ANALYSIS OF EFFECTS OF FLOODING ON SAXTON CONTAINMENT VESSEL

NUS-TM-EP-11

Prepared
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Prepared for

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SUMMARY

The Saxton Reactor Facility is located on the Juanita River in Saxton, Pennsylvania. On the same river, but 42.3 river miles downstream of the Saxton Site, the U.S. Corps of Engineers is constructing the Raystown flood control dam which will be completed in November 1973. A flooding evaluation performed by the Corps of Engineers predicted the following flood recurrence/flood level/inundation period data for the Saxton Site.

Period of Flood Recurrence	Without Raystown Dam		With Raystown Dam	
	Level	Period of Inundation	Level	Period of Inundation
225 yr.	811.5'	8 hrs.	812.0'	12 hrs.
1,500 yr.	821.7'	30 hrs.	822.5'	52 hrs.
15,000 yr.	836.2'	NA	839.0'	NA

The general grade elevation of the Saxton site is 811.0 feet above mean sea level. The level of the reactor operating floor is 812.0' and this is the elevation below which there is substantial inside support of the 0.69 inch steel containment sheel. The vessel is supported by the rotary bridge crane support ring between elevations 838.7' and 843.7' and by the hemispherical head above that.

Because potential flooding levels (of floods more severe than the 225 year flood) would exert an external pressure on the unsupported cylindrical section of the containment vessel, a stress analysis was performed to determine the maximum external flooding pressure that the vessel can withstand without buckling or collapse. This analysis is given in the Appendix.

The method of analysis was to assume that the containment vessel acts as a cylindrical thin-wall shell, uniformly loaded by external pressure, and then to verify or determine the following:

a. Whether collapse will be inelastic or elastic
b. Whether vessel acts as a long free tube or constrained tube
c. The uniform external pressure at which elastic buckling occurs
d. Effect of elipticity on critical pressure

The results were then compared with ASME Section III Design Bases and with the expected flood loadings.

The results of this analysis verified that the vessel will act as a constrained wall tube and that it can satisfactorily withstand uniform external pressures up to 5.84 psig. Since the pressure of flood waters rising to the Standard Project Flood (1500 yr flood) level of 822.5' would exert a maximum external pressure of less than 5 psig at the operating floor level, it is concluded that no structural damage to the containment vessel will result.

APPENDIX A

FLOODING PRESSURE ON SAXTON CONTAINMENT VESSEL

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SUBJECT Flooding Pressure on Saxton Containment Vessel BY B. Blackmon

Purpose of Analysis: To determine the maximum external flooding pressure that the Saxton Containment vessel will withstand to verify adequacy for 1500 yr flood rise.

Method of Analysis: Assume that containment vessel acts as a cylindrical thin-wall shell, uniformly loaded by external pressure.

Determine the following:

1. Whether collapse will be inelastic or elastic.
2. Whether vessel acts as a long free tube or constrained tube
3. External pressure at which elastic buckling occurs
4. Effect of elipticity on critical pressure.
5. Compare results with ASME Section III Design basis.
6. Compare results with expected flooding loadings.

References: 1. Roark, R.J. Formulas for Stress and Strain, 4th Edition, New York: McGraw-Hill, 1965

2. Timoshenko, S. Strength of Materials Part II, Advanced Theory and Problems, 3rd Edition, New York, Van Nostrand, 1956.

3. ASME Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components, 1971 Edition, New York, ASME, 1971

Design Data

Vessel radius = 25 feet
Vessel thickness = 0.6875 inches
Operating floor level = 812.0 feet above mean sea level
Polar Crane Support level = 838.67 feet above m.s.l.

