wings on the north and south, the tower on the east, the glass wall on the west and the glass roof overhead, is approximately 120 ft high. Because it is difficult to control temperature in a space this large, the large arched-roof pipe trusses were designed for a 100° F. temperature change. The horizontal and vertical trusses supporting the west wall were designed for a temperature gradient varying from 0°F. at the atrium floor to 100° F. at the roof. Horizontal displacements resulting from the temperature change were presented in graphic form to aid the skylight supplier in his design.

The Office Tower

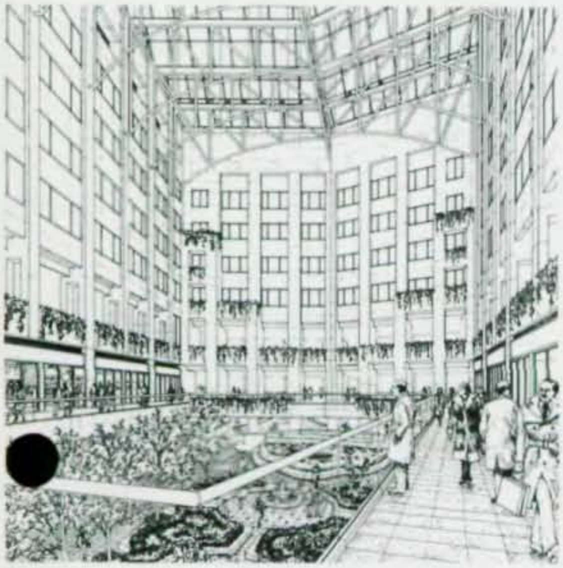
As the architectural design developed, it became desirable to use closely spaced columns along the east and west face of the tower. This column spacing was continued through the interior of the tower, at the north and south ends of the core, resulting in a tube-frame system. Preliminary analysis for wind loading in the east-west



Structural steel tower of Sohio Building rises in Public Square area. More than 20,000 tons of steel went into tower and atrium (foreground). Rendering of atrium above, r.

direction indicated that a tube frame acting alone would result in unacceptably large interior columns. Therefore, braced frames were added to the architectural core. Both a steel and a composite concrete tube were studied, with the final selection being steel.

The east and west walls of the tower step inward at 15-ft increments beginning at the 38th floor. Therefore, the north-south lateral loads are carried by two interior moment frames from Level 38 to the roof. Loading in the east-west direction from Level 38 to the roof is carried by the partially interrupted north and south rigid frames and the two braced frames. The two drift criteria used were 1/400 for wind and 1/200 for seismic. The wind loadings used for preliminary analysis came from both the Ohio State Building Code and ANSI. Seismic loading was based on UBC Zone 1. A number of loading combinations were analyzed for the structure.



A wind study was performed on a rigid model in a boundary layer wind tunnel at Colorado State University under the direction of Dr. Jack Cermack. Negative and positive pressures were developed to design the structural system, the building cladding and glass. In addition, the study indicated the potential effects on pedestrian traffic around the building. It resulted in a reduction in load for structural design, but an increase in design pressures on the exterior cladding, exceeding the city and state codes in many areas. These pressures were presented on the architectural elevations to provide the cladding supplier an opportunity to design an alternate support system as accurately and cost-efficiently as his plant capacities would allow.

To maintain the drift criteria, the structure was stiffened for loading in the east-west direction. However, due to the more extensive frame and lower tributary loading area, stress controlled in the north-south direction, minimizing the premium for drift.

The tube itself is 135 ft from east-to-west, 150 ft on the west side, 200 ft on the east side, and follows the kink in floor plan. Columns are spaced 15 ft o.c. The notch effect found on the north and south walls lies outside the perimeter of the tube. Built-up columns of plate to make wide-flange configurations, as well as plate box columns, were the rule for the lower two-thirds of the tower. The corner box columns were 30-in. square with 5-in. thick plate walls and weighed 1,700 pounds per lineal foot. The average column in the tube weighed between 850 and 900 pounds per lineal foot.

Column webs were designed to eliminate doubler plates which might be required due to column web shear, and to minimize the number of web stiffeners required for column web crippling, web buckling and flange bending stress. To this end, high-strength steel was used in many webs. Frame girders, although analyzed as fully continuous, were conceived as shop-welded to the columns with splices at mid-span to reduce the amount of field welding required. The bending stresses at girder mid-length were reviewed, and where none existed only a shear connection was required at the girder-to-girder connection. This encouraged the use of conventional construction trees for ease and economy of erection.

Floor System Designed for Flexibility

To determine the most economical floor system which would satisfy the owner's required flexibility, four floor framing schemes were studied:

- *Base Scheme:* 3-in. composite deck on long-span composite floor beams spaced at 15 ft o.c., carried by composite girders. Mechanical supply ducts are below the structure.
- *Alternate "A":* 3-in. composite deck on long-span composite girders supporting short span composite beams at 15 ft o.c. The main mechanical supply ducts pass through the structure.
- *Alternate "B":* 2-in. composite deck on long-span composite girders supporting short-span composite beams at 10 ft o.c. The main mechanical supply ducts pass through the structure.
- *Alternate "C":* 3-in. composite deck on short-span, articulated composite beams at 15 ft o.c., supported by stub girders. The main mechanical supply ducts pass through the structure.

