DESIGN CALCULATION COVER SHEET

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PART 1: DESIGN CALCULATION IDENTIFICATION

A) Design Calculation Number DC-5144	**B) Volume Number** I
C) Revision A **D) PIS Number** X2200 T2200, N3011	**E) QA Level** ☐ Non-Q ☒ 1 ☐ 1M
F) ASME Code Classification ☒ NA	**G) Certification Required** ☐ Yes ☒ No
H) Lead Discipline MECH/CIVIL	**I) Incorporation Code** F

J) Title TURBINE GENERATED MISSILE PROTECTION OF REACTOR/AUX. BUILDINGS AND RHR COMPLEX

K) Design Change Documents Incorporated (Number and Revision)

NONE

L) Design Calculations Superseded (Number and Revision)

DC-5144 Vol I, Rev. 0 & 2.3 Rev. 1

M) Revision Summary

- Incorporate the impact of EDP-26726. (Removal of 7th and 8th stage rotating & stationary blading and installation of pressure plates for each of three LP3 turbines) The new configuration of the main turbine will impact the design basis for turbine missile protection. DC-5144 Rev. A is prepared to verify the adequacy of missile barriers.

PART 2: PREPARATION, REVIEW, AND APPROVAL

A) Prepared By H. SAHINER
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Form NEP-CM1-20 ATT 1 P1/1 070693 DTC: TDPCAS DSN: DC-5144 File: 1801
Not decommissioning related Date: ______ Rev: A Recipient: VOL I

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6/25/94

DC-5144 Vol. I Rev. A
TURBINE MISSILE PROTECTION

TABLE OF CONTENTS

A

PURPOSE OF CALCULATION

In the unlikely event of a failure of the EF2 Turbine-Generator rotor, missiles emanating from the machine could penetrate its outer casing and take trajectories toward safety related targets. The purpose of this calculation is to review the present Turbine configuration with regard to the safety related equipment which is specified as being protected from turbine missiles as identified on UFSAR Figure 10.2-4, and evaluate if the protection provided by appropriate placement and orientation of the turbine units combined with missile barriers satisfies NRC guidelines. (Ref. ⑨)

Revision A of this calculation re-evaluates the adequacy of the missile barriers for the new turbine configuration. The removal of 8th stage blades will change the bursting speed of the last stage wheel. As a result, the design basis turbine missile will have a higher energy. The missile barriers are re-verified for adequacy. This rev. A also includes RHR Complex missile barrier evaluation.

A

CONCLUSION

Calculations performed demonstrate that missile protection by orientation, combined with the existing concrete missile barriers provides adequate protection for both high and low trajectory missiles. A

This calculation does not impact the existing documentation for the acceptance of the spent fuel pool by probability analysis against a turbine missile strike.

Rev.A of DC-5144 Vol.I has re-verified the adequacy of the existing turbine missile barriers due to the revised increased missile energies. The barriers are adequate to stop high and low trajectory turbine missiles. A

This page is Superseded. It is left in this revision A for historical information only.
8/23/94
Rev. A

SUPERSEDED

ASSUMPTIONS: Rev. 0 -

The most likely source of the turbine missile is given in UFSAR 10.2.3. The ERD report 70E12 (TDPCAS -70E12) which was prepared as a response to question 9.1 concerning missiles emanating from the turbine generator to AEC (Atomic Energy Commission) is the basis to our calculation. ERD Report analizes the most likely source, the energy values, its speed, possible trajectories (1 thru 4) which have been used in this calculation. These 4 trajectories are shown in UFSAR Figures 10.2.3 & 10.2.4. ①

The missile shape, area, weight, its velocity before impact, are the values used in the existing calc. 70E12. ②

The formulas used for the calculation of the penetration depth is also the same as used in (70E12) and (TDPCAS 2.3 Rev. 1 - Turbine Generated Missile Protection of RHR Complex) ⑥

In the body of the calcs there is a description of the...

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Turbine Missile Protection

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ASSUMPTIONS: (Rev. A)

After the Dec. 1993 turbine incident, the low pressure turbine 7th & 8th stage blades will be removed. However, the disks will remain in place including the blade roots. As a result of this configuration, the original turbine missile generation scenario will be revised as follows: In the new configuration, the design basis turbine missile is the same, which is the 120° segment of 8 stage disk, 8650 lbs. However, it is assumed to burst at 3280 rpm vs. 3000 rpm as originally assumed. The new turbine missile values are based on Appendix #5, English Electric letter.

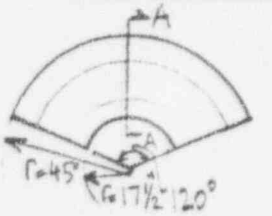
The missile trajectories in UFSAR Figures 10.2-3 & 10.2-4 ① have not changed. The safety related equipment to be protected remain the same. The missile barriers are to be re-verified to ensure their adequacy for design basis missiles with higher energy.

In this Rev. A calculation, the RHR complex is also included. Previously, Design Calculation 2.3 qualified the missile barriers for the RHR Complex.

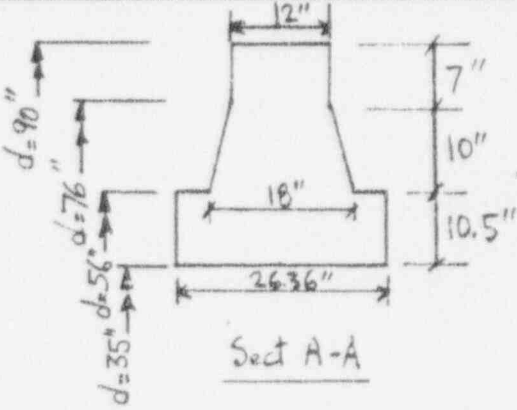
In the missile penetration calculations the originally used Modified Petry Formula is used. (Ref. ⑭)

In penetration depth calculations per the above formula, the coefficient K is selected for concrete with compressive strength of 5700 psi, to reflect the actual strength of concrete at Fermi 2 structures which is 5900psi (Actual f'_c, per Design calculations SF-0005 & SE-01-EF, Structural Design Criteria for Reac/Aux Bldgs)

The design basis missile characteristics. Ref. Pg. A19



Disc Segment
(Elevation)
Last stage



Sect A-A

Weight of Disc Segment: 8650 lbs.
Max. projected area: 11.65 ft^2
Min. projected area: 5.12 ft^2
Average projected area: $(11.65+5.12)/2 = 8.39 ft^2$

Ref. ② Also see Appendix #6 for the derivation of these values.

BODY OF CALCULATION

Energy of one fragment (ft lb x 10^6), Design basis missile (8650 lbs):

After Penetration of outer casing: $\frac{3000\,rpm}{34.2}$ $\frac{3280\,rpm}{42.5}$ [Ref 1 Pg A16]

3000rpm was the original missile generation speed. 3280rpm is the new missile generation speed for the modified turbine with the blades removed from last stage discs.

For low trajectory (Trajectory #1) the increase ratio: $\frac{42.5}{34.2} = 1.24$

For high trajectories (#2, #3 & #4) the air drag will reduce the impact energy as it hits the missile barrier. Air drag calculations are performed here, per Ref. ① GE Topical Report TR67SL211 Pg. 38-40. Original air drag calculations had used the same method.

Air drag impact for high trajectories:

$$\frac{T_F}{T_i} = \frac{1}{1 + 2\frac{T_i}{W \cdot L}}$$

T_F & T_i = Final and Initial Kinetic energies of the missile

W = 8650 lbs, missile weight

$L = \frac{2W}{w \cdot A \cdot C_D}$ [ft] where $w = 0.074$ lb/ft³ air density

A = 8.39 ft² Average Projected Area (App. #6)

C_D = 1.0 Drag Coefficient

Air Drag Calculations:

$$L = \frac{2 \times 8650}{0.074 \times 8.39 \times 10} = 27865 \text{ ft}$$

$$\frac{T_F}{T_i} = \frac{1}{1 + 2 \times \frac{42.5 \times 10^6}{8650 \times 27865}} = \frac{1}{1.35}$$

$$T_F = \frac{T_i}{1.35} = \frac{42.5 \times 10^6}{1.35} \cong 31.5 \times 10^6 \text{ ftlbs.}$$

For high trajectories, impact energy on missile barriers will be 31.5×10^6 ftlbs. For low trajectory calc.s, the impact energy is 42.5×10^6 ftbs., as no air drag is considered.

Missile Velocities:

Missile velocity after penetration through the turbine casing: (v_i)

$$\text{Kinetic Energy: } 42.5 \times 10^6 \text{ ftlbs} = \frac{1}{2} \frac{W}{g} \times v_i^2 = \frac{1}{2} \times \frac{8650}{32.2} \times v_i^2$$

$$v_i = \left(\frac{42.5 \times 10^6 \times 2 \times 32.2}{8650} \right)^{1/2} = 562.5 \text{ ft/sec.} = 383 \text{ mph} \qquad (1\text{mph} = 1.467 \text{ ft/sec})$$

For high trajectory case, after air drag energy loss, the missile impact velocity (v_F)

$$\text{Kinetic Energy} = 31.5 \times 10^6 \text{ ftlbs} = \frac{1}{2} \times \frac{8650}{32.2} \times v_F^2$$

$$v_F = \left(\frac{31.5 \times 10^6 \times 2 \times 32.2}{8650} \right)^{1/2} = 484 \text{ ft/sec} = 330 \text{ mph}$$

SUMMARY OF TURBINE MISSILE DATA

Fragment Angle, Deg.	120
Fragment Weight, lbs.	8650
Min. Projected Area, ft.^{2}	5.12
Max. Projected Area, ft^2	11.65
Failure Speed, rpm	3280
Initial Velocity, mph (Outside turbine casing)	383
Energies, ft.lb × 10^6	
Initial, Translational	72.2
Initial, Rotational	39.2
Outside turbine casing Translational	42.5
After Air drag, (Vertical Trajectory) Translational	31.5

DEFINITION OF TERMS AND UNITS - FORMULAS

The definition of terms and units are explained in the section of the calculations where they are used. However, here the main penetration depth formula "Modified Petry Formula" is described. This formula is detailed in Appendix #4, Page A11 & Appendix #2, Page A7.

$$D = K.A.\log_{10}\left(1+\frac{V^2}{215000}\right)$$ Petry Formula

D = Penetration depth in an infinitely thick slab [ft]
K = Material Property constant - See App #2, Pg. A8
K = 0.00282 for 5700psi concrete, 1.4% reinforcement (Fermi 2 concrete)
A or A_p is the sectional pressure, [lb/ft²] and it is obtained by dividing the missile weight by the average of the minimum and maximum projected areas of the wheel.
V is the missile velocity [ft/sec]

$$A = \frac{8650}{8.39} \cong 1030 \text{ lb/ft}^2$$

$$D' = D\left(1+e^{-4(\alpha'-2)}\right)$$ Modified Petry Formula

D' = Penetration depth in a finite thickness slab [ft]

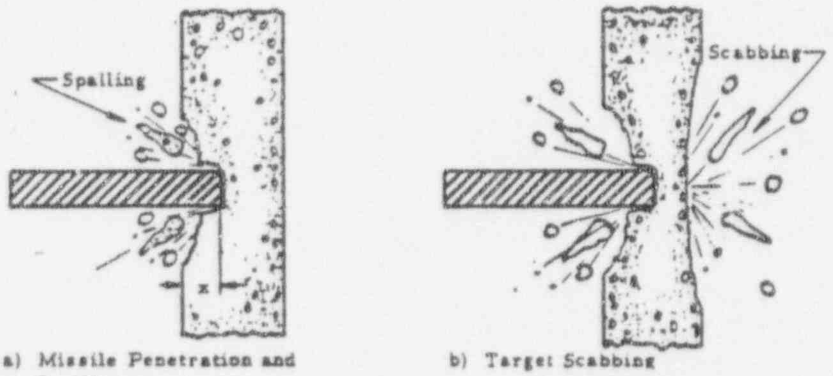
$$\alpha' = \frac{T}{D} = \frac{\text{slab thickness}}{\text{Penet. to an infinitely thick slab}}$$

Min. slab thickness to prevent perforation: T = 2D
Perforation: full penetration. The missile passes through the target with or without exit velocity.
Scabbing is the peeling off of the back face of target, opposite to the face of impact
Min. slab thickness to prevent scabbing: S = 2.2 D [Ref. 14, Pg. 186]

Definition of Terms: (Cont'd)

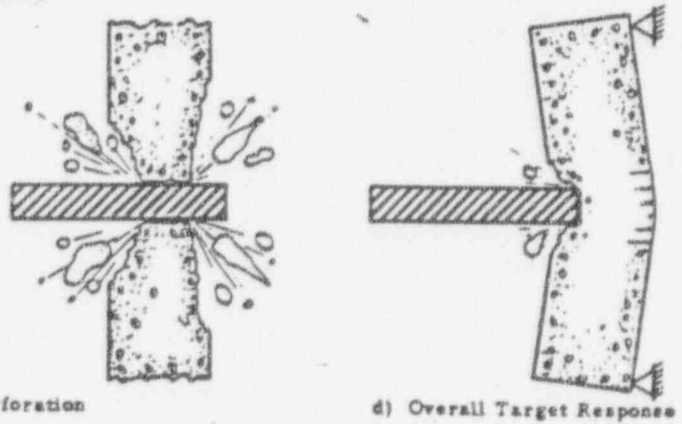
Spalling is the ejection of target material from the front face of the target (the face on which the missile impacts)

Penetration is the displacement of the missile into the target. It is a measure of the depth of the crater formed at the zone of impact.



a) Missile Penetration and Spalling

b) Target Scabbing



c) Perforation

d) Overall Target Response

Description of Terminology (Ref.# 14)

7/30/90

Trajectory #1 - This trajectory is the only low-trajectory turbine missile. The low-trajectory missiles are ejected from the turbine casing directly toward an essential system. They are more dangerous than the high trajectory missiles, which have almost vertical trajectories, because of their high energy and speed values. SRP 3.5.1.3 specifies in Acceptance criteria that the placement and orientation of the turbine generator and adherence to the Reg. Guide 1.115 will be considered acceptable. Exclusions of safety related structures, systems, or components from low trajectory turbine missile strike zones constitutes adequate protection against low trajectory turbine missiles. If safety related structures to be protected are within the low trajectory strike zones and are susceptible to potential missile damage, than missile barriers should provide sufficient missile protection.