Vessel material = ASTM A201 carbon Steel

$E = 29 \times 10^6$ psi
$\nu = 0.27$ (poisson's ratio)
$S_y = 30,000$ psi minimum

1. Determination of Inelastic Collapse Pressure

(Case 1, Table XIV, p298, Ref 1)

$$p' = \frac{t}{R}\left(\frac{S_y}{1 + 4\frac{S_y}{E}\left(\frac{R}{t}\right)^2}\right)$$

but this holds only for

$$\frac{p'R}{t} > \text{Proportional limit}$$

try 6psi $\frac{p'R}{t} = \frac{(6)(300)}{(0.6875)} = 2618 \text{ psi}$

2618 psi << proportional limit

∴ Collapse is not inelastic; formula does not hold

2. Determination of Free tube Collapse

(Case 30, Table XVI, p354, Ref 1)

$$p' = \frac{1}{4}\frac{E}{1-\nu^2}\left(\frac{t^3}{r^3}\right)$$ critical pressure at which elastic bending occurs

formula holds when

$$L > 4.90r\sqrt{\frac{r}{t}}$$

$$4.90\, r \sqrt{\frac{r}{t}} = (4.90)(300)\sqrt{\frac{300}{0.6875}}$$

$$= 30,700\,\text{in} \cong 2560\,\text{ft}$$

but height (unrestrained) = 26.75 ft

∴ Vessel acts as a restrained cylinder.

3 Determination of external pressure at which elastic buckling occurs for short tube, ends held circular

(Case 31, Table XVI, p354, Ref 1)

$$p' = 0.807 \frac{Et^2}{lr} \sqrt[4]{\left(\frac{1}{1-\nu^2}\right)^3 \frac{t^2}{r^2}}$$

$$l = 838.67 - 812.0 = 26'8" = 320"$$

$$p' = \frac{(0.807)(29\times10^6)(0.6875)^2}{(320)(300)} \sqrt[4]{\left(\frac{1}{1-.27^2}\right)^3 \left(\frac{0.6875}{300}\right)^2}$$

$$= 5.84\ \text{psi}$$

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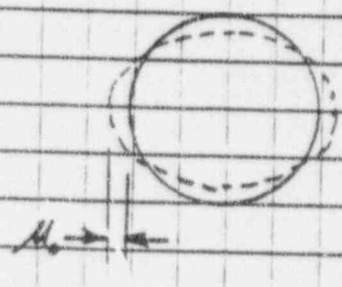
SUBJECT ________ BY BJK

4. Effect of Ellipticity on critical Buckling pressure

(Reference 2, pp 189 - 193)

NB: Treatment is for long thin tubes, for which the buckling will occur by a simple elliptical collapse. For short tubes, with edges built in or supported, the buckling is multinodal, i.e. the tube subdivides during buckling in several waves along the circumference, with the effect of initial ellipticity being less and less important. For these reasons, this analysis provides a conservative upper bound on effect of ellipticity. (See sketch)



Mode of buckling for long, thin tube

Mode of buckling for short tube with constrained ends.

$$p_{cr} = \frac{E h^3}{4(1-\mu^2)R^3}$$ (Eq. 158, p 189, Ref 2)

$$p_{cr} = \frac{(29\times10^6)(0.6875)^3}{4(1-.27^2)(300)^3} = 0.094 \text{ psi}$$

(this is critical pressure for long thin tube, used here only to determine effects of ellipticity.)

The limiting value of pressure is the pressure at which yielding of the material begins. Denoting this as p_{yp}, the following formula is derived by Timoshenko for the yield point

$$\sigma_{yp} = \frac{p_{yp} R}{h} + \frac{6 p_{yp} R u_0}{h^2} \cdot \frac{1}{1 - \frac{p_{yp}}{p_{cr}}}$$ (Eq. k, p 192, Ref 2)

where p_{yp} = limiting pressure with ellipticity
p_{cr} = critical pressure without ellipticity
R = radius of cylinder
h = thickness of cylinder
u_0 = initial deviation (see sketch, p 5)
σ_{yp} = yield strength, = 30,000 psi min

Rearranging:

$$P_{yp} = \frac{\sigma_{yp}}{\frac{R}{h}\left(1 + \frac{6U_o}{h}\left[\frac{1}{1 - P_{yp}/P_{cr}}\right]\right)}$$