Careful review of cost, anticipated construction time and occupant flexibility resulted in selection of the Base Scheme for the tower floor system. The 45-ft clear spans found in the tower provide unusual flexibility of space utilization for an office tower of this scope. All floors were designed for 100 psf, subject to the usual live load reductions. A 50-50 blend of 3-in. cellular deck was used for electrical and communications systems. All systems utilized a 3¼-in. lightweight concrete slab over the deck. Two-in. non-cellular deck with 3¼-in. lightweight concrete was used for the office space in the atrium section.

Differential Column Shortening

Columns in the lateral frames are subject to varying axial stress levels, but typically they are smaller than the freestanding columns sized for gravity loads only. To compensate for the varying shortening effects, an over-length criteria was developed for each group of columns. These were presented in tabular form in both the frame and gravity column schedules. Because the column lengths must be adjusted to accommodate the axial shortening, it can be difficult for the erector to know if the elevations he establishes upon erecting each tier are within accepted erection tolerances. To assist him, a table was developed which groups the columns into 10 categories having approximately the same total dead load axial stress. Certain loading assumptions were made in the development of the table:

- Dead load of structure erected
- Slabs poured to six floors below floor surveyed
- Exterior cladding erected up to ten floors below floor surveyed
- Additional dead load of 10 psf for material stockpiling, etc., up to 12 floors below floor surveyed

With this assumed distribution of loading, the anticipated elevation at time of erection was calculated for each column category at the top of each tier of the structure.

Foundations

Both caissons and driven piles were studied for the tower. Initial pricing indicated little difference between the two. Because of a successful construction history in Cleveland, caissons anchored in the shale bedrock 200 ft below grade were selected. Because its primary layers are unstable, penetration into the bedrock a minimum of 20 ft was necessary. The 76 caissons in the system varied in diameter from 42 to 90 in., some containing as much as 400 yards of concrete.

The lateral load from the tower is transmitted to the foundations through a series of tie beams designed to mobilize all of the caissons within the main tower footprint. The load, carried by the caissons in bending and shear, is transmitted into the overburden, with the result that the majority of caissons were designed for combined axial and horizontal loads. A spread footing system was selected for the atrium building because of its shorter height and the resulting cost savings. The maximum allowable soil bearing pressure was limited to assure a maximum settlement differential between the two foundation systems of one-half inch.

The Curtainwall

The tower facade is comprised of polished Sunset Red granite column covers and Sequoia granite horizontal spandrel panels. The two-story column covers are supported by steel brackets welded to the columns, and the spandrels are attached to the covers with steel weld plates. The 1¼-in. thick panels are backed with 1½-in. of insulation and a 4½-in. precast concrete section. The granite treatment was continued into the glass-enclosed atrium.

For energy conservation, tower windows facing north are clear, windows facing south are tinted to allow only 40% light and heat transmission, and windows on the east and west walls were tinted 50%. In the atrium roof, tinting will allow just 20% heat and light transmission. All window tinting is a shade of bronze to accent the granite facade.

Erection of the granite panels for the first eight floors was done with a ground crane. Above this level, tower cranes hoisted and set during the night shift, and facade detailing was done during the day.

Steel Erection

Steel erection began with a crawler crane setting the first floor of the atrium building. This permitted early access to the basement level for mechanical work. The first four floors of the tower were set next, allowing for erection of tower cranes. The ground crane then completed atrium erection from the tower out, and tower cranes erected tower steelwork from the fifth floor up.

Two special design Kodiak tower cranes were used to set the tower, one in each bank of elevator shafts. The cranes, each weighing 370,000 lbs., had 140 ft of tower and 140 ft of boom. A moving counterweight counteracted the thrust of the boom. The cranes were designed with 8-ft square towers, instead of the normal 9 ft-6 in., to fit inside the elevator shafts, eliminating the problem of "leave-out" steel. Jacking the towers was done in 54-ft lifts using hydraulic jacks, and was completed in just two hours. Floor beams around each elevator shaft were made heavier every four floors to support the tower cranes.

