Title:	**External Pressure for API-620 Tanks**
Date:	May 17th 2024
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Purpose:	**Add Reference to API-650 Annex V for External Pressure Design for API-620 Tanks**
Source:	INQ-D009
Revision:	3
Impact:	Improved design for External Pressure.
Background/Rationale:	API-620 does not have any calculations for external pressure (vacuum) on the shell. Instead, it has a singular statement saying any tank designed to API-620 should be good for 1-ounce vacuum. This Agenda Item adds a reference to API-650 Annex V and cleans up the use of “vacuum” or “partial vacuum” and uses “external pressure” instead. **Rev3 now has no external pressure limit.**

Proposal: **Existing in black. Changes in red. ~~Removed sections are stricken out.~~ Notes/Comments in blue (Notes/Comments do not appear in the code)**

1.2 Coverage

1.2.1 This standard covers the design and construction of large, welded, low-pressure carbon steel above ground storage tanks (including flat-bottom tanks) that have a single vertical axis of revolution. This standard does not cover design procedures for tanks that have walls shaped in such a way that the walls cannot be generated in their entirety by the rotation of a suitable contour around a single vertical axis of revolution.

1.2.2 The tanks described in this standard are designed for metal temperatures not greater than 250 °F and with pressures in their gas or vapor spaces not more than 15 lbf/in.^{2} gauge internal pressure. ~~or 1 lbf/in.^{2} external pressure.~~ Tanks that meet the requirements of this standard may be subjected to an external pressure of 1 oz/in.^{2} without the need to provide any additional supporting calculations.

Had added "or 1 lbf/in.^{2} external pressure" but removed per Eric Gnade (CB&I) request. LIN/LOX may be above 1 lbf/in.^{2}

3.1 Stress and Pressure Terms

3.1.1

design internal pressure (Pi)

The maximum positive internal gauge pressure permissible at the top of a tank when the tank is in operation. It is the basis for the pressure setting of the safety-relieving devices on the tank. The design internal pressure is synonymous with the nominal pressure rating for the tank as referred to in this standard (see 5.3.1).

3.1.2

partial vacuum (Pv)

A negative gauge pressure that is generated by a combination of product liquid and vapor withdrawal or by barometric pressure fluctuations. The maximum inflow of air (or another gas or vapor) through the vacuum relief valves occurs when the maximum partial vacuum is reached.

Added this definition per Eric Gnade's request

3.1.3

design external pressure (Pe)

~~Tanks that meet the requirements of this standard may be subjected to an external pressure of 1 oz/in.^{2} without the need to provide any additional supporting calculations. API-650 Annex V may be used for the design of external pressure greater than 1 oz/in.^{2}.~~

A maximum external pressure that may be caused by a partial vacuum, a uniformly applied external pressure or insulation pressure, or a combination of those based on the type of containment system. Refer to 5.10.5 for external pressure design limitations.

Removed stricken out part and added new sentence per Eric Gnade's request

3.1.4

maximum allowable stress value

The maximum unit stress permitted to be used in the design formulas given or provided for in this standard for the specific kind of material, character of loading, and purpose for a tank member or element (see 5.5 and 5.6).

5.1.2 Pressure Chambers

For tanks that consist of two or more independent pressure chambers and have a roof, bottom, or other elements in common, each pressure part shall be designed for the most severe combination of internal pressure or ~~vacuum~~ external pressure that can be experienced under the specified operating conditions.

5.3 Pressures Used in Design
5.3.1 Above Maximum Liquid Level

5.3.1.1 Tank components, including those above the maximum liquid level, subjected principally to gas pressure shall be designed for the following.

a) A pressure not less than the relief valves' set pressure. The maximum internal pressure ~~positive gauge pressure~~ shall be understood to be the nominal pressure rating for the tank (sometimes called the design pressure) and shall not exceed 15 lbf/in.^{2} gauge.

b) The design external pressure as defined in 3.1.3. ~~The maximum partial vacuum (also called the design vacuum) external pressure caused by a partial vacuum generated when the inflow of air (or another gas or vapor) through the vacuum relief valves is at the tank design maximum in-breathing flow rate.~~

Added per Eric Gnade's request

5.3.1.4 The set pressure of the vacuum relief valve shall limit the partial vacuum pressure ~~external pressure~~ accumulation in the tank to the ~~design vacuum pressure~~ maximum partial vacuum component of the design external pressure.

5.3.2 Below Maximum Liquid Level

All pressure-containing elements of the tank below the maximum liquid level shall be designed for the most severe combination of ~~gas~~ internal or external pressure ~~(or partial vacuum external pressure)~~ and static liquid head affecting the element.

5.4 Loads
5.4.1 Individual Loads

a) dead load (DL): the weight of the tank or tank component, including any insulation, lining, or corrosion allowance
unless otherwise noted.

b) hydrostatic and pneumatic tests (H,): the load due to conducting the tests specified in 7.18.

c) loads from connected piping (Lp)-

d) loads from platforms and stairways (Ls) (see Annex E).

e) minimum roof live load (L,): 20 lb/ft2 on the horizontal projected area of the roof.

f) internal pressure (~~Pg~~ Pi): the maximum ~~positive gauge~~ internal pressure given in 5.3.1.

g) external pressure (~~Pv~~ Pe): the maximum ~~partial vacuum~~ external pressure given in 5.3.1. The maximum partial vacuum component of the external pressure shall be at least ~~1 in. w_c~~ 1 oz/in.^{2})

5.4.2 Load Combinations

The tank shall be designed for the following load combinations. If the absence of any load other than dead load results in a more severe condition, that load shall not be included in the combination.

