Section 7
Tanks and Heat Exchangers Review

7.0 INTRODUCTION

This section describes the guidelines which should be used for evaluating the seismic adequacy of those tanks and heat exchangers which are needed for safe shutdown during and following a Safe Shutdown Earthquake (SSE) as identified in Section 3.

[1]These guidelines may also be used for replacement of existing tanks and heat exchangers, as well as for the design and construction of new tanks and heat exchangers. However, for new flat-bottom vertical tanks, different attributes, as defined in Sections 7.3.3.1, 7.3.3.3, and 7.3.7, must be used in some of the evaluations rather than the attributes given for existing or replacement tanks.

The guidelines contained in this section are based on Reference 26. Note, however, that to provide consistency with the remainder of the GIP some of the nomenclature and symbols used in this section are slightly different than those used in Reference 26.

This section contains the SQUG commitments (Section 7.1), a description of the overall evaluation methodology (Section 7.2), the steps for verifying the seismic adequacy of vertical tanks (Section 7.3), the steps for verifying the seismic adequacy of horizontal tanks and heat exchangers (Section 7.4), a description of how to treat outliers (Section 7.5), and a description of how to document the results of the evaluations (Section 7.6).

Successful completion of the review described in this section for large, flat-bottom, cylindrical vertical tanks, which are needed for safe shutdown or for refueling water storage in PWRs, is considered an acceptable method for resolving the seismic issues related to these types of tanks for Unresolved Safety Issue (USI) A-40, Seismic Design Criteria, as it applies to operating plants.

7.1 SQUG COMMITMENTS

Members of SQUG adopting the Generic Implementation Procedure for USI A-46 resolution commit to the following in regard to the verification of seismic adequacy of tanks and heat exchangers. [2]As specified in GIP, Part I, Section 1.3, any substantial deviations from the SQUG Commitments must be justified to the NRC in writing prior to implementation. Likewise the NRC should be notified of significant or programmatic deviations from the GIP guidance (Sections 7.2 through 7.6) but implementation may begin without first obtaining NRC concurrence (at the licensee's own risk).

7.1.1 Scope of Equipment

The licensee will evaluate for seismic adequacy tanks and heat exchangers identified pursuant to Section 3 of the GIP.

7.1.2 Evaluation Methodology

For identified tanks and heat exchangers, the licensee will perform an engineering evaluation which checks for the seismic adequacy of: (1) tank wall stability to prevent buckling (for large vertical ground- or floor-mounted, flat-bottom tanks only) including the effects of hydrodynamic loadings and tank wall flexibility; (2) anchor bolt and embedment strength; (3) anchorage connection strength between the anchor bolts and the shell of the tank or heat exchanger; and (4) flexibility of piping attached to large, flat-bottom, vertical tanks.

7.1.3 Documentation

The licensee will document the tank and heat exchanger evaluations performed pursuant to this section, including all calculations, assumptions, and data used to support the evaluations.

7.2 EVALUATION METHODOLOGY

The screening evaluations described in this section for verifying the seismic adequacy of tanks and heat exchangers cover those features of tanks and heat exchangers which experience has shown can be vulnerable to seismic loadings. These evaluations include the following features:

- Check that the shell of large, flat-bottom, vertical tanks will not buckle. Loadings on these types of tanks should include the effects of hydrodynamic loadings and tank wall flexibility.
- Check that the anchor bolts and their embedments have adequate strength against breakage and pullout.
- Check that the anchorage connection between the anchor bolts and the tank shell (e.g., saddles, legs, chairs, etc.) have adequate strength.
- Check that the attached piping has adequate flexibility to accommodate the motion of large, flat-bottom, vertical tanks.

Two Seismic Capability Engineers (as defined in Section 2) should review these evaluations to verify that they meet the intent of these guidelines. This review should include a field inspection of the tank, the anchorage connections, and the anchor bolt installation against the guidelines described in this section, Section 4.4, and Appendix C.

The derivation and technical justification for the guidelines in this section were developed specifically for: (1) large, flat-bottom, cylindrical, vertical, storage tanks; and (2) horizontal cylindrical tanks and heat exchangers with support saddles made of plates. The types of loadings and analysis methods described in this section are considered to be appropriate for these types of tanks and heat exchangers; however, a generic procedure cannot cover all the possible design variations. Therefore, it is the responsibility of the Seismic Capability Engineer to assess the seismic adequacy of other design features not specifically covered in this section. For example, the guidelines in this section do not specifically include a check of the stress in the weld connecting the steel support saddles to the shell of a horizontal tank or heat exchanger since this weld is typically very strong compared to other parts of the saddle and its anchorage. However, if the seismic review team finds there to be very little weld attaching these parts, then this weld should be evaluated for its seismic adequacy.

Other types of tanks and heat exchangers (e.g., vertical tanks supported on skirts and structural legs) which are not specifically covered by the guidelines in this section, should be evaluated by the Seismic Capability Engineers using an approach similar to that described in this section. Reference 26 provides guidelines for evaluating vertical tanks on legs or skirts. Likewise, the utility may use existing analyses which verify the seismic adequacy of its tanks and heat exchangers in lieu of the GIP, provided the Seismic Capability Engineers verify that these other analyses address the same type of loading as the GIP (e.g., hydrodynamic loading on the flexible wall of vertical, flat-bottom tanks, etc.) and the same failure modes (e.g., shell buckling of vertical, flat-bottom tanks, etc.).

The screening guidelines described in this section were developed to simplify the complex dynamic fluid-structure interaction analyses for large vertical tanks and to further simplify the equivalent static analysis procedure for smaller horizontal tanks. To accomplish this, it was necessary to make certain simplifying assumptions and to limit the range of applicability of the guidelines. Most tanks and heat exchangers used in the nuclear power industry fall within the restrictions and range of values for which the screening guidelines were developed. However, for those tanks and heat exchangers which are not covered by, or do not pass the screening guidelines, it may be possible to perform tank-specific evaluations, using the approach described in Reference 26, to verify the seismic adequacy of the tank or heat exchanger.

The screening guidelines described in this section are based on using 4% damped ground or floor response spectra for overturning moment and shear loadings on the tanks. The slosh height of the fluid surface for vertical tanks is based on using l/2% damped ground or floor response spectra. If 4% and l/2% damped response spectra are not directly available, then they may be estimated by scaling from spectra at other damping values using the standard technique described in Section 4.4.3 under the subsection “Equipment Damping.”

7.3 VERTICAL TANKS

This section covers the following topics for vertical tanks:

- Scope of vertical tanks
- Seismic demand applied to vertical tanks
- Overturning moment capacity calculation
- Shear load capacity vs. demand
- Freeboard clearance vs. slosh height
- Attached piping flexibility

7.3.1 Scope of Vertical Tanks

The type of vertical tanks covered by the screening guidelines are large, cylindrical tanks whose axis of symmetry is vertical and are supported, on their flat bottoms, directly on a concrete pad or a floor. A section through a typical large vertical tank is shown in Figure 7-l. (Note: All figures and tables applicable to vertical tanks are grouped together after Section 7.3.7.) The range of parameters and assumptions which are applicable when using the guidelines to evaluate large vertical tanks are listed in Table 7-l. The nomenclature and symbols used for vertical tanks are listed in Table 7-2.

The guidelines assume that the tank shell material is carbon steel (ASTM A36 or A283 Grade C) or stainless steel (ASTM A240 Type 304) or aluminum. The number of bolts used to anchor down the tank is assumed to be 8 or more cast-in-place anchor bolts or J-bolts made of regular-strength or high-strength carbon steel (ASTM A36 or A307 or better material A325). These bolts are assumed to be spaced evenly around the circumference of the tank. These assumptions and the range of parameters given in Table 7-l have been selected to cover the majority of vertical storage tanks in nuclear power plants.

7.3.2 Seismic Demand Applied to Vertical Tanks

The seismic demand applied to vertical tanks in the screening guidelines is based on using the maximum horizontal component of the ground or floor response spectra. The tank should be evaluated for the condition where it is filled with fluid to the maximum level to which the tank is filled during operation; this is the most severe loading condition for typical tanks at nuclear power plants. Other types of loads, such as nozzle loads, are not considered in this screening method since they are typically very small compared to the tank inertial loads.

The horizontal response of fluid-filled vertical tanks has been found to be reasonably represented by two modes of response. One is a low frequency mode called the sloshing mode, in which the contained fluid sloshes within the tank. The other is a high frequency mode wherein the structure and fluid move together, called the impulsive mode. Previously, tank walls were assumed to be rigid in determining the response from these two modes. More recent work has shown that while the assumption is appropriate for the sloshing mode, it is not appropriate for the impulsive mode. For large, thin-walled tanks, the tank may deform under the impulsive mode pressures and vibrate at frequencies in the amplified response range of earthquake motion (2 to 20 Hz). These screening guidelines account for fluid-structure interaction in the impulsive mode.

These hydrodynamic loads on the tank are characterized in the screening guidelines in terms of the tank overturning moment (M) and the base shear load (Q). By using certain simplifying assumptions and limiting the range of applicability, these loads can be determined using the step-by-step procedure given below.

Step 1 - Determine the following input data. [3]Where practical, as-built drawings should be used or a walkdown should be performed to gather data on the tank.

Tank Material:

- R (Nominal radius of tank) [in.]
- H′ (Height of tank shell) [in.]
- t_{min} (Minimum shell thickness along the height of the tank shell (H’), usually at the top of the tank) [in.]

t_s (Minimum thickness of the tank shell in the lowest 10% of shell height H') [in.]

σ_y (Yield strength of tank shell material) [psi]

h_c (Height of shell compression zone at base of tank – usually height of chair) [in.]

E_s (Elastic modulus of tank shell material) [psi]

V_s Average shear wave velocity of soil for tanks located at grade) [ft/sec]

Fluid:

γ_f (Weight density of fluid in tank) [lbf/in^3]

H (Height of fluid at the maximum level to which the tank will be filled) [in.]

h_f (Height of freeboard above fluid surface at the maximum level to which the tank will be filled) [in.]

Bolts:

N (Number of anchor bolts)

d (Diameter of anchor bolt) [in.]

h_b (Effective length of anchor bolt being stretched - usually from the top of the chair to embedded anchor plate) [in.]

E_b (Elastic modulus of anchor bolt material) [psi]

Loading:

Ground or floor response spectrum acceleration at 4% damping for overturning moment and shear loadings on tanks and at l/2% damping for fluid slosh height.

Step 2 - Calculate the following ratios and values:

H/R

t_s/R

$$t_{av} = \frac{\sum_{i=1}^{n} t_i h_i}{H'}$$

(Thickness of the tank shell averaged over the linear height of the tank shell (H′)) [in.]

Where:

n = total number of sections of the tank shell with different thicknesses

i = counter digit

t_i = thickness of the i^{th} section of the tank shell [in.]

h_i = height of the i^{th} section of the tank shell [in.]

H' = total height of tank shell [in.]

Note that $\sum_{i=1}^{n} h_i = H'$

t_{ef} = $\dfrac{t_{av} + t_{min}}{2}$ (Effective thickness of tank shell) [in.]

t_{ef}/R

A_b = $\dfrac{\pi d^2}{4}$ (Cross-sectional area of embedded anchor bolt) [in.^{2}]

t' = $\left(\dfrac{N A_b}{2\pi R}\right)\left(\dfrac{E_b}{E_s}\right)$ (Equivalent shell thickness having the same cross-sectional area as anchor bolts) [in.]

c' = $\left(\dfrac{t'}{t_s}\right)\left(\dfrac{h_c}{h_b}\right)$ (Coefficient of tank wall thicknesses and lengths under stress)

W = $\pi R^2 H \gamma_f$ (Weight of fluid in tank) [lbf]

Confirm that the parameters, values, and ratios determined in these first two steps are within the ranges given in Table 7-l. If they are, then the procedure given in this section is applicable to the subject vertical tank; proceed to Step 3. If the tank does not meet this guideline, classify the tank as an outlier and proceed to Section 5, Outlier Identification and Resolution.

Step 3 – Determine the fluid-structure modal frequency for vertical carbon steel tanks containing water.

F_f [Hz] (from Table 7-3)

by entering Table 7-3 with:

R [in.] (from Step 1)

t_{ef}/R (from Step 2)

H/R = (from Step 2)

Alternatively, enter Figure 7-2 with t_{ef}/R and H/R to obtain F'_f. Then compute F_f :

$$F_f = F'_f \left[\frac{1200}{R}\right]$$

This frequency is for carbon steel tanks containing water. For other tank material (stainless steel or aluminum) with modulus of elasticity E_s (psi) and fluid other than water with weight density γ_f [lbf/in^3], the frequency $F_f(s, f)$ may be computed from F_f, determined above, as follows:

$$F_f(s, f) = F_f \sqrt{\frac{0.0361}{\gamma_f}} \sqrt{\frac{E_s}{30 \times 10^6}}$$

Step 4 - Determine the spectral acceleration (Sa_f) for the fluid-structure modal frequency. (See Section 4.4.3, Step 1 for a discussion of input spectral acceleration.) Enter the 4% damped horizontal ground or floor response spectrum (the maximum horizontal component) for the surface on which the tank is mounted, with the fluid-structure modal frequency:

F_f [Hz] (from Step 3)

and determine the maximum spectral acceleration:

Sa_f [g] (from horizontal 4% damped response spectrum)

over the following frequency (F) range:

$0.8\ F_f < F < 1.2\ F_f$

For tanks with concrete pads founded on ground, soil-structure interaction (SSI) effects on frequency F_f, and thus on Sa_f, must be accounted for if V_s is less than 3,500 ft/sec. The SSI effects on frequency may be computed explicitly by appropriate methods as discussed in Reference 26, or by the following simplified procedure:

(a) If frequency F_f is smaller than the frequency at the peak of the applicable ground response spectrum, SSI effects may be ignored.

(b) If frequency F_f is larger than the peak frequency of the spectrum, then use the peak spectrum value for Sa_f.

Step 5 - Determine the base shear load (Q). Enter Figure 7-3 with:

H/R (from Step 2)

t_{ef}/R (from Step 2)

and determine the base shear load coefficient:

Q′ (from Figure 7-3)

Compute the shear load at the base of the tank:

$Q = Q' \, W \, Sa_f$ [lbf]

Step 6 - Determine the base overturning moment (M). Enter Figure 7-4 with:

H/R (from Step 2)

t_{ef}/R (from Step 2)

and determine the base overturning moment coefficient:

M′ (from Figure 7-4)

Compute the overturning moment at the base of the tank:

$M = M' \, W \, H \, Sa_f$ [in-lbf]

This completes the determination of the seismic demand applied to a vertical tank.

7.3.3 Overturning Moment Capacity Calculation

The seismic capacity of the tank shell and its anchorage to resist the overturning moment (M) calculated above is determined as explained below. The overturning moment is resisted by compression in the tank wall and tension in the anchor bolts. The overturning moment capacity is thus controlled by shell buckling on one side and anchor bolt capacity on the other side. The analysis procedure described below calculates the capacity of the shell to withstand buckling, assuming the anchor bolts stretch inelastically. The assumption of allowing the anchor bolts to stretch inelastically is used in these screening guidelines to distribute the overturning moment more evenly among several anchor bolts.