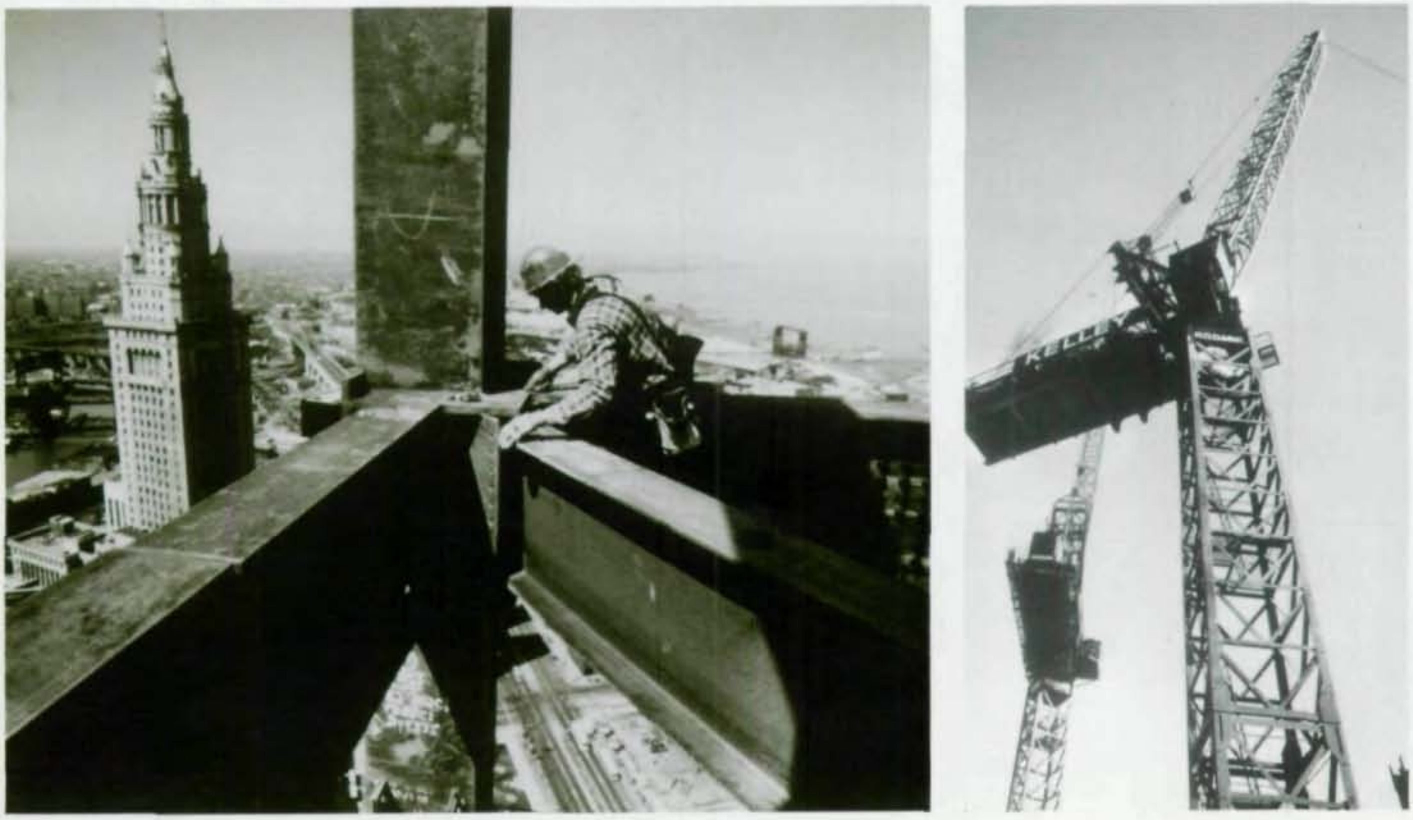
Pallets 16 ft wide and 36 ft long were used to raise entire floor areas, instead of one beam or girder at a time. The 20-ton lifts were made at a lift speed of 300 fpm. Columns, some weighing as much as 35 tons, were raised as individual pieces. Steel erection proceeded at the rate of one floor per week.

Summary

Twenty thousand tons of structural steel went into the Sohio tower and another 2,000 tons into the atrium, totalling just over 13,000 pieces. Forty-five percent of the tower weight is in the columns that formed the tube. The steel was predominantly A36 and A572 Gr.50, but a modified A588, 50-yield steel was used for plate thicknesses 4 in. and greater. All plates 3 in. and greater in thickness were tested ultrasonically on a 9-in. grid at the producing mill.

Sohio plans to begin the move into its new facilities in the second quarter of 1985, with final completion scheduled for the third quarter, a little more than two years after the start of steel erection. Eighty five percent of the building space will be occupied by Sohio, with the remainder available for leasing. ☐

High on 38th floor, worker erects steel frame. Historic Terminal Tower is in background. Kodiak cranes (r.) were designed especially for project. Four-story crane base fits in elevator shaft.



Aerial of Public Square area of downtown. Last steel erected June 22, 1984, with early occupancy slated for Spring, 1985.

Architect
Hellmuth, Obata & Kassabaum, Inc.
St. Louis, Missouri

Structural Engineer
KKBNA, Inc.
Wheat Ridge, Colorado

General Contractor (joint venture)
Gilbane Building Company
Cleveland, Ohio
and
Polytech Inc.
Cleveland, Ohio

Steel Fabricators
F.M. Weaver, Inc.
Lansdale, Pennsylvania
Williamsport Fabricators, Inc. (subcontractor)
Williamsport, Pennsylvania
P.B.I. Industries, Inc. (subcontractor)
Rochester, Pennsylvania

Steel Erector
Kelley Steel Erectors, Inc.
Bedford, Ohio

Development Manager
Urban Investment and Development Co.
Chicago, Illinois

Owner
Standard Oil Company of Ohio
Cleveland, Ohio

Low-Rise Office Buildings in Fast-Rising Growth

One of the fastest-moving trends in non-residential construction today is the dramatic increase in steel-framed, low-rise office buildings. Participating strongly in the current, annual non-residential private building market of $80 billion, they are now a common sight in office parks, shopping malls and other suburban areas throughout the U.S.

The trend commenced in the mid-70's with the start of the exodus from large cities. It has accelerated for several reasons:

- Unlike urban skyscrapers, the low-rise buildings are adaptable to both corporate and multi-tenant occupancy;
- They can be sited close to major cities, but at far more reasonable land and construction costs;
- Ample space permits as much as 125,000 sq ft per office floor, plus such employee amenities as fitness centers, jogging tracks and even tennis courts.