a) DL + ~~Pg~~ Pi + Pl

b) DL + WL + 0.7 ~~Pg~~ Pi

c) DL + WL + 0.4~~Pv~~ Pe

d) DL + ~~Pv~~ Pe + 0.4(Lr or S)

e) DL + 0.4 ~~Pv~~ Pe + (Lr or S)

f) DL + 0.7 ~~Pg~~ Pi + Pl + E + 0.1S

g) DL + Ht

h) DL + Ls

i) DL + Lp + ~~Pg~~ Pi + Pl

5.5.4 Maximum Compressive Stresses

5.5.4.1 Except as provided in 5.12.4.3 for the compression-ring region, the maximum compressive stresses in the outside walls of a tank, as determined for any of the loadings listed in 5.4 or any concurrent combination of loadings expected to be encountered in the specified operation, shall not exceed the applicable stress values determined in accordance with the provisions described in 5.5.4.2 through 5.5.4.8. ~~These rules do not purport to apply when the circumferential stress on a cylindrical wall is compressive (as in a cylinder acted upon by external pressure~~). However, values of S_{cs} computed as in 5.5.4.2, with *R* equal R1 when the compressive unit force is latitudinal or to R2 when the compressive unit force is meridional, in some degree form the basis for the rules given in 5.5.4.3, 5.5.4.4, and 5.5.4.5, which apply to walls of double curvature.

Table 5-2

NOTE 2 Regardless of any values given in this column, the efficiency for lap-welded joints between plates with surfaces of double curvature that have a compressive stress across the joint from a negative value of ~~Pg~~ Pi or other external loading may be taken as unity; such compressive stress shall not exceed 700 lbf/in.2. For all other lap-welded joints, the joint efficiency factor must be applied to the allowable compressive stress, Sca. The efficiency for full-penetration butt-welded joints, which are in compression across the entire thickness of the connected plates, may be taken as unity.

5.9.2 Levels of Analysis

Free-body analyses shall be made at successive levels from the top to the bottom of the tank for the purpose of determining the magnitude and character of the meridional and longitudinal unit forces that will exist in the walls of the tank at critical levels under all the various combinations of ~~gas~~ liquid head and internal and external pressure ~~(or partial vacuum) and liquid head~~ to be encountered in service, which may have a controlling effect on the design. Several analyses may be necessary at a given level of the tank to establish the governing conditions of ~~gas~~ liquid head and internal and external pressure ~~and liquid head~~ for that level. The thicknesses required in the main walls of the tank shall then be computed by the applicable procedures given in 5.10.3.

5.9.4 Flat Bottoms of Cylindrical Tanks

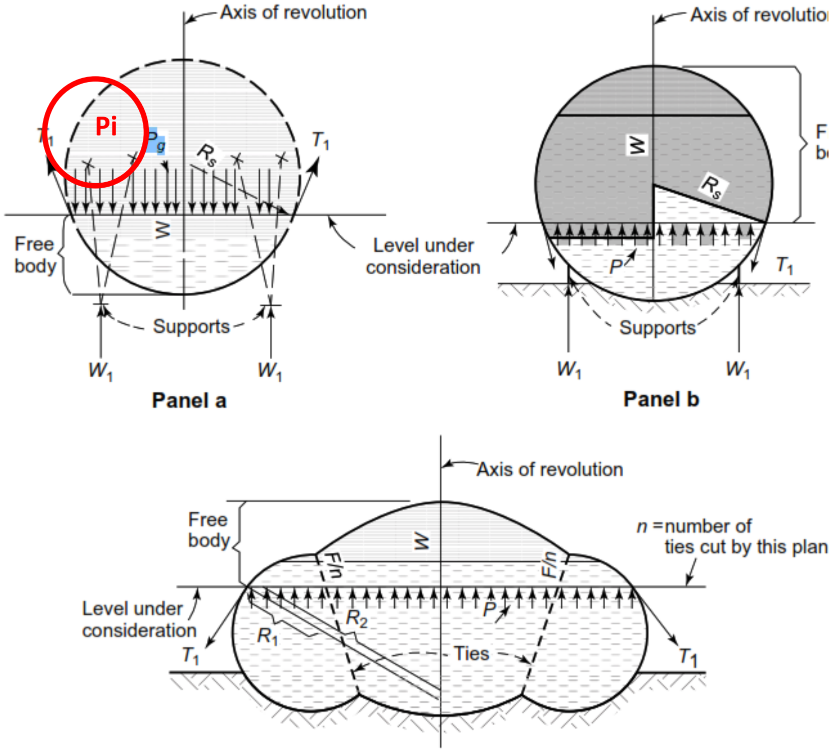
5.9.4.1 Flat bottoms of cylindrical tanks that are uniformly supported on a ringwall, grade, or concrete-slab foundation are pressure-resisting membranes but are considered nonstressed because of support from the foundation.
5.9.4.2 All bottom plates shall have a minimum nominal thickness of 1/4 in. exclusive of any corrosion allowance specified by the purchaser for the bottom plate. (See Q.3.5.7 for an exception to this requirement.)

5.10 Design of Sidewalls, Roofs, and Bottoms

5.10.1 Nomenclature

The variables used in the formulas of 5.10 are defined as follows.
P is the total pressure, in lbf/in.^{2} gauge, acting at a given level of the tank under a particular condition of loading,
Pl is the gauge pressure resulting from the liquid head at the level under consideration in the tank (see 5.4.1 b);
~~Pg~~ Pi see 5.4.1 g, ~~Pg~~ Pi is the internal pressure above the liquid level. ~~positive except in computations used to investigate the ability of a tank to withstand~~
~~a partial vacuum; in such computations, its value is negative;~~
Pe is the external pressure above the liquid level or acting on the roof or shell.