At Fermi II, the largest (eighth stage) main low-pressure turbine wheel is considered as the source of the worst missile. The review of drawing 6A721-2017 - Turbine House Third Floor Plan El. 643'-6" - shows that the Control Room/Computer Room which is the only possible low-trajectory missile target, is located outside the strike zone.

The strike zone, as defined in Reg. Guide 1.115 Fig. 1, indicates an area bounded by lines inclined at 25 degrees to the turbine wheel planes and passing through the end wheels of the low-pressure stages. The nearest Control Room corner is at approximately 60 degrees and 106 feet from the missile source. Per NRC-SRP 3.5.1.3 - II.1, exclusions of safety-Related structures from low-trajectory turbine missile strike zones constitutes adequate protection against low trajectory turbine missiles. This is the preferred method of protection. Sufficient missile protection is already provided at Fermi 2 for low trajectory turbine missiles by favorable turbine-generator placement and orientation.

In this calculation, concrete missile barrier adequacy is verified even though it is only required for plants that have unfavorable turbine orientation, such that safety-related structures are within the missile stike zones, should have sufficient missile barriers.

In addition, conservatively neglect the protection provided by the two barriers - 12" thick sandwich wall (steel and concrete) and 2'-4" thick reinforced concrete wall (Ref. 6A721-2017) which would probably provide adequate protection by stopping the missile before it reaches the Control Room.

The combined thickness of control room immediate barrier walls is 4'-6", 2'-6" thick Turbine Bldg. walls and 2'-0" on the Auxiliary Building side-Control Room walls. (Ref. 6A721-2017)

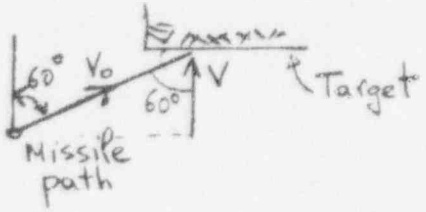
The missile characteristics are given on Page 10.

$D = K.A.\log_{10}\left(1+\frac{V^2}{215000}\right)$ Petry Formula

Initial Kinetic Energy = 42.5×10^6 ftlb.

$\frac{1}{2}mV_o^2 = E_k \rightarrow V_o = 383$ mph (Ref. Pg. 9)

The missile will hit the wall with a 30° angle. {due to the location of the wall vs. the missile source} Considering the component that will cause penetration:



$V = V_o . \cos 60°$

$V = 563 \times 0.5 \simeq 281.5$ ft/sec.

$D = 2.82\times10^{-3}\times1030\times\log_{10}\left(1+\overbrace{\frac{79242}{215000}}^{0.136}\right) = 0.4 \text{ ft} \cong 5 \text{ in}$

$D' = \left(1+e^{[-4(2.5/4-2)]}\right)D = 1.0\,D = 5 \text{ in}$

Perforation $\rightarrow 2D = 10$ in

To prevent scabbing, $T \geqslant C_1.A\times10^{-5}$ (Pg. A11) App. #4 (FIG.-1)

$140\times1030\times10^{-5} = 1.44 \text{ ft} \simeq 17 \text{ in}$

It must be noted that the above formula is more conservative for scabbing. Per Ref. #14, to prevent scabbing $T = 2.2D = 2.2\times5 = 11''$ is adequate

Increase the governing thickness (t_s) by 20% per ACI 349.(C7.2.1)

$17'' \times 1.2 = 20.5'' < 30'' \Rightarrow$ O.K.

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Punching shear and overall effects on the wall will be acceptable by Engineering judgement. The turbine wall and Control Room wall have a gap in between. The turbine wall, if hit by the missile, will not scab and not have secondary missiles to hit the control room wall so the control room will not be affected. The overall effects on the turbine wall will be neglected because of the separation between the walls and the large contact area of the missile. It must be noted that these missile formulas mainly address rigid and blunt/sharp nosed missiles such as pipes, rods. In our case, the shape of the missile is such that (12" × ~72") the load is more distributed (strip load) rather than a point load (concentrated). As a result a larger area of the wall/slab will be able to distribute the forces/stresses. In addition, the initial loads on the wall are small so the stresses caused by the missile impact will remain acceptable.

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High Trajectory Missiles:

These turbine missiles are characterized by their nearly vertical trajectories. Missiles that are ejected nearly vertical go thru the roof of the turbine building and then enter the Reactor Building thru the roof or strike the Auxiliary Building roof. Per NRC-SRP 3.5.1.3 – Section III.5, the risk from high trajectory turbine missiles is insignificant unless the vulnerable target area is on the order of 10^4 sqft. or more. The spent Fuel Pool missile protection was based on probability analysis. The probability of a turbine missile landing in the spent fuel pool is once in 10,000 years. The trajectory for this path is #3, which may also hit the Reactor Shield Plugs which are 6' thick concrete plugs. Traj. #2 targets the refueling floor - Reactor Bldg. 5th Floor - remaining areas which are analyzed in two parts: 1) Stand-by liquid Control (SLC) Roof (5'-8" thick) 2) 2 ft. thick R.B. 5th Floor. Traj. #4 targets the Control Room Air Cond. Equipment and SGTS roof in Aux. Bldg. which is 5'-6" thick concrete with metal deck combined. In the analysis, the energy losses due to penetrating Turbine and Reactor Bldg. metal deck roofs have been neglected. Ref. UFSAR Fig. 10.2-4

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High Trajectory Missile Barrier Analysis:

For high trajectory analysis, Traj. #2 with a missile barrier thickness of 5'-8" is more critical than Traj. #3 which is 6'-0" thick.

Traj. #2 & 3 Missile Barrier

As listed in this calc. on Pg. 10, after air drag losses, the kinetic energy of the missile will be 31.5×10^6 ft lbs. Conservative, as refuel floor elevation is 684'-6" vs. 643'-6" turbine deck elevation (~40' higher)

$$\frac{1}{2} m v^2 = E_k$$

$$\frac{1}{2} \times \frac{8650}{32.2} \times V^2 = 31.5\times10^6 \rightarrow V^2 = 23.45\times10^4 \rightarrow V = 484 \text{ ft/sec} \Rightarrow V = 330 \text{ mph}$$

Using the Modified Petry Equation:

$K = 2.82\times10^{-3}$ ft³/lb (Ref. App #2) for $f'_c = 5900$ lb/in²

$$D = 2.82\times10^{-3} \times 1030 \times \log_{10}\left(1 + \frac{\overline{484}^2}{21.5\times10^4}\right) = 0.93 \text{ ft}$$

$$D' = D\left[1 + e^{-4\left(\frac{5.67}{0.93} - 2\right)}\right] = 0.93 \times \left[1 + e^{-4\times4.1}\right] = 0.93 \text{ ft}$$

Perforation → $2D = 1.86$ ft → $1.2\times1.86 \cong 2.2$ ft < 5.67 ft (Per ACI 349.C7)

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Turbine Missile Protection

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In order to prevent scabing, check the inequality: (UFSAR 3.5, Ref. 12) App. #4

$T \geqslant C_1 . A \times 10^{-5} (L)$

$C_1 = 340 (Ft^3/Lb)$ From Fig. 1. (APP #4)
$A = 1030\ Lb/ft^2$ Sectional Mass - wt. of missile/area of contact

$T \geqslant 340 \times 1030 \times 10^{-5} = 3.5$ ft.

$T = 5.67 ft > 3.5 ft$ O.K. including $1.2 \times 3.5' = 4.2$ ft. < T per ACI 349-C.7

Overall Structural Response

Edge Impact: This impact is evaluated considering that the missile strikes near the slab (i.e. near the slab boundary) support/ As shear forces are generated due to the location of impact on the slab, the penetration formula that has been used will normally envelope the shear/punching shear effects on the slab.

The slab is S-206 (C-234B), 6.0" thick. Per D.C. SS-0009-2 Pg. 2.206.2, the interaction coefficient (I.C) ≡ 0.1. So the initial loading effects are negligible. The edge impact of missile on the slab and its supporting structure is acceptable per ACI 349-85 Sect. C.7.2.3.

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Central Impact:

When the missile strikes at the center of the slab, the critical mode of behavior is flexure. The energy absorbed and dissipated by the slab (Ea) will be calculated as:

$$\frac{1}{2} M_m \cdot V_o^2 = \frac{1}{2}(M_m + M_s) V^2$$ (Kin. Energy equation before/after impact)

$$M_m \cdot V_o = (M_m + M_s) V \Rightarrow V = \frac{M_m}{M_m + M_s} V_o$$ (Momentum Conservation)

The kinetic energy to be absorbed by the slab:

$$E_a = \frac{1}{2}(M_m + M_s) V^2 = \frac{1}{2}(M_m + M_s)\frac{M_m^2}{(M_m + M_s)^2} V_o^2 = \frac{1}{2}\frac{M_m^2}{(M_m + M_s)} V_o^2$$

$$E_a = \frac{1}{2}\left(\frac{M_m}{M_m + M_s}\right) \cdot M_m \cdot V_o^2$$

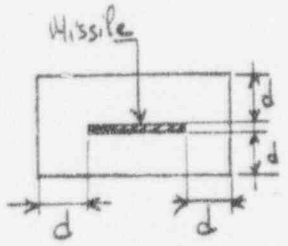
M_m = Mass of missile
M_s = Mass of slab participating
V_o = missile velocity before impact.

Assume the slab participating mass is limited to the thickness (d) added to four sides of the missile dimension. (1'×8' approx.) (Conservative) (UFSAR Sect. 3.5.4.5)

$$M_s = (1' + 2 \times 5.67') \times (8' + 2 \times 5.67') \times 5.67' \times \frac{.150}{32.2} = 6.3 \text{ kips/ft} \times \text{sec}^2$$

$$M_m = \frac{8.650}{32.2} = 0.27 \text{ kips/ft} \times \text{sec}^2$$

$$E_a = \frac{1}{2}\left(\frac{0.27}{0.27 + 6.3}\right) \times 0.27 \times \overline{484}^2 = 1300 \text{ kip ft.}$$



Slab participation relative to impact area

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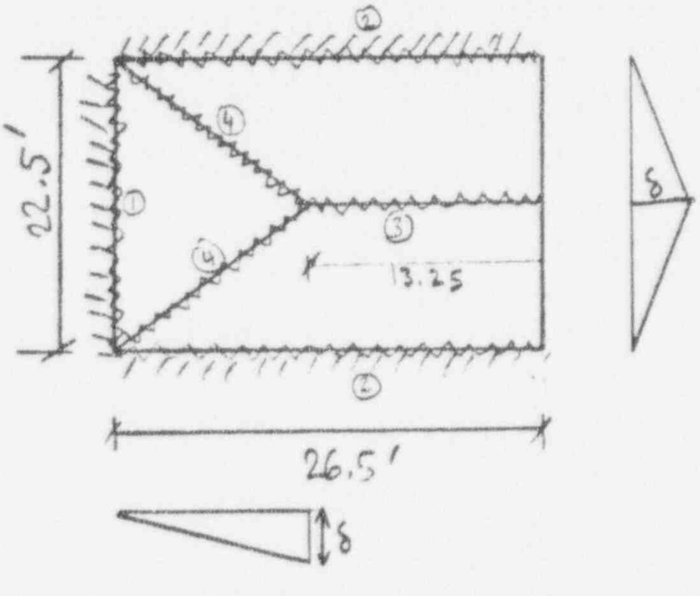
Yield line theory will be used in order to determine the energy required to yield and rotate the formed hinges to the values of ultimate rotation.

Assume the 5'-8" (5.67') thick slab (S-206) is supported 3 sides fixed and one side free. The configuration of the yield lines assumed are as shown. δ is the deflection of the slab at the center. δ will cause rotations at yield lines. Moment times rotation will give the internal energy of the slab.



Assumed Mechanism

Internal Energy $\Sigma M \cdot \theta$

$$①④\ 2\left(M \times \frac{\delta}{13.25}\right)22.5 +$$

$$②\ 2\left(M \times \frac{\delta}{11.25}\right)26.5 +$$

$$③\ 4\left(M \times \frac{\delta}{11.25}\right)13.25$$

$$M\delta\left(\frac{2 \times 22.5}{13.25} + \frac{2 \times 26.5}{11.25} + \frac{4 \times 13.25}{11.25}\right) =$$

Use $M = 594$ kipft/ft conservatively from D.C. SS-0009 Page 1.1. Multiply by 1.10 per ACI 349-82 - C.2. (DIF=1.10)

$594 \times 1.10 \times 12.82 \times \delta = 8376.6\,\delta$ [kipft.]

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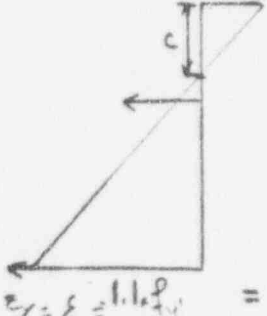
To calculate the ultimate rotational capacity of the yielding hinges by Ref.#10, Pg 112 Formula 3.5.6

$r_u = \left(0.0065 \frac{d}{c}\right)$ r_u = ultimate rotational capacity
d = effective depth of section 68"-3" = 65"
c = distance from the extreme compressive fiber to the neutral axis at ultimate axis.