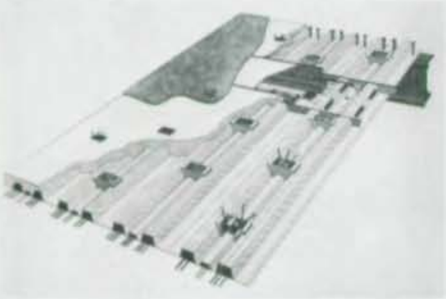
With 60% of its volume in low-rise office buildings, the Paric Corp., St. Louis, is a general contractor who specializes in design/build projects. Rick Jordan, Paric's president, says, "Our firm was founded in 1979, and we have already erected 14 of these structures, most in the two- to five-floor category, for a total of three million sq ft. With developers as clients, value and lower cost are our key objectives, which means that each of these 14 buildings had to be steel-framed. You cannot beat steel for price and design flexibility and, since structural steel goes up faster than other systems, our clients get their rental payback that much earlier."

A developer, Foster International Development, has plans to build 11 low-rise office buildings, varying from three to six stories, on a 100-acre site in a Pittsburgh office park. Seven are already up, another building is under construction, for a total of 750,000 sq ft of rentable space. William A. Robinette, president, comments, "The economics of this market dictated that all of these buildings be steel-framed, since it was our desire to keep the bays at maximum widths. Having more space between columns helped keep our floor layout flexible, and made the renting job easier."

Essentially, a low-rise office building can range up to 10 stories in height, and usually provides employee parking either adjoining or underground. Steel-framed con-

Circular steel-framing on Citizens Federal, Port Huron, Mich. (top), designed by Architect Richard Cogley, was erected in 1½ weeks. Four buildings above show diversity of architecture possible with steel framing. Erected by Koll Const., Newport Beach, Cal. Clockwise from top, l.: Bundy Building, West L.A.; Republic Bank, Irvine, Cal.; Computer Sciences, El Segundo, Cal.; and research labs of Allergan Pharmaceuticals, Irvine, Cal.

struction is a tailored arrangement of beams and columns to fit the exact needs of a company or the varying needs of a developer who will rent to a number of tenants. Structural steel members carry the load-bearing function; non-bearing curtain walls permit the buildings to be enclosed rapidly, even during winter.



Strong Cellular Floor Trend

Coinciding with the growth of the low-rise structures is another strong construction trend, now made virtually mandatory by the explosion in electronic office machines, information processing and telecommunications systems. This is the burgeoning popularity of cellular steel flooring, through which is routed all of the necessary PLEC wiring (for Power, Lighting, Electronics and Communications). Placed to serve the ever-changing locations of electronic units, cellular flooring puts no limitations on where an office can plug in calculators, typewriters, lighting, microfilm readers, computers, etc.

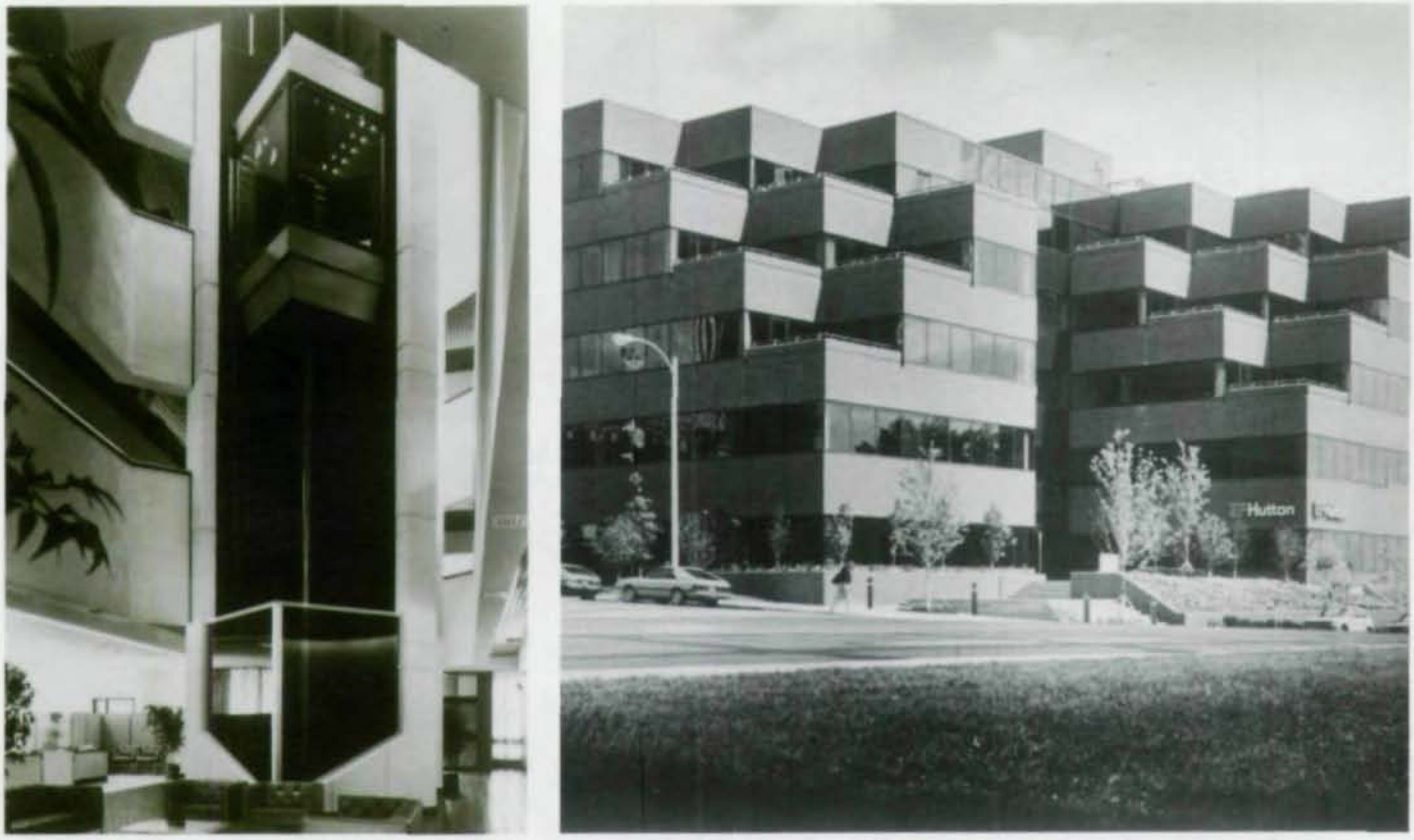
Charles H. Norris, Jr., marketing manager for structural/electrical systems at H.H. Robertson Co., Pittsburgh, remarks, "We made and installed the cellular steel flooring system in the five-story corporate headquarters of Western Life Insurance in Woodbury, Minn. The company executives wanted an electrical distribution and delivery system with enough flexibility to permit rearranging workstations in almost any configuration, without removing ceiling tile or drilling through the floor. What they got is a 345,000-sq ft structural flooring system that feeds all electrical, telephone and computer lines. The system is linked to approximately 7,000 preset outlet boxes located at regular intervals within the floor. When a service change is required, the most convenient outlet is located, the carpet is slit and the outlet quickly exposed and activated."