The overturning moment capacity calculation is broken down into four parts. First, the anchor bolt capacity is determined by the procedure given in Section 4 and Appendix C for cast-in-place bolts or J-bolts and is taken as the bolt yield capacity. Note, however, that the anchor bolt load using this allowable is subject to verification that there is adequate strength in the bolt chair and its connection to the shell to carry the anchor bolt yield capacity.

Therefore, the second part of the overturning moment capacity calculation is to determine the anchorage connection capacity. If it is determined that the anchorage connection assembly has lower capacity than that determined for the anchor bolt itself, then this lower capacity should be used. The failure mode governing the connection capacity should also be determined, i.e., is it ductile or brittle. For a brittle failure mode, the moment capacity is determined without allowing inelastic stretching (yielding) of the bolt.

The third part is to calculate the compressive axial buckling stress capacity of the tank shell. The fourth and final part is to determine the controlling overturning moment capacity using the calculated bolt tension capacity and tank shell buckling capacity and compare this to the overturning moment seismic demand determined in Step 6.

7.3.3.1 Bolt Tensile Capacity

<u>Step 7</u> - Determine bolt tensile load capacity, P_u (lbf), per guidelines for cast-in-place bolts in Section 4 and Appendix C. This value should reflect any effects of less than minimum embedment, spacing, and edge distance as well as concrete cracking as detailed in Section 4 and Appendix C. The bolt capacities from Section 4 and Appendix C are based on the weak link being the anchor bolt rather than the concrete such that the postulated failure mode is <u>ductile</u>. Compute the allowable bolt stress, F_b (psi):

$$F_b = \frac{P_u}{A_b} \quad \text{[psi]}$$

where:

P_u = bolt tensile load capacity [lbf] (from Section 4, Appendix C)

A_b = cross-sectional area of embedded anchor bolt [in^2] (from Step 2)

If the Section 4 and Appendix C criteria are not met for the anchorage, then the concrete is considered the weak link in the load path and the postulated failure mode is <u>brittle</u>. Determine an appropriate reduced allowable anchor bolt stress (F_r) per applicable code requirements or, alternately, classify the tank as an outlier and proceed to Section 5, Outlier Identification and Resolution, after completing all the evaluations in this section.

[1]For the design and construction of new flat-bottom vertical tanks, the cast-in-place anchor bolts and associated hardware (chairs, transfer plates, etc.) shall be designed and installed in accordance with embedment depth, edge distance, anticipated concrete cracking, and corrosion allowance specified in Section 4 and Appendix C. However, the allowable bolt stress, F_b, shall be limited to the yield strength of the bolting material.

7.3.3.2 Anchorage Connection Capacity

In the previous step for determining bolt tensile capacity, it is assumed that the anchorage connection details are adequate for the bolt to develop its yield capacity in tension, and subsequently deform in a ductile manner. For this type of ductile behavior to occur, it should be possible to transfer loads at least equal to the anchor bolt allowable capacity to the tank wall local to the anchor bolts, the connection between the tank wall and the anchor bolt chair, and the anchor bolt chair itself.

The purpose of this check is to determine if the capacity of the load path is greater than the tensile capacity, P_u, of the anchor bolt. The evaluation guidelines given in this section are taken from Reference 26 which primarily uses the design guidelines developed by the American Iron and Steel Institute (Reference 27). Figure 7-5 shows a typical detail of a vertical tank anchor bolt chair. The chair includes two vertical stiffener plates welded to the tank wall. A top plate, through which the bolt passes, transfers loads from the bolt to the stiffeners which, in turn, transfer the loads into the tank wall. Figure 7-6 depicts two other less commonly used anchor chair details. The detail shown in Figure 7-6(b) is an example of a poor anchorage connection design and is unlikely to satisfy the strength criteria for the connection. The procedure for checking the capacities of the various components of the anchorage connection is given below. This procedure applies to the typical chair assembly shown in Figure 7-5. A similar approach can be used for other types of anchor bolt chairs, however appropriate equations should be used. In particular, the tank shell stress equation given below in Step 9 is only applicable for the type of chair assembly shown in Figure 7-5.

If each of the anchorage connection components meets the acceptance criteria defined below, then the bolt tensile capacity determined in the previous Step 7 is limiting. If, however, any of the components does not meet these guidelines, the reduced anchor bolt tension capacity represented by the equivalent value of anchor bolt allowable stress (F_r), as calculated here, should be used. Note that, if the failure mode of the weak link is nonductile, the procedure for computing M_{cap} (in Section 7.3.3.4) is slightly different. Typically, plate or weld shear failure is considered nonductile, while tension yielding of the bolt or plastic bending failure is considered ductile. For the purposes of these guidelines, nonductile failure modes are classified as "brittle".

The procedure given below, Steps 8 through 11, is for carbon steel material (for tanks, connection elements and bolts), and is based on allowable stresses (adjusted for SSE loading) per AISC specifications. Adjustments should be made for other material such as stainless steel and aluminum for the allowable stress per applicable codes. The symbols used in the equations given in these steps are defined in Figure 7-5.

<u>Step 8 - Top Plate</u>. The top plate transfers the anchor bolt load to the vertical stiffeners and the tank wall. The critical stress in the top plate occurs between the bolt hole and the free edge of the plate (the area identified by dimension f in Figure 7-5) using the following equation. This bending stress is estimated. Note that if the top plate projects radially beyond the vertical plates, no more than l/2 inch of this projecting plate can be included in the dimension f used in the following equation. The maximum bending stress in the top plate is:

$$\sigma = \frac{(0.375g - 0.22d)\, P_u}{f\, c^2} \qquad \text{[psi]}$$

The top plate is adequate if the following guideline is satisfied:

$$\sigma < f_y$$

If the top plate does not meet this guideline, it is considered to fail in a ductile manner; therefore a load reduction factor:

$$\frac{f_y}{\sigma}$$

should be computed and multiplied by the anchor bolt allowable tensile stress (F_b):

$$F_r = F_b \left(\frac{f_y}{\sigma}\right) \qquad \text{[psi]}$$

This reduced allowable anchor bolt stress should then be used to compute the overturning moment capacity in Section 7.3.3.4.

Step 9 - Tank Shell Stress. The anchor bolt loads are transferred into the tank shell as a combination of direct vertical load and out-of-plane bending moment (due to the eccentricity between the bolt centerline and the tank wall). A check of shell stresses is considered necessary only for large, flat-bottom, vertical storage tanks because of past experience with such tanks in earthquakes. Note that the stress equation given below is only applicable for the type of chair assembly shown in Figure 7-5.

The maximum bending stress in the tank shell is:

$$\sigma = \frac{P_u e}{t_s^2}\left[\frac{1.32\ Z}{\frac{1.43\ a\ h^2}{R\ t_s} + (4a\ h^2)^{0.333}} + \frac{0.031}{\sqrt{R\ t_s}}\right] \text{ [psi]}$$

where:

$$Z = \frac{1.0}{\frac{(0.177\ \text{in}^{-1})\ a\ t_b}{\sqrt{Rt_s}}\left[\frac{t_b}{t_s}\right]^2 + 1.0}$$

Note: The terms a, t_b, t_s, and R in the above equation should all be in units of inches to be consistent with the proportionality factor of 0.177 which, as used in this equation, has units of [in.^{-1}].

The tank shell is adequate if the following guideline is satisfied:

$$\sigma < f_y$$

If the tank shell does not meet this guideline, it is considered to fail in a ductile manner; therefore a load reduction factor:

$$\frac{f_y}{\sigma}$$

should be computed and multiplied by the anchor bolt allowable tensile stress (F_b).

$$F_r = F_b\left(\frac{f_y}{\sigma}\right) \text{ [psi]}$$

This reduced allowable anchor bolt stress should then be used to compute the overturning moment capacity in Section 7.3.3.4.

Step 10 - Vertical Stiffener Plates. The vertical stiffener plates are considered adequate for shear stress, buckling, and compressive stress if the following three guidelines are satisfied:

- $\frac{k}{j} < \frac{95}{\sqrt{\frac{f_y}{1000}}}$
- $j > 0.04(h - c)$ and $j > 0.5$ in.
- $\frac{P_u}{2\,k\,j} < 21{,}000$ psi

If the vertical stiffener plates do not meet these guidelines, then the anchorage connection will fail in a nonductile manner before the anchor bolts will yield. For the purposes of these guidelines, nonductile failure modes are classified as "brittle". Determine an appropriate reduced allowable anchor bolt stress (F_r) per applicable code requirements, and compute the overturning moment capacity in Section 7.3.3.4. Alternately, classify the tank as an outlier and proceed to Section 5, Outlier Identification and Resolution, after completing the remainder of the evaluations in this section.

Step 11 - Chair-to-Tank Wall Weld. The load per linear inch of weld between the anchor bolt chair (i.e., the top plate plus the vertical stiffener plates) and the tank wall is determined from the following equation for an inverted U-weld pattern of uniform thickness:

$$W_w = P_u \sqrt{\left[\frac{1}{a + 2h}\right]^2 + \left[\frac{e}{a\,h + 0.667\,h^2}\right]^2}$$

The weld is adequate if the following guideline is satisfied:

$$W_w \leq \frac{30{,}600\ t_w}{\sqrt{2}}$$

where 30,600 psi in the above equation is the allowable weld strength.

If the chair-to-tank wall weld does not meet this guideline, then the anchorage will fail in a nonductile manner before the anchor bolts will yield. For the purposes of these guidelines, nonductile failure modes are classified as "brittle." Determine an appropriate reduced allowable anchor bolt stress (F_r) per applicable code requirements, and compute the overturning moment capacity in Section 7.3.3.4. Alternately, classify the tank as an outlier and proceed to Section 5, Outlier Identification and Resolution, after completing the remainder of the evaluations in this section.

This completes the evaluation of the anchorage connection capacity for vertical tanks.

7.3.3.3 Tank Shell Buckling Capacity

The compressive axial buckling stress capacity of the tank shell is most likely limited by the "elephant-foot" buckling mode near the base of the tank wall. Another possible buckling mode for vertical tanks is the "diamond-shape" buckling mode. Both of these buckling modes are dependent upon the hydrodynamic and hydrostatic pressure acting at the base of the tank which is determined below:

Step 12 - Determine the fluid pressure for elephant-foot buckling (P_e) by entering Figure 7-7 with:

Sa_f [g] (from Step 4)

H/R (from Step 2)

and determine the pressure coefficient for elephant-foot buckling of the tank:

P_e' (from Figure 7-7)

Compute the fluid pressure at the base of the vertical tank for elephant-foot buckling:

$P_e = P_e' \gamma_f R$ [psi]

Step 13 - Determine the elephant-foot buckling stress capacity factor

σ_{pe} [ksi] (from Figure 7-8)

by entering Figure 7-8 with:

P_e [psi] (from Step 12)

t_s/R (from Step 2)

Convert σ_{pe} into units of psi by multiplying by 1000.

This value of σ_{pe} is for carbon steel. For other material, use the following formula:

$$\sigma_{pe} = \frac{0.6E_s}{R/t_s}\left[1-\left(\frac{P_eR}{\sigma_y t_s}\right)^2\right]\left[1-\frac{1}{1.12+S_1^{1.5}}\right]\left[\frac{S_1+\sigma_y/36{,}000\text{ psi}}{S_1+1}\right]\text{ [psi]}$$

where:

$S_l = \dfrac{R}{400\ t_s}$

σ_y = yield strength of tank shell material [psi] (from Step 1)

E_s = elasticity modulus of tank shell material [psi] (from Step 1)

t_s = minimum thickness of tank shell in the lowest 10% of the shell height (H′) [in.] (from Step 1)

R = nominal radius of tank [in.] (from Step 1)

P_e = fluid pressure at the base of tank for elephant-foot buckling of tank shell [psi] (from Step 12)

Step 14 - Determine the fluid pressure for diamond-shape buckling (P_d) by entering Figure 7-9 with:

Sa_f [g] (from Step 4)

H/R (from Step 2)

and determine the pressure coefficient for diamond-shape buckling of the tank:

P_d' (from Figure 7-9)

Compute the fluid pressure at the base of the vertical tank for diamond-shape buckling:

$P_d = P_d'\ \gamma_f\ R$ [psi]

Step 15 - Determine the diamond-shape buckling stress capacity factor:

σ_{pd} [ksi] (from Figure 7-10)

by entering Figure 7-10 with:

P_d [psi] (from Step 14)

t_s/R (from Step 2)

Convert σ_{pd} into units of psi by multiplying by 1000.

This value of σ_{pd} is for carbon steel. For other material use the following formula:

$$\sigma_{pd} = (0.6\gamma + \Delta\gamma)\ \frac{E_s}{R / t_s}$$

where:

γ = $1 - 0.73\ (1-e^{-\phi})$

ϕ = $\frac{1}{16}\sqrt{\frac{R}{t_s}}$

E_s = elastic modulus of tank shell material [psi] (from Step 1)

R = nominal radius of tank [in.] (from Step 1)

t_s = minimum thickness of tank shell in the lowest 10% of the shell height (H′) [in.] (from Step 1)

$\Delta\gamma$ = increase factor for internal pressure (from Figure 7-11)

Step 16 – Select the allowable buckling stress, σ_c, as 72% of the lower value of σ_{pe} or σ_{pd}:

$$\sigma_c = 0.72\ [\min.\ (\sigma_{pe}, \sigma_{pd})] \quad [psi]$$

[1]For newly designed and constructed flat-bottom vertical tanks, the following equation should be used instead:

$$\sigma_c = 0.6\ [\min.\ (\sigma_{pe}, \sigma_{pd})] \quad [psi]$$

7.3.3.4 Overturning Moment Capacity

Step 17 - The overturning moment capacity of the tank, M_{cap} is dependent upon whether the postulated weak link failure mode is ductile or brittle. A ductile failure mode is defined as one in which the weak link is one of the following:

- Anchor bolt stretching (Step 7)
- Chair top plate bending (Step 8)
- Tank shell bending (Step 9)

A brittle mode of failure is defined as one in which the weak link is one of the following:

- Concrete cone failure (Step 7)
- Chair stiffener plate shear or buckling failure (Step 10)
- Chair-to-tank wall weld shear failure (Step 11)

(a) Determine the base overturning moment coefficient for ductile failure:

M'_{cap} [dimensionless] (from Figure 7-12)

by entering Figure 7-12 with:

c' [dimensionless] (from Step 2)

σ_c [psi] (from Step 16)

F_b = smaller of F_b (from Step 7) or F_r (from Steps 8 or 9) [psi]

h_c [in.] (from Step 1)

h_b [in.] (from Step 1)

If the postulated weak link failure mode is ductile, go to Step (c), below. If the postulated weak link failure mode is brittle, continue on to Step (b), below.

(b) If the postulated weak link failure mode is brittle, then enter Table 7-4 with:

c' [dimensionless] (from Step 2)

and determine the base overturning moment coefficient for the elastic limit:

M'_{cap} [dimensionless] (from Table 7-4)

Compare the M'_{cap} value determined above with the M'_{cap} value determined in Step (a), above, and select the lower of the two values for use in Step (c), below.

