SEISMIC QUALIFICATION REPORT FOR
THE WASTE HOLD-UP TANK
AT THE R. E. GINNA PLANT

Prepared for

ROCHESTER GAS & ELECTRIC COMPANY
89 East Avenue
Rochester, New York

September 1983

Prepared by

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Topsfield, Massachusetts

[illegible]

CERTIFICATION

The undersigned, a registered Professional Engineer, competent in the field of component stress analysis, certifies that to the best of his knowledge and belief the analysis calculations for the subject tanks as presented in this seismic stress report comply with the provisions of the applicable portions of the ASME Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components and standard acceptable engineering practice.

Components: Horizontal Waste Hold-Up Tank
Plant: R. E. Ginna

COMMONWEALTH OF MASSACHUSETTS
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SEISMIC QUALIFICATION REPORT FOR

HORIZONTAL WASTE HOLD-UP TANK

AT THE R. E. GINNA PLANT

Revision 0, September 1983

Prepared by ______________________
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Walter Djordjevic

SA

TABLE OF CONTENTS

APPENDICES

FIGURES

TABLES

S&A

1. INTRODUCTION

The ability of the waste hold-up tank to withstand dead weight and SSE seismic forces is investigated in this evaluation.

The waste hold-up tank is a horizontal thin cylindrical shell with spherical heads. The tank is supported by three saddle supports, each of which is anchored to the concrete mat through four (4) 1-inch bolts. There is no specific code requirement for this tank; however, in the following analysis, ASME III, Class C criteria will be adopted. The tank has a total volume of 2,866 ft^3 and a design temperature of 150^0F.

Figure 1 shows the sketches of the waste hold-up tank and the saddle support. Analysis is made assuming the full weight of water. The total weight of water is 202.8 kips and the total weight of steel is 24 kips.

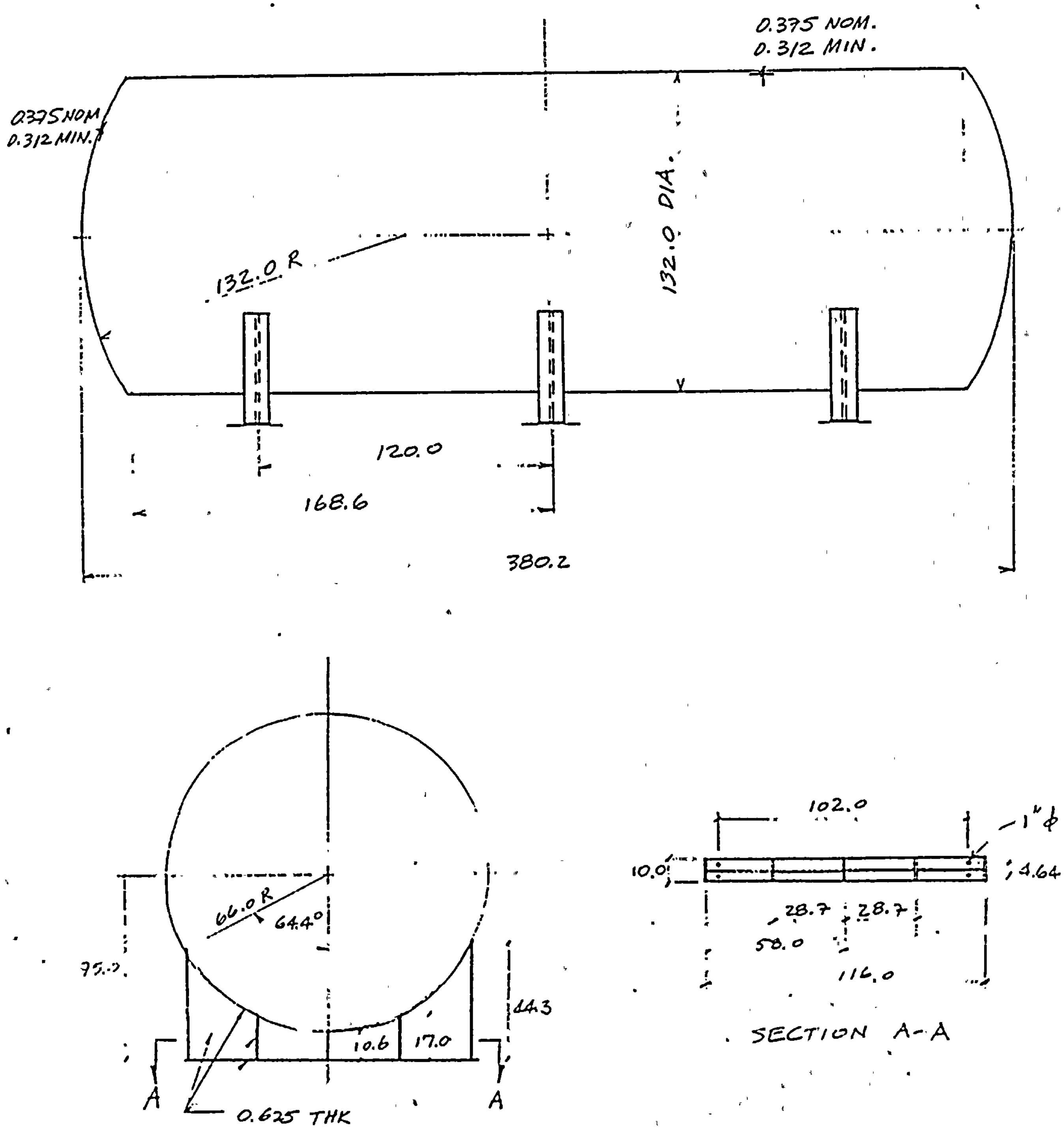

FIGURE 1
ELEVATION VIEW OF THE HORIZONTAL WASTE HOLD-UP TANK

2. RESULTS

The results of the analysis indicate that all parts of the waste hold-up tank resist the combination of the dead weight and faulted seismic load within the limits of the acceptance criteria.

Results of the dynamic modal response analysis are summarized in Table 1. The components of the waste hold-up tank were checked for stresses due to dead weight and seismic forces. Table 2 summarizes the results of stress analysis.

The minimum factor of safety in the tank shell is 1.23 for the local bending at the horn of saddle support. The minimum factor of safety for the saddle support is 1.11 for the flange bending. Analysis results indicate that dead weight is the major loading component and the stress due to seismic loads is minor except in the anchorage.

	TRANSVERSE MODE	LONGITUDINAL MODE
Frequency (Hz)	36.9	23
Spectral Acceleration (g)	0.17	0.19

TABLE 1 MODAL RESPONSES

COMPONENT	MAXIMUM STRESS (ksi)	ALLOWABLE STRESS (ksi)	MINIMUM SAFETY FACTOR
TANK WALL			
Membrane Stress	4.7	35.6	7.57
Local Bending Stress	65	80	1.23
Ring Compression	11.9	35.6	2.99
SPHERICAL HEAD			
Membrane Tension	1.2	35.6	29.7
ANCHOR BOLTS			
Tensile Stress	17.4	40.6	2.33
SADDLE SUPPORT			
Tension in Flange	1.0	24	24.0
Flange Bending	35.7	39.6	1.11
Web Compression	1.6	45	28.1
Center Stiffener	4.0	36	9.0
End Stiffener	2.9	36	12.4
[illegible]DING			
Tank-Saddle	9.5	36	3.79

TABLE 2 CALCULATED MAXIMUM STRESSES AND SAFETY MARGINS

3. LOAD CRITERIA AND FAILURE MODE ASSUMPTIONS

Analysis loads for the waste hold-up tank consist of the dead weight of the tank and content, and seismic loads in two horizontal and the vertical directions. The seismic loads are defined by the site specific ground response spectrum for R. E. Ginna as specified by the USNRC [1] for a ZPA of 0.17g. Figure 2 shows the response spectrum curve. The full spectrum was used for the horizontal analysis. Two thirds of the full spectrum was used for the vertical analysis.

Since the fundamental frequency of the tank is 23 Hz, the damping value is not important for the analysis.