Intelligent Building—the Future is Steel

Carrying the organized electrification concept to its ultimate, the Intelligent Building appears to be the future of the low-rise office structure. Here, all systems will be self-regulating, orchestrated by a computer and linked by fiber optics or wires. Throughout the Intelligent Building, control units will diagnose their particular environments and then regulate them in the most energy-efficient manner. What the system will control are elevators, heating, ventilation, air conditioning, lighting, energy usage, telephones, fire alarms, security, telecommunications and electronic office services—all providing reduced life-cycle costs for the tenants and the building owner.

But it all begins with a piece of land and a steel frame that supports all elements of the building. Increasingly, the framing material is an economical, high-strength A572-Gr.50 steel. With a minimum yield strength of 50,000 psi, it permits shallow-depth beams to reduce floor-to-floor height and provide long, column-free spans. And, as another cost reducer, these structures can be provided by smaller, local fabricators and erectors.

Energy-efficient Citizens First Bank, Glen Rock, N.J. headquarters. Shading and sun control accomplished with steel-framed cantilevers at 3rd and 4th levels. Designed by Tellefsen & Mader Associates.



Dramatic atrium (l.) of Woonsocket Savings, designed with steel frame, has size reduced at each floor to increase usable space. Park Place, (r.), Clayton, Mo., built by Paric Corp., features steel-framed balconies overlooking park.

Ideas for High Efficiency in Low-rise, Steel-framed Structures

1. Not yet a trend, but a likely one, is the cost-saving sharing of equipment in one multi-tenant building or in a central location that services satellite buildings in an office park. Instead of having each tenant purchase and staff its own word processors, data processing equipment, etc., access to technology may be included in the price tenants pay per square foot.

2. Steel framing permits virtually any type of building facing material. Nashville House, near Nashville, Tenn., is faced with concrete aggregate panels. The buildings use these panels as sunshielding overhangs, not only to keep the sun's direct rays from each floor, but also to conceal mechanical ducts that carry air conditioning and electrical-service conduit.

3. As mentioned earlier, electrified flooring facilitates change. However, due to the multiplication of high-tech devices, it is a good idea, before initial office construction, to advise the builder of the anticipated placement of each, or most of them: audiovisual equipment, calculators, call directors, closed circuit TV, computers, copiers, CRT terminals, electronic mail stations, microfilm, microprocessors, paging systems, printers, shredders, task lighting, teleconferencing, telephones, telex equipment, typewriters and word processors.

4. The Woonsocket Institution for Savings Building, Woonsocket, R.I., used the fast-track construction approach. For example, the structural steel order was placed even before the drawings were completed. The foundations, grade beams and stair/elevator walls were placed and ready for the fabricated structural steel when it was delivered. The combined savings of steel framing and fast-track construction cut two months off the building schedule.

5. One of the newest low-rise office buildings is Aetna Life and Casualty's 1.5-million sq ft structure in Middletown, Conn. For amenities for its 6,000 employees, the three-to-six-level building houses three cafeterias, a company store and indoor fitness facility with running track and exercise room. Outdoor recreational facilities planned for the future include softball fields, a jogging trail with exercise stations, a soccer field and volleyball courts.

6. Lest anyone think that the Intelligent Building, described earlier, is strictly for the future, it is actually the state of the art today. Many of its self-regulating mechanisms are feasible with current technology. Elevator systems are available to heighten efficiency during peak use periods such as morning arrivals, lunch hour and leaving time. Passive electric sensors can now detect changes in the occupancy of each office, turn lights on and off automatically. Similarly, based on occupancy and use, heating, cooling and ventilation can be automatically adjusted today for maximum efficiency and cost savings.