Including Dynamic increase factors (DIF) per ACI-349 App. C, the c value:

$\varepsilon_c = .003$ → concrete strain



$P_c = 0.85 \times 7.375 \times 12 \times 0.68^{*} c = 51.153 c$

$T = 2.08 \times 1.1 \times 60 = 137.28$ kips → $c = 2.7"$

Slab bottom reinforcement

As compression steel is very close to the neutral axis, (3"-2.7"=0.3") neglect its effect on the rotational capacity of the slab.
[c ≅ 6" is needed to have a lower than $r_u = 0.07$ rad. ∴ $r_u = 0.07$ rad. governs]

$\varepsilon_y = \varepsilon_s = \frac{1.1 f_y}{E} = \frac{1.1 \times 60}{29 \times 10^3} = 0.0023$

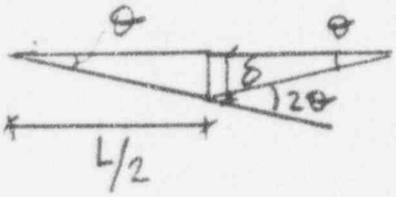
* $a = \beta_1 \cdot c$ $\beta_1 = 0.85$ for $f'_c = 4$ ksi and decreases 0.05 for each 1 ksi increase in f'_c. Assume $f'_c = 5900$ psi $\times 1.25 = 7375$ psi $= 7.375$ ksi

$\beta_1 = 0.85 - 0.05\left(\frac{7.375-4}{1.0}\right) = 0.68$

$r_u = 0.0065 \cdot \frac{65}{2.7} = 0.156$ rad. > 0.07 rad.

Use 0.07 rad for r_u per Ref.#10 Pg. 111 par. C.3.5.

7/30/90



$\delta = \theta \frac{L}{4} \Rightarrow \theta = \frac{4\delta}{L}$ (Conservative, because the θ obtained will be two times larger than $\theta = \frac{2\delta}{L}$ which will be compared with $\theta_u = 0.07$ rad.)

δ is the max. vertical displacement of the yielded slab, due to the rotation.

The Internal energy $M\theta = 8376.6\,\delta$ kipft

The energy to be absorbed: 1300 kipft (Pg. 20) $\theta = \frac{4\delta}{L}$

Equating both energies: $M\theta = E_a \Rightarrow 8376.6\delta = 1300 \rightarrow \delta = 0.155' \Rightarrow \theta = \frac{4 \times 0.155}{22.5} = .0275$ rad

$\theta = 0.0275$ rad $< \theta_u = 0.07$ rad ∴ Rotation of plastic hinge does not exceed the ultimate rotation capacity.

Conclusion: As slab S-206 is hit by the missile, the local penetration will be limited to 0.93 ft with perforation of 1.86 ft. The overall slab will experience yielding conditions and rotations which will remain under the ultimate rotation capacity and the impact energy will be absorbed completely thus protecting safety related components below.

The 5'-6" thick slab with a metal deck, over Air-Conditioning equipment is O.K. by comparison due to the metal deck's additional strength. (Trajectory #4 has the path which may hit this slab.)

Traj. #2 also includes the possibility of striking the 2'-0" thick section of the 5th Fl. Reactor Bldg. The penetration into an infinitely thick slab was calculated to be 0.93 ft. To calculate penetration into 2ft thk. slab:

$$D' = D\left[1 + e^{-4\left(\frac{2.0}{0.93} - 2\right)}\right] = 1.44 \text{ ft} < 2 \text{ ft}.$$ A

$$\text{Perforation: } 2 \times D = 2 \times .93 = 1.86' < 2', \quad \underset{}{1.86 \times \overset{\text{ACI Factor}}{1.2}} = 2.23 \text{ ft} > 2. \text{ ft}$$

Scabbing will occur. The possibility of perforation is not very likely because some energy losses (such as penetration thru turbine and reactor Bldg. roof) have been neglected. Even if the missile perforates thru the 5th FL. and causes secondary missiles, their energy level will be small enough to be absorbed by the lower floor slab. The 4th FL. Reac. Bldg. slab is 42" thk and 12" thk. which will provide inherent protection from the low energy missiles. We can conclude that the missile impact will not go below the 4th Floor Level. As a result safety related equipment will be protected from missiles as identified in UFSAR Fig. 10.2-4.

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Overall Slab Impact

Edge Impact - Shear failure of the slab by punching shear.

Per Ref #14 - 4.2, "It has become general practice in the US to require that the slab thickness be greater than either the perforation thickness or the scabbing thickness (if scabbing of the concrete is undesirable) and to ignore punching shear capacity for slabs subjected to hard missile impact... punching shear failures have not occurred in the missile impact tests which have been performed."

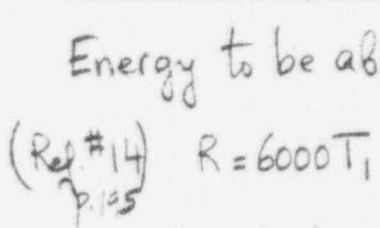
For overall beam adequacy refer to the end of this section.

Central Impact

Energy to be absorbed (E_a), assuming total slab participating

(Ref. #14 p. 105) $R = 6000 T_1 = 6000 \times \left(\frac{2x}{v}\right) = 6000 \times \left(\frac{2 \times 1.44}{484}\right) = 35.7$ ft.

R = Radius of participating concrete. Use $26/2 = 13'$



Consider S-209 instead of S-203 because of its lower Mu, and lower energy absorption capacity. Also consider as a 26 ft. square slab with 2'-0" thickness and 1.27 in^2 reinforcement. Mu = 114.6 kipft/ft per SS-0009 Pg. 1.1

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(4.) $E_a = \left(\frac{8650}{8650 + 26 \times 26 \times 2 \times 150} \right) \frac{1}{2} \times 268.6 \times \overline{484}^2 = 1287$ kipft

$\uparrow \frac{8650 \text{ lbs}}{32.2 \text{ ft/sec}^2}$

Moment × Rotation = $\Sigma M.\theta \times L$

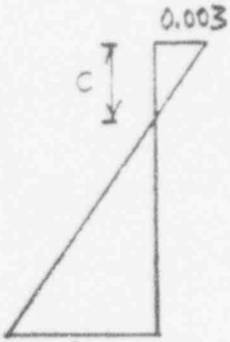
$2 \times 4 \times M.\theta \times 26 = 208 M\theta$

$M_p = 1.1 M_u = 1.1 \times 114.6 = 126$ kipft/ft

$208 \times 126 \times \theta = 26208 \theta$

$\theta = \frac{1287}{26208} = 0.05$ rad. rotation is required to absorb E_a.

Calculate rotational capacity $r_u = 0.0065 \frac{d}{c}$



(Pg. 22)

$\varepsilon_s = \frac{1.1 \times 60}{29 \times 10^3} = 0.0023$

$T = 1.27 \times 1.1 \times 60 = 83.82$ kips

$\uparrow$ reinf. area for slab

$P_c = 0.68 \times c \times 0.85 \times 7.375 \times 12 = 51.153 c$

$c = T/P_c$

$c = 1.64''$ $r_u = 0.0065 \times \frac{22}{1.64} = 0.087$ rad.

In order to have $r_u < 0.07$ rad c should be $> \frac{0.0065 \times 22}{0.07} = 2.04''$

So $r_u = 0.07$ rad will govern as the ultimate rotational capacity of the slab. $\theta = 0.05$ rad $< r_u$ So the slab can absorb the energy.

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Beam, Column & Wall Adequacy: |A

In this calculation, during local and overall slab/wall checks, the adequacy of these components has been verified. In most cases loads will be distributed to more than one beam. In addition beams are stronger members with larger moment capacities and rigidity. Thus, by engineering judgement, all beams will be able to withstand missile impact effects either directly or thru the supported slabs. The same judgement is valid for columns in low trajectory case particularly. The missile hitting the wall with a tangential component is divided into two components. The component 90° to the wall is reviewed for penetration. the component parallel to the wall generates horizontal, in-plane forces which are resisted by diaphragm action. The overall impact of this type of force has not been considered significant for control room walls and is accepted by engineering judgement. The walls and columns can safely absorb the impact energy.

TURBINE GENERATED MISSILE PROTECTION OF RHR COMPLEX

This revision supersedes the original calc. 2.3 Rev. 1. The following changes were made in this revision:

1 - The new missile energies, which are larger, have been considered.

2. The missile properties used now are consistent with the Reactor/Aux. building missile properties. In the previous calc. an approximate missile geometry was considered. (6 ft radius & 1 ft thick)

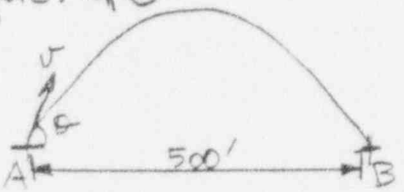
3 - In the modified Petry Formula*, for penetration depth the same K coefficient is used as in the Reactor/Aux. Bldgs. Previously used coefficient corresponded to 3200 psi concrete, whereas the actual strength of concrete at Fermi 2 is 5900 psi. For this reason, the K coefficient closest to our concrete strength (5700 psi) is selected in this revision.

* For detailed explanation of these items, refer to the "Assumptions" and "Definition of Terms and Units - Formulas" in the beginning of this calc. book.

Calculate the missile velocity & impact angles.

Horizontal distance between RHR & Turbine deck is taken as 500 ft. as before. Ref. ⑥

Assume air drag will not change the trajectory.



$500 = v\cos\theta \times t \rightarrow t = \dfrac{500}{v\cos\theta}$

$y = v\sin\theta \cdot t - \dfrac{1}{2}gt^2$

$0 = v\sin\theta - \dfrac{1}{2}gt = v\sin\theta - \dfrac{1}{2}g\dfrac{500}{v\cos\theta}$

$\dfrac{250g}{v^2} = \sin\theta \cdot \cos\theta = \dfrac{1}{2}\sin 2\theta$

$\sin 2\theta = \dfrac{500g}{v^2} = \dfrac{500 \times 32.2}{484^2} = 0.0687$

$\sin 2\theta = \sin(\pi - 2\theta) = 0.0687$

$\pi - 2\theta = 3.94°$

$2\theta = 176.06°$

$\theta = 88°$

$\swarrow$ after air drag

Vertical Velocity: $484\sin\theta = 484 \times 0.999 = 484$ ft/sec

Horizontal velocity: $484\cos\theta = 484 \times .034 = 16.5$ ft/sec.

Therefore horizontal velocity and impact are ignored.

Consider vertical impact on the RHR roof, at the Division I & II common wall as Case 3 of Ref. ① UFSAR 3.5.4.8.3. For cases 1, 2 & 3 refer to UFSAR 3.5.4.8.1 thru 3 and Ref. ⑤ & ⑥

Case 3 _

$$D = K.A.\log_{10}\left(1+\frac{V_0^2}{215000}\right)$$

$$= 0.00282 \times 1030 \times \log_{10}\left(1+\frac{\overline{484}^2}{215000}\right) = 0.98'$$

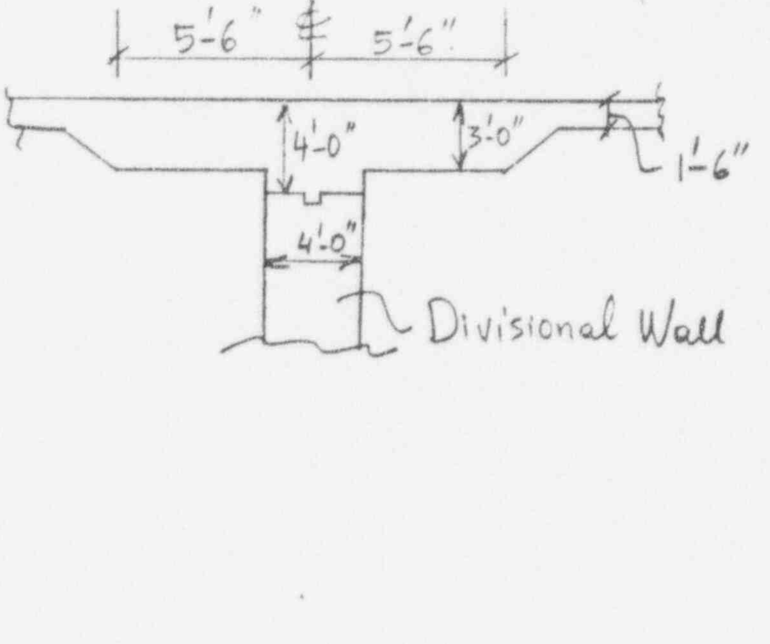
Min. thickness to prevent perforation: $2D = 1.96' < 4'$ O.K.

$$D' = D\left(1+e^{-4\left(\frac{T}{D}-2\right)}\right) = 0.93\left(1+e^{-4\left(\frac{4}{.93}-2\right)}\right) = 0.93'$$

To prevent scabbing, $T \geq C_1 . A \times 10^{-5}$

$\geq 340 \times 1030 \times 10^{-5}$

$\geq 3.5'$ (O.K.)



CASE 1.

Assume the missile hits the roof (1.5ft thick) and after perforating it strikes the common wall.

Energy loss during perforation of slab:

$$D' = KAV'\left(1+e^{-4(h/D-2)}\right)$$

h = 1.5' (slab perforated)
D = penetration into an infinitely thick slab

$$1.5 = 0.00282 \times 1030 \times V'\left\{1+e^{-4\left(\frac{1.5}{.00282 \times 1030 \times V'}-2\right)}\right)$$

$$.516 = V'\left\{1+e^{(-2.066/V'+8)}\right\} =$$

$$V' = .26$$

$$V' = \log_{10}\left(1+\frac{v^2}{215000}\right) = .26$$

$$1+\frac{v^2}{215000} = 1.8197$$

$$v^2 = 176235.5 \Rightarrow v = 420 \text{ fps.}$$

$v = 420$ fps is required as (V_o) in order to penetrate a 1.5 thk. slab.