Failure modes considered in this evaluation include:

- o tank wall yielding
- o anchor bolt yielding
- o saddle flange yielding
- o web yielding
- o stiffener buckling

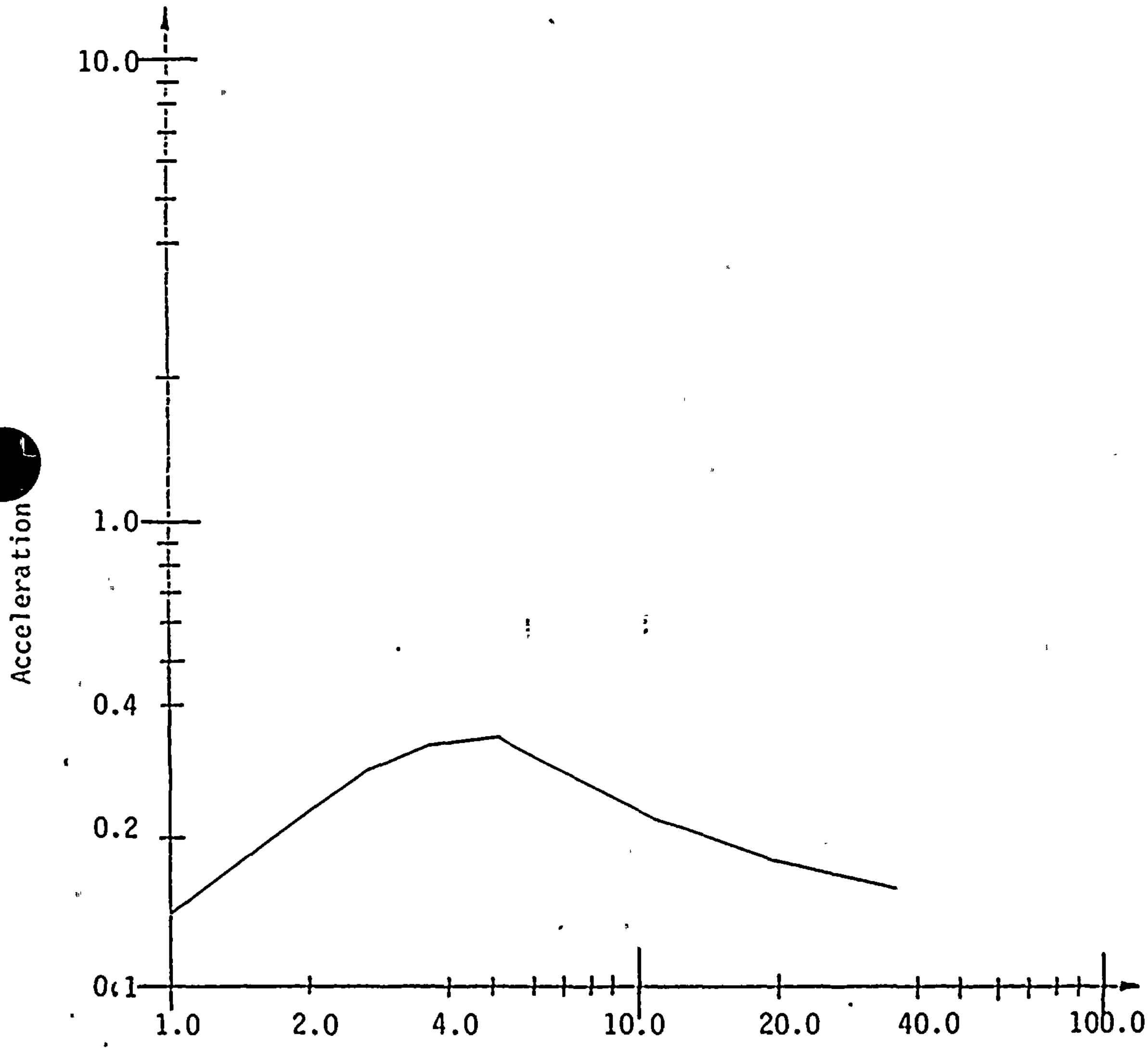

FIGURE 2
USNRC SITE SPECIFIC GROUND RESPONSE
SPECTRUM FOR R. E. GINNA (7% DAMPING)

4. ALLOWABLE STRESS CRITERIA

Allowable stresses used in this analysis are based on ASME B&PV Code, Section III, Division I [2], Subsections NC and NF.

For tank wall yielding,

$$\sigma_m \leqslant 2S$$

where σ_m = maximum principal stress
S = allowable stress from Ref. 2, Table I-7.1

For local secondary stress,

$$(\sigma_m + \sigma_b) \leqslant (1.5)\ (3.0)S,$$

where σ_b = local secondary bending stress and the shape factor for plastic stress redistribution is 1.5.

For anchor bolts,

$$F_{tb} = 0.7\ S_u,$$

where S_u = ultimate strength of the material at temperature (Table I-13.3).

For the saddle support,

$$F_t = \frac{2}{3}\ (2.0)\ (0.6)\ S_y,$$

where S_y = yield strength from Table I-13.3, and 2/3 is the factor suggested in Reference 3, .

$$F_b = (2.0)\ (0.66)\ S_y$$

For the stiffneers in compression,

$$F_c = (2.0)\ (0.6)\ S_y$$

For the web in compression,

$$F_c = (2.0)\ (0.75)\ S_y$$

For the welding stresses,

Allowable Stress = (2.0)S

where S = allowable stress from Table NF-3292.1-1

5. METHOD OF ANALYSIS

Analysis of the stresses under dead weight follows the procedure by Zick [3], and where applicable, the additional factor of safety suggested in Reference 3 is also included in the allowable stress calculations. For the dynamic response analysis, the following assumptions were made:

- o Saddle support is rigid in the transverse mode of vibration.
- o Tank body is rigid in the longitudinal mode of vibration.

The sloshing effects are not considered in this evaluation.

6. REFERENCES

1. USNRC Letter LS05-81-06-068, "Site Specific Ground Response Spectra for SEP Plants Located in the Eastern United States," June 17, 1981.

2. ASME, Boiler and Pressure Vessel Code, Section III, Division I, 1980.

3. Zick, L. P., "Stresses in Large Horizontal Cylindrical Pressure Vessels on Two Saddle Supports," Welding Research Supplement, pp. 435-445, September 1951.

APPENDIX A

ANALYTICAL CALCULATIONS

SYSTEM . Waste Hold-up Tank

COMPONENT NAME Waste Hold-up Tank COMPONENT Nº N/A

LOCATION Auxiliary Building ELEVATION 236'

COMPONENT SAFETY FUNCTION: ACTIVE ☐ PASSIVE 1 ☐ 2 ☒

S-LIST PAGE Nº N/A

METHOD OF ANALYSIS: Analytical Stress Analysis

SPECTRAL CURVES USED: Site Specific Ground Spectrum for R.E. Ginna (see 83C2209-DR-005, File 3)

DAMPING VALUE ASSUMED: 7%

ACCEPTANCE BEHAVIOR CRITERIA USED: ASME B&PV Code, Section III, 1980.

COMPUTER CODE USED: N/A

REMARKS:

S&A	DESIGN REPORT COVER SHEET FIGURE 9.0	CONTRACT Nº 83C2209	REV. Nº	0
			BY	TMT
			DATE	8/31/83
			CHK'D	WD
			DATE	8/31/83
			APPR.	SA
			DATE	9/6/83

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SUBJECT GINNA WASTE HOLDUP TANK

SHEET 1 OF 38
JOB No. 83C2209
BY TMT DATE 8/26/83
CHKD. BY ______ DATE ______
REV. No. ______ APP: ______

TABLE OF CONTENTS

Introduction

The ability of the waste holdup tank to withstand dead weight and seismic force is investigated in this calculation. The design conditions and geometry of the tank are explained in p. 5 and 6.

Analysis loads consist of the dead weight of the tank and contents in full, and seismic loads in two horizontal and the vertical directions. The seismic loads are based on the site specific ground spectrum for R. E. GINNA specified in the USNRC letter LS 05-81-06-068, "Site Specific Ground Response Spectra for SEP plants Located in the Eastern United States," June 17, 1981.

Stress analysis of the tank for dead weight follows the procedure developed by Zick (1951). For dynamic response analysis, reasonable behavior of the tank body and the saddle support is assumed. Since the design condition is full

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SUBJECT GINNA WASTE HOLDUP TANK

SHEET 3 OF 38
JOB No. 83C2209
BY TMT DATE 8/26/83
CHKD. BY WJ DATE 8/26/83
REV. No. APP:

water content, sloshing effect of non-full tank is not considered.