That's the Intelligent Building—complete with the flexibility of steel framing.☐

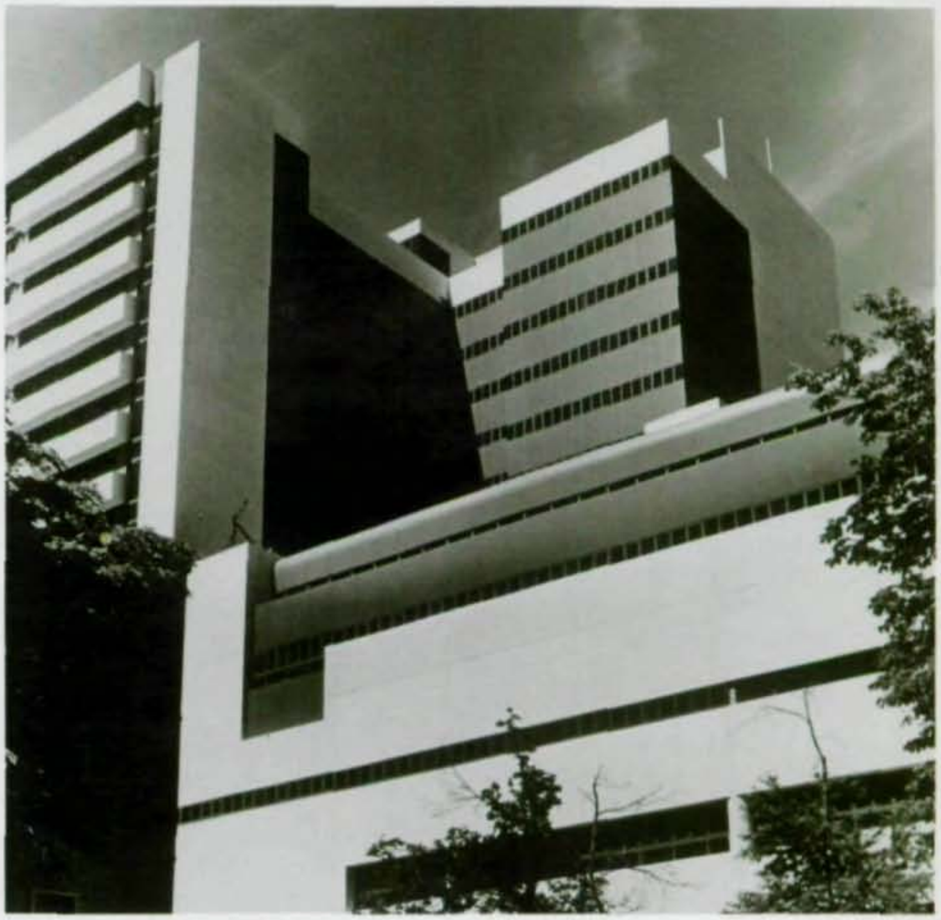
We are indebted to the Steel Products News Bureau for information and photographs.

Structural Steel Framing Offers Maximum Flexibility for Hospital Design

by James R. Kunkle and Lee M. Stottele

James R. Kunkle is senior associate and structural engineer for The Buffalo General Hospital Project, Buffalo, New York.

Lee M. Stottele is manager of proposals and presentations at Cannon, Grand Island, New York.



Completed Buffalo General Hospital, Buffalo, N.Y. Steel-framing kept costs down, provided early occupancy.

With the experience of well over 300 healthcare projects, the Cannon Corporation has gained a heightened awareness of the issues confronting the planning, design and development of hospital projects. The ever-rising cost of construction coupled with increasing demands of regulatory agencies make it imperative to design healthcare/hospital facilities for optimal use—now and in the future—and to use construction materials, such as structural steel, which lend themselves to greater flexibility.

General Concerns In Hospital Planning

Several major concerns are central to the successful development of hospital facilities. These concerns are based on the functional requirements of the facility as well as its general goal to meet the medical needs of the community it serves. Functional/operative requirements and potential future expansion present unique design challenges to architect/engineer teams. The determination of an appropriate structural system must accommodate several key design requirements:

- Use of materials which are structurally flexible and easily adapted for future expansion
- Conformance to existing floor-to-floor heights of adjoining structures to circumvent the use of steps or ramps in major circulation corridors.
- Allowance of greater bay size without space restrictions imposed by columns
- Incorporation/meeting of specific functional design requirements such as maximum allowable window fenestration on patient floors
- Continuance, with little disruption, of day-to-day hospital activities during construction.

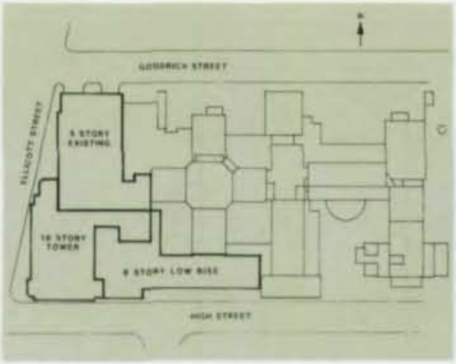
Material Adaptability/Flexibility

Structural steel provides the adaptability and flexibility required to meet various constraints inherent in most hospital projects. In many cases, site development is limited by the size of the site. This limitation requires that hospital expansions/additions must be shoe-horned into and around existing buildings. Connections to structural frames of existing buildings often involve awkward angles and large cantilevered floor areas so new footings can clear existing footings with minimal shoring or underpinning. More often than not, transfer girders or trusses are required to span existing wings or departments to allow them to remain functional as construction proceeds. Statistics show the expected life for diagnostic and treatment departments is 15 to 20 years before they become technologically obsolete. For this reason, existing steel structures are more flexible to changes in floor loadings or equipment loads when major departments are reorganized or updated.