(c) Compute M_{cap} :

$$M_{cap} = (M'_{cap})\,(2F_b)\,(R^2 t_s)\,(h_b/h_c)$$

using:

M'_{cap} [dimensionless] (from Step 17(a) for ductile failure mode or 17(b) for brittle failure mode)

F_b = smaller of F_b or F_r (from Steps 7, 8, 9, 10, or 11) [psi]

R [in.] (from Step 1)

t_s [in.] (from Step 1)

h_b [in.] (from Step 1)

h_c [in.] (from Step 1)

Step 18 - Compare the overturning moment capacity of the tank (M_{cap}, from Step 17) with the overturning moment (M, from Step 6). If

$$M_{cap} \geq M$$

then the tank is adequate for this loading; proceed to Step 19. If the tank does not meet this guideline, classify the tank as an outlier and proceed to Section 5, Outlier Identification and Resolution, after completing the remainder of the evaluations in this section.

7.3.4 Shear Load Capacity vs. Demand

The seismic capacity of the tank to resist the shear load (Q) is determined below. The shear load is assumed to be resisted by sliding friction between the tank base plate and the supporting foundation material. The base shear load capacity is therefore a function of the friction coefficient and the pressure on the base plate. A friction coefficient of 0.55 is used in the screening guidelines. The pressure on the base plate is made up of hydrostatic pressure from the weight of the contained fluid less the hydrodynamic pressure from the vertical component of the earthquake. The hydrodynamic pressure from the horizontal component (from overturning moment) of the earthquake is ignored since its net or average pressure distribution over the entire base plate is zero. The weight of the tank shell is conservatively neglected.

Step 19 - Compute the base shear load capacity of the tank:

$$Q_{cap} = 0.55\ (1 - 0.21\ Sa_f)\ W$$

using:

Sa_f	[g]	(from Step 4)
W	[lbf]	(from Step 4)

Step 20 - Compare the base shear load capacity of the tank (Q_{cap}, from Step 19) with the shear load (Q, from Step 5). If

$$Q_{cap} \geq Q$$

then the tank is adequate for this loading; proceed to Step 21. If the tank does not meet this guideline, classify the tank as an outlier and proceed to Section 5, Outlier Identification and Resolution, after completing the remainder of the evaluations in this section.

This procedure assumes that no shear load is carried by the anchor bolts. Note that this assumption is theoretically valid only if there is a slight gap between the hole in the tank base and the anchor bolt; this is usually the case.

7.3.5 Freeboard Clearance vs. Slosh Height

The screening guidelines described above are based on the assumption that there is enough freeboard clearance available between the liquid surface and the tank roof such that the tank roof is not subjected to significant forces from sloshing liquid. The procedure given below simply compares the freeboard clearance to the slosh height; this is considered to be conservative since it allows no contact of the fluid with the tank roof.

Step 21 - The slosh height is given by the following equation:

$h_s = 0.837 \text{ R } Sa_s$

where:

R	=	nominal radius of tank [in.] (from Step 1)
Sa_s	=	spectral acceleration (1/2% damping) of the ground or floor on which the tank is mounted at the frequency of the sloshing mode (F_s, determined below).

In calculating the slosh height from this equation, the Sa_s value must be obtained from the input demand spectrum at the sloshing mode frequency, F_s, and damping value of 1/2%. Care should be exercised in assuring that the spectrum values are accurately defined in the sloshing mode frequency range, typically for 0.5 Hz to 0.2 Hz. The sloshing mode frequency can be calculated from the following equation:

$$F_s = \frac{1}{2\pi}\sqrt{\frac{1.84G}{R}\tanh\left(\frac{1.84H}{R}\right)} \quad \text{[Hz]}$$

where:

G	=	acceleration of gravity
	=	386.4 [in/sec^2]
R		[in.] (from Step 1)
H		[in.] (from Step 1)

Alternately, determine the slosh height by entering Table 7-5 with:

H/R (from Step 2)

R [in.] (from Step 1)

and determine the slosh height of the fluid in the tank for a ZPA of 1g at the base of the tank:

h'_s [in.] (from Table 7-5)

In calculating the slosh height given in Table 7-5, it has been assumed that for an input spectrum normalized to a ZPA of 1 g, the Sa_s (l/2% damping) values vary linearly from 0.75 g at 0.5 Hz to 0.4 g at 0.2 Hz.

Compute the slosh height of the fluid in the tank for the ZPA of the ground or floor on which the tank is mounted:

$$h_s = h'_s \, ZPA$$

using:

h'_s [in.] (from above)

ZPA [g] (from horizontal response spectrum)

<u>Step 22</u> - Determine the available freeboard above the fluid surface at the maximum level to which the tank will be filled (h_f, in.).

For conical tank roofs, measure the freeboard from the fluid surface to the intersection of the wall and the roof (a distance R from the tank centerline).

For tanks with a domed roof, measure the freeboard from the fluid surface to the point where the roof surface is at a distance of 0.9R from the tank centerline.

Compare the available freeboard (h_f) to the slosh height of the fluid (h_s, from Step 21). If

$$h_f \geq h_s$$

then the tank is adequate for this condition; proceed to Step 23. If the tank does not meet this guideline, classify the tank as an outlier and proceed to Section 5, Outlier Identification and Resolution, after completing the remainder of the evaluations in this section.

7.3.6 Attached Piping Flexibility

For evaluation of large, flat-bottom, cylindrical, vertical tanks, the loads imposed on the tank due to the inertial response of attached piping can be neglected. It is considered that these piping loads have very little effect on the loads applied to the anchorage of large, flat-bottom tanks compared to the large hydrodynamic inertial loads from the tank and its contents. However, the relative motion between the tank and the piping presents a potential failure mode for the attached piping which could result in rapid loss of the tank's contents. This has occurred under certain circumstances in past earthquakes. Therefore this concern is addressed by requiring adequate flexibility in the piping system to accommodate tank motion as described below:

Step 23 - Flexibility of Attached Piping. The Seismic Review Team should be aware that the analytical evaluation method for vertical tanks allows for a limited amount of base anchorage inelastic behavior. This, in turn, means that there may be a very slight uplift of the tank during seismic motion. When performing in-plant evaluations of tank anchorage, the Seismic Review Team should assess attached piping near the base of the tank to ensure that the piping has adequate flexibility to accommodate any anticipated tank motion. Near the top of the tank, there will be considerably more motion and any attached piping should have substantial flexibility.

7.3.7 Tank Foundation

The screening guidelines contained herein are for use with all types of tank foundations typically found in the nuclear industry except ring-type foundations. Ring foundations should be identified as outliers and evaluated separately.

An acceptable outlier evaluation method for ring-type foundations is to check the tank overturning resistance and the adequacy of the rebar in the foundation. The overturning resistance may be checked by using the energy method to compute how much the tank and attached ring foundation lift up and whether there is adequate flexibility in the tank floor, shell, and associated welds, .as well as any attached piping.

[1]For newly designed and constructed flat-bottom vertical tanks, the tank foundation (ring-type or otherwise) shall be designed to resist the overturning moment.

This completes the seismic evaluation for vertical tanks.

Table 7-1
Applicable Range of Parameters and Assumptions for Vertical Tanks

Tank Material[1]	Carbon or Stainless Steel, Aluminum		
Nominal Radius of Tank	R	=	5 to 35 ft. (60 to 420 in.)
Height of Tank Shell	H′	=	10 to 80 ft. (120 to 960 in.)
Height of Fluid at the Maximum Level to Which the Tank Will be Filled	H	=	10 to 80 ft. (120 to 960 in.)
Minimum Thickness of the Tank Shell in the Lowest 10% of the Shell Height (H′)	t_s	=	3/16 to 1in.
Effective Thickness of Tank Shell Based on the Mean of the Average Thickness (t_{av}) and the Minimum Thickness (t_{min})	t_{ef}	=	3/16 to 1 in.
Diameter of Anchor Bolt[2]	d	=	1/2 to 2 in.
Number of Anchor Bolts[3]	N	=	8 or more
Tank Wall Thickness (at Base)-to-Tank Radius Ratio	t_s/R	=	0.001 to 0.01
Effective Tank Wall Thickness-to-Tank Radius Ratio	t_{ef}/R	=	0.001 to 0.01
Fluid Height-to-Tank Radius Ratio	H/R	=	1.0 to 5.0

Assumptions:

1 The tank material is assumed to be carbon steel (ASTM A36 or A283 Grade C), stainless steel (ASTM A240 Type 304), aluminum, or better material.

2 Anchor bolts are assumed to be cast-in-place or J-bolts and made of regular-strength or high-strength carbon steel (ASTM A36 or A307 or better material A325).

3 Anchor bolts are assumed to be evenly spaced around the circumference of the tank.

Table 7-2
Nomenclature Used for Vertical Tanks

Symbol		Description [Units]
A_b	–	Cross-sectional area of embedded anchor bolt [in^2]
a	–	Width of chair top plate parallel to shell (see Figure 7-5) [in.]
b	–	Depth of chair top plate perpendicular to shell (see Figure 7-5) [in.]
c	–	Thickness of chair top plate (see Figure 7-5) [in.]
c′	–	Coefficient of tank wall thicknesses and lengths under stress [dimensionless]
d	–	Diameter of anchor bolt [in.]
E_s	–	Elastic modulus of tank shell material [psi]
E_b	–	Elastic modulus of anchor bolt material [psi]
e	–	Eccentricity of anchor bolt with respect to shell outside surface (see Figure 7-5) [in.]
F	–	Frequency [Hz]
F_b	–	Allowable tensile stress of bolt [psi]
F_f	–	Frequency of fluid-structure interaction mode [Hz]
F_r	–	Reduced allowable tensile stress of bolt [psi]
F_s	–	Sloshing mode frequency [Hz]
f	–	Distance from outside edge of chair top plate to edge of hole (see Figure 7-5) [in.]
f_y	–	Minimum specified yield strength of shell, chair, saddle, or base plate material [psi]
G	–	Acceleration of gravity [386.4 in/sec^2]
g	–	Distance between vertical plates of chair (see Figure 7-5) [in.]
H	–	Height of fluid at the maximum level to which the tank will be filled (see Figure 7-1) [in.]
H′	–	Height of tank shell (see Figure 7-1) [in.]
h	–	Height of chair (see Figure 7-5) [in.]
h_b	–	Effective length of anchor bolt being stretched (usually from top of chair to embedded anchor plate) (see Figure 7-1) [in.]
h_c	–	Height of shell compression zone at base of tank (usually height of chair) (see Figure 7-1) [in.]
h_f	–	Height of freeboard above fluid surface at the maximum level to which the tank will be filled (see Figure 7-1) [in.]

Table 7-2 (Continued)
Nomenclature Used for Vertical Tanks

Symbol		Description [Units]
h_s	–	Slosh height of fluid in tank [in.]
h_s'	–	Slosh height of fluid for a ZPA of 1g applied at tank base [in.]
j	–	Thickness of chair vertical plate (see Figure 7-5) [in.]
k	–	Width of chair vertical plate (see Figure 7-5). Use average width for tapered plates [in.].
M	–	Overturning moment at base of tank [in-lbf]
M′	–	Base overturning moment coefficient [dimensionless]
M_{cap}	–	Overturning moment capacity of tank [in-lbf]
M'_{cap}	–	Base overturning moment capacity coefficient [dimensionless]
N	–	Number of anchor bolts [dimensionless]
P_e	–	Fluid pressure at base of tank for elephant-foot buckling of tank shell [psi]
P_e'	–	Pressure coefficient for elephant-foot buckling [dimensionless]
P_d	–	Fluid pressure at base of tank for diamond-shape buckling of tank shell [psi]
$P_{d'}$	–	Pressure coefficient for diamond-shape buckling [dimensionless]
P_u	–	Allowable tensile load of anchor bolt [lbf]
Q	–	Shear load at base of tank [lbf]
Q′	–	Base shear load coefficient [dimensionless]
Q_{cap}	–	Base shear load capacity of tank [lbf]
R	–	Nominal radius of tank [in.] (see Figure 7-1)
r	–	Least radius of gyration of vertical stiffener plate cross-sectional area about a centroidal axis [in.]
S_1	–	Coefficient of tank radius to shell thickness $\left(\frac{R}{400\ t_s}\right)$ [dimensionless]
Sa	–	Spectral acceleration of ground or floor [g]
Sa_f	–	Spectral acceleration (4% damping) of the ground or floor on which the tank is mounted at the frequency of the fluid-structure interaction mode (F_f) [g]
Sa_s	–	Spectral acceleration (1/2% damping) of the ground or floor on which the tank is mounted at the frequency of the sloshing mode (F_s) [g]

Table 7-2 (Continued)
Nomenclature Used for Vertical Tanks

Symbol		Description [Units]
t_{av}	–	Thickness of the tank shell averaged over the linear height of the tank shell (H') [in.]
t_b	–	Thickness of bottom or base plate of tank (see Figure 7-5) [in.]
t_{ef}	–	Effective thickness of tank shell based on the mean of the average thickness (t_{av}) and the minimum thickness (t_{min}) [in.]
t_{min}	–	Minimum shell thickness anywhere along the height of the tank shell (H'), usually at the top of the tank [in.]
t_s	–	Minimum thickness of the tank shell in the lowest 10% of the shell height (H') [in.]
t_w	–	Thickness of leg of weld [in.]
t'	–	Equivalent shell thickness having the same cross-sectional area as the anchor bolts [in.]
V_s	–	Average shear wave velocity of soil for tanks founded at grade [ft/sec]
W	–	Weight of fluid contained in tank [lbf]
W_t	–	Weight of tank without fluid [lbf]
W_w	–	Average shear load on weld connecting anchor bolt chair to tank shell per unit length of weld (i.e., total shear load on chair divided by total length of chair/shell weld) [lbf/in. of weld]
Z	–	Tank shell stress reduction factor [dimensionless]
ZPA	–	Zero period acceleration [g]
β	–	Percentage damping [%]
γ	–	Buckling coefficient $[1 - 0.73 (1 – e^{-\phi})]$ [dimensionless]
γ_f	–	Weight density of fluid in tank [lbf/in^3]
$\Delta\gamma$	–	Increase factor for internal pressure; given in Figure 7-10
σ	–	Stress at a point [psi]
σ_c	–	Stress at which shell buckles [psi]
σ_{pe}	–	Stress at which shell buckles in elephant-foot pattern [psi]
σ_{pd}	–	Stress at which shell buckles in diamond-shape pattern [psi]
σ_y	–	Yield strength of tank shell material [psi]
ϕ	–	Buckling coefficient $[(1/16) (R/t_s)^{1/2}]$ [dimensionless]

Table 7-3
Fluid-Structure Impulsive Mode Frequencies (F_f, Hz)
for Vertical Carbon Steel Tanks Containing Water
(Source: Reference 26, Table 2.2)