The acceptance criteria are

1. Tank wall material stress: The stresses developed in the tank wall are compared to material allowables per ASME code NC3800

2. Saddle support and anchorage stresses: These include the stresses in the bolts, stiffeners, web, and top flange. Allowables are calculated per ASME code, NF3300

3. Since Zick's procedure is used in stress analysis, the additional multiplier on allowable stresses as suggested by Zick are also incorporated.

Waste Holdup Tank

Design conditions: (Ref: Document 83C2209-DR-002)

Code: No code

Volume: 2866 ft^3

Pressure: Atmosphere

Temperature: 150 °F

Materials: Tank — stainless steel
Saddle support — unknown

In the analysis, Type 304 stainless steel is assumed for tank and A285 Gr.C steel for saddle support and A307 steel for anchor bolts.

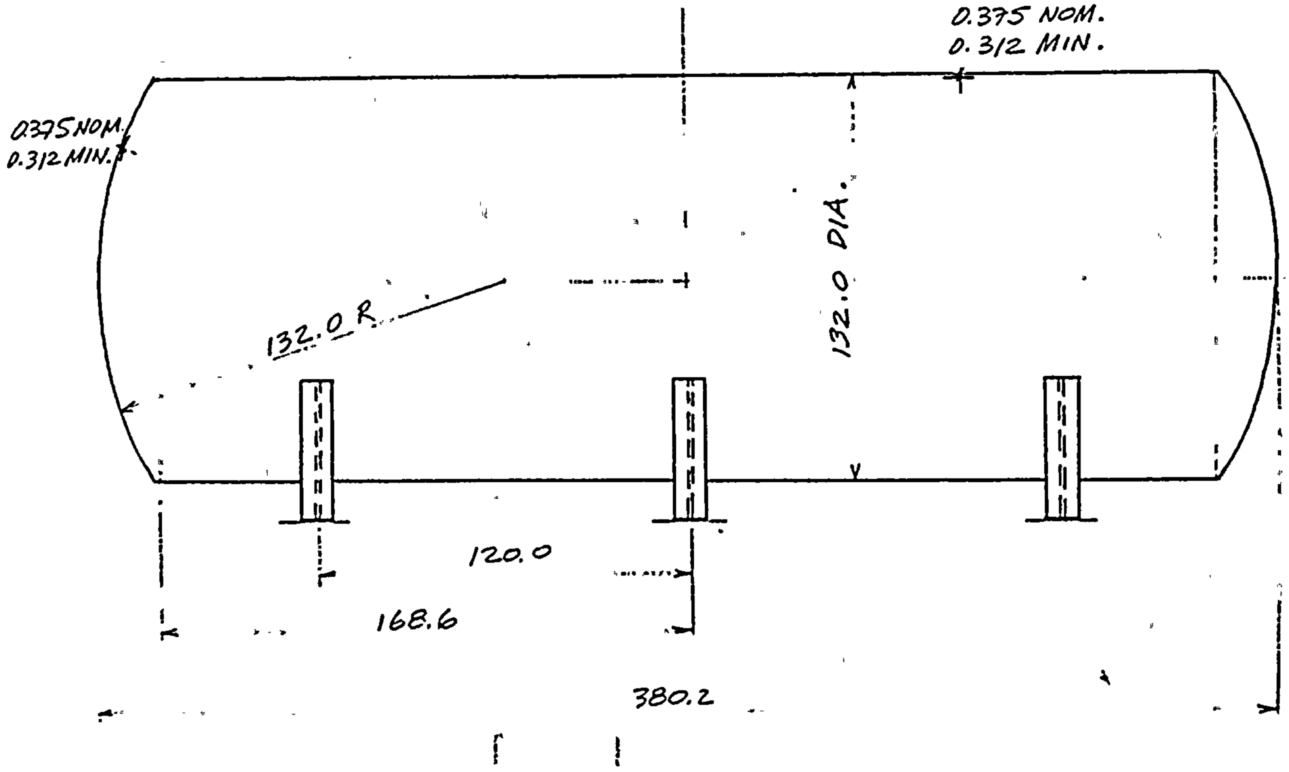
Weight of water	62.4 x 2866 =	178,800 lbs
Weight of steel		24,000 lbs
Total Weight		✓202,800 lbs

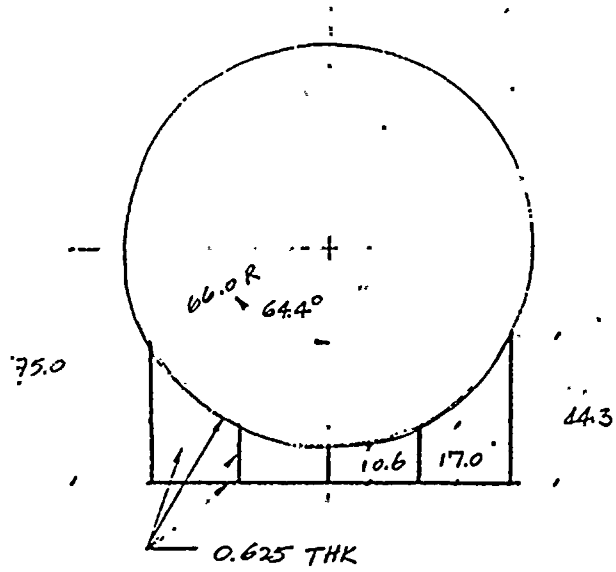
(Ref.: Document 83C2209-DR-004)

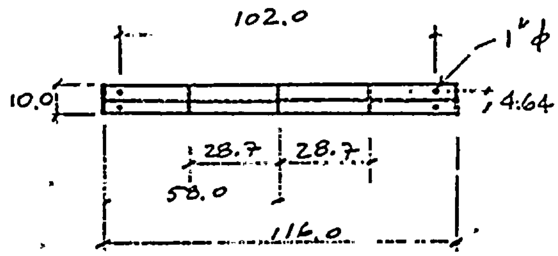
The thickness of the tank is: 0.375 in nominal and 0.312" minimum. The nominal thickness is used in the subsequent analysis.

SHEET 5/38

BY TMT 8/22/83







S&A STEVENSON & ASSOCIATES a structural-mechanical consulting engineering firm	SUBJECT GINNA WASTE HOLDUP TANK	SHEET 6 OF 38 JOB No. 83C2209 BY TMT DATE 8/22/83 CHKD. BY WD DATE 8/29/83 REV. No. APP:

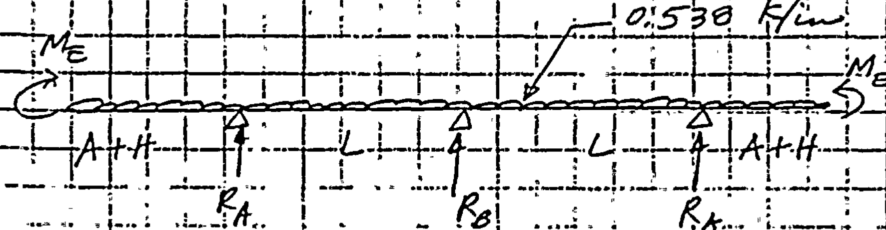
Dead Load Stress Analysis

Weight per unit length $= \frac{62.4 \times \pi \times 66^2 + 490 \times 2\pi \times 66 \times 0.375}{1728000}$

$= 0.538$ K/in

Equivalent beam length $= \frac{202.8}{0.538} = 377$ in

Two span continuous beam

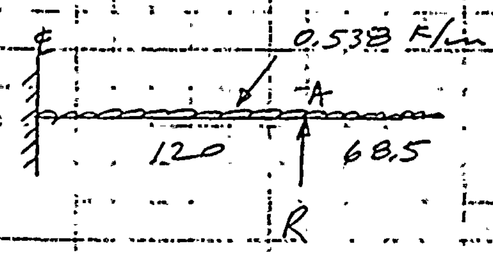


$L = 120$ in

$A = 168.6 - 120 \div 2$

$= 50.6$ in

$H = 377/2 - 120 - 50.6 = 17.9$ in



$\delta_A = \frac{0.538}{24EI}\left(68.5^4 - 4(68.5)(188.5)^3 + 3(188.5)^4\right)$

$- \frac{R(120)^3}{3EI} = 0$

↑ (Ref. AISC 8th ed. pp. 2-120, 2-121)