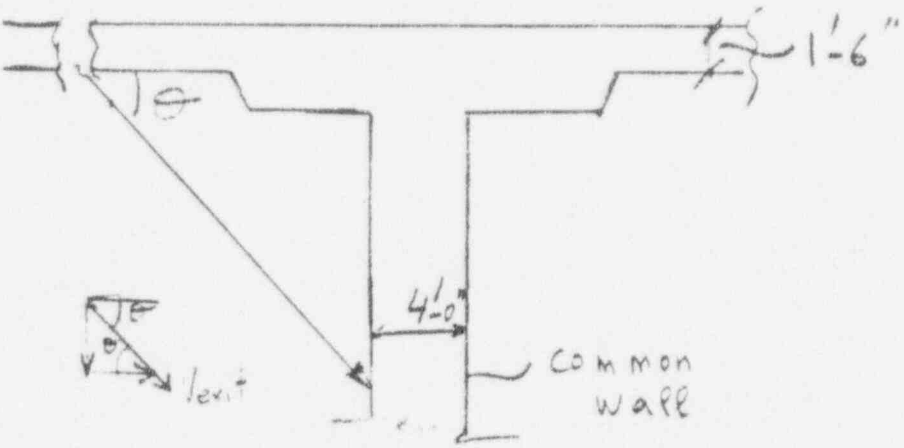
Energy Lost: $\frac{1}{2} \times \frac{8650}{32.2} \times \overline{420}^2 = 23.7 \times 10^6$ lbft.

Initial Energy: (Pg. 10) after air drag: 31.5×10^6 lbft.

Balance (Remaining) Energy: $(31.5 - 23.7)10^6 = 7.8 \times 10^6$ lbft.

Exit Velocity after perforation: $E_B = \frac{1}{2} m v_{ex}^2 \rightarrow V = \left(\frac{2E_B}{m}\right)^{1/2} = 241$ fps.

CASE 1 – (Cont'd)



Assume that after perforating the 1.5ft thick roof slab, the missile will be deflected towards the common wall with θ=30°

∴ Velocity normal to wall surface: $V \cdot \cos 30° = 241 \times .866 = 209$ fps.

$$D = .00282 \times 1030 \log_{10}\left(1 + \frac{209^2}{215000}\right) = .233' = 2.8''$$

$$D' = D\left\{1 + e^{-4\left(\frac{4.0}{.233} - 2\right)}\right\} = D \times 1 = 2.8''$$

$D' = D \cong 3$ in → No spalling or scabbing to common wall.

Case 2 – Horizontal impact at the junction of the exterior east wall, with the common wall causing damage to both divisions, due to spalling of concrete.

The horizontal velocity is insignificant ~16.5ft/sec. No damage is expected.

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REFERENCES

① - FERMI 2 UFSAR - Sect. 3.5.4.7, 3.5.4.8 & 3.5.5 & 10.2.3. Fig. 10.2-3 & 4.

② - ERD Report 70E12 (TDPCAS - 70E12)

③ - USAEC/ACRS Subcommittee Meeting Minutes, March 2, 1971. Enrico Fermi Atomic Power Plant - Unit 2, AEC Docket No. 50-341.

④ - Safety Evaluation By the division of Reactor Licensing USAEC, In the matter of the Det. Edison Co. E. Fermi A.P.P. Unit 2, Docket No. 50-341 dated May 17, 1971.

⑤ - S&L Report SL-3075 - Protection Against Turbine Missile - RHR Complex. (TDDATA - SL 3075)

⑥ - TDPCAS 2.3 Rev. 1 - Turbine Generated Missile Protection of RHR Complex.

⑦ - "Design of Barricades for Hazardous Pressure Systems" by C.V. Moore.

⑧ - Drawings - 6A721-2017, 2003-2, 6C721-2348, 2349, 2376, 2377, 2506

⑨ - USNRC Standard Review Plan 10.2, 3.5.1.3, 3.5.3.
USNRC Reg. Guide 1.115.

⑩ - ACI 349-76 App. C - Special Provisions for Impulsive and Impactive Effects

⑪ - DC-SS-0009 & 0009-2 - Final Load Check - Reactor Bldg. El. 684'-6".
(11.a) - Design Calc. SF-0005
(11.b) - Project structural Design Criteria SE-01-EF
A

⑫ - PSAR Amendments # 5, 12 & 16.

⑬ - E.F. Unit 2, Docket No. 50-341 - Question: 9.1. Missile Report (VANRCA 50 341 1 Film# 1601→200-231)

⑭ A Review of Procedures For The Analysis and Design of Concrete Structures To Resist Missile Impact Effects - R.P. Kennedy

Appendix #-1 D.C. 5144 Vol. 1 Pg. A1

TOPCAS 70E12

Appendix A

APPENDIX A

* Historical Document. The new information is inserted, wherever appropriate, for reference only. } Rev. A

Question 9.1

Provide the following information which can be supported by analysis, drawings and the experience gained from previous failures, for the three different kind of rotors, (i.e., Hp and Lp turbine rotors and the generator rotor).

a. Establish the maximum energy contained in a missile from each of the three types of rotors.

b. Establish the minimum energy lost by the missile in passing through its rotor housing.

c. Using the remaining kinetic energy of each of the above missiles discuss possible trajectories and the adequacy of the intervening barriers provided for all essential equipment, power, control, and coolant systems required to achieve and maintain a safe shutdown condition.

Response

It is assumed that an accident to the turbine generator might result in a progressive increase in rotor speed culminating in bursting of the turbine generator rotors. Heavy fragments might then be projected from the turbine generator with considerable energy. An estimate has been made of the maximum possible energy of flying missiles so that the adequacy of the intervening barriers between the missile and all essential equipment, power, control and coolant systems required to achieve and maintain a safe shut-down condition of the reactor could be investigated.

The approach taken to establish the maximum possible energy of a missile emanating from the Hp or Lp rotor duplicates the analysis described in General Electric Topical Report 67SL211 by E. E. Zwicky, Jr. entitled, "An Analysis of Turbine Missiles Resulting from Last-Stage Wheel Failure." This analysis concentrates on the last stage wheel of these rotors. Based on various fragment sizes and energies together with the nature of the surrounding structure the last stage wheel fragments are considered to be the most dangerous missiles emanating from these rotors. This was confirmed by the failure of Hinkley Point Station "A" turbine generator on September 19, 1969. These wheels are also highly stressed and thus the most probable candidates for failure. Wheel failure is assumed to occur at machine overspeed when the mean hoop stress in the wheel is 0.85 times the ultimate tensile strength of the wheel material. The total kinetic energy at bursting is proportional to the weight of the fragment, while the relative amount of translational energy is dependent upon the fragment geometry. It was assumed that the wheel burst into three 120° segments since this mode of failure approximates a shape for which the missile

DC-51[illegible] App. #1 Pg. A2

translational kinetic energy would be maximum. For the HP rotor an additional missile was considered having a length equal to one complete flow and a sector of 120° for the discs concerned. A summary of the maximum energy of missiles emanating from the HP and LP rotors is given in Table I below.

TABLE I

ENERGY OF HP AND LP ROTOR MISSILES

Fragment Description:	Enrico Fermi LP Wheel 8	Enrico Fermi HP Stage 7 Disc	Enrico Fermi HP Discs One Flow
Fragment Dimensions:			
Angle (deg)	120	120	120
Weight (lb)	8650	1460	10,270
Assumed Bursting Speed (rpm):	3000 3280	4000	4000
Initial Energy:			
Translational (ft-lb x 10^6)	60.8 72.[illegible]	2.4	17.3
Rotational (ft-lb x 10^6)	33.0 39.2	4.8	34.6

The above postulated accident is most improbable since it assumes:

1. Failure of various turbine protection devices despite the fact that probability of a complete failure to all protective systems is virtually zero,
2. That the turbine is capable of producing the torque required to accelerate the rotor system to the bursting speed,
3. That blading or other turbine damage does not prevent the bursting speed from being attained.

In the analysis performed to evaluate the maximum possible energy of missiles emanating from the generator rotor attention was focused on the failure of the generator rotor body, end bells, and fan blades. The maximum kinetic energy for each missile is given in Table II with each failure assumed to occur at 120 percent of machine running speed.

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TABLE II

ENERGY OF MISSILES FROM GENERATOR

Missile Type	Kinetic Energy
Rotor Body Segment	32.8×10^6 in.-lb/in.
End Bell Segment	345.0×10^6 in.-lb
Fan Blade	0.073×10^6 in.-lb

Although details may differ, the general behavior of a portion of the turbine rotor which has lost its integrity is as follows:

> It leaves the rotor and travels with its c.g. moving in a tangential direction at its original linear velocity and rotating about its c.g., with a sudden increase in angular velocity. Initial impact with the surrounding stationary parts occurs in a few micro-seconds with the stationary parts crumpling while deflecting the missile. The angular momentum of the missile enhances the irregularity and unpredictability of its path in trying to penetrate the outer casing of the machine.

Although the rotational kinetic energy contributes to the confusion of the missile path it does not contribute significantly to the severity of penetration. Hence, in all cases the translational kinetic energy has been taken as the parameter to be associated with penetration. Energy losses in penetrating the machine casing were calculated using the "Standford Formula" which is based on tests with long right circular cylinders. This analysis is considered conservative because of the ineffectural shape of the generated missiles. Calculations indicate that missiles emanating from the HP rotor and the generator rotor will be stopped before they can completely breach their respective outer casings. The HP and generator perforation energies are sufficient to preclude the emergence of a missile with any translational kinetic energy. The LP rotor missile is thought to be the only missile that could breach the casing of the machine. The energy contained by this missile as it emerges from the outer LP casing is given in Table III below.

TABLE III

ENERGY OF MISSILES PENETRATING THE OUTER CASING OF THE TURBINE GENERATOR

Missile Description	Rotational Energy	Translational Energy
LP Wheel No. 8 120° Fragment	7.1 6.1×10^6 ft-lb	42.5 34.2×10^6 ft-lb

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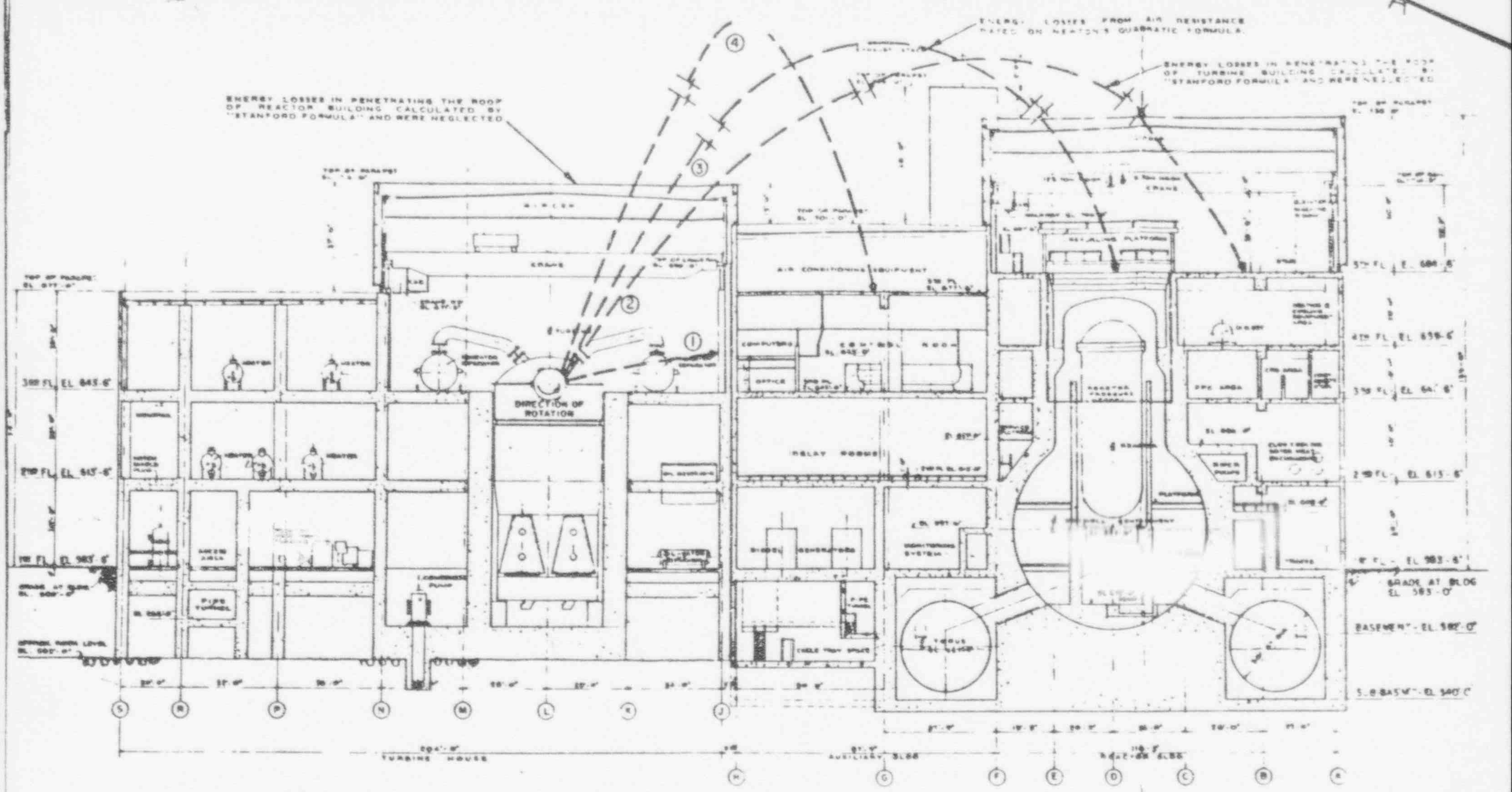
The only missile that could possibly do damage to essential equipment would be a missile emanating from the LP section of the turbine generator. This missile could break through the turbine casing in any radial direction. However, the direction of rotation of the machine is such that the motion of the top half of the rotor carries it away from the reactor and auxiliary buildings. Furthermore, these buildings are not in direct radial alignment with the LP sections of the machine. Thus, the possibility of the missile taking a direct horizontal path toward the reactor and auxiliary building is remote. If, however, the missile were directed horizontally toward the reactor as a result of an internal or external collision its emerging translational energy would be absorbed and the missile stopped by the concrete shielding which surrounds the turbine. This shielding would be only partially penetrated by the missile with the missile surrendering all of its kinetic energy.