		Tank Radius (R, in.)						
H/R	t_{ef}/R	60	120	180	240	300	360	420
1.0	0.001	46.7	23.3	15.6	11.7	9.3	7.8	6.7
1.0	0.002	65.2	32.6	21.7	16.3	13.0	10.9	9.3
1.0	0.003	79.3	39.7	26.4	19.8	15.9	13.2	11.3
1.0	0.004	91.2	45.6	30.4	22.8	18.2	15.2	13.0
1.0	0.005	101.6	50.8	33.9	25.4	20.3	16.9	14.5
1.0	0.007	119.5	59.7	39.8	29.9	23.9	19.9	17.1
1.0	0.010	142.0	71.0	47.3	35.5	28.4	23.7	20.3
1.5	0.001	32.2	16.1	10.7	8.0	6.4	5.4	4.6
1.5	0.002	45.1	22.6	15.0	11.3	9.0	7.5	6.4
1.5	0.003	55.0	27.5	18.3	13.7	11.0	9.2	7.9
1.5	0.004	63.3	31.6	21.1	15.8	12.7	10.5	9.0
1.5	0.005	70.6	35.3	23.5	17.6	14.1	11.8	10.1
1.5	0.007	83.2	41.6	27.7	20.8	16.6	13.9	11.9
1.5	0.010	99.0	49.5	33.0	24.7	19.8	16.5	14.1
2.0	0.001	23.6	11.8	7.9	5.9	4.7	3.9	3.4
2.0	0.002	33.0	16.5	11.0	8.2	6.6	5.5	4.7
2.0	0.003	40.1	20.1	13.4	10.0	8.0	6.7	5.7
2.0	0.004	46.1	23.1	15.4	11.5	9.2	7.7	6.6
2.0	0.005	51.4	25.7	17.1	12.8	10.3	8.6	7.3
2.0	0.007	60.5	30.2	20.2	15.1	12.1	10.1	8.6
2.0	0.010	71.8	35.9	23.9	18.0	14.4	12.0	10.3
2.5	0.001	17.8	8.9	5.9	4.5	3.6	3.0	2.5
2.5	0.002	25.0	12.5	8.3	6.2	5.0	4.2	3.6
2.5	0.003	30.4	15.2	10.1	7.6	6.1	5.1	4.3
2.5	0.004	35.0	17.5	11.7	8.7	7.0	5.8	5.0
2.5	0.005	39.0	19.5	13.0	9.7	7.8	6.5	5.6
2.5	0.007	45.9	23.0	15.3	11.5	9.2	7.7	6.6
2.5	0.010	54.6	27.3	18.2	13.7	10.9	9.1	7.8
3.0	0.001	13.9	7.0	4.6	3.5	2.8	2.3	2.0
3.0	0.002	19.5	9.7	6.5	5.9	3.9	3.2	2.8
3.0	0.003	23.7	11.8	7.9	4.9	4.7	3.9	3.4
3.0	0.004	27.2	13.6	9.1	6.8	5.4	4.5	3.9
3.0	0.005	30.3	15.1	10.1	7.6	6.1	5.0	4.3
3.0	0.007	35.6	17.8	11.9	8.9	7.1	5.9	5.1
3.0	0.010	42.2	21.1	14.1	10.6	8.4	7.0	6.0

Table 7-3 (Continued)
Fluid-Structure Impulsive Mode Frequencies (F_f, Hz)
for Vertical Carbon Steel Tanks Containing Water
(Source: Reference 26, Table 2.2)

		Tank Radius (R, in.)						
H/R	t_{ef}/R	60	120	180	240	300	360	420
3.5	0.001	11.2	5.6	3.7	2.8	2.2	1.9	1.6
3.5	0.002	15.5	7.8	5.2	3.9	3.1	2.6	2.2
3.5	0.003	18.8	9.4	6.3	4.7	3.8	3.1	2.7
3.5	0.004	21.6	10.8	7.2	5.4	4.3	3.6	3.1
3.5	0.005	24.0	12.0	8.0	6.0	4.8	4.0	3.4
3.5	0.007	28.2	14.1	9.4	7.0	5.6	4.7	4.0
3.5	0.010	33.4	16.7	11.1	8.3	6.7	5.6	4.8
4.0	0.001	9.1	4.6	3.0	2.3	1.8	1.5	1.3
4.0	0.002	12.6	6.3	4.2	3.2	2.5	2.1	1.8
4.0	0.003	15.2	7.6	5.1	3.8	3.0	2.5	2.2
4.0	0.004	17.4	8.7	5.8	4.4	3.5	2.9	2.5
4.0	0.005	19.3	9.7	6.4	4.8	3.9	3.2	2.8
4.0	0.007	22.6	11.3	7.5	5.7	4.5	3.8	3.2
4.0	0.010	26.7	13.4	8.9	6.7	5.3	4.5	3.8
4.5	0.001	7.5	3.8	2.5	1.9	1.5	1.3	1.1
4.5	0.002	10.3	5.2	3.4	2.6	2.1	1.7	1.5
4.5	0.003	12.4	6.2	4.1	3.1	2.5	2.1	1.8
4.5	0.004	14.2	7.1	4.7	3.5	2.8	2.4	2.0
4.5	0.005	15.7	7.9	5.2	3.9	3.1	2.6	2.2
4.5	0.007	18.3	9.2	6.1	4.6	3.7	3.1	2.6
4.5	0.010	21.6	10.8	7.2	5.4	4.3	3.6	3.1
5.0	0.001	6.2	3.1	2.1	1.6	1.2	1.0	0.9
5.0	0.002	8.5	4.2	2.8	2.1	1.7	1.4	1.2
5.0	0.003	10.2	5.1	3.4	2.5	2.0	1.7	1.5
5.0	0.004	11.6	5.8	3.9	2.9	2.3	1.9	1.7
5.0	0.005	12.8	6.4	4.3	3.2	2.6	2.1	1.8
5.0	0.007	14.9	7.4	5.0	3.7	3.0	2.5	2.1
5.0	0.010	17.5	8.7	5.8	4.4	3.5	2.9	2.5

Table 7-4
Base Overturning Moment Capacity Elastic Limit Values
(Source: Reference 26, Table 2.5)

c'	$\left(\frac{\sigma_c}{F_b}\right)\left(\frac{h_c}{h_b}\right)$	M'_{cap}
0.01	0.052	0.0231
0.02	0.081	0.0454
0.05	0.147	0.1092
0.10	0.230	0.2087
0.15	0.300	0.3045
0.20	0.358	0.3932
0.40	0.560	0.7271

Table 7-5
Slosh Height of Water (h'_s, in.) in Vertical Tanks for 1G Lateral Acceleration
(Source: Adapted from Reference 26, Table 2.7)

	Tank Radius (R, in.)						
H/R	**60**	**120**	**180**	**240**	**300**	**360**	**420**
1.0	39.0	60.2	78.7	95.5	111.5	126.7	141.4
1.5	39.6	61.2	79.8	96.8	112.9	128.3	143.2
2.0	39.7	61.3	79.9	97.1	113.2	128.5	143.4
2.5	39.7	61.3	80.0	97.1	113.2	128.6	143.4
3.0	39.7	61.3	80.0	97.1	113.2	128.6	143.4
3.5	39.7	61.3	80.0	97.1	113.2	128.6	143.4
4.0	39.7	61.3	80.0	97.1	113.2	128.6	143.4
4.5	39.7	61.3	80.0	97.1	113.2	128.6	143.4
5.0	39.7	61.3	80.0	97.1	113.2	128.6	143.4

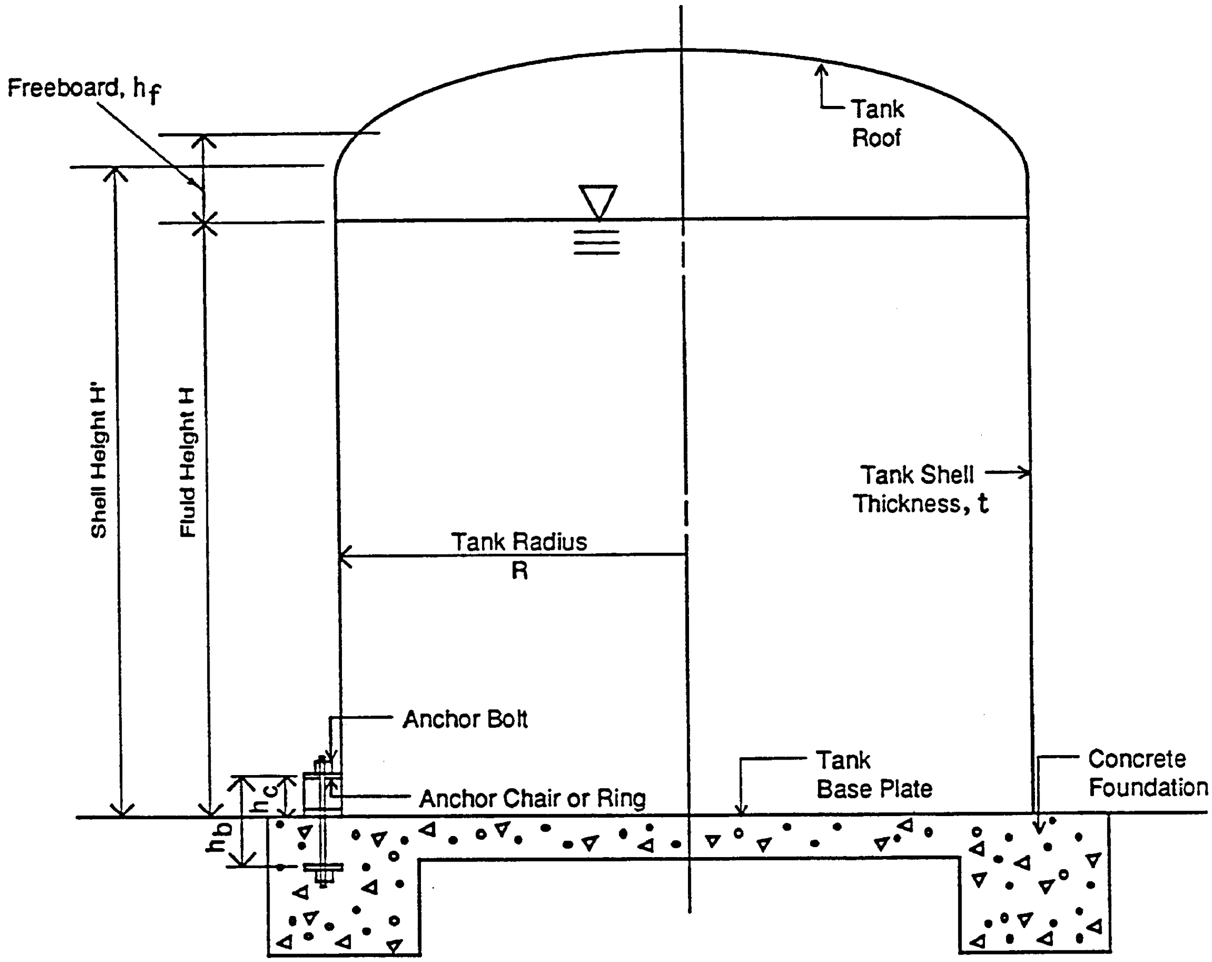


Figure 7-1. Large Vertical Tank
(Source: Reference 26, Figure 2.1)

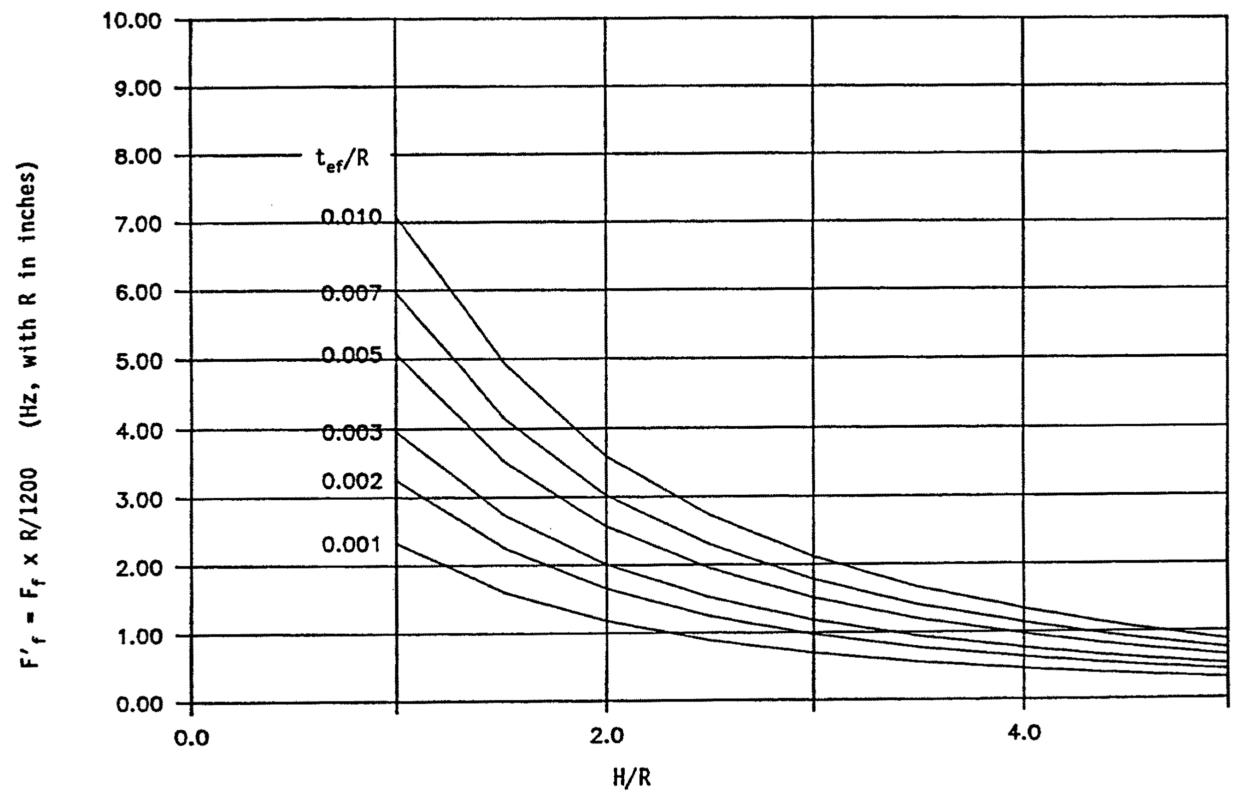


Figure 7-2. Fluid-Structure Impulsive Mode Frequency Coefficient for Vertical Carbon Steel Tanks Containing Water. (Source: Reference 26, Figure 2.3)