$R = 76.8$ kips

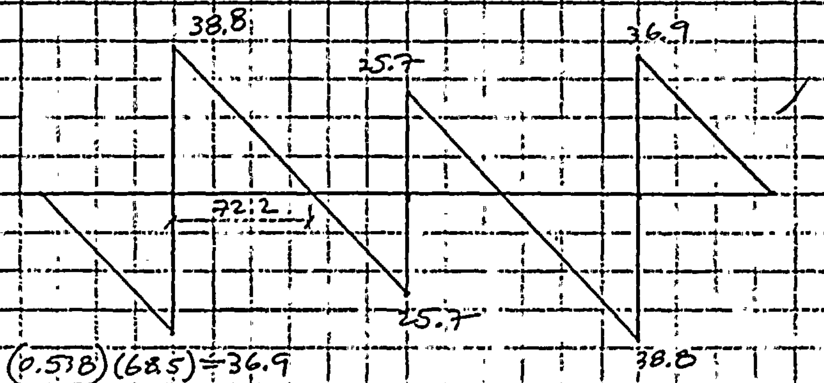
End moment correction (the spherical head produces no moment at the junction with cylindrical part) $M_E = \frac{1}{2}(0.538)(17.9)^2 = 86.2$ K-in

STEVENSON & ASSOCIATES a structural-mechanical consulting engineering firm	SUBJECT: GINNA WASTE HOLDUP TANK	SHEET 9 OF 38 JOB No. 83C2209 BY TMT DATE 8/22/83 CHKD. BY WD DATE 8/29/83 REV. No. ____ APP: ____

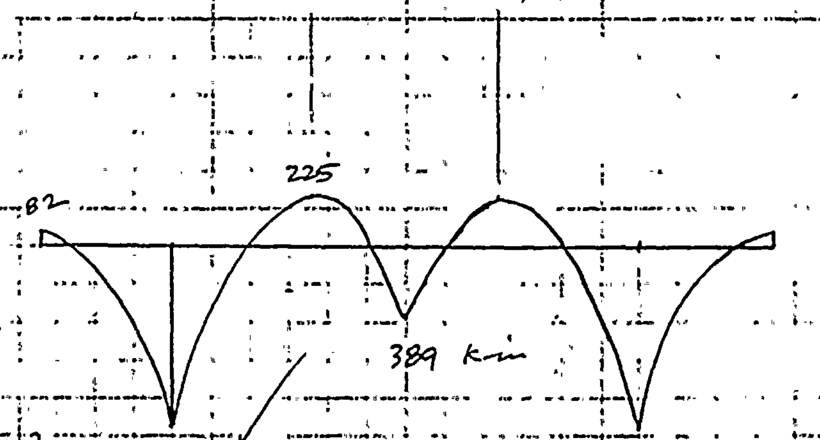
$$R_A = 76.8 - \left(\tfrac{1}{2}\,86.2\,(120)^2\right) / \left(120^3/3\right) = 75.7 \text{ kips}$$

$$R_B = 202.8 - 2 \times 75.7 = 51.4 \text{ kips} \qquad \frac{75.7}{202.8} = 0.373$$

Shear diagram



Moment diagram



$$\tfrac{1}{2}\,0.538\,(68.5)^2 - 86.2 = 1176$$

Calculate stresses according to Zick's procedure

- Maximum longitudinal bending stress at max. (+) moment

$$S = \pi R^2 t = \pi (66)^2 (0.375) = 5130 \text{ in}^3$$

$$\sigma_{xm} = \frac{225}{5130} = \underline{0.04 \text{ ksi}}$$ ✓

- Maximum longitudinal bending stress in the shell in the plane of end saddle

Effective arc of the unstiffened shell

$$2\Delta = 2\left[\frac{\pi}{180}\left(64.4 + \frac{180 - 64.4}{6}\right)\right] = 2.92 \text{ rad}$$ ✓

$$S = \pi R^2 t \left[\frac{\Delta + \sin\Delta\cos\Delta - (2\sin^2\Delta/\Delta)}{\pi(\sin\Delta/\Delta - \cos\Delta)}\right]$$ ✓

$$= 621 \text{ in}^3$$ ✓

$$\sigma_{xm} = \frac{1176}{621} = \underline{1.9 \text{ ksi}}$$ ✓

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SUBJECT: GINNA WASTE HOLDUP TANK

SHEET 9 OF 38
JOB No. 83C2209
BY TNT DATE 8/22/83
CHKD. BY WD DATE 8/29/83
REV. No. APP:

- Maximum shear stress in the plane of the end saddle

$A > R/2 = 33$ (unstiffened by head)

Effective angle $2\Delta = \frac{2\pi}{180}\left[64.4 + \frac{180-64.4}{20}\right]$

$= 2.45$

$\alpha = \pi - \Delta = 1.915$

$$\sigma_{x\phi} = \frac{38.8}{(66)(0.375)(\pi - \alpha + \sin\alpha\cos\alpha)}$$

$= 1.7$ ksi

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SUBJECT GINNA WASTE HOLDUP TANK

SHEET 10 OF 38
JOB No. 83C2209
BY TMT DATE 8/22/83
CHKD. BY WD DATE 8/29/83
REV. No. APP:

- Circumferential Stress at Horn of Saddle

End saddle

$A/R = 50.6/66 = 0.77$ (some stiffening from head)

$\theta = 128.8°$

$K_3 = 0.029$

$M_\beta = K_3 Q r$

$= 0.029 \times 75.7 \times 66$

$= 145$ k-in

Effective length that resist the moment is the smaller of

$L/2 + A = 110.6$ in ← governs

or $4R = 264$ in

$$\sigma_{\phi b} = \frac{145}{110.6 \times \frac{0.375^2}{6}} = 56 \text{ ksi}$$

Center saddle

No head stiffening

$\theta = 120.0°$ ✓

$K_6 = 0.046$ ✓

Effective length = 120 in

$M_\beta = 0.046 \times 51.4 \times 66 = 156$ k-in

$\sigma_{\phi 6} = \dfrac{156}{120 \times \dfrac{0.375^2}{6}} = 55$ ksi ✓

- Ring compression at the horn of end saddle

$\sigma_{\phi m} = \dfrac{Q}{4t(b + 1.56\sqrt{rt})} = \dfrac{75.7}{4(0.375)(10 + 1.56\sqrt{66 \times 0.375})}$ ✓

$= 2.8$ ksi ✓

Center saddle $\sigma_{\phi m} = 2.8 \times \dfrac{51.4}{75.7} = 1.9$ ksi ✓

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SUBJECT: GINNA WASTE HOLDUP TANK

SHEET 12 OF 38
JOB No. 83C2209
BY TMT DATE 8/23/83
CHKD. BY [signature] DATE 8/31/83
REV. No. ____ APP: ____

• Ring Compression in the Shell over the saddle

$$T_\pi = Q(1+\cos\alpha)/(\pi-\alpha+\sin\alpha\cos\alpha)$$

$$= 75.7(1+\cos 1.915)/(\pi-1.915+\sin 1.915\cos 1.915)$$

$$= 55.2 \text{ kips}$$

Maximum stress in compression

$$\sigma_{\phi m} = \frac{T_\pi}{t(b+10t)} = \frac{55.2}{0.375(10+3.75)} = 10.7 \text{ ksi}$$

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SUBJECT GINNA WASTE HOLDUP TANK

JOB No. 83C2209
BY TMT DATE 8/23/83
CHKD. BY WJ DATE 8/31/83
REV. No. APP:

- Additional tension in the head

$$\sigma'_{hm} = \frac{3Q}{8rt_h} \frac{\sin^2\alpha}{\pi - \alpha + \sin\alpha\cos\alpha}$$ ✓

← $\alpha = 1.915$

$$= \frac{0.366\ Q}{r\ t_h}$$

$$= \frac{0.366 \times 75.7}{66 \times 0.375}$$

$$= \underline{1.1\ \text{ksi}}$$ ✓

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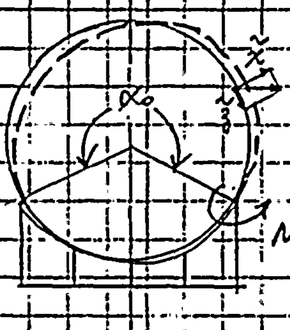
SUBJECT: GINNA WASTE HOLDUP TANK