Figure 5-4



Panel c

Figure 5-4—Typical Free-body Diagrams for Certain Shapes of Tanks

5.10.2.2 Positive values of *T1* and *T2* indicate tensile forces; negative values indicate compressive forces.
5.10.2.3 Free-body analyses shall be made at the level of each horizontal joint in the sidewalls, roof, and bottom of the tank and at any intermediate levels at which the center of curvature changes significantly. The maximum total pressure (liquid head plus gas pressure) that can exist at a given level will not necessarily be the governing condition for that level. Sufficient analyses shall be made at each level to determine the combination of liquid head and ~~gas~~ internal and external pressure ~~(or partial vacuum)~~ that, in conjunction with the allowable tensile and compressive stresses, will control the design at that level. A tank may normally be operated at a fixed height of liquid contents, but the tank must be made safe for any conditions that might develop in filling or emptying the tank. This will necessitate a particularly careful investigation of sidewalls of double curvature.

5.10.2.5

a) For a spherical tank or a spherical segment of a tank, R1 = R2 = Rs (the spherical radius of the tank or segment), and Equation (1) and Equation (2) become the following:

$$T_1 = \frac{R_s}{2}\left(P + \frac{W+F}{A_t}\right)$$

(4

$$T_2 = R_s P - T_1$$

(5

$$T_2 = \frac{R_1}{2}\left(P - \frac{W+F}{A_t}\right)$$

(6

Furthermore, if the sphere is for gas pressure only and if (W + F)/At is negligible compared with ~~Pg~~ Pi, Equation (4) and

Equation (5) reduce to the following:

T1 = T2 = 1/2 ~~Pg~~ Pi Rs

b) For a conical roof or bottom,

R1 = infinity

R2 = R3/cos α

c) For cylindrical sidewalls of a vertical tank, R1 = infinity; R2 = Rc, the radius of the cylinder; and Equation (1) and

Equation (2) become the following:

$$T_1 = \left(\frac{R_c}{2}\right)\left(P + \frac{W+F}{A_t}\right) \qquad (10)$$

$$T_2 = PR_c \qquad (11)$$

Furthermore, if the cylinder is for gas pressure only and (W + F)/At is negligible compared with ~~Pg~~ Pi, Equation (10) and

Equation (11) reduce to the following:

T1 = 1/2 ~~Pg~~ Pi Rc (12)

T2 = ~~Pg~~ Pi Rc (13)

5.10.2.6 Where a horizontal plane that passes through a tank intersects the roof or bottom in more than one circle, thus isolating more than one free-body at that level, the formulas given in 5.10.2.1 and 5.10.2.5 apply only to the central free-body whose walls continue across and are pierced by the axis of revolution. (An example of the kind of plane described would be one passed through the bottom of the tank shown in Figure 5-4, Panel c, just a short distance below the lower ends of the internal ties.) The meridional and latitudinal unit forces acting along the edges of the annular free-body or bodies lying outside of the central free-body must be computed from formulas developed especially for the particular shape of free-body cross section involved. This standard cannot provide formulas for all shapes of cross sections and conditions of loading that might be used at these locations; however, for a toroidal segment that rests directly on its foundation (see 5.11.1) and has a constant meridional radius, R1, such as is used in the outer portion of the bottom of the tanks shown in Figure 5-4, Panel c, applicable equations for the meridional and

latitudinal unit forces in the walls of the segment are as follows:

T1 = ~~Pg~~ Pi R1(1 – R1/2R2) (14)

T2 = $\frac{1}{2}$~~Pg~~ Pi R1 (15)

5.10.2.7 Equation (2), Equation (5), and Equation (9) have been derived from a summation of the normal-to-surface components of the T1 and T2 forces acting on a unit area of the tank wall subjected only to pressure P. To be technically correct, the normal-to-surface components of other loads, such as metal, snow or insulation, should be added to or subtracted from P. For the usual internal design pressure, these added loads are small compared with P and can be mooted without significant error. Where the pressure P is relatively small, as in the case of a partial vacuum loading, the other load components can have a substantial effect on the calculated T2 force and resultant thickness.

Equation (3) and Equation (6) are correct only when P is the free-body pressure without the normal-to-surface components of other loads
5.10.2.7

The example in F.3 calculates the required roof thicknesses under a small ~~vacuum~~ external pressure by considering the metal, insulation and snow loads in Equation (1) through Equation (5). The designer should note that if these loads had been omitted, the calculated thicknesses would have been much less than the correct values.

In Equation (1), Equation (4), Equation (8), and Equation (10), W is intended to include loads of insignificant value, such as metal weight. At points away from the vertical centerline of the roof, the value of T2 is required for the thickness calculations of Equation (18), Equation (20), and Equation (22) and the value of P in Equation (2), Equation (5), and Equation (9) must be modified by the normal components of the added loads for the correction determination of *T2.*

5.10.3 Required Thickness

5.10.3.1 The thickness of the tank wall at any given level shall be not less than the largest value of *t* as determined for the level by the methods prescribed in 5.10.3.2 through 5.10.3.5. In addition, provision shall be made by means of additional metal, where needed, for the loadings other than internal pressure or possible ~~partial vacuum~~ external pressure enumerated in 5.4. If the tank walls have points of marked discontinuity in the direction of the meridional tangent, such as occur at the juncture between a conical or dished roof (or bottom) and a cylindrical sidewall, the portions of the tank near these points shall be designed in accordance with the provisions of 5.12.