Substituting in values of σ_{yp}, R, h yields

$$P_{yp} = \frac{30,000}{436\left(1 + 8.73U_o\left[\frac{1}{1 - 10.64P_{yp}}\right]\right)}$$

Solution is by trial-and-error, yields following results

U_o	P_{yp}	P_{yp}/P_{cr}
1"	0.0929	0.988
2"	0.0918	0.978
3"	0.0907	0.965
4"	0.0897	0.954
6"	0.0877	0.933

The effect of as high as 3" initial deviation on the reduction of critical stress is only 3.7%. This would require a difference in measured diameter from major to minor axis of 1 foot, which is considered unreasonable.
∴ Ellipticity is <u>not</u> a problem.

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SUBJECT ______ BY BJM

5 Comparison of Results with ASME Section III Design Bases

(See p 85-86 of Ref 3)

These formula give the allowable external design pressure for cylindrical shells under stress from uniform external pressure loading. The permissible external pressure is 120 percent of that given by the rules of NB-3133 (See Section NB-3224.2)

Following Section 3133.3,

$$t = 0.6875 \text{ inches}$$
$$L/D_o = (26.67)/(50) = 0.533$$
$$D_o/t = (600)/(0.6875) = 873$$

From Figure VII-1100-2, (See page 9)
FACTOR B = 1500

$$P_a = \frac{4}{3}\frac{B}{D_o/t} = \frac{(4)(1500)}{(3)(873)} = 2.29 \text{ psi}$$

From Section NB-3224.2, Maximum permissible pressure is 1.20 x P_a or 2.75 psi

Note that the Section III analysis gives conservatively lower allowable uniform external pressure than does Roark, viz. 2.75 psi vs 5.89 psi

From ASME Boiler and Pressure Vessel Code, Section III
Nuclear Power Plant Components, 1971 Ed.