Another path that the missile emanating from an LP section of the turbine generator could take is nearly vertically upwards through the roof of the turbine building. It is estimated that such a missile would lose very little energy in penetrating the roof barrier and would leave the turbine building with about ~~34.2~~ 42.5 x 10^6 ft-lb of translational kinetic energy. Again this missile would have to be deflected elastically or acted upon by wind forces to give it a trajectory which would allow it to fall directly atop the reactor or auxiliary building. It is estimated that the missile will strike these structures with ~~26.6~~ 31.5 x 10^6 ft-lb of residual translational kinetic energy after allowance for energy losses due to air-drag forces. The missile, as it strikes the reactor building will surrender little of its energy in passing through the roof of the steel superstructure and will reach the refueling floor elevation of the reactor building with about ~~26.6~~ 31.5 x 10^6 ft-lb of kinetic energy. The LP missile would be potentially damaging to these building structures and the essential equipment each structure contains. Consideration will be given to the design of the upper floor portion of these structures to preclude the possibility of a missile penetrating an area directly above essential equipment. (See Figure Q9.1-3).

Consideration has been given to the probable effect of the LP missile on the Fuel Storage Pool. Analysis shows that there is a probable missile path to the Fuel Storage Pool, see Figures Q 9.1-1 and Q 9.1-2. The probability of a missile striking the fuel pool has been calculated to be a probable occurence of less than once in every 10,000 years.

The following description of the Enrico Fermi Unit 2 Turbine Speed Governing System and overspeed trip system is simplified and is intended to provide a basic statement on the unique system characteristics which minimize the probability of occurence of an overspeed condition.



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App. #1
Pg. A5

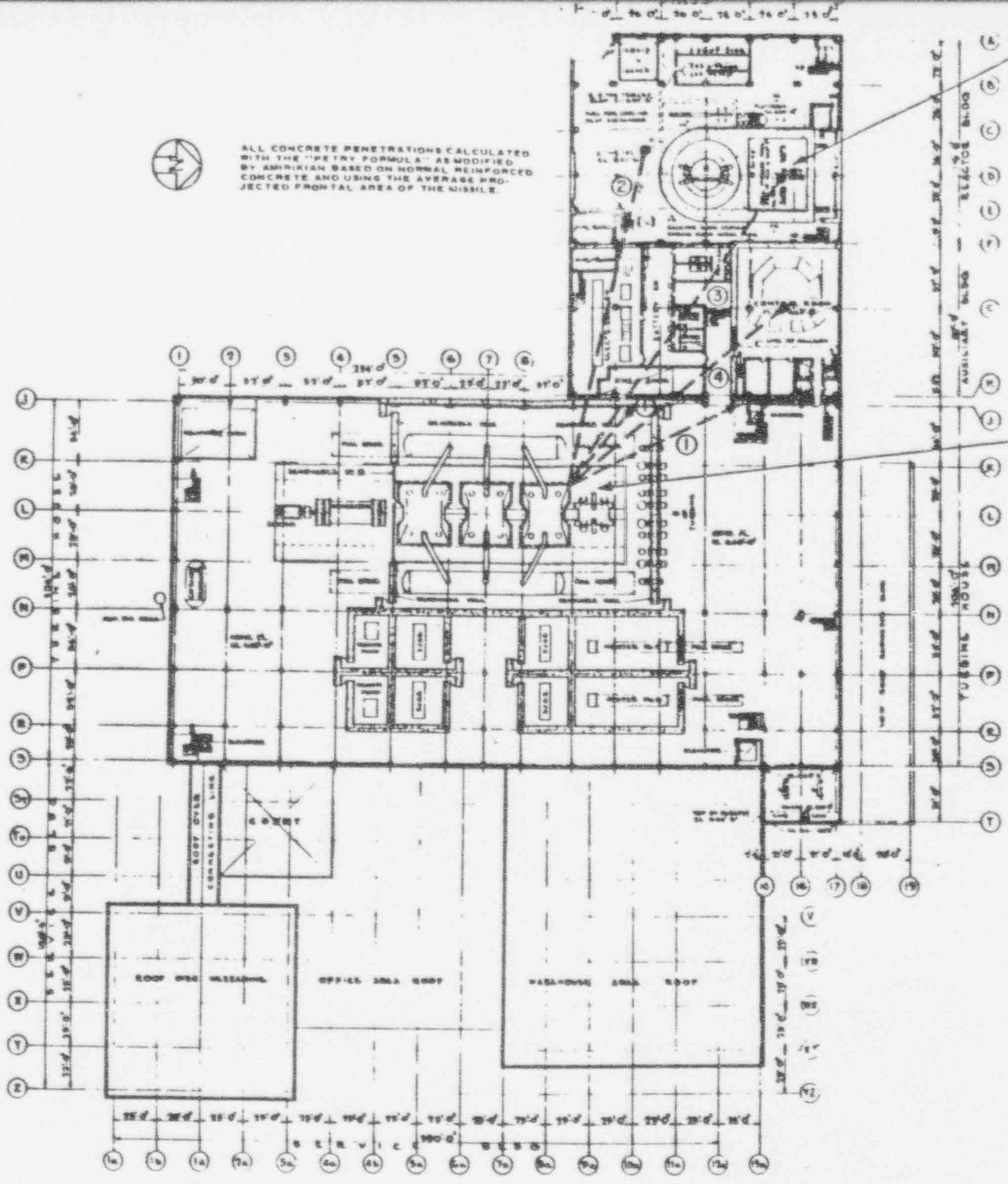
ENRICO FER
ATOMIC POWER PLANT - UN
PRELIMINARY
SAFETY ANALYSIS REPO

TITLE TRANSVERSE VIEW
SHOWING TURBINE GENERAT
MISSILE TRAJECTORIES
FIGURE Q 9.1-2
AMENDMENT 12
11-20-70

DC-5147

App #1

Pg. A6



ALL CONCRETE PENETRATIONS CALCULATED WITH THE "PETRY FORMULA" AS MODIFIED BY AMIRIKIAN BASED ON NORMAL REINFORCED CONCRETE AND USING THE AVERAGE PROJECTED FRONTAL AREA OF THE MISSILE.

ENERGY LOSSES FOR TRAVEL IN THE FUEL STORAGE POOL AND IMPACT WITH LINER AND BASED ON PROCEDURES OUTLINED IN GENERAL ELECTRIC REPORT APED 5083, PAGES 32-43

MISSILE FRAGMENT HAVING THE MAXIMUM POSSIBLE ENERGY DERIVED USING THE PROCEDURE DESCRIBED IN GENERAL ELECTRIC TOPICAL REPORT GTSL211 BY E.E. ZWICKY, JR. ENERGY LOSSES IN PENETRATING THE TURBINE CASING WERE CALCULATED BY THE "STANFORD FORMULA".

ENRICO FERMI
ATOMIC POWER PLANT - UNIT 2
PRELIMINARY
SAFETY ANALYSIS REPORT

TITLE
PLAN VIEW
SHOWING TURBINE GENERATOR
MISSILE TRAJECTORIES
FIGURE Q 9.1-3
AMENDMENT 12
11-20-70

App. #2

DC-5144

Pg. A7

I. Penetration of Concrete Slab

The evaluation of missile effects in a particular plant is a matter for the plant designer. In this report, a comparison between various missiles was desired. For this, the work of Amirikian (7) appears most applicable. Moore (6) also summarizes Amirikian's approach. In these papers, the missile penetration is predicted by the empirical relation:

I-1) $$D = k A_p V'$$

where D is the penetration depth in feet
k is the penetration coefficient (experimentally determined, see below)
A_p is the sectional pressure, #/ft², obtained by dividing the missile weight by its cross-sectional area
V' is a velocity factor $= \log_{10}\left[1 + \frac{V^2}{215000}\right]$
V is the missile velocity, ft/sec.

This formula applies to penetration into an infinite slab. Amirikian reports Navy experiments which resulted in a correction factor for finite slabs:

-2) $$D' = D\left[1 + e^{-4(\alpha' - 2)}\right]$$

where D is the penetration depth in an infinite slab, ft.
D' is penetration depth in a finite thickness slab, ft.
$\alpha' = T/D$
T is the slab thickness, ft.

For complete penetration of a slab, we must have

I-3) $$D' = T = D\left[1 + e^{-4(T/D - 2)}\right]$$

Rearrangement of this equation shows that D = ,/2 gives complete penetration. Therefore, from eq. (I-1), the thickest slab which will be perforated by a missile is:

I-4) $$T = 2 k A_p V'$$

This formula was used for the present calculations. A_p was determined using the weight divided by the average of the minimum and maximum projected areas of the wheel. It was felt that the fragment rotation would tend to reduce penetration somewhat so that using the minimum wheel area was too conservative.

Amirikian gives several values for the penetration coefficient, k. From his table 1 (also given by Moore) and his Fig. 10, we have the values:

k	Material	
.00799	2200 psi concrete	
.00476	3200 psi concrete, 1.4% reinforcement	
.00282	5700 psi concrete, 1.4% reinforcement	
.00348	3000 psi concrete	Specially reinforced according to Amirikian Fig. 10
.00277	4000 psi concrete	
.00224	5000 psi concrete	

In the present calculations, $k = .00476$ was used as probably representative of current construction. Obviously, from eq. I-4) and the table, this may overestimate the penetration by a factor of 2 if special construction is used.

One further remark should be made. By use of eq. I-1) and I-2), it can be seen that the penetration depth in a slab at least twice as thick as the perforation thicknesses given on pgs. 60 and 62 (i.e., for $T > 2D'$) would be one-half the perforation thicknesses shown.

Pages From GE Report TR67SL211
"An Analysis of Turbine Missiles Resulting From Last-Stage Wheel Failure" by E.E. Zwicky, Jr.

APPENDIX #3

DC-5144

REF. ④ Safety Evaluation

Reference 2 Safety Evaluation USAEC 5-17-71

Pg. A9

possible missile protection will be achieved through basic plant component arrangement such that direction of flight of these missiles will be away from critical components. Special consideration will be given to the segregation of components associated with the engineered safety systems (e.g., core spray and containment spray) such that the failure of any component could not render the engineered safety systems inoperable. We find these design considerations to be acceptable and we will review the detailed plant layout prior to completion of the plant.

[illegible] R:R 4/19

3.5.7.3 Protection From Turbine Missiles

In Amendments 12, 15, and 16 the applicant discusses the steps taken in the design of the facility to reduce the possibility of generating missiles as a result of turbine failures and to reduce the damaging effects of turbine missiles should they be created. The applicant's governing criterion will be safe shutdown of the plant.

The applicant has stated that the turbine overspeed protection system will be designed, to the maximum practical extent, to meet the IEEE-279 Proposed Criteria for Nuclear Power Plant Protection Systems to enhance the reliability of the overspeed protection system and limit the maximum energy of potential turbine missiles.

R:R

The orientation and location of the three low pressure turbines are such that any potentially generated missiles would have to be deflected in order to cause their trajectory to intersect the volumes occupied by equipment essential to attaining and maintaining a safe shutdown condition for the plant. In the highly unlikely event that turbine missiles are generated and thus deflected, reinforced concrete barriers are provided to protect the plant equipment essential for safe shutdown. The thickness of these barriers has been made at least twice the calculated missile penetration depth in order to prevent the creation of secondary missiles. Detroit Edison specifically discussed the adequacy of the barriers (in the form of walls and ceilings) that were provided for the control, battery, and relay rooms, the standby liquid control system and the standby gas treatment system. It also stated that the 6 feet thick concrete shield plug will adequately protect the reactor vessel bead.

We have concluded that the applicant's preliminary design decreases the probability of turbine missiles being generated, the turbine orientation with respect to the reactor building reduces the probability that turbine missile trajectories will intersect vital systems, and the use of protective barriers will mitigate the consequences in the unlikely event that missiles are generated.

DC-5147 App #4 Pg A10

DESIGN OF MISSILE RESISTANT CONCRETE PANELS

J. M. DOYLE

Department of Materials Engineering, College of Engineering,
University of Illinois at Chicago Circle, Chicago, Illinois 60680, U.S.A.
and Consultant to: Sargent & Lundy Engineers

M.J. KLEIN, H. SHAH

Structural Department
Sargent & Lundy Engineers, Chicago, Illinois 60603, U.S.A.

SUMMARY

Protection against structural failure in case of accidental impact of several types of projectiles must be a consideration in nuclear power plant design. The critical nature of certain items of equipment makes it necessary to surround some areas of the plant with missile resistant structures. Ordinarily, missile barriers consist of reinforced concrete walls, roofs and floors. A design procedure for rectangular concrete panels subject to various types of missile impact is outlined in this paper.