5.10.3.2 If the unit forces T1 and T2 are both positive, indicating tension, for the governing combination of liquid head and ~~gas~~ internal and external pressure ~~(or partial vacuum) and liquid head~~ at a given level of the tank, the larger of the two shall be used for computing the thickness required at that level, as shown in the following equations:

5.10.3.3 If the unit force T1 is positive, indicating tension, and T2 is negative, indicating compression, for the governing combination of ~~gas~~ liquid head and internal and external pressure ~~(or partial vacuum) and liquid head~~ at a given level of the tank or if T2 is positive and T1 is negative, the thickness of tank wall required for this condition shall be determined by assuming different thicknesses until one is found for which the simultaneous values of the computed tension stress, S_{tc}, and the computed compressive stress, S_{cc}, satisfy the requirements of 5.5.3.3 and 5.5.4.5, respectively. The determination of this thickness will be facilitated by using a graphical solution such as the one illustrated in F-2.[17] Notwithstanding the foregoing provisions, if the unit force acting in compression in the case described does not exceed 5 % of the coexistent tensile unit force acting perpendicular to it, the designer has the option of determining the thickness required for this condition by using the method specified in 5.10. 3.2 instead of complying strictly with the provisions of this paragraph. The value of the joint efficiency factor, *E,* will not enter into this determination unless the magnitude of the allowable tensile stress, S_{ta}, is governed by the product ES_{ts} as provided in 5.5.3.3.

5.10.3.6 The procedure described in 5.10.3.5 is for the condition in which biaxial compression with unit forces of unequal magnitude is governing. In many cases, however, a tentative thickness will have been previously established by other design conditions and will need to be checked only for the external pressure ~~or partial vacuum~~ condition. In such cases, the designer has only to compute the values of S_{ec} for both T1 and T1 and then check to see that these satisfy the requirements of 5.5.4.4, as specified in Step 6. (See F.3 for examples illustrating the application of 5.10.3.5.)

5.10.5 External Pressure Limitations

5.10.5.1 The thicknesses computed using the formulas and procedures specified in 5.10, where ~~*Pg*~~ Pi is a negative value equal to the ~~partial vacuum~~ external pressure for which the tank is to be designed, will ensure stability against collapse for tank surfaces of double curvature in which the meridional radius, *R1,* is equal to or less than *R2* or does not exceed *R2* by more than a very small amount. Data on the stability of sidewall surfaces of prolate spheroids are lacking; the formulas and procedures are not intended to be used for evaluating the stability of such surfaces or of cylindrical surfaces against external pressure. ~~API-650 Annex V may be used for the design of tanks with cylindrical shells for external pressure greater than 1 oz/in.^{2}.~~

Removed & moved to 5.10.5.2
per Eric Gnade request (CB&I)

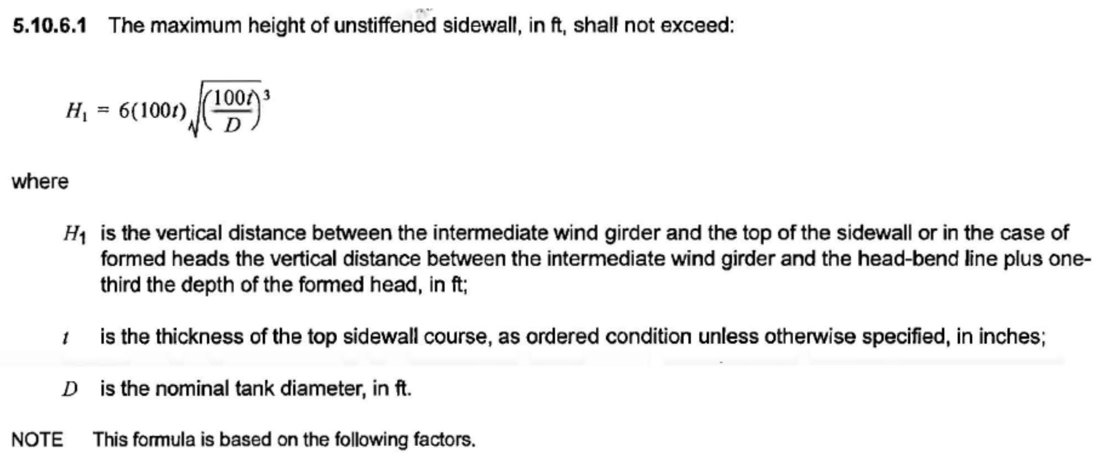
5.10.5.2 This standard does not contain provisions for the design of cylindrical sidewalls that are subject to ~~partial internal vacuum~~ external pressure in tanks constructed for the storage of gases or vapors alone. However, cylindrical sidewalls of vertical tanks designed in accordance with these rules for storing liquids (with the thickness of upper courses not less than specified in 5.10.4 for the tank size involved and with increasing thickness from top to bottom as required for the combined gas and liquid loadings) may be safely subjected to ~~a partial vacuum~~ an external pressure in the gas or vapor space not exceeding **1** oz/in.^{2} ~~**ounce per square in.**~~ with the operating liquid level in the tank at any stage from full to empty. ~~The vacuum relief valve or valves shall be set to open at a smaller partial vacuum external pressure so that the **1** oz/in.^{2} **-ounce partial vacuum** external pressure will not be exceeded when the inflow of air (or gas) through the valves is at the maximum specified rate.~~ API 650 Annex V may be used for the design of cylindrical tanks within the range of external pressures allowed by API 650 Annex V. ~~using the allowable compressive stresses in API 620~~. The API 650 Annex V procedure is not applicable to all tank configurations and is primarily suited to cylindrical tanks with a uniformly supported flat bottom floor and a fixed roof with uniform external pressure equally applied to the surfaces of the shell and roof. The API 650 Annex V rules shall not be used for sizing of the top stiffener of an open top tank. Refer to Section 9 to ensure the design external pressure is not exceeded.