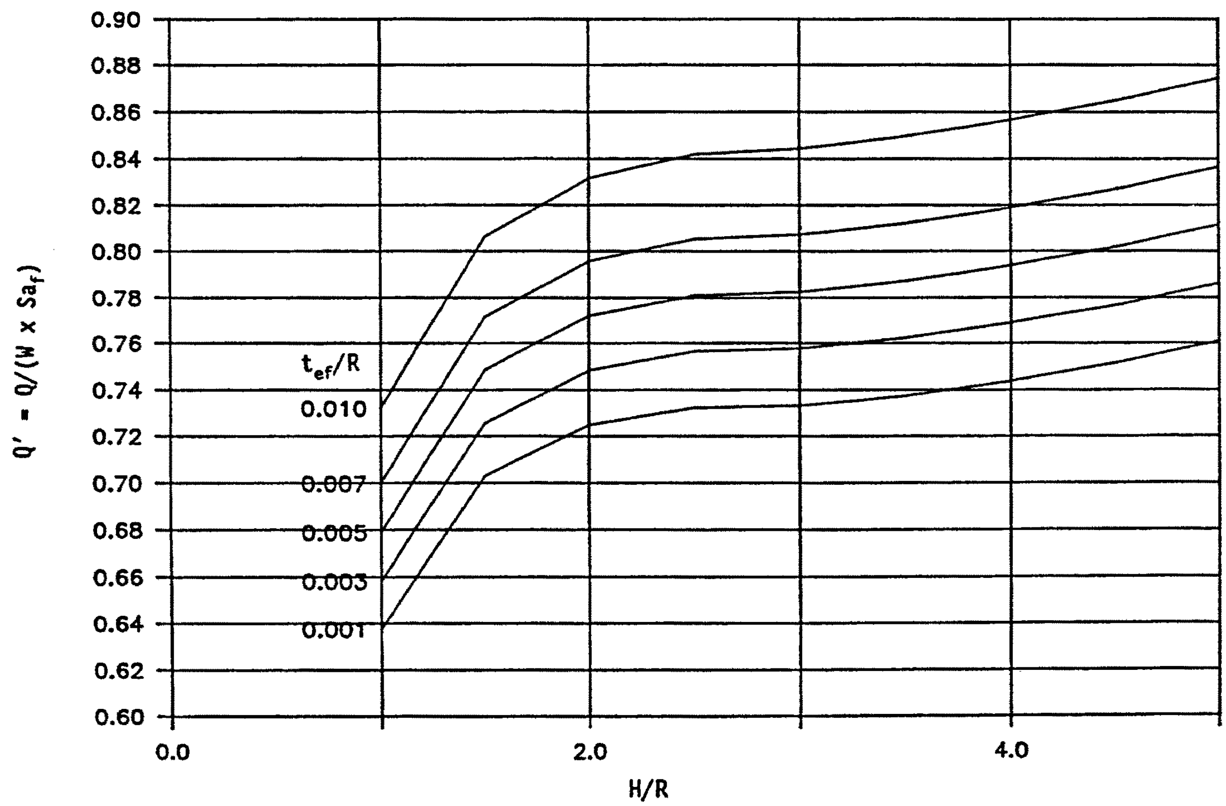


Figure 7-3. Base Shear Load Coefficient For Vertical Tanks
(Source: Reference 26, Figure 2.4)

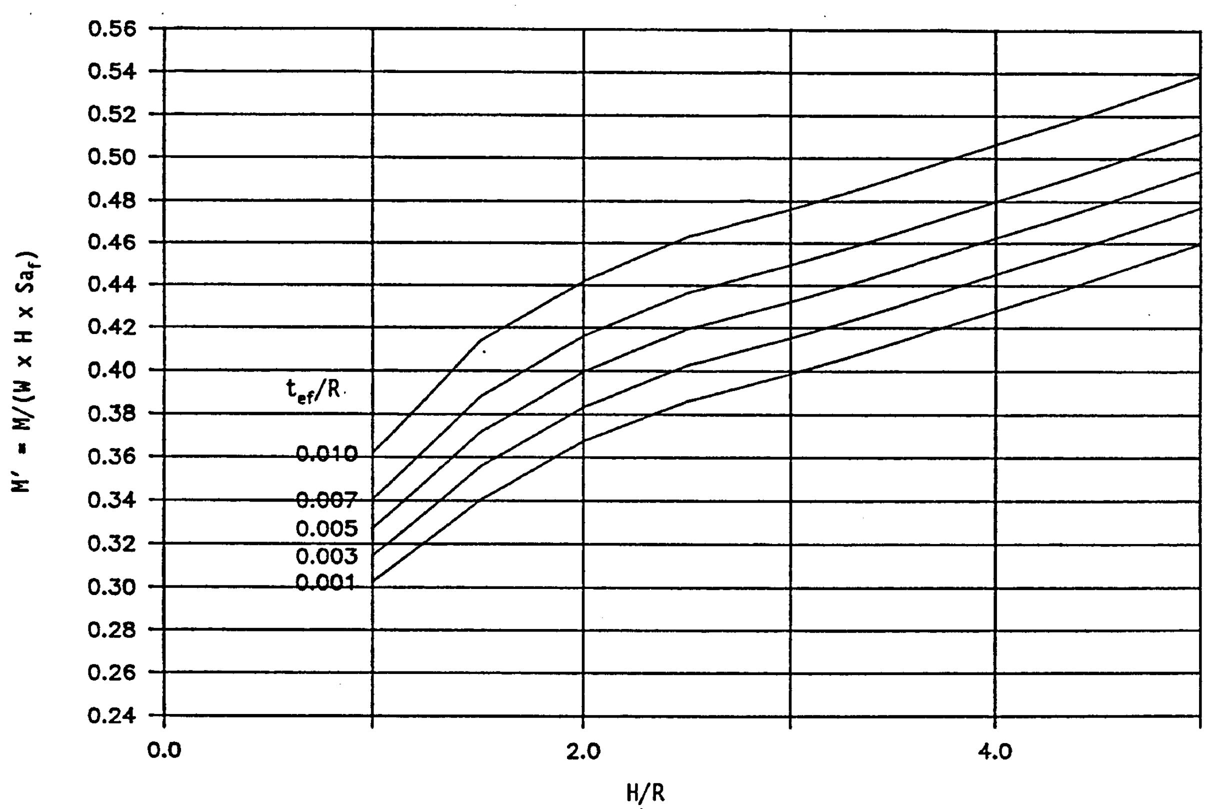
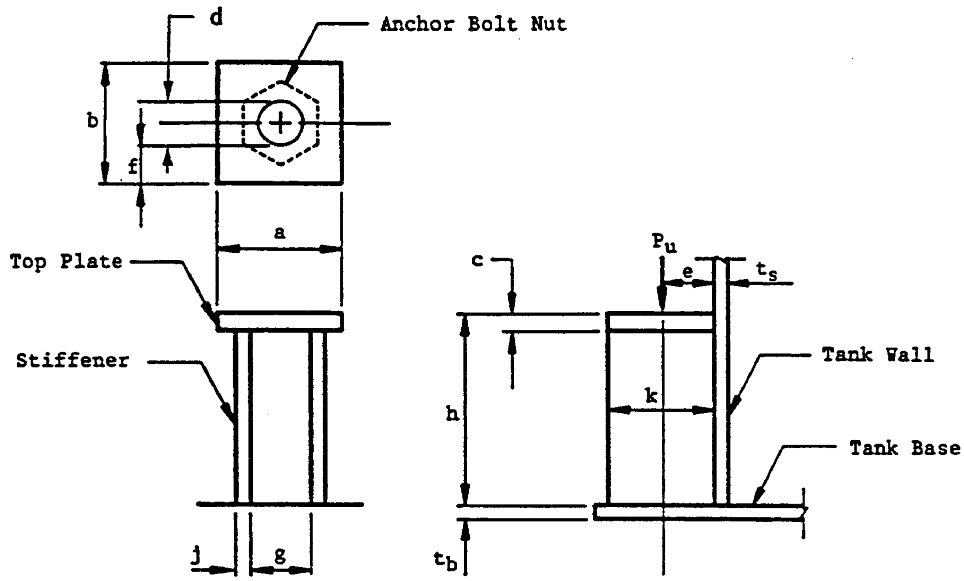


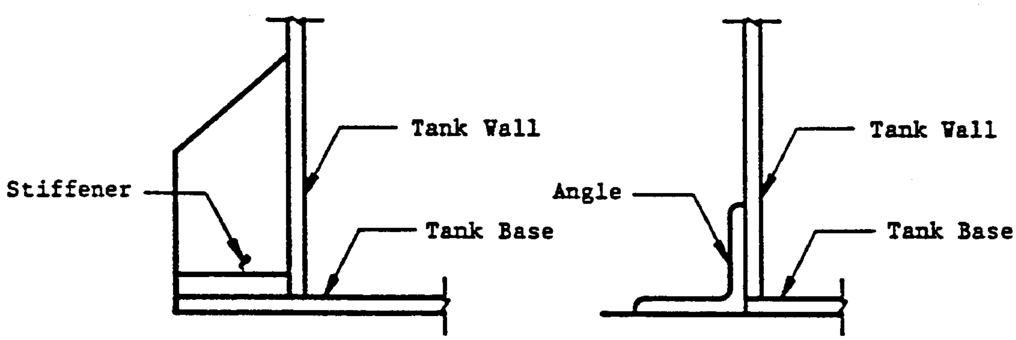
Figure 7-4. Base Overturning Moment Coefficient For Vertical Tanks
(Source: Reference 26, Figure 2.5)



(a) Typical Plan and Outside Views

(b) Side View

Figure 7-5. Typical Anchor Bolt Chair
(Source: Reference 26, Figure 2.13)



(a) Side View

(b) Angle Chair Side View

Figure 7-6. Alternate Anchor Bolt Chairs
(Source: Reference 26, Figure 2.14)

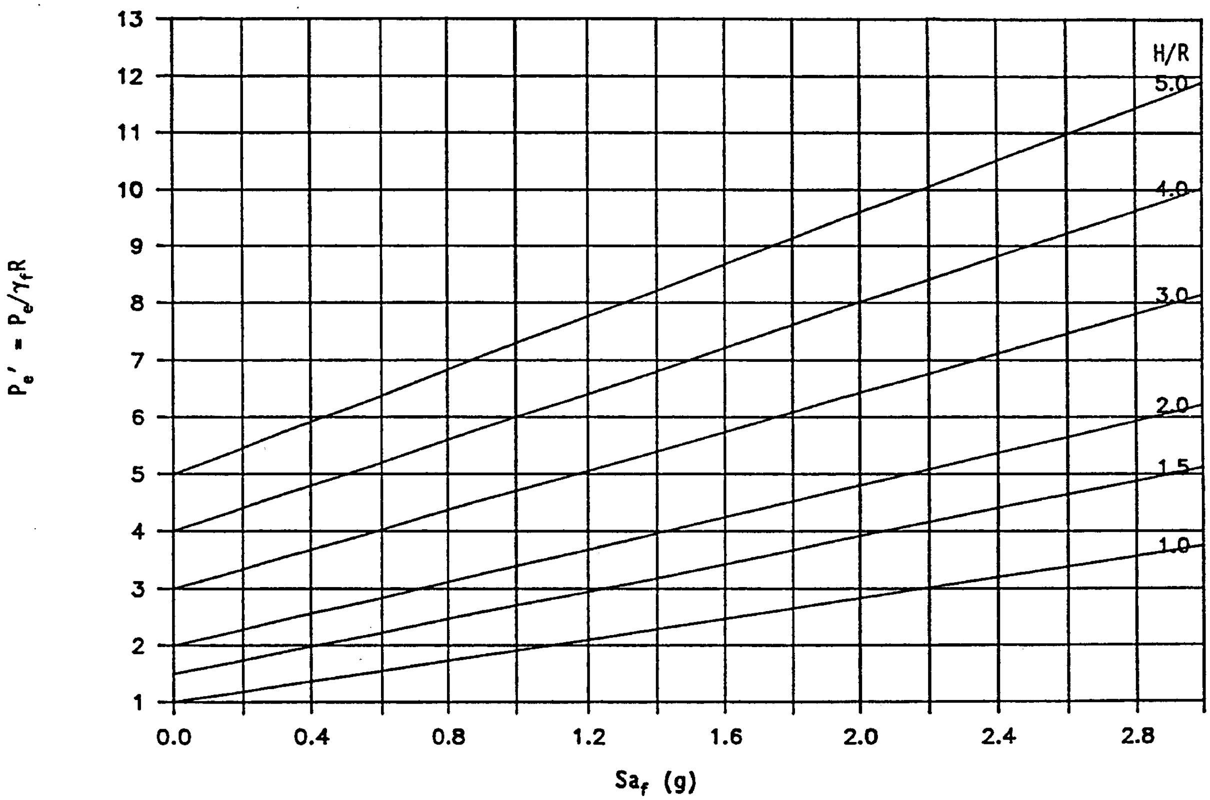


Figure 7-7. Pressure Coefficient For Elephant-Foot Buckling of Vertical Tanks (Source: Reference 26, Figure 2.6)

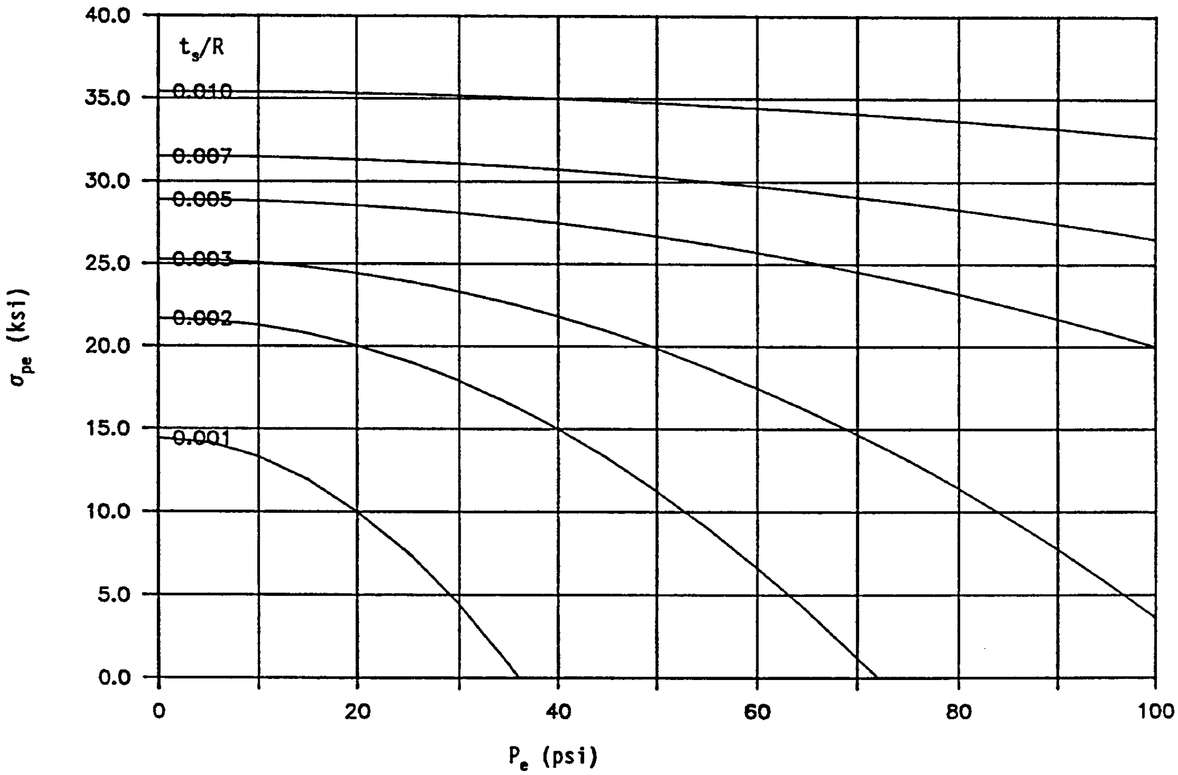


Figure 7-8. Compressive Axial Stress Capacity For Vertical Tanks, Elephant-Foot Buckling (Steel, E = 30,000 psi, σ_y = 36,000 psi) (Source: Reference 26, Figure 2.8)