SHEET 14 OF 38
JOB No. 83C2209
BY TMK DATE 8/23/83
CHKD. BY WJ DATE 8/24/83
REV. No. ____ APP. ____

Dynamic Response

- Fundamental mode in the lateral direction is assumed to have the shape



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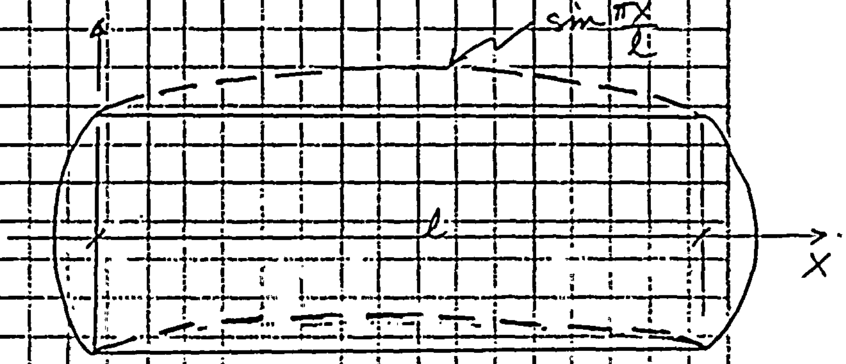


Top View

In the cross-section view, the mode looks like a fix-fix supported circular arc, the frequency is given in Blevins (P. 208) ✓

$$f_2 = \frac{\lambda_2^2}{2\pi (R\alpha_o)^2} \left[\frac{1 - 2\sigma_2^2\left(1 - \frac{2}{\sigma_2 \lambda_2}\right)\left(\frac{\alpha_o}{\lambda_2}\right)^2 + \left(\frac{\alpha_o}{\lambda_2}\right)^4}{1 + 5\sigma_2^2\left(1 - \frac{2}{\sigma_2\lambda_2}\right)\left(\frac{\alpha_o}{\lambda_2}\right)^2} \right]^{1/2} \left(\frac{EI}{m}\right)^{1/2}$$

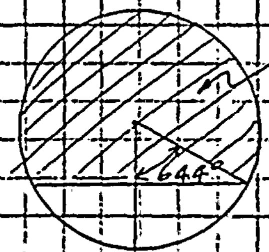
$\lambda_2 = 7.85$

$\sigma_2 = 1.0$

$\alpha_o = 4.035$

$$EI = 29000 \times \frac{1 \cdot 0.375^3}{12} = 127.4 \ \text{k-in}^2$$

m may be approximated by distributing the fluid mass uniformly on steel shell



$$\pi R^2 \frac{4.035}{2\pi} + \frac{1}{2} R^2 \sin 128.8$$

$$= 8788 + 169.8$$

$$= 10486 \ \text{in}^2$$

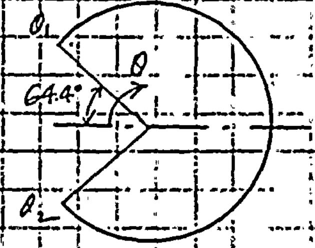
$$m = \frac{490 \times 0.375 + 62.4 \times 10486 / (66 \times 4.035)}{1728000 \cdot (386.4)} = 3.96 \times 10^{-6} \ \text{k-sec}^2/\text{in}^2$$

$$f_2 = \frac{7.85^2}{2\pi (66 \times 4.035)^2} \left[\frac{1 - \left(1 - \frac{2}{7.85}\right)\left(\frac{4.035}{7.85}\right)^2 + \left(\frac{4.035}{7.85}\right)^4}{1 + 5\left(1 - \frac{2}{7.85}\right)\left(\frac{4.035}{7.85}\right)^2} \right] \sqrt{\frac{127.4}{3.96 \times 10^{-6}}}$$

$$= 0.784 \times 0.44$$

$$= 0.345 \ \text{Hz}$$

In the longitudinal direction, the mode can be approximated by a pin-pin supported flexural beam with cross-section



$$I_1 = \int_{\theta_1}^{\theta_2} (R \sin\theta)^2 \, tR \, d\theta$$

$$= 2R^3 t \int_{\theta_1}^{\pi} \sin^2\theta \, d\theta$$

$$= 2R^3 t \left[\frac{\theta}{2} - \frac{\sin 2\theta}{4} \right]_{\theta_1}^{\pi}$$

$$= 2R^3 t \left[\frac{\pi - \theta_1}{2} + \frac{\sin 2\theta_1}{4} \right]$$

$\theta_1 = \pi \; 64.4/180 = 1.124$

$I_1 = 2.4 R^3 t = 2.59 \times 10^5 \text{ in}^4$

L_1 = Length of beam = 168.6 × 2 = 337.2 in

$$m_1 = \text{mass/unit length} = \frac{62.4 \times 10486 + 490 \times 66 \times 4.035 \times 0.375}{1728{,}000\,(386.4)}$$

$= 0.00105$ K-sec²/in²

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SUBJECT GINNA WASTE HOLDUP TANK

SHEET 17 OF 38
JOB No. 83C2209
BY TMT DATE 8/23/83
CHKD. BY WJ DATE 8/29/83
REV. No. APP:

$$f_1 = \frac{\pi}{2L_1^2}\sqrt{\frac{EI_1}{m_1}}$$

$$= \frac{\pi}{2(337.2)^2}\sqrt{\frac{29000 \times 2.59 \times 10^5}{0.00105}}$$

$$= 36.9 \text{ Hz}$$

Combined frequency

$$f = \left(f_1^2 + f_2^2\right)^{1/2} = \underline{36.9 \text{ Hz}} \Rightarrow \text{Rigid}$$

Modal moment at horn of saddle

$$M_\phi = \frac{Et^3}{12} \cdot \frac{1}{R^2} \frac{d\,\tilde{x}(0)}{d\alpha^2}$$

$$= \frac{Et^3}{6R^2}\left(\frac{\lambda_2}{\alpha_0}\right)^2$$

STEVENSON & ASSOCIATES a structural-mechanical consulting engineering firm	SUBJECT GINNA WASTE HOLDUP TANK	SHEET 18 OF 38 JOB No. 83C2209 BY TMT DATE 8/23/83 CHKD. BY WD DATE 8/29/83 REV. No. ______ APP: ______

Modal bending stress at horn of saddle with displacement ϕ_2 · 1 inch

$$\sigma_b^* = \frac{Et}{R^2}\left(\frac{\lambda_2}{\alpha_0}\right)^2$$

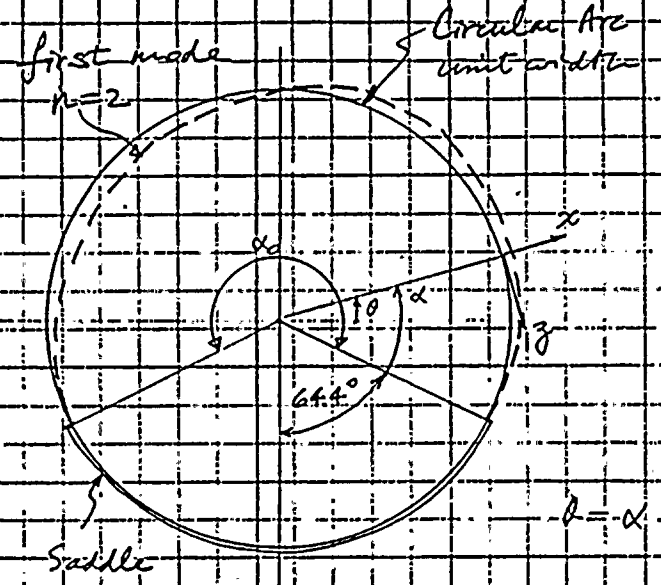
$$= \frac{29{,}000 \times 0.375}{66^2}\left(\frac{7.85}{4.035}\right)^2$$

$$= 9.45 \text{ ksi}$$ ✓

Spectral acceleration at 36.9 Hz is ZPA = 0.17 g ✓

STEVENSON & ASSOCIATES a structural-mechanical consulting engineering firm	SUBJECT GINNA WASTE HOLDUP TANK	SHEET 19 OF 38 JOB No. 83C2209 BY TMT DATE 8/23/83 CHKD. BY [initials] DATE 8/29/83 REV. No. ____ APP: ____