Added per Eric Gnade's request

5.10.5.3 Tanks with conical or dished bottom heads shall be designed for external pressure by other methods if the external pressure is greater than 1 oz/in.^{2}.

5.10.6 Intermediate Wind Girders for Cylindrical Sidewalls

5.10.6.1 The maximum height of unstiffened sidewall, in ft, shall not exceed:



5.10.6.1 The maximum height of unstiffened sidewall, in ft, shall not exceed:

$$H_1 = 6(100t)\sqrt{\left(\frac{100t}{D}\right)^3}$$

where

H_1 is the vertical distance between the intermediate wind girder and the top of the sidewall or in the case of formed heads the vertical distance between the intermediate wind girder and the head-bend line plus one-third the depth of the formed head, in ft;

t is the thickness of the top sidewall course, as ordered condition unless otherwise specified, in inches;

D is the nominal tank diameter, in ft.

NOTE This formula is based on the following factors.

a) A 3-sec gust design wind velocity, *V,* of 120 mph which imposes **a** dynamic pressure of 25.6 lbf/ft^2. The velocity is increased by 10 % for either a height above the ground or a gust factor. The pressure is thus increased to 31 lbf/ft^2. An additional 5 lbf/ft^2 is added for ~~internal vacuum~~ external pressure. This pressure is intended by these rules to be the result of a 120 miles per hour 3-sec wind gust at approximately 33 ft above the ground. *H1* may be modified for other wind velocities, as specified by the Purchaser, by multiplying the formula by $(120/V)^2$. When a design wind pressure, rather than a wind velocity, is stated by the Purchaser, the preceding increase factors should be added, unless they are contained within the design wind pressure.

5.11.1 Shaped Bottom

Where the bottom of a tank is a spherical segment or a spherical segment combined with one or more toroidal segments, or is conical in shape, and the entire bottom area rests directly on the tank foundation in such a way that the foundation will absorb the weight of the tank contents without significant movement, the liquid head may be neglected in computing the internal pressure, P, acting on the bottom and in computing the unit forces, T1 and T2, in the bottom. Under these conditions, the unit forces in the bottom of the tank may be computed considering that P in each case is equal to ~~Pg~~ Pi.

7.18.2.6 After all the welding has been examined and tested and all defective welding disclosed by such examination and testing has been repaired and retested, the tank shall be filled with air to a pressure of 2 lbf/in.^{2} gauge or one-half the pressure ~~Pg~~ Pi for which the vapor space at the top of the tank is designed, whichever pressure is smaller. A solution film shall be applied to all joints in the tank wall above the high liquid (capacity) design level. If any leaks appear, the defects shall be removed and rewelded, and the applicable preliminary tightness tests specified shall be repeated. When anchors are not provided near the boundary of contact to hold down a dished tank bottom resting directly on the tank grade, the bottom at this boundary may be rise slightly off the foundation during the tightness test when air pressure is in the tank. In this case, sand shall be tamped firmly under the bottom to fill the gap formed while the tank is under pressure (see 7.18.8).

7.18.3.2 After the preliminary tightness tests specified in 7.18.2 have been completed, the pressure-vacuum relief valve or valves shall be blinded off. With the top vented to the atmosphere to prevent accumulation of pressure, the tank shall be filled with water to its high liquid (capacity) design level (see 7.18.7). Tank anchor retainers shall be adjusted to a uniform tightness after the tank is filled with water. If the pressure-vacuum valve or valves are not available at the time of the test, the tank connections may be blinded off and the test procedure continued by agreement between the purchaser and the manufacturer. With the vents at the top of the tank closed, air shall be injected slowly into the top of the tank until the pressure in the vapor space is about one-half the pressure ~~Pg~~ Pi, for which this space is designed. The air pressure shall be increased slowly until the pressure in the vapor space is 1.25 times the pressure, ~~Pg~~ Pi, for which the space is designed.

7.18.3.4 As the pressure is being increased, the tank shall be inspected for signs of distress. The maximum test pressure of 1.25 times the vapor space design pressure shall be held for at least one hour, after which the pressure shall be released slowly and the blinds shall be removed from the pressure-vacuum relief valves. The operation of the relief valves shall then be checked by injecting air into the top of the tank until the pressure in the vapor space equals the pressure, ~~Pg~~ Pi, for which this space is designed, at which time the relief valves shall start to release air. :

7.18.4.2 Following the test preliminaries called for in 7.18.2, the pressure-vacuum relief valve or valves shall be blinded off; with the top of the tank vented to the atmosphere, the tank shall be filled with water to the top of the roof (see 7.18.7) while allowing all air to escape to prevent the accumulation of pressure. If the pressure-vacuum relief valve or valves are not available at the time of the test, the tank connections may be blinded off and the test procedure continued by agreement between the purchaser and the manufacturer. The vents used during water filling of the tank shall then be closed, and the pressure in the tank shall be increased slowly until the hydrostatic pressure under the topmost point in the roof is 1.25 times the pressure, ~~Pg~~ Pi, which the vapor space is designed to withstand when in operation with the tank filled to its specified high liquid (capacity) level.

7.18.4.3 This test procedure shall be held for at least one hour. The hydrostatic pressure under the topmost point in the roof shall then be reduced to the pressure, ~~Pg~~ Pi, for which the vapor space is designed and shall be held at this level for a sufficient time to permit close visual inspection of all joints in the walls of the tank and all welding around manways, nozzles and other connections.