A number of different flying objects are usually postulated as possible missiles in power plant designs, including planks, pieces of pipe, turbine parts and even automobiles. In general, missiles fall in two different classes, rigid and nonrigid. The behavior of a panel, of course, is different for each. High velocity, rigid missiles can penetrate and, in some cases, cause little structural damage to the panel outside the area of impact. On the other hand, nonrigid or collapsible missiles do not punch through the wall, but may cause failure of the panel by shear or bending, depending on the location of the point of impact. Both localized penetration and general structural behavior of plate elements are considered for a variety of possibilities.

The well known Petry formula is utilized to determine adequate thickness to prevent total penetration and spalling on the inside of panels struck by rigid missiles. As an extension to the usual analysis, this formula is also exploited to obtain impact times for rigid missiles and to estimate maximum dynamic response of panels impacted by rigid missiles.

Two different regions of impact are considered when evaluating general structural action; near an edge and in the center. For edge impact, shear forces are of primary concern. Here, they are computed using momentum principles, rather than the energy methods usually employed. Flexure is the mode of main concern when the impact is in the central area of a panel. In the analysis presented here, the plate is replaced by an equivalent fixed end beam, and response calculations are made using standard methods of structural dynamics. Experimentally determined information on time history of contact force is incorporated in these computations, thus rendering a more nearly correct estimate than would be expected by previous methods. Design recommendations are based on ultimate strength. A method of calculating the extra energy absorbing capacity of the reinforcing steel after failure of the concrete in flexure is included.

J 3/3

1.0 Introduction

Protection against structural failure in case of impact by several different types of projectiles must be a consideration in nuclear power plant design. In most power plant designs, a number of flying [illegible] are usually postulated as possible missiles ranging from wooden planks to a small automobile.

This paper presents a method for analyzing reinforced concrete plate elements subject to impact loads and outlines a design procedure to insure that the structural integrity of such panels is maintained. Since the walls surrounding critical equipment areas are usually made up of a series of concrete panels, the method presented here is particularly useful.

2.0 Missiles

In the design of structures against impact, two general types of missiles are usually considered; high velocity, approximately rigid missiles such as a wooden plank, a piece of pipe, or turbine parts, and non-rigid bodies such as a small automobile.

To analyze a structural component for its behavior when impacted by a missile, four items of information concerning the missile are necessary. They are the weight, the area of contact, the velocity and the variation of contact force during impact. Realistic assumptions on the first three can be made quite easily; however, data on contact forces are limited.

3.0 Penetration

For the smaller, nearly rigid missiles, penetration of the panel is usually the dominant concern rather than overall structural damage. The depth of penetration into a concrete wall may be calculated using the Modified Petry Formula:

$$D' = KAV'R \tag{1}$$

where:

D' = Depth of penetration in slab of thickness h (L)

K = Material property constant (L^3/F)

$= 4.76 \times 10^{-3}\ ft^3/lb.\ (2.97 \times 10^{-4}\ m^3/kg)$ for reinforced concrete

A = Sectional Mass, weight of the missile per unit cross sectional area of contact (F/L^2)

V' = Velocity factor = $\mathrm{Log}_{10}\left(1 + \frac{Vo^2}{V*^2}\right)$

V_o = Initial velocity of missile

$V*^2 = 215000\ ft^2/sec^2\ (19973\ m^2/sec^2)$

R = Thickness ratio

$= \frac{D}{D} = 1 + \exp\ [-4\ (\alpha'-2)]$

where $\alpha' = \frac{h}{D} = \frac{h}{KAV'}$

and D is the depth of penetration in an infinitely thick slab.

In order to prevent spalling of the concrete on the interior surface, the penetration depth should be restricted to less than 2/3 of the panel thickness to satisfy the inequality:

$$T \geq C_1 A \times 10^{-5}\ (L) \tag{2}$$

in which C_1 depends on the missile velocity and can be obtained from the curve in Figure 1.

The absolute minimum requirement for a panel design is to prevent the penetration by any missiles postulated to strike it.

4.0 Impact Times and Contact Forces

As mentioned previously, only limited data are available for determining contact forces. Suitable force-time relationships have been determined for some of the larger non-rigid missiles. Figure 2 shows contact forces vs. time variations for two different automobiles crashing into a rigid barrier. In each case, the impact speed was different. Unfortunately, similar data are not available for smaller, more nearly rigid missiles. A simplified analysis for such cases can be utilized, however, provided the time of impact can be established.

An equation of motion, which may be used to obtain an estimate of the time required for penetration, can be derived using the Modified Petry Formula. If it is assumed that the ratio of resisting force (F) to the mass of the missile (m) is given by:

$$\frac{F}{m} = V\frac{dV}{dx} = -1.15\ \frac{V*^2}{KA}\ \exp\left(\frac{2.3x}{KA}\right) \tag{3}$$

where:

$V*^2 = 215000\ ft^2/sec^2\ (19973\ m^2/sec^2)$

x = Depth of penetration at any instant

V = Missile velocity at any instant

then, straight forward integration of the equation of motion for the missile yields a terminal penetration which is in agreement with the Petry Formula. However, the solution of the equation determines velocity as a function of distance. Due to the nonlinear nature of the motion equation, a numerical integration is necessary in order to determine the velocity as a function of time, which is required.

Two separate cases must be considered in any design and the form of the motion equation is different for each. The two cases are: (1) missile impact occurring near a panel support and (2) missile impact near the center of the panel.

For the first type of impact, the panel will not deflect and the equation of motion to be solved is:

$$\ddot{x} = -1.15\ \frac{V*^2}{KA}\ \exp\left(\frac{2.3x}{KA}\right) \tag{4}$$

subject to the initial conditions

$t = 0;\ x = 0,\ \dot{x} = V_o$

A11

On the other hand, for impact in the center of the panel, the panel itself deflects. It can be considered as a single degree of freedom system. Its equivalent mass and equivalent spring constants, which depend on the panel geometry, can be readily determined. Treating the system of the missile and the slab, such that the force between the missile and the slab is of the same form as the case where no motion of the slab is assumed, the following two equations result:

$$\ddot{x} = -1.15 \frac{V^{*2}}{KA} \exp\left(\frac{2.3\ (x-y)}{KA}\right) \tag{5}$$

$$M\ddot{y} + ky = - m\ddot{x} \tag{6}$$

with initial conditions:

$$t = 0;\ x = y = \dot{y} = 0,\ \dot{x} = V_o$$

In equations (4), (5) and (6),

x = missile displacement

y = panel displacement

M = equivalent mass of slab

k = equivalent slab stiffness

m = mass of the missile

It is noted that if the properties of the slab are such that its displacement y vanishes, the two equations reduce to Equation 3, which in turn yields the final displacement predicted by the Petry Formula.

An examination of the equation of motion of the panel shows that initially, when y = 0, the slab acceleration is equal to $\frac{m}{M}$ times the missile acceleration. For subsequent time, this acceleration is even less. Therefore, neither the velocity nor the displacement of the panel, at the completion of embedment, will exceed $\frac{m}{M}$ times the missile velocity and displacement. For many cases of practical interest the mass ratio is less than 1%. In such instances, penetration time could be based on rigid target conditions with very little error. The error would be on the conservative side since the predicted time would be shorter than actual.

By solving the equation of motion for several different values of missile weight and initial velocities a graph such as shown in Figure 3 may be established and used to determine impact times for a wide range of these parameters.

5.0 Impact Near Support

The chief concern when a missile strikes near a support, is the limiting punching shear. In order to calculate the shear stress, the conservation of momentum is used. An area of slab is assumed to be activated immediately upon impact. This active area is enclosed by a perimeter which extends outside the contact area of the missile by a distance of 1/2 the panel thickness. The shearing force is considered to be distributed uniformly around this periphery.

For the small, rigid missiles, it is further assumed that the shear forces are constant throughout the duration of the impact. The time of

impact may be computed by the methods described in the previous section. Then the impulse-momentum relationship gives the following expression for total impulsive shear force on the periphery:

$$Q_s = \frac{mV_o}{ST^*}$$

where:

Q_s = shear force per unit length of perimeter

V_o = initial velocity of the missile

m = mass of the missile

T* = impact time

S = length of perimeter of active area

Since the time history of the contact force is known for the vehicular missiles, the maximum shear force is given by:

$$Q_s = \frac{F_1}{S}$$ (

where F_1 is the maximum value of contact force.

With either expression for shear force, the punching shear stress can be calculated from the formula:

$$v = \frac{Q_s}{\phi d}$$ (

where:

v = shear stress

φ = capacity reduction factor for shear force (Section 9.2 ACI Standa 318-71 [1])

d = depth from extreme compression surface to centroid of tension rei forcement.

This value of shear stresses must be compared with some allowable such as ACI allowable

$$v \leq \sqrt{\phi f'_c}$$ (1

where:

f'_c is the 28 day compression strength of the concrete used.

When the stress exceeds the allowable, either the energy absorbing capacity of the reinforcement must be investigated (Sec. 7), or the panel thickness increased.

6.0 Missile Impact Near Center of Panel

In this case, the critical mode of behavior is flexure. To treat the flexural problem, the maximum flexural displacement due to impact is obtain by integration of the equation of motion.

When small, rigid missiles are considered, the displacement and veloci at the conclusion of embedment may be estimated by:

$$Y = \frac{m}{M} D'$$

$$V_s = \frac{m}{M} V_o$$ (11

DX-51

A12

Then the maximum displacement is

$$Y_{max} = \frac{m}{M}\left(D'^2 + (V_o/\omega)^2 \quad ^{1/2}\right). \qquad (12)$$

If this approximation yields unsatisfactory results, the deflection (Y) and velocity after impact (V_s) can be computed by carrying out the actual integration. The values found in this way would be less than those obtained by the short cut method. The maximum displacement is given in either case by Equation (12).

On the other hand, when the time course of the contact force is known, the panel deflection can be obtained by an integration of the equation of motion for the panel using the prescribed contact as a forcing function.

As one approach to the solution, the panel may be replaced by an equivalent fixed end beam. Equivalent mass and spring constants for a single degree of freedom spring-mass model of the beam are tabulated in many sources including Norris et al. [2]. The analysis can further be simplified by replacing the known force-time curve by an idealized triangular variation of equal impulse. A typical idealization superimposed on the original is illustrated in Figure 4. With the triangular pulse and a given spring-mass model, the maximum deflection can be obtained from the shock spectra given by, for example, Biggs [3]. If the maximum deflection exceeds the ultimate, the energy capacity of the reinforcing steel must be considered or the panel thickness increased.

7.0 Energy Absorption of Reinforcement

In the case that either the allowable punching shear stresses are exceeded or the maximum deflection exceeds the ultimate value, the reinforcing bars will still offer some resistance to penetration. In addition, there will also be some resistance left in the concrete, even though local failures have occurred. A conservative evaluation of the additional resistance results from considering,only that of the reinforcing steel. The bars, in effect, form a net to hold the missile. To determine the capacity of the "net", it may be assumed that the steel in the impact area is strecthed to its ultimate and evaluate the stored strain energy. If the sum of the energy absorbed in the crushing of ductile missiles, the energy absorbed in the panel to reach the allowable shear or ultimate deflection, and the ultimate energy capacity of the steel in the impact area exceeds the initial kinetic energy of the missile, penetration can be prevented although considerable local damage might result.

Acknowledgement

The authors wish to thank Mr. R. E. Koppe for his many constructive comments made during the preparation of this work.

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[2] Norris, Charles H., Hansen, Robert J., Holley, Myle J., Biggs, John M. Namyet, Saul and Minami, John K., Structural Design for Dynamic Loads, pp. 160-162, McGraw-Hill Book Compeny, New York, (1959).

[3] Biggs, John M., Introduction to Structural Dynamics, pp. 72-79, McGraw-Hill Book Company, New York (1964).

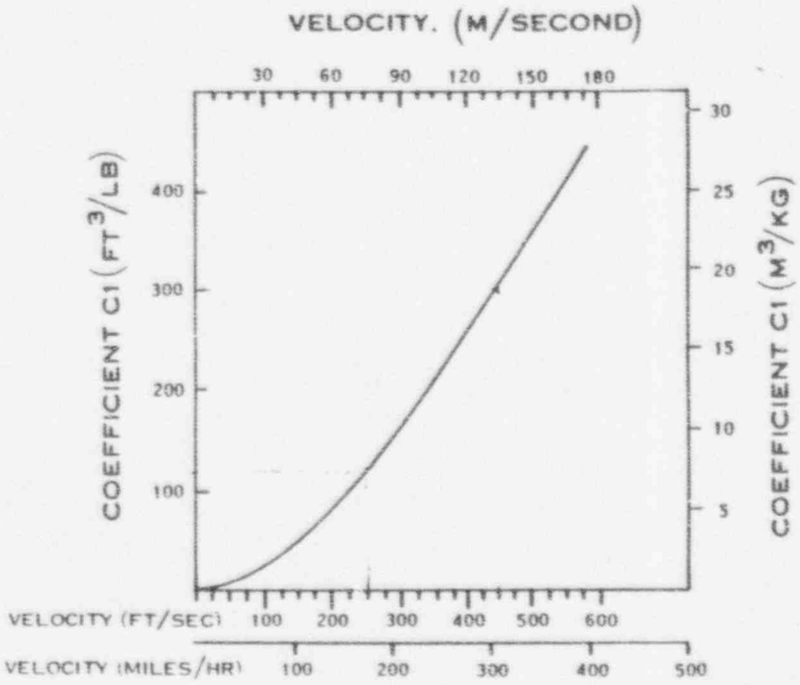

Figure 1. Minimum Thickness Needed to Prevent Penetration and Spalling.