Calculation of Participation Factor for Lateral Mode



Mode shape: (Empty Tank)

$$\tilde{x} = \psi_n$$

$$\tilde{z} = \frac{\alpha_0}{\lambda_n}\left(\frac{1}{\lambda_n^3}\frac{d^3\psi_n}{d\left(\frac{\alpha}{\alpha_0}\right)^3} + 2\sigma_n\right)$$

Reference: Blevins p. 208

$$\theta = \alpha - \frac{\alpha_0 - \pi}{2}$$

from table 8-1, frame 7

$$\psi_n = \cosh\frac{\lambda_n\alpha}{\alpha_0} - \cos\frac{\lambda_n\alpha}{\alpha_0} - \sigma_n\left(\sinh\frac{\lambda_n\alpha}{\alpha_0} - \sin\frac{\lambda_n\alpha}{\alpha_0}\right)$$

$$\frac{d^3\psi_n}{d\left(\frac{\alpha}{\alpha_0}\right)^3} = \lambda_n^3\left(\sinh\frac{\lambda_n\alpha}{\alpha_0} - \sin\frac{\lambda_n\alpha}{\alpha_0} - \sigma_n\left(\cosh\frac{\lambda_n\alpha}{\alpha_0} + \cos\frac{\lambda_n\alpha}{\alpha_0}\right)\right)$$

Assume mode shape of a full tank is the same as that of an empty tank, and that fluid participates in the horizontal direction only.

$$\Gamma_2 = \frac{\int_0^{\alpha_0} m(\tilde{x}\cos\theta + \tilde{z}\sin\theta)\, d\alpha}{\int_0^{\alpha_0} \left[m_f(\tilde{x}\cos\theta + \tilde{z}\sin\theta)^2 + m_s(\tilde{x}^2 + \tilde{z}^2) \right] d\alpha}$$

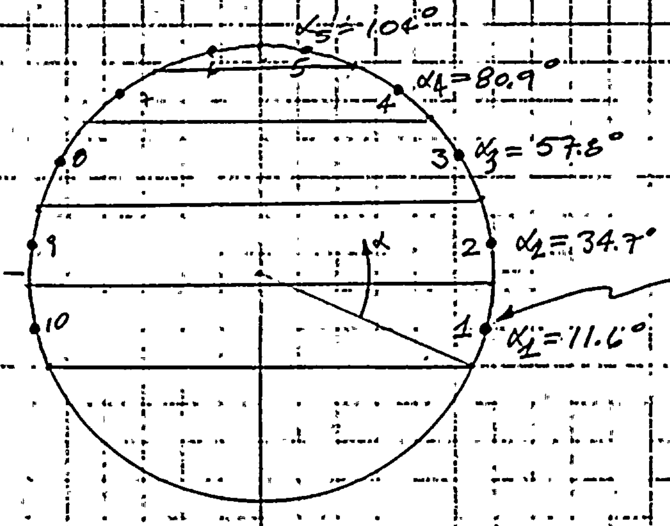
where $m = m_f + m_s$

m_s = shell mass / rad.

m_f = fluid mass associated with m_s

Discretize the system, cut α_0 into 10 equal sectors, $\alpha_0/10 = 23.1° = \Delta\alpha_i$

$\theta_i = \alpha_i - 25.6°$



due to symmetry, only one half needs to be summed.

$$\Gamma_2 = \frac{\sum_{i=1}^{5} m_i(\tilde{x}_i\cos\theta_i + \tilde{z}\sin\theta_i)}{\sum_{i=1}^{5}\left[m_{f_i}(\tilde{x}_i\cos\theta_i + \tilde{z}\sin\theta_i)^2 + m_s(\tilde{x}_i^2 + \tilde{z}_i^2)\right]}$$

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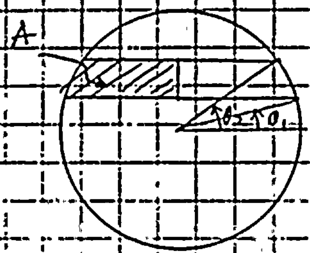
SUBJECT: GINNA WASTE HOLDUP TANK

SHEET 21 OF 38
JOB No. 83C2209
BY TMT DATE 8/23/83
CHKD. BY WD DATE 8/29/83
REV. No. ____ APP: ____

$$m_{si} = \rho_s \frac{\pi}{180} \frac{\alpha_0}{10} R t = 0.404 \rho_s R t$$



$$A = R^2 \left(\frac{\theta_2 - \theta_1}{2} + \frac{\sin 2\theta_2 - \sin 2\theta_1}{4} \right)$$

NODE	α_i	m_{si}	θ_1	θ_2	$m_{fi} = A_i \rho_w$
1	11.6	$0.404 \rho_s R t$	-25.6	-2.5	$0.375 \rho_w R^2$
2	34.7	↓	-2.5	20.6	$0.388 \rho_w R^2$
3	57.8	↓	20.6	43.8	$0.288 \rho_w R^2$
4	80.9	↓	43.8	66.9	$0.132 \rho_w R^2$
5	104	↓	66.9	90	$0.021 \rho_w R^2$

First mode

$n = 2$

$\lambda_2 = 7.85$

$\sigma_2 = 1.00$

SHEET 22/38

BY TMT 8/23/83

BASIC Program calculating Γ_2

WD check by Biggs' Table 5.1 OK

```
DEFINT I-L
DEF FN COSH(X)=(EXP(X)+EXP(-X))/2
DEF FN SINH(X)=(EXP(X)-EXP(-X))/2
DIM A(5),M(5)
PI=3.14159
A(1)=11.6:A(2)=34.7:A(3)=57.8:A(4)=80.9:A(5)=104
FOR I=1 TO 5:A(I)=PI*A(I)/180:NEXT I
M(1)=.375:M(2)=.388:M(3)=.288:M(4)=.132:M(5)=.021
S=1!:D=7.85:A0=4.035:T=.375:R=66
SUM1=0:SUM2=0:MS=.404*7.85*T/R
FOR I=1 TO 5:B=D*A(I)/A0
X=COSH(B)-COS(B)-S*(SINH(B)-SIN(B))
Z=A0*(SINH(B)-SIN(B)-S*(COSH(B)+COS(B))+2*S)/D
TH=A(I)-.447:XHOR=X*COS(TH)+Z*SIN(TH)
SUM1=SUM1+(M(I)+MS)*XHOR
SUM2=SUM2+M(I)*XHOR^2+MS*(X*X+Z*Z)
NEXT I
GAMMA=SUM1/SUM2
PRINT "GAMMA = ";GAMMA
```

Γ = .5004235 ⟹ $k_m = 0.5$ uniform mass OK

• Maximum bending stress at horn of saddle is

$K_M = \frac{\Sigma M_Y \phi_i}{\Sigma M_Y} = 0.5$ uniform mass

$$\sigma_b = \Gamma_1 \Gamma_2 \phi_{1max} \frac{S_a}{\omega^2} \sigma_b^{*} = \underbrace{1.273}_{4/\pi} \times 0.5 \times 1 \times \frac{0.17 \times 386.4}{(2\pi(36.9))^2} \times 9.45$$

$$= \underline{0.007 \text{ ksi}}$$

• Maximum membrane stress

$$\sigma_m^{*} = \frac{EI}{S}\left(\frac{\pi}{L}\right)^2$$ assuming displacement $\phi_1(x)$ 1 inch

$$= ER\left(\frac{\pi}{L}\right)^2$$

$$\sigma_m = \Gamma_1 \Gamma_2 \phi_{2max} \frac{S_a}{\omega^2} ER\left(\frac{\pi}{L}\right)^2$$

$$\phi_{2max} = \tilde{z}\left(\frac{\alpha_0}{2}\right) = \frac{\alpha_0}{\lambda_2}\left(\sinh\frac{\lambda_2}{2} - \sin\frac{\lambda_2}{2} - \sigma_2\left(\cosh\frac{\lambda_2}{2} + \cos\frac{\lambda_2}{2}\right) + 2\sigma_2\right)$$

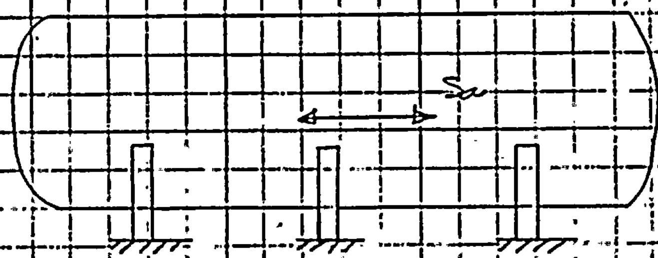
$$= \frac{4.035}{7.85}\left(\sinh 3.925 - \sin 3.925 - \cosh 3.925 - \cos 3.925 + 2\right)$$

$$= 1.75$$

$$\sigma_m = 1.273 \times 0.5 \times 1.75 \times \frac{0.17 \times 386.4}{(2\pi\ 36.9)^2} \times 29000 \times 66 \times \left(\frac{\pi}{337.2}\right)^2$$

$$= \underline{0.23 \text{ ksi}}$$

• Fundamental mode in the longitudinal direction

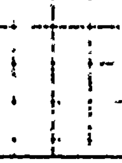


Assumptions:

✓ — Tank body is rigid, all the strain energy from saddle support

✓ — Saddle support acts like a cantilever bending – shear beam free at the junction with vessel and fixed at bottom.