7.18.4.4 The tank shall then be vented to atmosphere, the water level shall be lowered below the inlets to the pressure-relief valves, and the blinds shall be removed from the relief valves. The operation of the relief valves shall then be checked by injecting air into the top of the tank until the pressure in the vapor space equals the pressure, ~~Pg~~ Pi, for which this space is designed, at which time the relief valves shall start to release air.

7.18.5 Partial vacuum ~~External Pressure~~ Tests

7.18.5.1 Following the tests specified in 7.18.3 (or in 7.18.4) where this latter procedure has been used), the pressure in the vapor space of the tank shall be released and a manometer shall be connected to this space. The ability of the upper part of the tank to withstand the partial vacuum ~~external pressure~~ for which it is designed and the operation of the vacuum-relief valve or valves on the tank shall then be checked by withdrawing water from the tank, with all vents closed, until the design partial vacuum ~~external pressure~~ is developed at the top of the tank and by observing the differential pressure at which the valve or valves start to open. The vacuum-relief valve or valves must be of a size and be set to open at a partial vacuum ~~external pressure~~ closer to the external atmospheric pressure than the ~~partial vacuum~~ external pressure for which the tank is designed. The partial vacuum ~~external pressure~~ in the tank should never exceed the design value (see Annex K).

7.18.5.2 After completing 7.18.5.1, the withdrawal of water from the tank shall be continued, with the vents closed and without exceeding the specified maximum partial vacuum ~~external pressure~~ in the top of the tank, until the level in the tank reaches one-half the high liquid (capacity) level for which the tank is designed. Alternatively, to speed up the withdrawal of water to the degree thought expedient, the vents may either be kept closed and air pressure not exceeding ~~Pg~~ Pi at the top of the tank applied, or the vents may be opened during most of this interval if in either procedure they are closed long enough before the level in the tank reaches half height for the specified partial vacuum ~~external pressure~~ to be developed by the time the level of the water reaches half height. Air shall then be again injected into the tank until the pressure above the water level equals the pressure, ~~Pg~~ Pi, for which the vapor space at the top of the tank is designed. These provisions presuppose that an ejector or vacuum pump is not available for drawing a partial vacuum ~~external pressure~~ on the tank. However, if such equipment is available, it may be used; vents may be opened during the entire period while the water level is being lowered, and the sequence of the vacuum and pressure test may be reversed if either the tank manufacturer or the purchaser so selects.

7.18.5.4 The water remaining in the tank shall then be withdrawn and when the tank is substantially empty, a vacuum test comparable to that specified in 7.18.5.1, except with regard to the level of water in tank, shall be applied to the tank. After this, air shall again be injected into the tank until the pressure in the tank equals the pressure, ~~Pg~~ Pi, for which the vapor space at the top of the tank is designed. Observations shall be made, both with the specified partial vacuum ~~external pressure~~ and with the vapor space design pressure above the surface of the water, to determine whether any appreciable changes in the shape of the tank occur under either condition of loading. In the case of a tank whose dished bottom rests directly on the tank grade, if the bottom rises slightly off the foundation during the pressure test, sand shall be tamped firmly under the bottom to fill the gap formed while the tank is under pressure (see 7.18.2.6 and 7.18.8).

9.2.3 Vacuum-relieving devices shall be installed to permit the entry of air (or other gas or vapor ~~is~~ if so designed) to avoid collapse of the tank wall if this could occur under natural operating conditions. These devices shall be located on the tank so that they will never be sealed off by the contents of the tank. Their size and pressure (or vacuum) setting shall be such that the partial vacuum ~~external pressure~~ developed in the tank at the maximum specified rate of air (or gas) inflow will not exceed the partial vacuum component of the design external pressure for which the tank is required to be designed (see 5.10.5).

Added per Eric Gnade's request

9.7 Pressure Setting of Safety Devices

9.7.1 Except as provided in 9.5 for certain liquid relief valves, the pressure setting of a pressure-relieving device shall in no case exceed the maximum pressure that can exist at the level where the device is located when the pressure at the top of the tank equals the nominal pressure rating for the tank (see 5.3.1) and the liquid contained in the tank is at the maximum design level.

9.7.2 Vacuum-relieving devices shall be set to open at such a~~n internal or external~~ partial vacuum pressure ~~or partial vacuum~~ that the partial vacuum ~~external pressure~~ in the tank cannot exceed the maximum partial vacuum component of the design external pressure.~~that for which the tank is designed when the inflow of air (or other gas or vapor) through the device is at its maximum specified rate~~.

Added per Eric Gnade's request

F.3.1 Given Conditions

In this example, the tank used to store liquid has a dome-shaped, self-supporting roof with varying values for R1 and R2. The size and vacuum settings of the vacuum-relieving devices are such that the partial vacuum ~~external pressure~~ developed in the tank at the maximum air inflow is 0.40 lbf/in.^{2} ~~gauge~~ (see 5.3.1). The roof is covered with insulation weighing 2 lb/ft^2 . The design requirements include a live snow load of 25 lb/ft^2 on the horizontal projection of the surface of the roof, which has a slope of 30° or less with the horizontal and a 1/16 in. corrosion allowance.

Changed back for Eric Gnade

F.3.2 Problem

The problem in this example is to find the required plate thicknesses for the ~~vacuum~~ external pressure and external loading (a) at the center of the roof, where R1 = R2 = 1200 in. and (b) at a radial distance of 12.5 ft from the center of the roof, where R1 = 1117 in. and R2 = 1172 in.