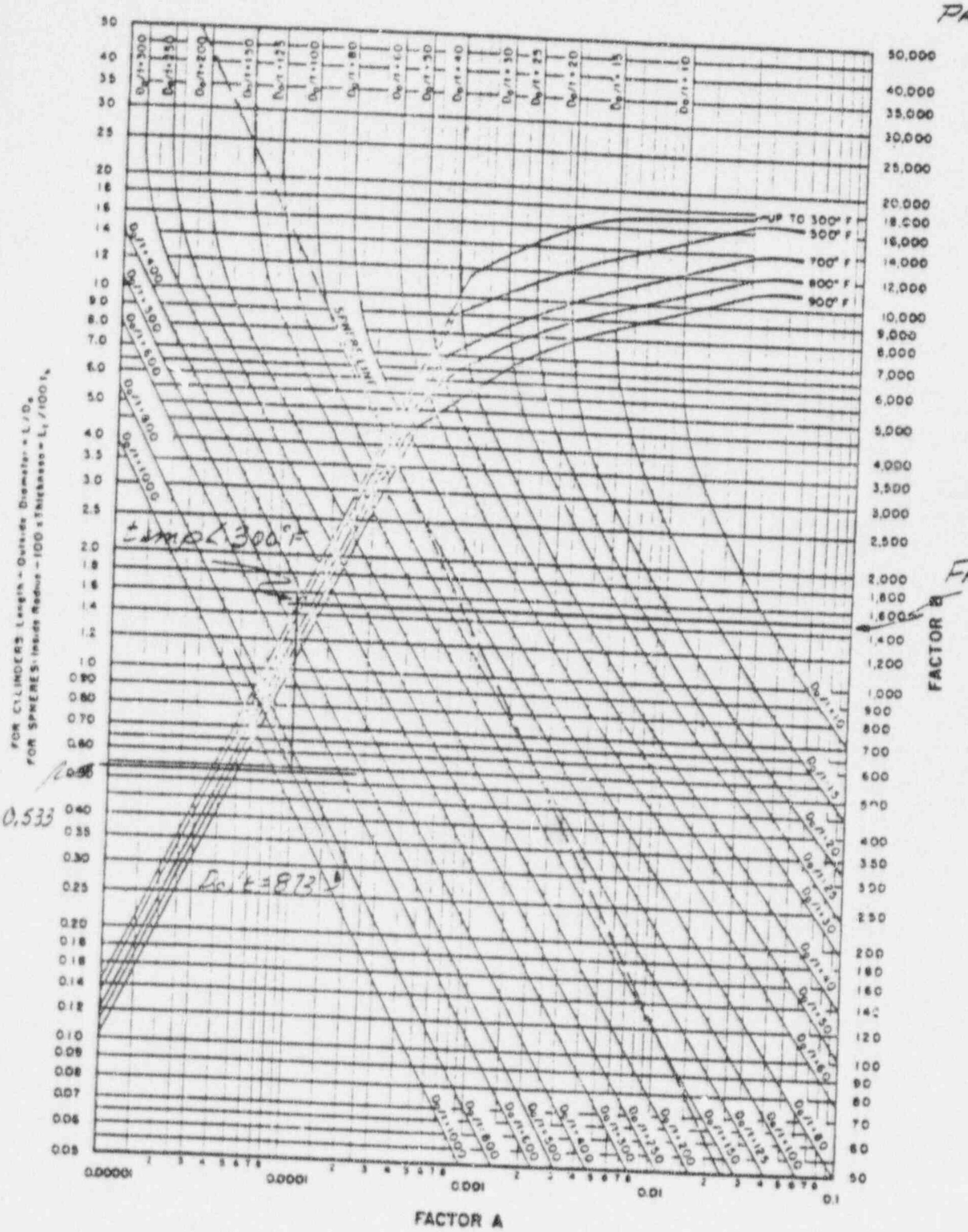

FIG. VII-1100-2 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF CARBON STEEL (Specified Yield Strength 30,000 to 38,000 psi inclusive) AND TYPE 405 AND TYPE 410 STAINLESS STEEL

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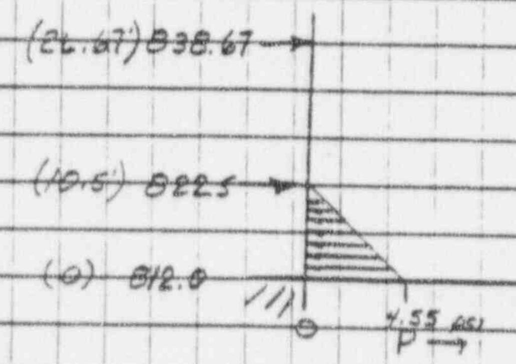
6 Comparison of Results with Expected flood loading

Maximum flood level = 822.5 feet above msl.

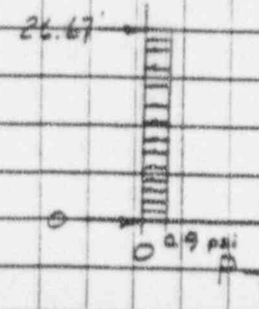
(This is the 1500 yr or Standard Project Flood as defined by the Corps of Engineers, with the Raystown Dam)

With this flooding, the actual external pressure loading on the containment will be as follows:



This loading can be conservatively applied as a uniform loading over the entire unsupported height of 26.67 feet by dividing the area under the pressure-height curve by the actual height:

$$P(\text{uniform}) = \frac{(4.55)\left(\frac{10.5}{2}\right)}{(26.67)} = \underline{0.90\ psi}$$



This average pressure is significantly lower than the critical pressure for buckling.

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The actual height of water from the Standard Project Flood is 10.5 ft above the operating floor. The average external pressure over this height is equal to:

$$p\,(\text{uniform, over flood height}) = \frac{4.55}{2} = 2.28 \text{ psi}$$

Even if this pressure were applied uniformly over the entire unsupported height of the vessel wall, it would be lower than the critical pressure for buckling.

Conclusion: Flooding of the Saxton site will not cause buckling of the containment shell, and no damage to the containment vessel would be expected from the Standard Project Flood (1500 yr flood), with or without the Raystown Dam in operation.