Generalized stiffness for a cantilever beam



$$\frac{P}{\Delta} = \frac{1}{\frac{L}{GA_s} + \frac{L^3}{3EI}}$$ ✓

$A_s = \frac{5}{6} A$ for rectangular section

STEVENSON & ASSOCIATES a structural-mechanical consulting engineering firm	SUBJECT GINNA WASTE HOLDUP TANK	SHEET 25 OF 38
		JOB No. 83C2209
		BY TMT DATE 8/23/83
		CHKD. BY WD DATE 8/29/83
		REV. No ___ APP: ___

Stiffness

E = 29000 ksi ✓
G = 11000 ksi ✓

$A_s = \frac{5}{6} \times 10 \times 0.625$ ✓
$= 5.2$ ✓

$I = \frac{1}{12} \times 0.625 \times 10^3 = 52$

ELEMENTS	STIFFNESS	Quantity	Total
44.3" STIFFENER	$\dfrac{1000}{\frac{44.3}{11 \times 5.2} + \frac{44.3^3}{3 \times 29 \times 52}} = 50$	6 ✓	300
17.6" STIFFENER	$\dfrac{1000}{\frac{17}{11 \times 5.2} + \frac{17^3}{3 \times 29 \times 52}} = 723$	6 ✓	4340
10.6" STIFFENER	$\dfrac{1000}{\frac{10.6}{11 \times 5.2} + \frac{10.6^3}{3 \times 29 \times 52}} = 2230$ ✓	3 ✓	6690 ✓
			11330 k/in

Mass $\dfrac{202.8}{386.4} = 0.525$ k-sec²/in

$$f = \frac{1}{2\pi}\sqrt{\frac{11330}{0.525}} = 23 \text{ Hz}$$ ✓

Spectral acceleration $S_a = 0.19\,g$ ✓

Anchor Bolts Stresses

Moment for each pair of anchor bolts

$$M_b = 202.8 \times 0.19 \times \left(\frac{44.3 \times 300 + 17.0 \times 434.0 + 10.6 \times 669.}{1133.0} \right) \times 0.373/2$$

$$= 100 \text{ k-in}$$

Anchor bolt tensile area 1" φ $A_b = 0.606 \text{ in}^2$

(AISC 8th ed. p 4-141)

Anchor bolt stress due to longitudinal earthquake

$$\sigma_t = \frac{100}{4.64\,(0.606)} = 35.6 \text{ ksi}$$

Bolt stress due to transverse earthquake

rigid Sa

$$\sigma_t = \frac{202.8 \times 0.17 \times 75}{3 \times 102 \times 0.606\,(2)} = 6.97 \text{ ksi}$$

Maximum bolt stress

$$\sigma_t = \underbrace{(35.6^2 + 6.97^2)^{1/2}}_{36.3} - \frac{75.7}{4} = \underline{17.4 \text{ ksi}}$$

STEVENSON & ASSOCIATES a structural-mechanical consulting engineering firm	SUBJECT GINNA WASTE HOLDUP TANK	SHEET 27 OF 38 JOB No. 83C2209 BY TMT DATE 8/25/83 CHKD. BY WD DATE 8/29/83 REV. No. ____ APP: ____

Forces on Saddle Support

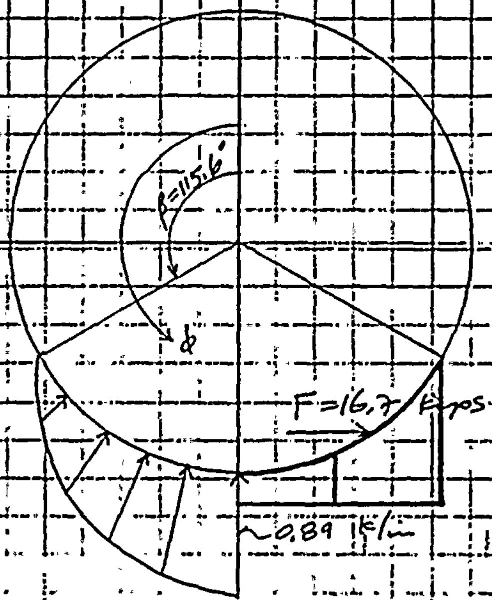
Dead load:

Radial forces:

$$p = \frac{Q}{R}\,\frac{\cos\beta - \cos\phi}{\pi - \beta + \sin\beta\cos\beta}$$

maximum at $\phi = 180°$

$$p_{\pi} = \frac{75.7}{66}\,\frac{1 - 0.432}{\pi - 2.02 - 0.39} = 0.89 \text{ k/in}$$



Horizontal force

$$F = \frac{Q(1+\cos\beta - 0.5\sin^2\beta)}{\pi - \beta + \sin\beta\cos\beta} = 0.22\,Q = 16.7 \text{ kips}$$

∴ Tension on cross-section

$$\sigma_t = \frac{F}{A} = \frac{16.7}{2\times10\times0.625 + 10.6\times0.625} = \underline{0.87 \text{ ksi}}$$

• Upper flange bending $a/b = 28.7/4.66 = 6.2$
⇒ one-way action

max moment $= 0.89 \times \frac{10-0.625}{4} = 2.09$ k-in/in

$$\sigma_b = \frac{2.09}{(0.625)^2/6} = \underline{32 \text{ ksi}}$$

bending stress in the other direction negligible.

• Web compressive stress near center:

$$\sigma_c = \frac{0.89}{0.625} = \underline{1.4 \text{ ksi}}$$

• Center stiffener in compression

$$\sigma_c = \frac{0.89 \times 28.7}{0.625 \times [(10-0.625)+28.7]} = \underline{1.1 \text{ ksi}}$$

• End stiffener in compression

$$\sigma_c = \frac{75.7 \times \frac{(58-28.7)}{2 \times 11.6}}{0.625 \times 10} = \underline{1.5 \text{ ksi}}$$

S&A STEVENSON & ASSOCIATES a structural-mechanical consulting engineering firm	SUBJECT GINNA WASTE HOLDUP TANK	SHEET 29 OF 38 JOB No. 83C2209 BY TMT DATE 8/25/83 CHKD. BY WD DATE 8/29/83 REV. No. APP:

Seismic loads:

(i) Longitudinal earthquake

- End stiffener bending stress

$$\sigma_b = \frac{202.8 \times 0.19 \times \frac{300}{11330} \times \frac{0.373}{2} \times 44.3}{52/5}$$

$= 0.8$ ksi

- Center stiffener bending stress

$$\sigma_b = \frac{202.8 \times 0.19 \times \frac{2230}{11330} \times 0.373 \times 10.6}{52/5}$$

$= 2.9$ ksi

STEVENSON & ASSOCIATES a structural-mechanical consulting engineering firm	SUBJECT GINNA WASTE HOLDUP TANK	SHEET 30 OF 38 JOB No. 83C2209 BY TNT DATE 8/25/83 CHKD. BY WJ DATE 8/30/83 REV. No. APP:

(ii) Transverse earthquake

- End stiffener axial compression

$$I = 2 \times 10 \times 0.625 \times (58^2 + 28.7^2) + \frac{1}{12} \times 0.625 \times 116^3$$

$$= 133\,600 \text{ in}^4$$

$$\sigma_c = \frac{202.8 \times 0.17 \times 75 \times 58}{133600} = 1.1 \text{ ksi}$$