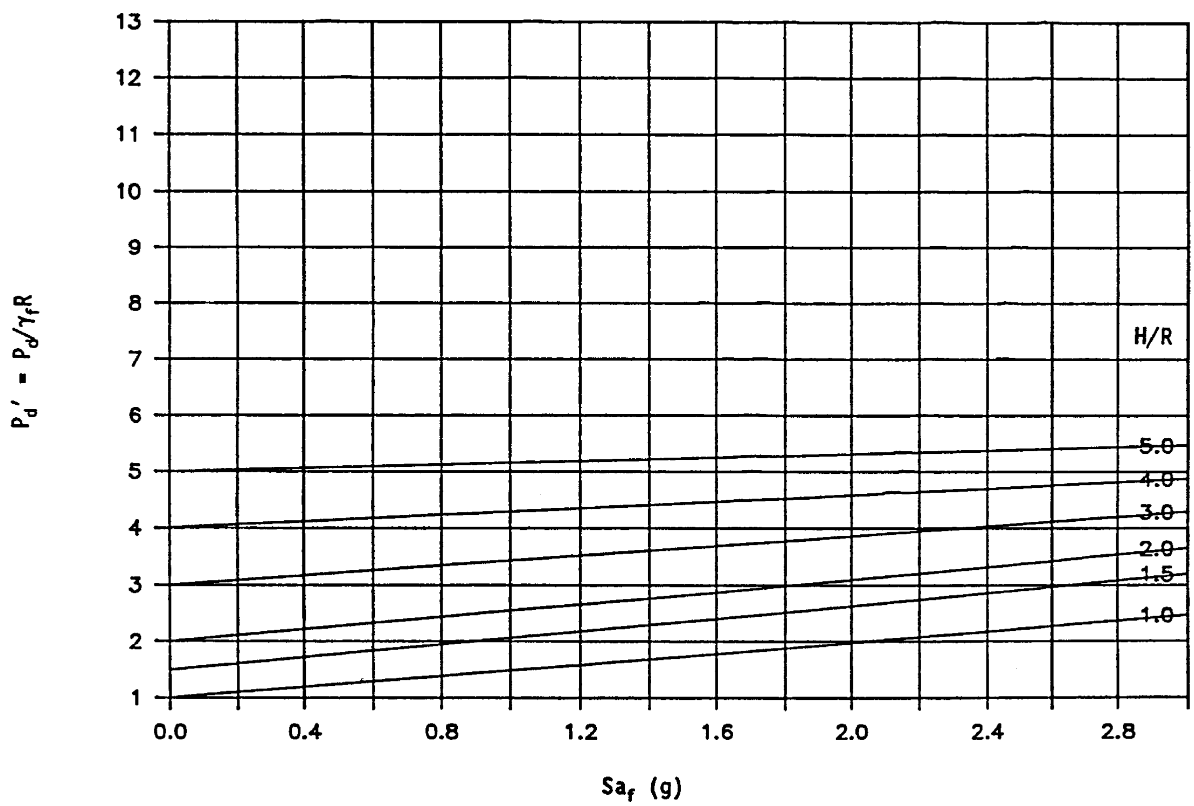


Figure 7-9. Pressure Coefficient For Diamond-Shape Buckling of Vertical Tanks (Source: Reference 26, Figure 2.7)

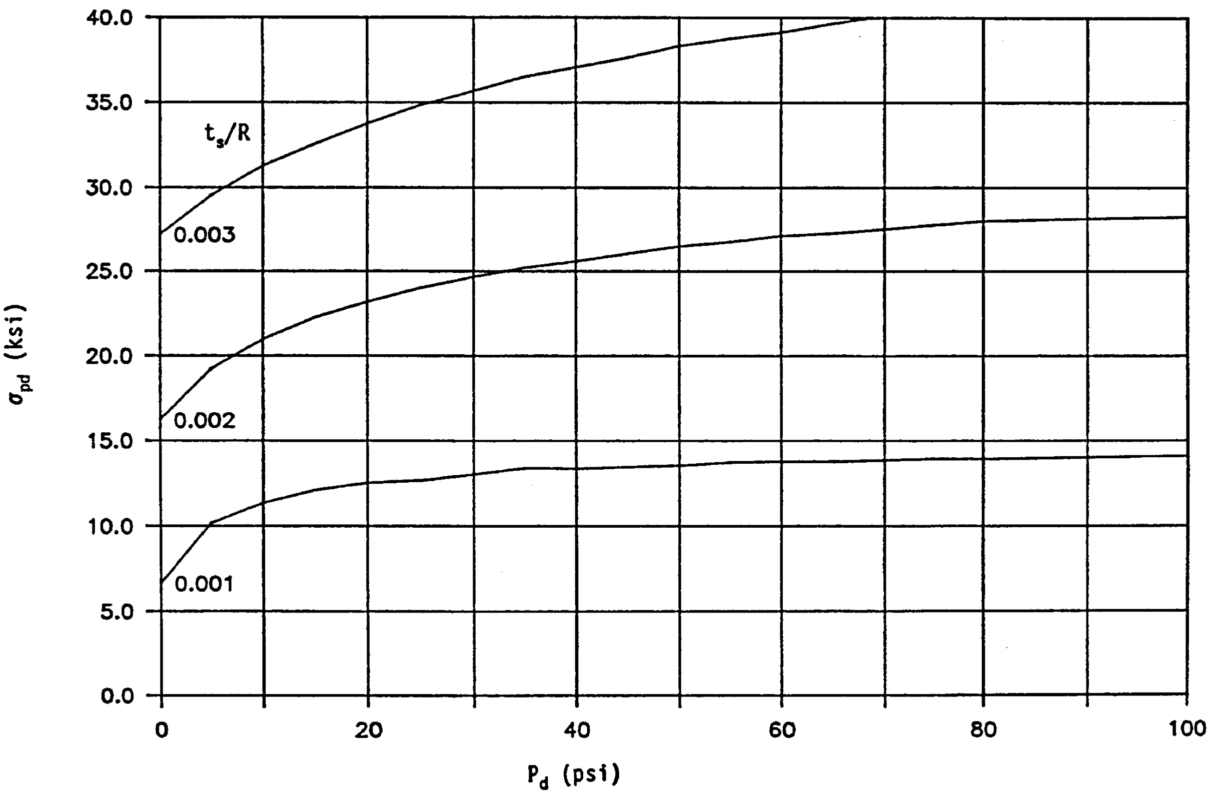


Figure 7-10. Compressive Axial Stress Capacity For Vertical Tanks, Diamond-Shape Buckling (Steel, E = 30,000 psi) (Source: Reference 26, Figure 2.10)

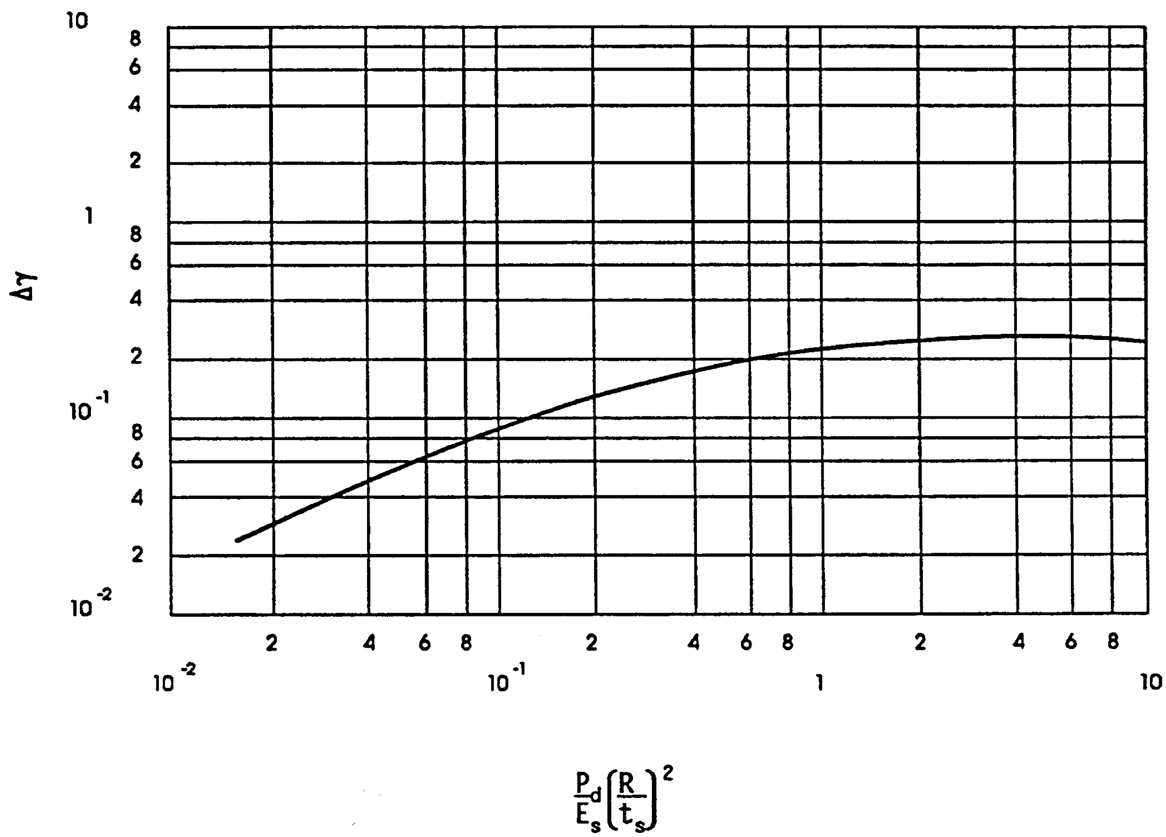


Figure 7-11. Increase Factor Δγ for Diamond-Shape Buckling
(Source: Reference 26, Figure 2.9)

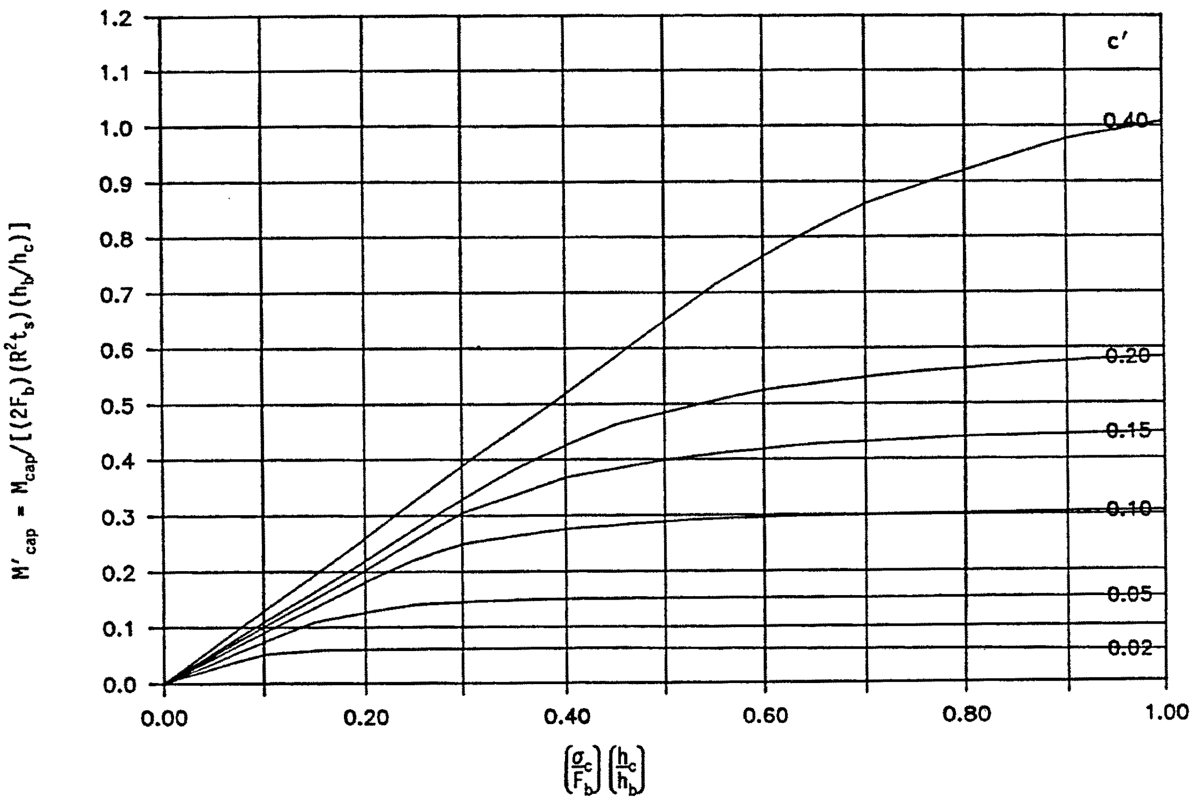


Figure 7-12. Base Overturning Moment Capacity Coefficient For Vertical Tanks (Source: Reference 26, Figure 2.12)

7.4 HORIZONTAL TANKS

This section describes (1) the scope of horizontal tanks and heat exchangers and range of parameters which are covered by the screening guidelines and (2) the analysis procedure for determining the seismic demand on, and the seismic capacity of horizontal tanks and heat exchangers including their supports and anchorages.

7.4.1 Scope of Horizontal Tanks

The types of tanks covered by the screening guidelines in this section are cylindrical steel tanks and heat exchangers whose axes of symmetry are horizontal and are supported on their curved bottom by steel saddle plates. These types of tanks will be called "horizontal tanks" throughout this section. A typical horizontal tank on saddles is shown in Figure 7-13. (Note: All the figures and tables applicable to horizontal tanks are grouped together after Step 11 at the end of Section 7.4.) The range of parameters and assumptions which are applicable when using the guidelines to evaluate horizontal tanks are listed in Table 7-6. The nomenclature and symbols used for horizontal tanks are listed in Table 7-7.

The screening guidelines are based on the assumption that the horizontal tanks are anchored to a stiff foundation which has adequate strength to resist the seismic loads applied to the tank. All the base plates under the saddles are assumed to have slotted anchor bolt holes in the longitudinal direction to permit thermal growth of the tank, except for the saddle at one end of the tank which is fixed. The saddles are assumed to be uniformly spaced a distance S apart, with the two ends of the tank overhanging the end saddles a maximum distance of S/2. These assumptions and the range of parameters given in Table 7-6 have been selected to cover the majority of horizontal tanks and heat exchangers in nuclear power plants.

7.4.2 Seismic Demand/Capacity of Horizontal Tanks

A simple, equivalent static method is used to determine the seismic demand on and capacity of the anchorages and the supports for horizontal tanks. This approach is similar to the seismic demand/capacity evaluations described in Section 4.4 and Appendix C for other types of equipment requiring anchorage verification (switchgear, transformers, pumps, battery chargers, etc.). Note that it is not necessary to evaluate the seismic adequacy of the shell of horizontal tanks or the shell-to-support welds since these items are normally rugged enough to withstand the loads which can be transmitted to them from the anchor bolts and support saddles.

The screening guidelines contained in this section specifically address only the seismic loads due to the inertial response of horizontal tanks. If, during the Screening Verification and Walkdown of a tank, the Seismic Capability Engineers determine that the imposed nozzle loads due to the seismic response of attached piping may be significant, then these loads should be included in the seismic demand applied to the anchorage and supports of the tank. There is some discussion provided on this subject for piping loads applied to horizontal pumps in Appendix B, Section B.5.1, HP/BS Caveat 4; this discussion is also applicable to horizontal tank evaluations.