A13

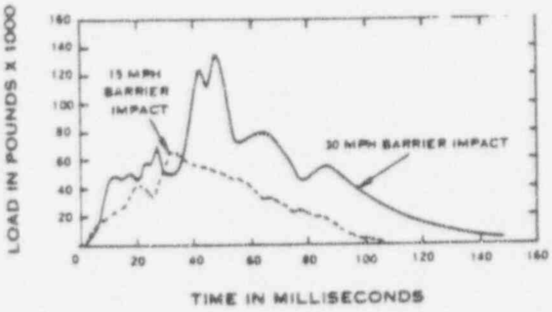

Figure 2. Vehicle/Barrier Impact - Force-Time History

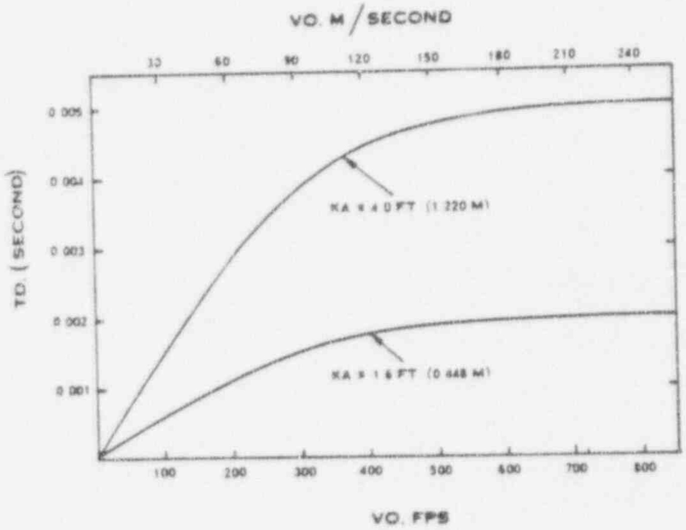

Figure 3. Impact Time vs. Initial Velocity for Rigid Missiles

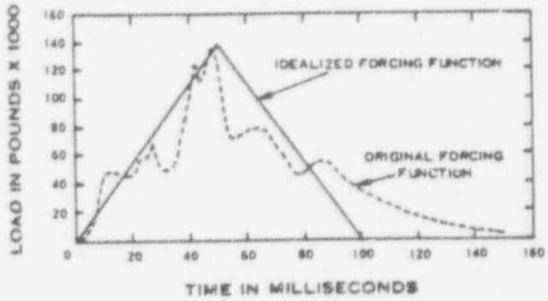

Figure 4. Vehicle/Barrier Impact - Idealized Force-Time History

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A14

DC-5144

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SUMMARY

The potential of danger
plants and the possible seri
impact loading must be tak
especially in the case of co
of view it is often necessary
structures against impact lo
problems yet to be solved a

This article only deals w
made of reinforced concret

At first, the problem o
load-time history is know
The amount of the impact
However, also loads well d
taking the response of the

Then, some notes are m
in structures loaded by imp
ticated methods of analysi
of no use for this purpose. A
of the material is not the be
Therefore simple methods

Such methods of appro

1. Only the amount of the in
2. The amount of the pulse
   is known, the shape of t
3. Impact loading; impact
   impacted body is known
4. Load time history is kno

For all these methods it
the possible maximum of d
field of reinforced concret
results of systematic investig
mation capacity of structu
forced concrete structures
patterns.

Appendix #5 Pg. ~~A14~~ A15 B

DC-5144

GEC ALSTHOM

ELECTROMECHANICAL

Large Steam Turbines

Mr L.C.Fron,
Director: Turbine and Special Projects,
Fermi 2

Dear Mr.Fron,

Fermi 2 LP Rotor Missile Analysis

During our meetings with NRC at Fermi on 3rd and 4th August they raised a number of points regarding the missile analysis for the LP rotors when they return to service without the stage 7 and 8 blades. In subsequent discussions with Mr.J.Walker and Mr.H.Sahiner I was requested to provide additional information to enable DECo to carry out a revised analysis. The required data is detailed below.

1. LP Rotor Blade and Disc Weights.

The attached table lists the weights of each of the shrunk on discs and the individual blade weights for each stage. The disc weight includes the blade root up to the bottom of the aerofoil and the blade weight is the weight of the aerofoil together with the shroud, lacing wire or lacing rods as appropriate. For stages 1-4 the LP2 cylinder blade heights are different to those in the LP1 and LP3 cylinders. For these stages the blade weight value given in the table is that of the heaviest blade but in each case the difference does not exceed 10%.

2. Bursting of LP Discs

a) the burst speed for the no.6 disc (stage 8) was originally calculated to be 3000rpm. In arriving at this value it was assumed that the blades were attached at the instant of fracture so that the effects of blade centrifugal pull were included in the calculation. However, it was also assumed that the blades were lost from the resulting worst case 120° missile before it exited from the turbine. Hence, the mass and energy used for the 120° missile were of the disc and blade roots only and did not include the blades.

App. #5 Pg. ~~A15~~ A16

DC-5144

b) the revised burst speed for the no.6 disc (stage 8) with blades removed but with root blocks in place is 3600rpm.

c) with both no.5 and 6 discs debladed the first disc to burst would be no.4 (stage 6) at a speed of 3280rpm. This includes the centrifugal pull of the stage 6 blades.

d) 3280 rpm is therefore the upper limit of speed at which fragments of any disc could be released from the rotor.

e) the worst case fragment of the debladed no.6 (stage 8) disc is more massive and energetic than a corresponding fragment of any other disc. Hence the bounding case is to assume that at the burst speed for no.4 disc (3280rpm) there is a consequential failure of the debladed no.6 disc. The mass and energies of the corresponding worst case fragment (120°) at the instant of fracture are listed below together with the corresponding values for the original case.

	Original Analysis 3000rpm	Revised Analysis 3280rpm
Fragment Mass (lb)	8650	8650
Translational Energy (10^6ft lbf)	60.8	72.2
Rotational Energy (10^6ft lbf)	33.0	39.2

f) part of the fragment energy at the instant of fracture is lost in penetrating the surrounding casing and therefore the escape energy is less than the values given above. An estimate of the total losses for the debladed case has been made by scaling the dependent losses and the resultant escape energy for the debladed case relative to the original are given below.

	Original Analysis 3000rpm	Revised Analysis 3280rpm
Translational Escape Energy (10^6ft lbf)	34.2	42.5
Rotational Escape Energy (10^6ft lbf)	6.1	9.1

App. #5 Pg. ~~A16~~ A17
DC-5144

3. Cyclic Loading of Foundation

Drawing no. R5031/2572 gives details of the cyclic loads for a fault condition corresponding to the less at rated speed of 3 adjacent last stage blades. The centrifugal pull in this condition is equivalent to 1.6×10^6lbs (705 imperial tons). During the incident on 25th December 1993 5 adjacent last stage blade aerofoils were lost. The centrifugal pull in this case would have been 2.6×10^6lbs (1159 imperial tons).

P.M.McGuire,
Head of Blading Design Group.

Copy: Mr.H.Sahiner - Fermi 2

App. #5 Pg. ~~A17~~ A18

DC-5144

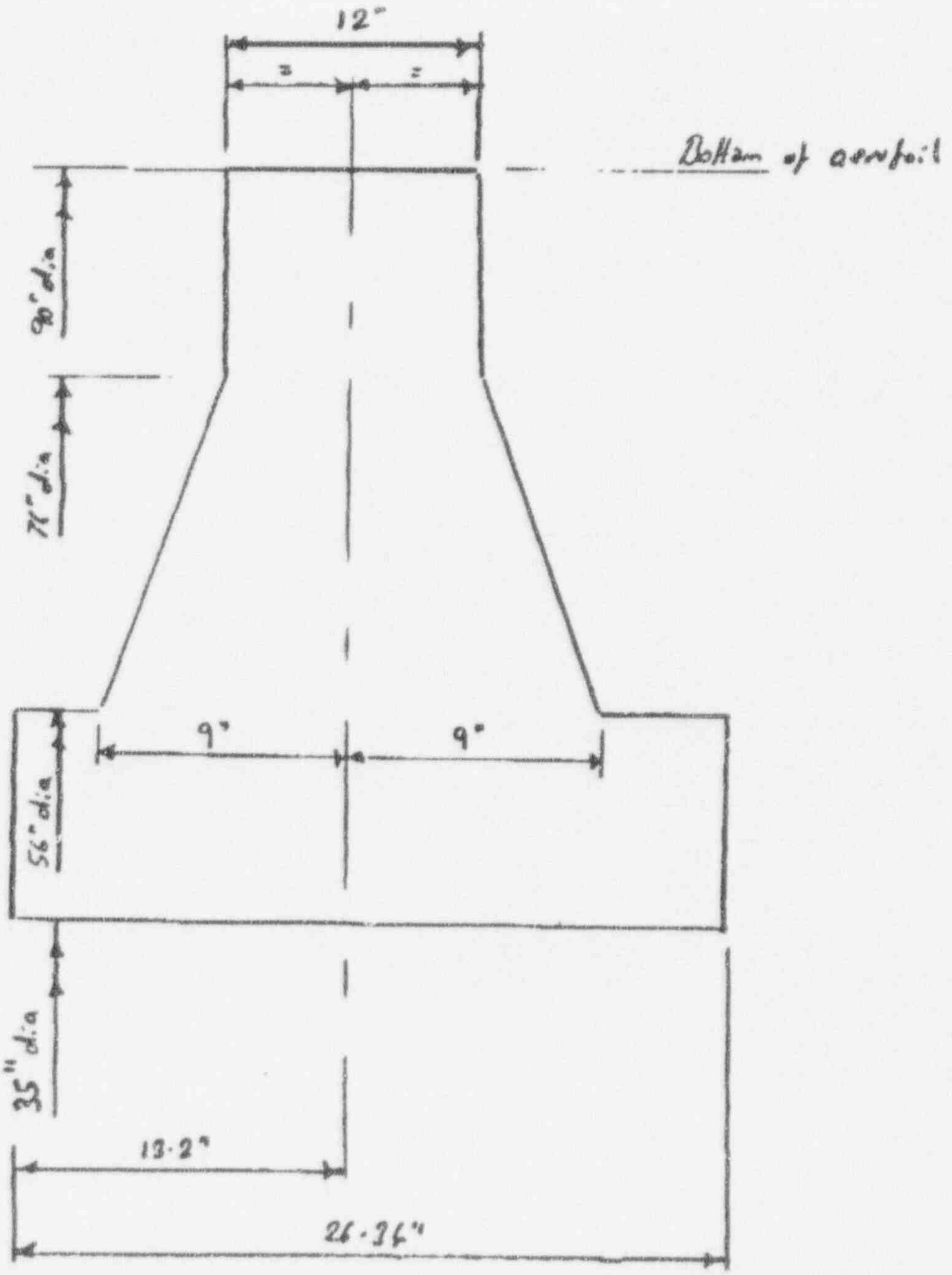
Fermi 2 LP Rotor

Blade and Disc Weights

Disc No.	Disc Wt. lbs	Stage No.	No.of Blades/row	Wt. of Each Blade lbs
1	17,300	1	299	0.65
		2	299	0.85
2	17,650	3	299	1.10
		4	237	2.30
3	11,500	5	189	4.45
4	14,600	6	152	11.10
5	20,100	7	132	22.10
6	25,950	8	64	90.30

Note:
1. Disc weight includes blade root.
2. Blade weight is the weight of the aerofoil section, plus shroud and lacing wire/rods as appropriate.
3. In those cases where different blade heights are used in LP2 cylinder the figure given above is for the heaviest blade.

App. #5 Pg. ~~A18~~ A19
DC-5177



Fermi 2

Dimensions of LP No. 6 (Stg. 8) Disc

15.8.94

END

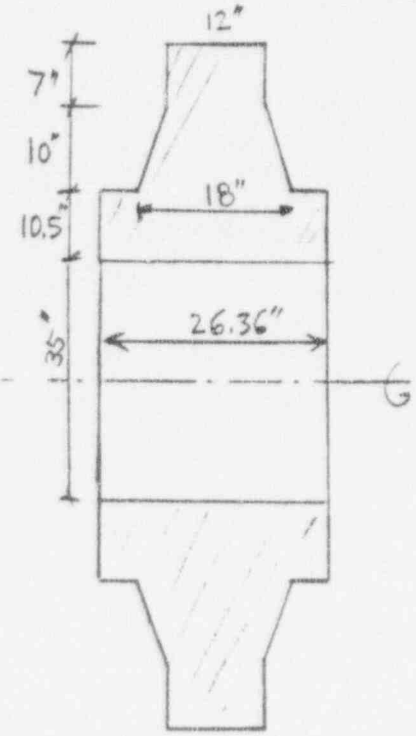
Turbine Missile characteristics:

LAST Stage disc Weight: 25,950 lbs

120° Segment of last stage disc weight: $\frac{25,950}{3} = 8650$ lbs. (Design basis missile weight)

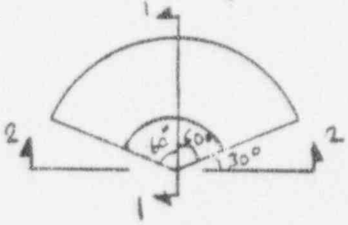
This weight includes the blade roots. This is the same as before modification.

The cross sectional areas of the disc segment: (Projected areas which have been used for air drag and penetration formulas)

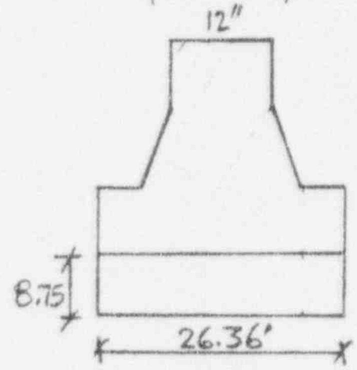


View 2-2

* Maximum projected area



120° Segment
Last stage disc



View 1-1

* Minimum Projected area

* These areas of the wheel fragment are taken in a plane perpendicular to the shaft axis, as defined in GE Report TR67SL211, Pg 40 & 72.