S&A STEVENSON & ASSOCIATES a structural-mechanical consulting engineering firm	SUBJECT GINNA WASTE HOLDUP TANK	SHEET 31 OF 38 JOB No. 83C2209 BY TMT DATE 8/25/83 CHKD. BY WD DATE 8/30/83 REV. No. APP:

∴ Stresses in weldment between saddle plate and vessel 1/4" weld, 2" long every 6" c/c

Longitudinal seismic: — end saddle reaction

Shear $v_L = \dfrac{75.7 \times 0.19}{(0.707)\frac{1}{4}\underbrace{\left(2\pi \frac{644}{180} 66 \cdot \frac{2}{6}\right)}_{49.5}} = \underline{1.6}$ ksi ✓

Bending $f = \dfrac{(75.7 \times 0.19 / 116)(44.3)(6)}{(0.707)\frac{1}{4}(2)(10)} = \underline{9.3}$ ksi

Transverse seismic

Shear $v_t = 1.6 \times \dfrac{1.7}{1.9} = \underline{1.4}$ ksi ✓

max. Stress in weldment = $(1.6^2 + 9.3^2 + 1.4^2)^{1/2} = \underline{9.5}$ ksi ✓

STEVENSON & ASSOCIATES a structural-mechanical consulting engineering firm	SUBJECT: CoINNA WASTE HOLDUP TANK	SHEET 32 OF 38
		JOB No. 83C2209
		BY TMT DATE 8/26/83
		CHKD. BY WD DATE 8/30/83
		REV. No. APP:

Allowable Stresses

- Tank wall material

ASME code Appendix Table I-7.2, for Type 304 Stainless steel at 200°F

$S = 17.8$ ksi ✓

For Level D service limits, Table NC-3821.5-1 gives

$\sigma_m \leq 2S = 35.6$ ksi ✓

For (membrane + bending) stresses

$(\sigma_m + \sigma_b) \leq 2.4S = 43.9$ ksi ✓

Zick suggests an additional factor of 1.25 to this allowable with the argument that when the region at the horn of the saddle yields, the upper portion of the shell becomes a two-hinged arch which is still stable.

$(\sigma_m + \sigma_b) \leq 1.25 \times 43.9 = 54.9$ ksi ✓

ASME Secondary Stress Allowable 3.0 S (x 1.5 shape factor for plastic stress redistribution $\Rightarrow$ level Service B allowable is 4.5S = 80 ksi

S&A STEVENSON & ASSOCIATES a structural-mechanical consulting engineering firm	SUBJECT GINNA WASTE HOLDUP TANK	SHEET 33 OF 38 JOB No. 83C2209 BY TMT DATE 8/26/83 CHKD. BY WD DATE 8/30/83 REV. No. APP:

- Anchor bolts

From ASME code Table I-13.3, the tensile strength of A307 bolts is

$$S_u = 58 \text{ ksi}$$

For Level D service limits, Paragraph F-1370 gives

$$F_{tb} = 0.7 S_u = 40.6 \text{ ksi}$$ ✓

- Saddle Support, including flange, web, and stiffeners:

Material is A285 Gr. C which has $S_y = 30$ ksi and $S_u = 55$ ksi (ASME code Appendix Table I-7.1). The allowables will be based on Appendix XVII-2000 with an increase for Level D service limit in accordance with F-1370.

The increase is based on a factor of the lesser of ✓

$$\frac{1.2\, S_y}{F_t} = \frac{1.2\, S_y}{0.6\, S_y} = 2.0 \leftarrow \text{governs}$$

or.

$$\frac{0.7\, S_u}{F_t} = \frac{0.7 \times 55}{0.6 \times 30} = 2.14$$

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SUBJECT: GINNA WASTE HOLDUP TANK

SHEET 34 OF 38
JOB No. 83C2209
BY TMT DATE 8/26/93
CHKD. BY WD DATE 8/30/93
REV. No. ____ APP: ____

Tension allowable $F_t = 2.0 \times 0.6 \times 30 = 36$ ksi ✓

For top flange in tension, Zick suggests to use $\frac{2}{3} F_t = 24$ ksi

Bending allowable of flange

$$\text{width-thickness ratio} = \frac{4.66}{0.625} = 7.5 < \frac{65}{\sqrt{S_y}} = 11.9$$ ✓

⇒ compact section

$$F_b = 2.0 \times 0.66 \times 30 = 39.6 \text{ ksi}$$ ✓

Compression allowable for stiffeners can be taken as the same as tension

$$F_c = 36 \text{ ksi}$$ ✓

since critical buckling stress is much higher than yielding stress. For example, the theoretical buckling stress of the end stiffener, assuming simply-supported on three sides and free on the remaining side

$$\sigma_{cr} = \left(0.456 + \left(\frac{4.66}{44.3}\right)^2\right) \frac{\pi^2 \, 27700 \, 0.625^2}{12(1-0.3^2)\, 4.66^2}$$

$$= 210 \text{ ksi}$$ ✓

Ref. Timoshenko (1961), p 362

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Compressive allowable for web (XVII-2260)

$$\frac{10.6}{0.625} = 17 < \frac{14000}{\sqrt{30(30+16.5)}} = 375 \qquad OK$$

$$F_c = 2.0 \times \left(5.5 + \frac{4}{(28.7/10.6)^2}\right) \frac{10000}{(10.6/0.625)^2}$$

$$= 420 \text{ ksi}$$

$$\text{or } 2 \times 0.75\, S_y = \underline{45 \text{ ksi}}$$ ✓

Welding, from Table NF-3292.1-1, S = 18 ksi

Allowable = 2.0 × 18 = 36 ksi

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SUBJECT GINNA WASTE HOLDUP TANK

SHEET 36 OF 38
JOB No. 83C2209
BY TMT DATE 8/26/83
CHKD. BY WD DATE 8/30/83
REV. No. ____ APP: ____

Summary Table of Safety Margins

LOCATION	Dead Load stress (ksi)	Vertical Seismic (ksi)	Horizontal Seismic (ksi)	Total[2]	Allowable Stress
VESSEL					
• Mid-span					
σ_{xm}	0.04	~0	~0	0.04	35.6
• Plane of the Saddle					
σ_{xm}	1.9	0.2	0.23	2.2 }	
Shear $\sigma_{x\phi}$	1.7	0.2	0	1.9 } 4.7[1]	35.6
$\sigma_{\phi m}$	2.8	0.3	0.23	3.2 }	
$\sigma_{\phi b} + \sigma_{\phi m}$ *	56+2.8	6.2+0.3	0+0.23	65	80.0 *
Ring Compression $\sigma_{\phi m}$	10.7	1.2	0	11.9	35.6
• Head					
Tension σ_{hm}	1.1	0.1	0	1.2	35.6
• Anchor					
Tension σ_t	-18.9	2.1	36.3	17.4	40.6
• Saddle Support					
Tension in flange	0.87	0.1	0	0.97	24
Flange bending	32	3.5	0	35.7	39.6
Web compression	1.4	0.2	0	1.6	45
Center stiffener	1.1	0.1	2.9	4.0	36
End stiffener	1.5	0.2	1.4[3]	2.9	36
• Welding between Saddle and Vessel	0	0	9.5	9.5	36

* Local Secondary Stress + Level B EQ (OBE) < 4.5 S = 3.0 S × 1.5 Shape factor for rectangular section

Note that SSE EQ was used for conservatism

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SUBJECT: GINNA WASTE HOLDUP TANK

SHEET 37 OF 38
JOB No. 83C2209
BY TMT DATE 8/26/83
CHKD. BY WL DATE 8/30/83
REV. No. ____ APP: ____

(1) Maximum principal stress as determined by

$$\sigma_1 = \frac{\sigma_{xm} + \sigma_{\phi m}}{2} + \sqrt{\left(\frac{\sigma_{\phi m} - \sigma_{xm}}{2}\right)^2 + \sigma_{x\phi}^2}$$

(2) SRSS of horizontal and vertical seismic stresses plus dead load stress

(3) two horizontal seismic stress SRSSed:

STEVENSON & ASSOCIATES a structural-mechanical consulting engineering firm	SUBJECT GINNA WASTE HOLDUP TANK	SHEET 38 OF 38 JOB No. 83C2209 BY TMT DATE 8/24/83 CHKD. BY WD DATE 8/30/83 REV. No. ___ APP: ___

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