F.3.3 Solution

F.3.3.1 General

Figure F-4 is a free-body sketch of the roof above the plane of the level under consideration. Specific values for the variables used in this figure are as follows (see Figure 5-4 for typical free-body diagrams and 5.10.1 for definitions of the other variables):

P equals –0.40 lbf/in.^{2} ~~gauge~~, a negative value because of the ~~internal vacuum~~ external pressure;

W is the sum of the weights of the steel plate, insulation load, and snow load. W must be given the same sign as P in this case because it acts in the same direction as the pressure on the plane of the level under consideration; therefore, W is negative (see 5.10.1 of the definition of W);

F equals zero because no ties, braces, supports, or other similar members are cut by the plane of the level under consideration.

F.4.1.3 Solution

From Figure 5-5, cos = 15/30 = 0.5. Hence, θ = 60 degrees and sin θ = 0.866.

Equations 7 and 13 in 5.10.2.5 govern the design of the roof and sidewall because the term (W + F) ÷ At is negligible compared with ~~Pg~~ Pi.

F.4.3.3 Solution

From Figure 5-5, cos α = 31.25/50 = 0.625. Hence, α = 51.4 degrees and sin α = 0.781.

Equations 7 and 13 in 5.10.2.5 govern the design of the roof and sidewall, since the term (W + F)/At is negligible compared with ~~Pg~~ Pi.

F.5.1 Example 1

The 20 in. x 29 in. obround manhole shown in Figure F-5 is located in solid plate in the sidewall of a cylindrical storage tank 45 ft in diameter in an area where the thickness of the wall plate, tw, is 1/2 in. No corrosion allowance is required. The total internal pressure, Pl + ~~Pg~~ Pi, at the horizontal centerline of the opening is 27.5 lbf/in.^{2} gauge. The thickness of the wall plate, t, required by 5.10.3 for the latitudinal unit forces, T2, acting at this level is 0.485 in. The manhole neck is fabricated by welding from 3/8 in. plate. The materials in the tank wall, the manhole neck, and the reinforcing pad conform to ASTM A516, Grade 60. The joints in the tank wall and the longitudinal joint or joints in the manhole neck are double-welded butt joints, spot radiographed in accordance with 7.16 and 7.17. The adequacy of the reinforcement and attachment welds shown in Figure F-5 shall be determined.

F.5.2 Example 2

The 20-in. inside-diameter nozzle shown in Figure F-6 is located in solid plate in the sidewall of a cylindrical storage tank 148 ft in diameter in an area where the thickness of the wall plate, tw, is 1/2 in. A corrosion allowance of 0.10 in. is required on all surfaces of the tank exposed to the stored liquid. The total internal pressure, Pl + ~~Pg~~ Pi, at the center of the opening is 24.9 lbf/in.^{2} gauge. The thickness of the wall plate, t, required by 5.10.3 for the latitudinal unit forces, T2, acting at this level is 1.44 in. The nozzle neck is fabricated by welding from 1/2-in. plate. The materials in the tank wall, the nozzle neck, and the reinforcing pad conform to ASTM A442, Grade 55. The main joints in the tank wall are fully radiographed, double-welded butt joints. The longitudinal joint in the nozzle neck is of the same type but is not radiographed; however, the longitudinal joint and all other parts of the nozzle-and-wall-plate assembly have been shop stress relieved after fabrication, as required by 5.25. The adequacy of the reinforcement and attachment welds shown in Figure F-6 shall be determined.

F.5.3 Example 3

A cylindrical nozzle with a 12-in. inside diameter is located in solid plate in the sidewall of a cylindrical storage tank 60 ft in diameter so that its axis lies in a horizontal plane and forms an angle of 55° with a perpendicular to the sidewall at the point of intersection, as shown in Figure F-7. The thickness of the sidewall plate, tw, in this area is 5/8 in., and no corrosion allowance is required. The total internal pressure, Pl + ~~Pg~~ Pi, at the center of the opening is 26.1 lbf/in.^{2} gauge. The thickness of the wall plate, t, required by 5.10.3 for the latitudinal unit forces, T2, acting at this level is 0.57 in. The nozzle neck is seamless steel pipe and conforms to ASTM A53, Grade A; the materials in the tank wall and reinforcing pad conform to ASTM A442, Grade 55. The main joints in the tank walls are fully radiographed, double-welded butt joints. The adequacy of the reinforcement and attachment welds shown in Figure F-7 shall be determined.

F.5.4 Example 4

The pressed-steel, round manhole with a 20-in. inside diameter shown in Figure F-8 is located in solid plate in spherical portion of a torispherical roof on a cylindrical storage tank 72 ft in diameter. The internal pressure, ~~Pg~~ Pi, on the underside of the roof is 15 lbf/in.^{2} gauge. The thickness, t, of the roof plate required by 5.10.3 for the spherical portion of the roof is 1/2 in., which is exactly the thickness provided. No corrosion allowance is required. The materials in the roof plates and manhole frame conform to ASTM A283, Grade C; the main joints in the roof are double-welded butt joints, spot radiographed in accordance with 7.16 and 7.17. The adequacy of the Reinforcement and attachment welds shown in Figure F-8 shall be determined.

Q.3.6.1 Internal or external shell stiffening rings may be required to maintain roundness when the tank is subjected to wind, ~~vacuum~~ external pressure, or other specified loads. When stiffening rings are required, the stiffener-to-shell weld details shall be in accordance with Figure Q-1 and Q.3.6.2 through Q.3.6.5.