This section of calc.s are performed to verify the initial calc. values used which were taken from referenced documents. Ref ① and ②

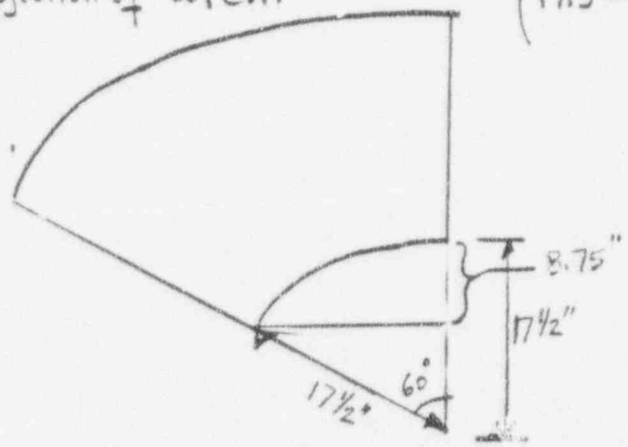
Minimum Projected area:

$(12\times7)+10\times\left(\frac{12+18}{2}\right)+10.5\times26.34=510.78\,in^2\Rightarrow3.55\,ft^2$

Projection of arch: $(17.5-17.5\times\cos60^\circ)\times26.36=230.65\,in^2\Rightarrow1.6\,ft^2$

$A_{Min}=3.55+1.6=5.15\,ft^2$

Used in references. $5.12\,ft^2$ O.K.



120° Segment min. Projection

Maximum Projected area: As shown on view 2-2, 120° segment horizontal projection area is calculated.

Outer section area (combed): $3.55\times2=7.10\,ft^2$
Center " " : $35\times26.36\times\frac{1}{144}=6.41\,ft^2$

Total area: $7.10+6.41=13.51\,ft^2$
Projection: $13.51\times\cos30^\circ=13.51\times0.866=11.70\,ft^2$. $11.65\,ft^2$ used in references

∴ O.K.

Using the original projected areas; Average proj. area: $\frac{11.65+5.12}{2}=8.39\,ft^2$

ATTACHMENT 14

NUCLEAR GENERATION MEMORANDUM

Date: October 17, 1994 File 0801.21
TMPE-94-0588

To: R. A. Newkirk, Supervisor
Licensing & RA

From: K. E. Howard, Supervisor K. E. Howard
Mechanical & Civil

Subject: **Turbine Overhead Crane**

During the turbine incident, a missile had hit and dented the Turbine Building overhead crane east girder at approximately 4'-10" north of column row 4. As we had stated earlier, an engineering evaluation had concluded that this dent did not have any significant impact and was left as-found. Since the event, major lifts have been performed by the overhead crane. The largest load, close to the design limit of the crane, was the generator stator lift. This load was 425 tons and both turbine cranes (each with 250 tons capacity) were used simultaneously. The attachments (one drawing and two sketches) will clarify the location of the hit/dent relative to the generator lift. The exact crane wheel locations during the lift and laydown positions, superimposed on the dent location of the east girder are also included in the attachments. It is clear that during the generator lift all four wheels of the north crane and the northern wheel of the south crane were on the girder span between column lines 4 and 5, where the hit had occurred. After lifting the 425 tons, the cranes traveled simultaneously 12 feet south and placed the generator on the floor. During this travel, two southern wheels of the north crane passed over the dented location. Later, the generator was placed back into its original location.

In addition to this lift, many heavy turbine components were moved over the hit location and either laid down on the southern area of the floor or sent out through the equipment hatch. Our inspection following these lifts found the crane structure in satisfactory condition, as stated in our previous response, dated September 26, 1994.

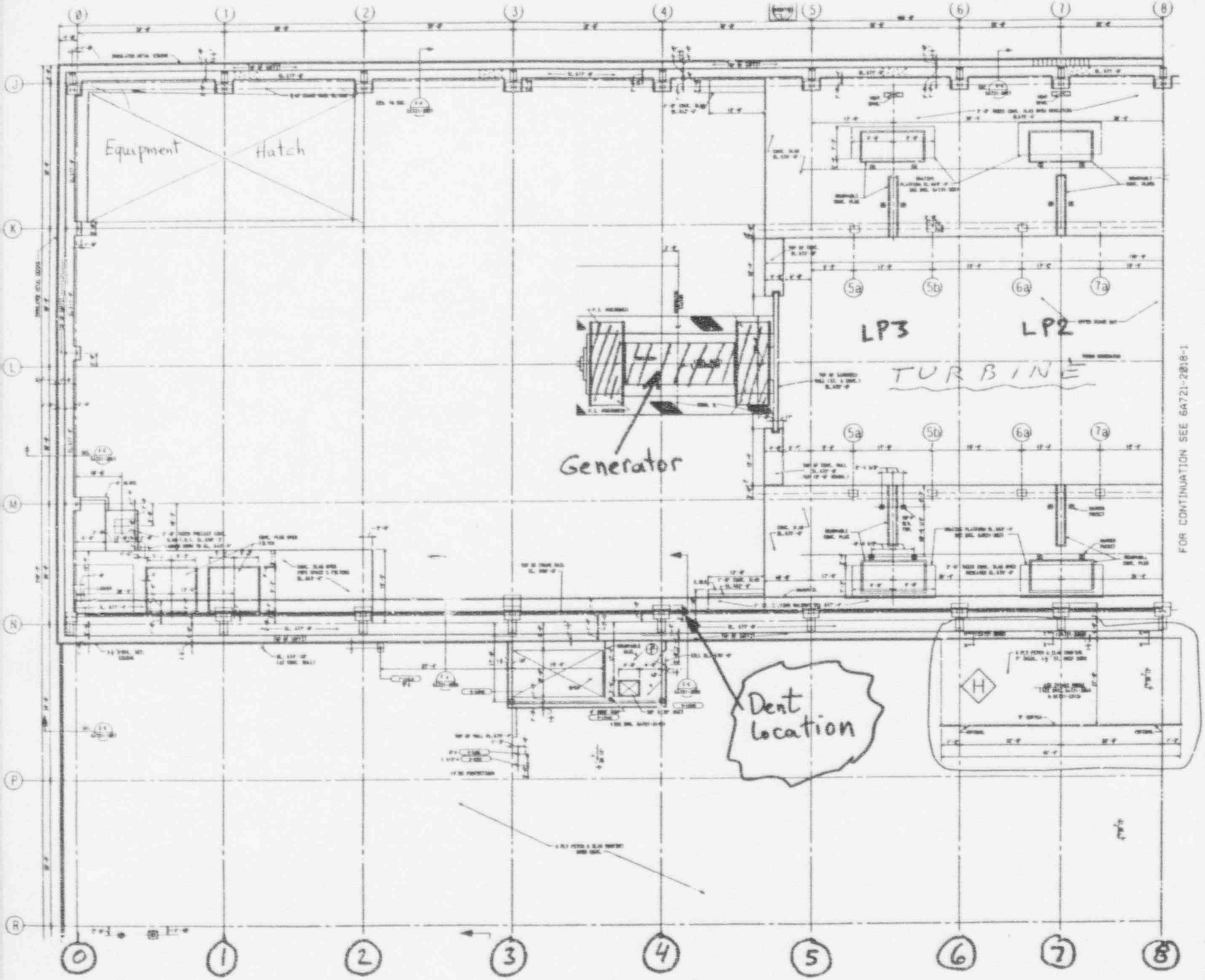
Written By: H. Sahiner

HS:dsb

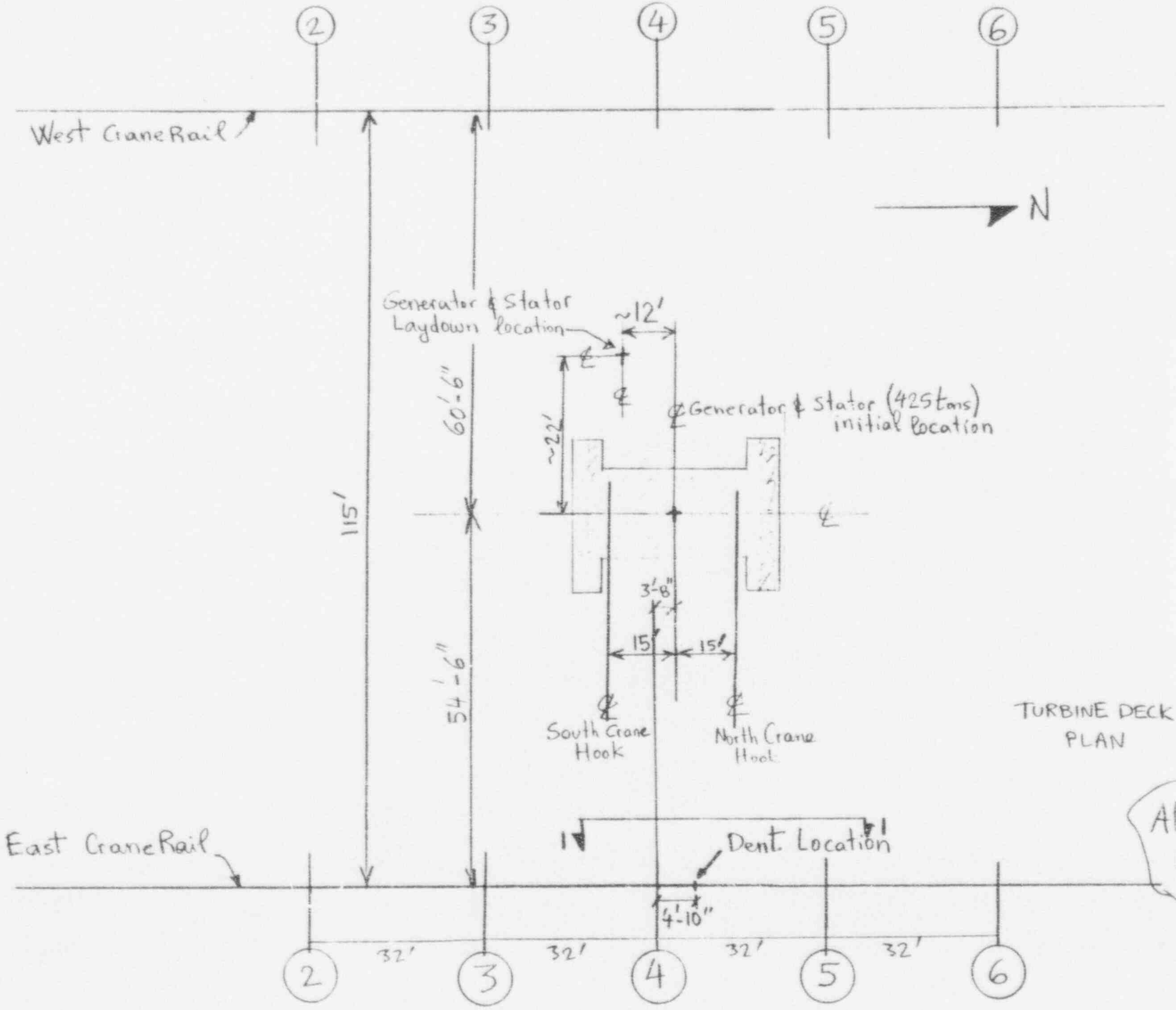
Attachments

cc: A. M. Alchalabi
ETS Correspondence

Attachment
Page 1/3



6A721-2018
Turbine House
Lower Roof Plan &
Crane Bay



TURBINE DECK
PLAN

Attachment
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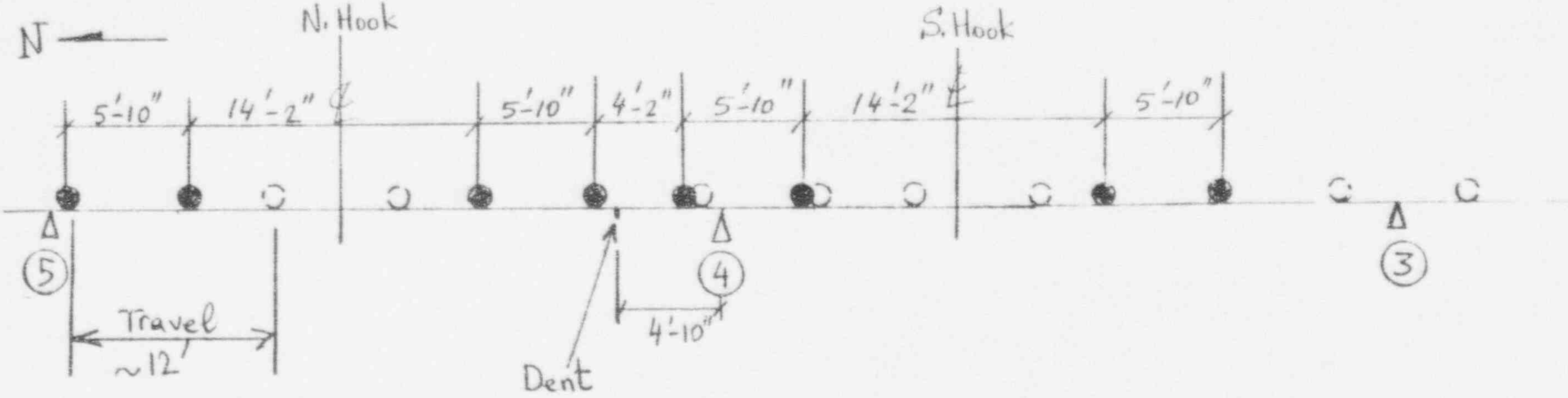

SECTION 1-1
East girder-looking East

Δ → columns
● → wheel locations when removing the generator from its foundation
○ → wheel locations at laydown area

Dent location details were submitted in DC-5882 Vol. I. [Attachment A, Page 13.]

Attachment
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ATTACHMENT 15