Floor-to-Floor Heights

Additions to existing hospitals always require matching of floor-to-floor heights to circumvent the need for steps or ramps in major circulation corridors. In addition, existing hospital structures have often been constructed with relatively low floor-to-floor heights because of the general lack of in-floor air conditioning duct work. Since new additions are typically air conditioned, the existing floor-to-floor heights present problems to the design team. This requires close coordination between structural, mechanical and architectural disciplines.

Fig. 1. Original hospital rendering.



Site plan shows new construction.

Fig. 2. Site prior to construction. Building in front was demolished; 5-story existing structure on left.

Existing steel-framed buildings permit ease of retrofitting and savings in construction cost over concrete slab buildings. The ability to cut and adapt structural steel to required floor-to-floor heights provides added flexibility and ease of construction.

Bay Size

Various functional departments within each hospital require bay sizes which best suit their operations. Bay sizes for each department can vary from floor-to-floor and within floors, and can have varied load requirements ranging from 40 to 360 psf. Hospital equipment adds to structural loading concerns. Special equipment may be very concentrated and/or be highly sensitive to vibrations.

Given the various functional requirements of each department, it is critical that structural and mechanical engineers and hospital architect/planners coordinate the design efforts early on in the process. The result can be a framing system which best suits hospitals as well as structural requirements.

Future Horizontal/Vertical Expansion

Many hospitals are built with limited monies and are originally planned to meet healthcare needs of the surrounding community. To meet the need for increased medical services, architect/engineer teams must provide for potential future expansion. Typically, hospitals must either expand through totally new construction or renovate by adding on to existing facilities.

Structural system plans for hospitals do not lend themselves to uniform structural grids. Central elevator/mechanical cores generally do not exist because of the required separation of critical care functions and public/visiting activities. The building perimeter is generally dedicated to patient rooms which require generous window fenestration. As a result, bracing systems needed to resist lateral loads cannot be located in convenient places. Steel framing lends itself to the unique bracing requirements of each project.

Structural steel framing provides other benefits related to future expansion. In many cases where existing hospitals are concrete construction and planned for future expansion, the high-strength, lightweight characteristics of steel frames and composite lightweight concrete floor systems make it possible to add one and sometimes two additional floors over and above initial expansion plans. Its capacity to accept new load requirements for hospital functions and equipment aids structural engineers in bringing the building into compliance with existing codes such as those for earthquakes, wind loadings, and/or snowdrift loads.

Buffalo General Hospital—a Case In Point

Buffalo General Hospital exhibits many of the same characteristics which confront the expansion of other hospitals. In downtown Buffalo, Buffalo General is situated on a tight urban site with little room for lateral expansion (see Fig. 1). The 626,000-gross-sq-ft, L-shaped addition being built adjacent to the hospital's eight-story main building is contained in the 16-story tower. The tower includes medical/surgical units (patient rooms) and support offices, labor and delivery/obstetrics, surgical suite, medical intensive care unit, critical care unit, cardiopulmonary functions, clinical laboratories, diagnostic radiology, admitting/discharge, dental clinic, lobby, radiation therapy and general clinics.

When planning for the expansion began, structural engineers were confronted with several challenges. The site had limited buildable area within the property owned by the hospital. Also, construction of the new 16-story tower required the existing main entrance lobby and admitting department be demolished. The new tower had to be constructed within a tight property line along two major downtown streets and directly adjacent to two existing buildings (see Fig. 2). A major part of the 16-story tower had to be perched over an existing five-story steel moment-framed structure which had originally been designed to extend to a maximum of 14 floors. The structural design had to conform to the limited floor-to-floor heights of the adjoining buildings as well as provide use of lightweight structural steel framing to minimize new loads on existing footings. In addition, all construction activities had to be planned to allow continuance of all hospital functions with little disruption or loss of patient beds.

A primary planning and operations requirement was to locate all patient rooms in the tower central to the major circulation corridors and diagnostic/treatment departments. To accommodate the required number of patient rooms it was essential to evaluate the possibility of additional floors.

Early investigations of lateral loads for the tower design indicated the existing five-story building did not meet drift limitations established for this project. Further studies indicated that existing footings had limited capacity for supporting the proposed additional axial loads due to wind and gravity. To maximize the number of additional floors which could be provided over and above original plans (two more than original design), the wind axial effects had to be minimized. This led to use of perimeter rigid frames around the tower, supplemented with braced frames at lower levels. Braces had to be placed in locations where existing footings could be underpinned if required. Furthermore, the construction sequence required the part of the tower to be built over the existing building proceed concurrently with

Fig. 3. Demolition of main entrance and preparation of 5-story existing structure for steel tower.