The guidelines in this section are in the form of tables, charts, and a few simple calculations to determine the seismic capacity of horizontal tanks in terms of the peak acceleration the tanks can withstand. This peak acceleration capacity is assumed to be composed of a uniform acceleration capacity, λ, in the two horizontal directions, and 2/3 λ in the vertical direction. The screening guidelines include the effect of combining the three directions of acceleration by the square-root-of-the-sum-of-squares (SRSS) method. The seismic acceleration capacity, λ, is then compared with either the ZPA or the peak of the 4% damped, horizontal floor response spectrum, depending on whether: (1) the horizontal tank is rigid in the vertical or traverse direction (i.e., whether the tank shell acts as a rigid or flexible beam between the saddles); or (2) the horizontal tank and its support system is rigid in the longitudinal direction.

The seismic adequacy of the following critical parts of horizontal tanks are evaluated in these screening guidelines:

- Anchor bolts and their concrete embedment
- Base plate bending

- Base plate-to-saddle weld
- Saddle bending and compression

Step-By-Step Procedure for Horizontal Tanks

Step 1 - Determine the following input data. See Figure 7-13 for location of some of these dimensions.

Tank: D (Diameter of tank) [ft.]

L (Length of tank) [ft.]

t (Thickness of tank shell) [in.]

W_{tf} (Weight of tank plus fluid) [lbf]

γ_t or γ_h (Weight density of horizontal tank or heat exchanger including fluid) [lbf/ft^3]

H_{cg} (Height of center-of-gravity of tank and fluid above the floor where the tank is anchored) [ft.]

Saddles: S (Spacing between support saddles) [ft.]

h (Height of saddle plate from the bottom of the tank to the base plate) [in.]

G (Shear modulus of saddle plate and stiffener material) [psi]

E (Elastic modulus of saddle plate and stiffener material) [psi]

NS (Number of saddles)

Base Plate: t_b (Thickness of base plate under saddle) [in.]

f_y (Minimum specified yield strength of saddle base plate) [psi]

t_w (Thickness of leg of weld between saddle and base plate) [in.]

e_s (Eccentricity from the anchor bolt centerline to the vertical saddle plate) [in.]

Bolts: NL (Number of bolt locations on each saddle)

NB (Number of anchor bolts at each bolt location)

d (Diameter of anchor bolt) [in.]

D' (Distance between extreme anchor bolts in base plate of saddle) [ft.]

Loading: Floor response spectrum at 4% damping

Confirm that the parameters and values determined in this step are within the range of applicable parameters given in Table 7-6. If they are, then the procedure given in this section is applicable to the subject horizontal tank; proceed to Step 2. If the horizontal tank does not meet this guideline, classify the tank as an outlier and proceed to Section 5, Outlier Identification and Resolution.

Step 2 - Determine the anchor bolt tension and shear load allowables from Appendix C, accounting for the effects of embedment, spacing, edge distance, and cracking in concrete, as discussed in Section 4.4 and Appendix C.

P_u' [lbf] (from Section 4.4 and Appendix C)

V_u' [lbf] (from Section 4.4 and Appendix C)

Step 3 - Determine the base plate bending strength reduction factor (RB). The width of the base plate that is stressed in bending is conservatively assumed to be equal to twice the distance between the centerline of the bolt and the vertical saddle plate; i.e., $2e_s$. The strength reduction factor is determined by taking the ratio of the base plate yield strength (f_y) over the maximum bending stress (σ):

$$RB = \frac{f_y}{\sigma} = \frac{f_y\, t_b^2}{3P_u'}$$

Step 4 - Determine the base plate weld strength reduction factor (RW). The length of weld assumed to carry the anchor bolt load is taken to be equal to twice the distance from the bolt centerline to the vertical saddle plate; i.e., $2\ e_s$. The strength reduction factor is the ratio of the weld allowable strength (30,600 psi) over the weld stress (σ):

$$RW = \frac{30{,}600\,\text{psi}}{\sigma} = \frac{\sqrt{2}\ t_w\, e_s\,(30{,}600\,\text{psi})}{P_u'}$$

Step 5 - Determine the anchorage tension allowable using the strength reduction factors. The tension allowable anchorage load is based on the smaller of the strength reduction factors for base plate bending or base plate weld:

$P_u = P_u' \cdot$ (Smaller of: 1.0, RB or RW) [lbf]

The shear allowable anchorage load is:

$V_u = V_u'$ [lbf]

Step 6 - Calculate the following ratios and values:

$$\alpha = P_u/V_u$$

$$W_b = \frac{W_{tf}}{NS \cdot NL \cdot NB}$$

V_u/W_b

H_{cg}/D'

H_{cg}/S

$$F_1 = \sqrt{(NS)^2 + 1}$$

$$F_2 = \sqrt{NL^2 \left(\frac{H_{cg}}{D'}\right)^2 + \left(\frac{2}{3}\right)^2 + \left(\frac{H_{cg}}{S}\right)^2 \left(\frac{(NS)^2}{(NS-1)^2}\right)}$$

Step 7 - Determine the acceleration capacity of the tank anchorage. The acceleration capacity (λ) of the tank anchorage is defined as the smaller of the two anchorage acceleration capacities λ_l or λ_u:

$$\lambda_l = \left(\frac{V_u}{W_b}\right)\left(\frac{1}{F_1}\right) \quad [g]$$

$$\lambda_u = \frac{\frac{V_u}{W_b} + \frac{0.7}{\alpha}}{\left(\frac{0.7}{\alpha}\right)F_2 + F_1} \quad [g]$$

$$\lambda = (\text{Smaller of } \lambda_l \text{ or } \lambda_u) \quad [g]$$

Step 8 - Determine whether the tank is rigid or flexible in the transverse and vertical directions. Enter Figure 7-14 (for horizontal tanks with weight density $\gamma_t \leq 75$ lbf/ft^3) or Figure 7-15 (for horizontal heat exchangers with weight density $\gamma_h \leq 180$ lbf/ft^3) with:

D (Diameter of tank) [ft.]

t (Thickness of tank shell) [in.]

and determine the maximum saddle spacing for rigid transverse and vertical frequency response (i.e., $F_{trans.} \geq 30$ Hz):

S_c [ft.] {from Figure 7-14 or 7-15)

If the maximum saddle spacing (S_c) is more than or equal to the actual spacing (S):

$S_c \geq S$

then the tank is rigid in the transverse and vertical directions, otherwise it is flexible.

Step 9 - Determine whether the tank is rigid or flexible in the longitudinal direction. The rigidity of the one saddle not having slotted holes in its base plate controls the frequency response of the tank in the longitudinal direction. The longitudinal stiffness (k_s) of the tank is determined by assuming the saddle plate and its stiffeners bend with a fixed (built-in) connection at the tank and a pinned connection at the base plate. The moment of inertia (I_{yy}) of the cross-sectional area of the saddle plate and its stiffeners should be determined at a cross section just below the bottom of the cylindrical tank. Compute the resonant frequency of the tank in the longitudinal direction using the following equation:

$$F_{long.} = \frac{1}{2\pi}\sqrt{\frac{k_s\, g}{W_{tf}}} \qquad \text{[Hz]}$$

Where the saddle stiffness (k_s) is:

$$k_s = \frac{1}{\dfrac{h^3}{3\,E\,I_{yy}} + \dfrac{h}{A_s\,G}} \qquad \text{[lbf/in]}$$

If the longitudinal resonant frequency ($F_{long.}$) is greater than or equal to about 30 Hz:

$F_{long.} \geq 30$ Hz

then the tank is rigid in the longitudinal direction, otherwise it is flexible.

Step 10 - Determine the seismic demand acceleration and compare it to the capacity acceleration. If the tank is rigid in all three directions; i.e.,

$S_c \geq S$ and

$F_{long.} \geq 30$ Hz

then determine the ZPA from the 4% damped floor response spectrum (maximum horizontal component). See Section 4.4.3, Step 1 for a discussion of input spectral acceleration.

ZPA [g] (from 4% damped floor response spectrum at 33 Hz)

and compare it to the acceleration capacity of the tank anchorage:

λ [g] (from Step 7)

If

$\lambda \geq$ ZPA

then the tank anchorage is adequate; proceed to Step 11. If the tank anchorage does not meet this guideline, classify the tank as an outlier and proceed to Section 5, Outlier Identification and Resolution, after completing the remainder evaluations in this section.

If the tank is flexible in any of the three directions, i.e.,

$S_c < S$ or

$F_{long.} < 30$ Hz

then determine the spectral peak acceleration* from the 4% damped floor response spectrum (maximum horizontal component):

---

* This horizontal tank evaluation procedure uses the assumption that the tank is full of water. This assumption always results in a conservative evaluation when the peak of the response spectrum is used to estimate the seismic demand acceleration.

If, however, the Seismic Capability Engineers elect to determine the fundamental natural frequency of the tank more accurately, and use a spectral acceleration corresponding to a frequency less than the frequency at the peak of the demand spectrum, then they should also consider the case where the tank may not be full. For seismic demand spectra with sharp increases over small frequency changes, the seismic demand load for evaluation of the tank anchorage (weight x spectral acceleration) may be greater for the partially filled tank than for the full tank.

SPA* [g] (from peak of 4% damped response spectrum)

and compare it to the acceleration capacity of the tank anchorage:

λ [g] (from Step 7)

If

$$\lambda \geq SPA$$

then the tank anchorage is adequate; proceed to Step 11. If the tank anchorage does not meet this guideline, classify the tank as an outlier and proceed to Section 5, Outlier Identification and Resolution, after completing the remainder of the evaluations in this section.

Step 11 - Check the saddle stresses. Longitudinal shear is the main load that the saddle and its stiffeners must carry if the other saddles have slotted anchor bolt holes in the base plate. Except for small tanks, the saddle which carries the longitudinal earthquake shear loading should have stiffeners to resist this weak axis bending. In addition to the longitudinal shear load, there are several other loads in the other directions which should be considered; these other loads are carried equally by all the saddles. The loads to include in determining the stresses in the saddle and its stiffeners are listed below.

- Longitudinal seismic loads
- Vertical compression load from dead weight
- Vertical seismic loads
- Overturning moment from transverse seismic load

The stresses in the saddle and its stiffeners should be determined in accordance with the combined compression and bending provisions of Part 1 of the AISC Manual of Steel Construction (Reference 29). If the stresses are less than or equal to 1.7 x AISC allowables (for safe shutdown earthquake loading), then the saddle is adequate and hence the tank is satisfactory for seismic loadings. If the saddle stresses exceed the AISC allowable, then classify the tank as an outlier and proceed to Section 5, Outlier Identification and Resolution.

This completes the seismic evaluation for horizontal tanks.

Table 7-6
Applicable Range of Parameters and Assumptions for Horizontal Tanks[1]

Diameter of Tank	D	=	1 to 14 ft.
Length of Tank	L	=	4 to 60 ft.
Height of Center-of-Gravity of Tank and Fluid Above the Floor Where the Tank is Anchored	H_{cg}	=	1 to 12 ft.
Number of Saddles[2]	NS	=	2 to 6
Spacing Between Support Saddles[3]	S	=	3 to 20 ft.
Number of Bolting Locations[4] per Saddle[5]	NL	=	2 or 3
Number of Anchor Bolts per Bolting Location	NB	=	1 to 2
Distance Between Extreme Anchor Bolts in Base Plate of Saddle	D'	=	1 to 12 ft.
Ratio of Tank C.G. Height-to-Saddle Spacing	H_{cg}/S	=	0.1 to 2.0
Ratio of Tank C.G. Height-to-Distance Between Extreme Anchor Bolts	H_{cg}/D'	=	0.5 to 2.0
Weight Density of Horizontal:			
- Tanks (including fluid)	γ_t	=	60 to 75 lbf/ft^3
- Heat Exchangers (including fluid)	γ_h	=	130 to 180 lbf/ft^3

Assumptions:

1 Tanks are assumed to be cylindrical, horizontally oriented, and made of carbon steel.

2 Tanks are assumed to be supported on carbon steel plate saddles.

3 Saddles are assumed to be uniformly spaced a distance S apart with the tank overhanging the end saddles a distance S/2.

4 One or two anchor bolts are assumed at each bolting location.

5 All the base plates under the saddles are assumed to have slotted anchor bolt holes in the longitudinal direction to permit thermal growth of the tank, except for the saddle at one end of the tank which is fixed.

Table 7-7
Nomenclature Used for Horizontal Tanks

Symbol		Description [Units]
A_s	–	Cross-sectional area of saddle plate and its stiffeners (see Figure 7-13) [in.^{2}]
D	–	Diameter of tank (see Figure 7-13) [ft.]
D′	–	Distance between extreme anchor bolts in base plate of a saddle (see Figure 7-13) [ft.]
d	–	Diameter of anchor bolt [in.]
E	–	Elastic modulus of saddle plate and stiffener material [psi]
e_s	–	Eccentricity (distance) from the anchor bolt centerline to the vertical saddle plate (see Figure 7-13) [in.]
$F_{long.}$	–	Resonant frequency of tank in longitudinal direction [Hz]
$F_{trans.}$	–	Resonant frequency of tank in transverse/vertical direction [Hz]
F_1	–	Coefficient [dimensionless]
F_2	–	Coefficient [dimensionless]
f_y	–	Minimum specified yield strength of shell, chair, saddle, or base plate material [psi]
G	–	Shear modulus of saddle plate and stiffener material [psi]
g	–	Acceleration of gravity [386 in/sec^2]
H_{cg}	–	Height of center-of-gravity of tank and fluid above the floor where the tank is anchored [ft.]
h	–	Height of saddle plate from the bottom of the tank to the base plate (see Figure 7-13) [in.]
I_{yy}	–	Moment of inertia of cross-sectional area of saddle plate and its stiffeners about axis Y-Y (see Plan of Support S1 in Figure 7-13) [in.^{4}]
k_s	–	Stiffness of the saddle plate and its stiffeners in the direction of the longitudinal axis of the tank [lbf/in]
L	–	Length of tank (see Figure 7-13) [ft.]
NB	–	Number of anchor bolts at each bolt location [dimensionless]
NL	–	Number of bolt locations on each saddle [dimensionless]
NS	–	Number of saddles [dimensionless]
P_u	–	Allowable tensile load of tank anchorage [lbf]
P_u'	–	Allowable tensile load of anchor bolt [lbf]
RB	–	Strength reduction factor for base plate bending [dimensionless]

Table 7-7 (Continued)
Nomenclature Used for Horizontal Tanks

Symbol		Description [Units]
RE	–	Strength reduction factor for an anchor bolt near an edge [dimensionless]
RS	–	Strength reduction factor for closely spaced anchor bolts [dimensionless]
RW	–	Strength reduction factor for base plate weld [dimensionless]
S	–	Spacing between support saddles (see Figure 7-13) [ft.]
S_c	–	Maximum saddle spacing for rigid tank ($F_{trans.} \geq 30$ Hz) [ft.]
SPA	–	Spectral peak acceleration [g]
t	–	Thickness of tank shell [in.]
t_b	–	Thickness of base plate under saddle [in.]
t_w	–	Thickness of leg of weld [in.]
V_u	–	Allowable shear load of tank anchorage [lbf]
V_u'	–	Allowable shear load of anchor bolt [lbf]
W_b	–	Weight of tank per anchor bolt, $W_b = \dfrac{W_{tf}}{NS \cdot NL \cdot NB}$ [lbf]
W_{tf}	–	Weight of tank plus fluid [lbf]
ZPA	–	Zero period acceleration [g]
α	–	Ratio of tensile to shear allowable anchorage load, $\alpha = \dfrac{P_u}{V_u}$ [dimensionless]
γ_h	–	Weight density of horizontal heat exchanger including fluid [lbf/ft^3]
γ_t	–	Weight density of horizontal tank including fluid [lbf/ft^3]
λ	–	Acceleration capacity of tank anchorage [g]
λ_l	–	Lower acceleration capacity of tank anchorages [g]
λ_u	–	Upper acceleration capacity of tank anchorages [g]
σ	–	Stress [psi]