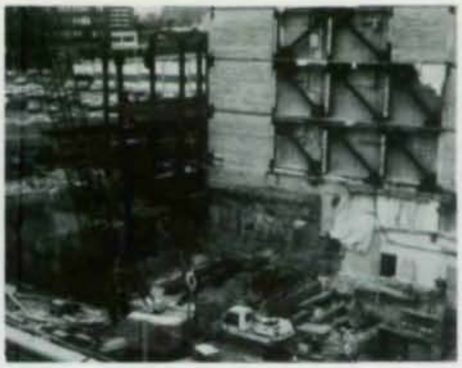


Fig. 4. Foundation work begins for new tower—with minimal disturbance to patients.

Fig. 5. High-strength steel framing extends over existing structure.

the foundation work of the new adjoining tower element (see Figs. 3 & 4). As a result, the existing building bracing system had to be designed to carry wind loads independent of that part, as well as serve the new tower as a whole.

To permit maximum window fenestration as well as flexibility for planning and circulation in interior spaces, perimeter walls had to remain free of braces. Acceptable locations for diagonal braces at interior walls were also limited. This meant little or no bracing above the sixth or seventh floors. Collectively, these concerns and/or restrictions led to a satisfactory solution; namely, the use of high-strength steel framing with 3-in. composite metal deck floor topped with 4¼-in. lightweight concrete to achieve a 3-hr. fire rating (Fig. 5).

Structural Solutions

Structural concerns centered around constructing over and adjacent to the existing five-story building. The desire to add two more stories than indicated in the original plans required extensive analysis. Generally, every element in the existing building became highly sensitive to the additional loads. Specifically, the existing footings had limited capacity for additional loads. New floors were shored during construction to reduce the ponding-weight effect of concrete which normally occurs if

Fig. 6. Detail of wind bracing

beams are free to deflect. Exterior skin loads were minimized as much as possible.

Several alternate bracing systems were considered. It became evident that only perimeter bracing or moment frames could accommodate the loads. Perimeter column footings had higher wind axial capacities for the following reasons: a metal panel skin was used primarily in lieu of initially planned brick; the existing brick facade could be removed if required to save further weight; and the existing building had two-story foundation walls which were able to distribute new column loads. These walls were accessible from the outside if underpinning was required. The use of an in-house computer to model the lateral load system played a key role in the feasibility of the project. Two buildings had to be analyzed simultaneously: the tower as a whole, and half the tower which was to be built over the existing building.

The five-story existing building required additional stiffness because of the increased height. Diagonal braces were added in the north and south faces. Later, temporary braces were used in the east-west direction on the first five floors to provide load capacity until the full tower was completed. Each frame had different stiffness characteristics. Increasing the stiffness would overstress the existing footings.

Looking at the tower as a whole, the two halves of the tower plan are offset from each other by 35 ft, which reduced the efficiency of the moment frames on the east and west faces (see typical framing plan). To enhance the stiffness of these frames, columns were added at midspan between each major grid line, creating perimeter column spacings of 25 ft-6 in. to 13 ft. Similarly, on the north and south faces, W18 beam shapes were used for columns to provide greater stiffness (see Fig. 6). That resulted in a savings of approximately one psf of steel over previous bracing schemes and simplified the interior framing. Standard framed connections were used for all interior beam and girder connections. Finally, a computer model linking all the frames in each direction was used to determine torsional effects for the design and to locate any hotspots or overstressed areas within the existing building. Several iterations with this model were required before all problems within the existing structure could be economically resolved. The final solution required bracing at two lines at the south end (existing elevator core) and bracing at the north face. The foundation wall along the north face was underpinned between column spread footings to carry additional wind axial loads that could not otherwise be accommodated.

The floor framing comprised conventional composite design beams and girders with 3-in. metal decking and 4¼-in. lightweight concrete topping. Cost studies indicated that shoring during construction was a tradeoff with the cost of additional concrete, so all floors were shored to reduce effects of differential settlement between the two tower halves (see Fig. 7). The exterior skin was a blend of three materials: precast concrete, metal panels and Dryvit. Use of these materials was carefully coordinated to limit the use of precast concrete, so as to minimize exterior skin loadings on existing footings.

Construction Phase

Fast-track scheduling required that the steel frame be erected early over the existing building, using existing foundations. To accomplish this, structural steel and foundation drawings were completed six months prior to architectural drawings.

The construction management process was very complex. And the congestion of the inner-city site presented other logistic problems. For instance, since no space was available for material storage, steel deliveries had to be timed so they could be hoisted into place directly from the trucks. The construction manager assured that both steel deliveries and major transportation routes, as well as primary hospital functions, were not seriously affected.

Concluding Notes

Although the project involved complex floor plans requiring additions over and adjacent to existing buildings on a tight urban site, the coordinated construction scheduling, cooperative working relationship with the hospital's board of trustees and use of structural steel permitted early occupancy—and addition of two floors over original plans. The flexibility of the steel aided in reinforcing the existing building for new wind loads. Using a 66-ft transfer truss permitted construction against the existing building without disruption to hospital functions. In addition, the extensive use of high-strength steel and composite design floor systems reduced the overall steel tonnage, averaging less than 11 psf. As a result, construction material costs were maintained well below the construction manager's initial budget allotment, and early occupancy helped to realize substantial operational cost savings. The new additions were constructed as designed. ☐

Fig. 7. Steel frame of new tower nears completion.

Architect/Engineer
Cannon
Grand Island, New York

Construction Manager
Cowper/Turner (a joint venture)
Buffalo, New York

Steel Fabricator
Sen-Wel Industries, Inc.
Buffalo, New York

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