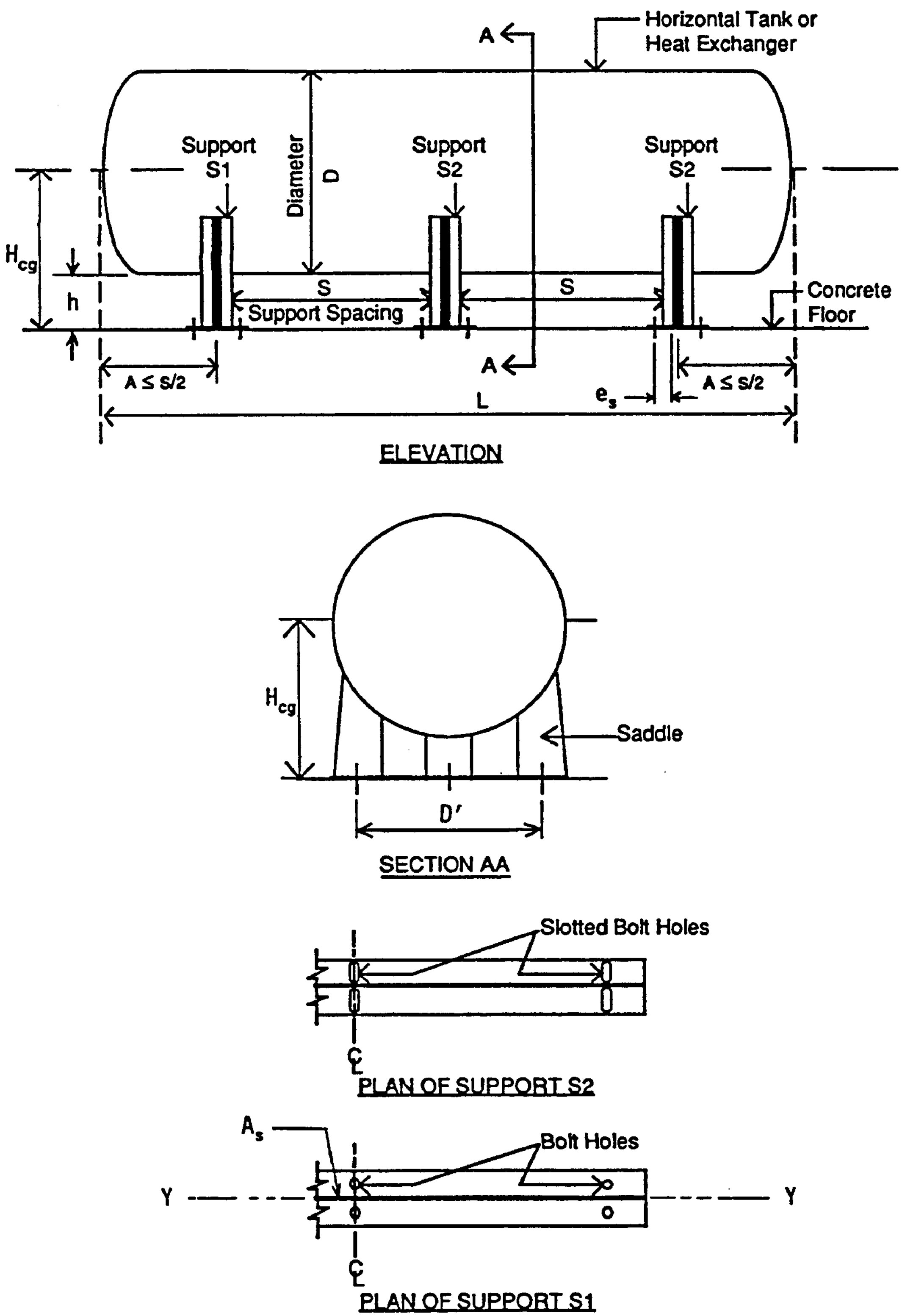


Figure 7-13. Horizontal Tank or Heat Exchanger
(Source: Reference 26, Figure 3.1)

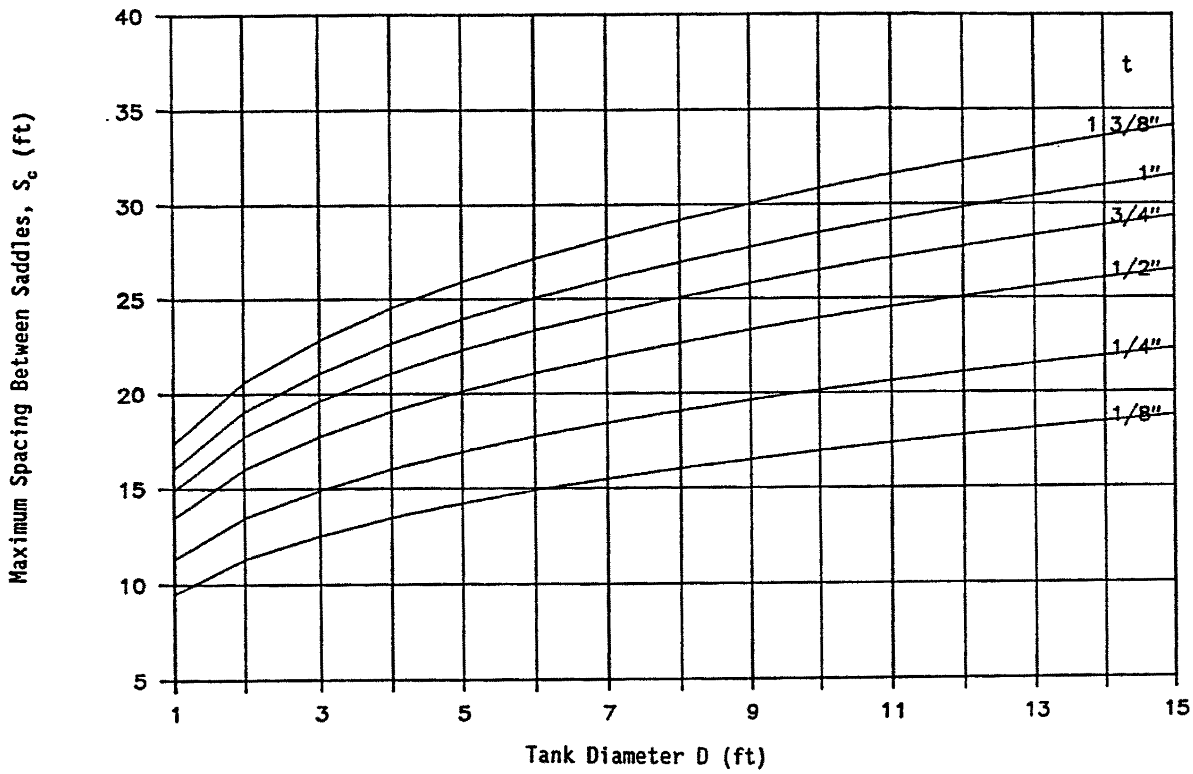


Figure 7-14. Maximum Saddle Spacing For Rigid ($F_{trans.} \geq 30$ Hz) Horizontal Tanks ($\gamma_t \leq 75$ lbf/ft^3)
(Source: Reference 26, Figure 3.7)

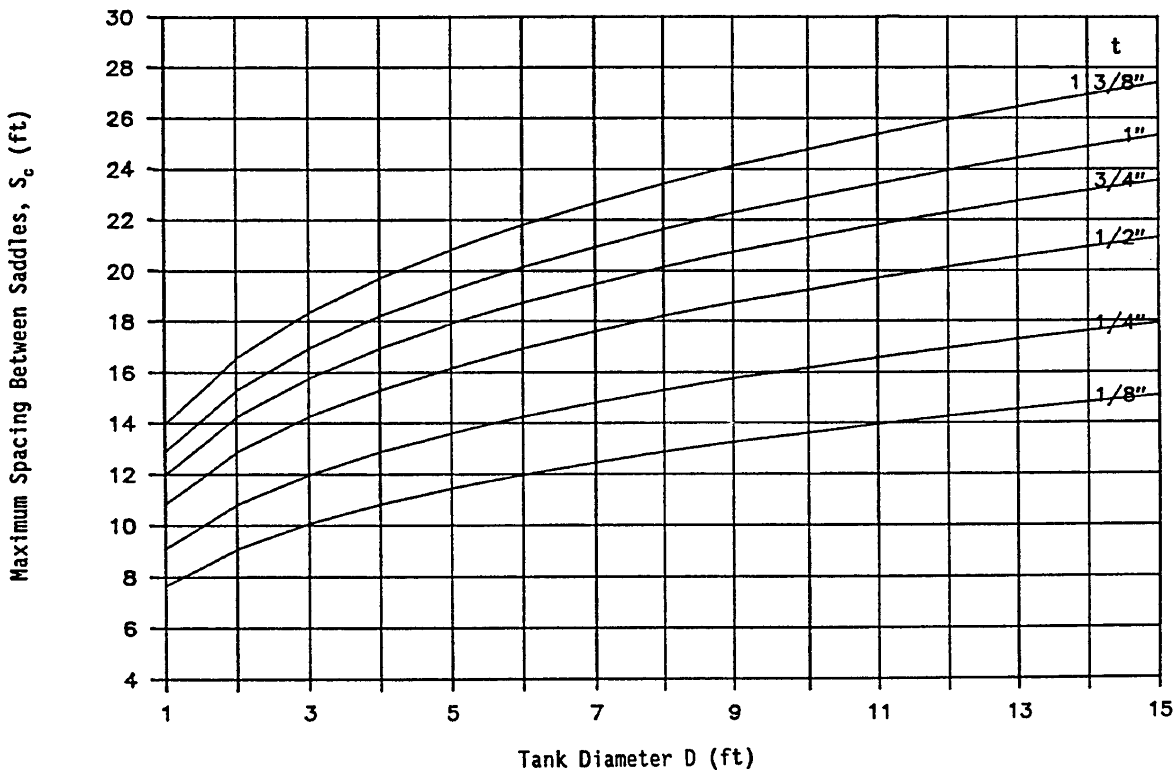


Figure 7-15. Maximum Saddle Spacing for Rigid ($F_{trans.} \geq 30$ Hz) Horizontal Heat Exchangers ($\gamma_h \leq 180$ lbf/ft^3) (Source: Reference 26, Figure 3.8)

7.5 OUTLIERS

An outlier is defined as a tank or heat exchanger which does not meet the screening guidelines for:

- Buckling of the shell of large, flat-bottom, vertical tanks,
- Adequacy of anchor bolts and their embedments,
- Adequacy of anchorage connections between the anchor bolts and the tank shell, or
- Flexibility of piping attached to large, flat-bottom, vertical tanks.

When an outlier is identified, proceed to Section 5, Outlier Identification and Resolution, and document the cause(s) for not meeting the screening guidelines on an Outlier Seismic Verification Sheet (OSVS) (Exhibit 5-l).

Note that all of the screening guidelines should be evaluated (i.e., go through all the steps in this procedure) so that all possible causes for a tank or heat exchanger being classified as an outlier are identified before proceeding to Section 5 to resolve it.

The screening guidelines given in this section are intended for use as a generic screen to evaluate the seismic adequacy of tanks and heat exchangers. Therefore, if a tank or heat exchanger fails this generic screen, it may not necessarily be deficient for seismic loading; however, additional outlier evaluations are needed to show that it is adequate. Such analyses could include use of the principles and guidelines contained in this section and in Reference 26 for those types of tanks and heat exchangers not covered herein; e.g., vertical tanks supported on skirts or structural legs. When a tank or heat exchanger which is covered by this section fails to pass the screening guidelines, refined analyses could be performed which include use of more realistic or accurate methods instead of the simplified, generic analysis methods used in this section and Reference 26. Other generic methods for resolving outlier are provided in Section 5.

7.6 DOCUMENTATION

The results of the engineering evaluations and field inspections performed using the guidelines in this section should be retained in the utility's files.

The results of the evaluations and inspections should also be documented by completing a Screening and Verification Data Sheet (SVDS) as described in Section 4.6. This SVDS would be included in the Seismic Evaluation Report submitted to the NRC at the completion of the Screening Verification and Walkdown.

If any of the screening guidelines contained in this section cannot be met, the tank should be classified as an outlier. The Outlier Seismic Verification Sheet (OSVS), found in Exhibit 5-1, should be completed to document the cause(s) for not meeting the screening guidelines.

REASONS FOR CHANGES TO GIP, PART II, SECTION 7

Listed below are the specific reasons for making the changes marked with a vertical line in the margin of this section to create GIP-3A from GIP-3, Updated 5/16/97. The endnote numbers listed below correspond to the bracketed numbers (e.g., [1]) located in the text of this section where the changes are made.

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[1] SSER No. 2, Sec. II.7.2 – The Staff position is that the criteria and guidelines contained in Part II, Section 7.0 of the GIP are not acceptable for new installations of tanks and heat exchangers. Subsequent to issuance of SSER No. 2, SQUG proposed (in Reference 39) and the NRC Staff accepted (in Reference 40) use of Part II, Section 7.0 for new tank and heat exchanger installations but with different attributes for newly designed and constructed flat-bottom, vertical tanks.

The GIP has been amended in Part II, Sections 7.0, 7.3.3.1, 7.3.3.3, and 7.3.7 to reflect the additional requirements in References 39 and 40 that must be used when applying the GIP for newly designed and constructed flat-bottom, vertical tanks as described in the NARE Guidelines (Reference 41). These additional requirments are listed below.

- Part II, Section 7.3.3.1 – The allowable bolt stress for the cast-in-place anchorage is limited to the yield strength of the bolting material.
- Part II, Section 7.3.3.3, Step 16 – The allowable buckling stress equation defined in this step is revised to use a factor of 0.6 instead of 0.72.
- Part II, Section 7.3.7 – The tank foundation shall be designed to resist uplift and overturning moment.

[2] SSER No. 2, Sec. II.4.1 – The Staff position is that the licensee must commit to both the SQUG commitments and the use of the entire implementation guidance provided in GIP-2, unless otherwise justified to the staff as described in GIP-2 and SSER No. 2.

The GIP has been amended in the "SQUG Commitments" sections of Part II to reiterate the requirement contained in the GIP, Part I, Section 1.3 to (1) provide written justification to the NRC for prior approval of any substantial deviations from the SQUG commitments and (2) notify the NRC of significant or programmatic deviations from the GIP guidance no later than the summary report.

[3] SSER No. 2, Sec. II.7.1 – The Staff strongly recommends that the input data required in Step 1 of Section 7.3.2 be based on the pertinent as-built drawings and verification through walkdowns of the condition of the tanks and supporting foundation.

The GIP has been amended in Part II, Section 7.3.2, Step 1 to suggest that, where practical, as-built drawings should be used or walkdowns performed to gather data on the tank.