Q.3.8.5 Full Containment Outer Wall

A metallic outer wall for a full containment tank system shall be designed for the load combinations specified for the outer wall of a single containment tank system. The metallic outer wall shall also be designed for the following upset conditions:

a) Dead load, design pressure and liquid head [DL + ~~Pg~~ Pi + PL],

b) Dead load, design pressure, liquid head, and seismic [DL + ~~Pg~~ Pi + PL + E],

where DL, ~~Pg~~ Pi, PL, and E are defined in Q.3.8.6.

Q.3.8.6 Nomenclature

DL	is the dead load;
~~Pg~~ Pi	is the design pressure of the secondary liquid container or the membrane containment tank system;
PL	is the liquid head in the secondary liquid container or membrane tank outer container determined from the maximum normal operating capacity of the primary liquid container or the membrane containment tank system;
E	is the ALE seismic as required by L.4, including 10 % snow load.

Q.3.9 Combination of Design Loads for Membrane Tank Outer Containers

Although the metallic outer container for a membrane containment tank system is not in direct contact with the product, the liquid head, gas pressure, OBE, and SSE loads are transferred through membrane and insulation systems to the metallic outer wall. Therefore, the metallic outer wall shall be designed for the load combinations per 5.4.2 for both Type M-1 and M-CC membrane containment tank systems.

The membrane tank outer container for M-CC membrane containment tank system shall contain liquid in the event of liquid leakage from the membrane. It shall be designed for the following additional upset condition:

a) dead load, design pressure, liquid head, and seismic [DL + ~~Pg~~ Pi + PL + E], where DL, ~~Pg~~ Pi, PL, and E are defined in Q.3.8.6.

R.3.6.1 Internal or external shell stiffening rings may be required to maintain roundness when the tank is subjected to wind, ~~vacuum~~ external pressure, or other specified loads. When stiffening rings are required, the stiffener-to-shell weld details shall be in accordance with Figure R-1 and R.3.6.2 through R.3.6.5.

R.3.8.5 Full Containment Outer Wall

A metallic outer wall for a full containment tank system shall be designed for the load combinations specified for the outer wall of a single containment tank system. The metallic outer wall shall also be designed for the following upset conditions:

a) Dead load, design pressure, and liquid head [DL + ~~Pg~~ Pi + PL]

b) Dead load, design pressure, liquid head, and seismic [DL + ~~Pg~~ Pi + PL + E]

where DL, ~~Pg~~ Pi, PL, and E are defined in R.3.8.6.

R.3.8.6 Nomenclature

DL is the Dead load;

~~Pg~~ Pi is the design pressure of the secondary liquid container or the membrane containment tank system;

PL is the liquid head in the secondary liquid container or membrane tank outer container determined from the maximum normal operating capacity of the primary liquid container or the membrane containment tank system;

E is the ALE seismic as required by L.4. including 10 % snow load.

R.3.9 Combination of Design Loads for Membrane Tank Outer Containers

Although the membrane tank outer container for a membrane containment tank system is not in direct contact with the product, the liquid head and gas pressure loads are transferred through membrane and insulation systems to the outer wall. Therefore, the outer wall shall be designed for the load combinations per 5.4.2 for both Type M-1 and MCC membrane containment tank systems.

The membrane tank outer container for M-CC membrane containment tank system shall contain liquid in the event of liquid leakage from the membrane. It shall be designed for the following additional upset condition:

a) Dead load, design pressure, liquid head, and seismic [DL + ~~Pg~~ Pi + PL + E], where DL, ~~Pg~~ Pi, PL, and E are defined in R.3.8.6.

Y.3.4 Design Loads

Y.3.4.1 Individual Loads

The membrane shall be designed for both static load and cyclic load.

a) Static (non-cyclic) loads include the following:

….

….

b) Cyclic loads include the following:

1) Liquid pressure (Δ PL)—Maximum operating range of liquid pressure fluctuations caused on each part of membrane.

2) Gas pressure (Δ ~~PG~~ PI)—Maximum operating range of gas pressure fluctuations caused on each part of membrane.

Y.3.4.2 Load Combinations

a) Stability under static loading.

The following load combinations shall be used for the demonstration of stability under static loading.

b) Progressive deformation (ratcheting).

The following load combinations shall be used for the demonstration of progressive deformation.

1) ΔPL (maximum 10 cycles)

2) ΔT2 (maximum 10 cycles)

3) ΔT2 + Δ~~PG~~ PI + ΔT2 (maximum 10 cycles)

c) Fatigue behavior.

As a minimum, the following load combination and corresponding number of cycles shall be used to evaluate the fatigue behavior of each part of the membrane. When the membrane tank outer container deformations are significant, Mc shall be added to each load combination indicated below.

NOTE In evaluating the significance of the Mc load, note that steel outer membrane tank containers have greater movements than those made from concrete. These movements are both from internal liquid/pressure loads as well as for outside ambient temperature swings.

Bottom membrane

a) ΔPL + Δ~~PG~~ PI (n1 operating cycles)

b) ΔT2 (n2 cycles)

c) ΔPL + Δ~~PG~~ PI + ΔT2 (n2 cycles)

Wall membrane below maximum operating liquid level

a) ΔPL + Δ~~PG~~ PI (n1 operating cycles)

b) ΔT1 (n1 operating cycles)

c) ΔT2 (n2 cycles)

d) ΔPL + Δ~~PG~~ PI + ΔT1 (n1 operating cycles)

e) ΔPL + Δ~~PG~~ Pi+ T2 (n2 cycles)

Wall membrane above maximum operating liquid level and roof membrane

a) Δ~~PG~~ PI (n1 operating cycles)

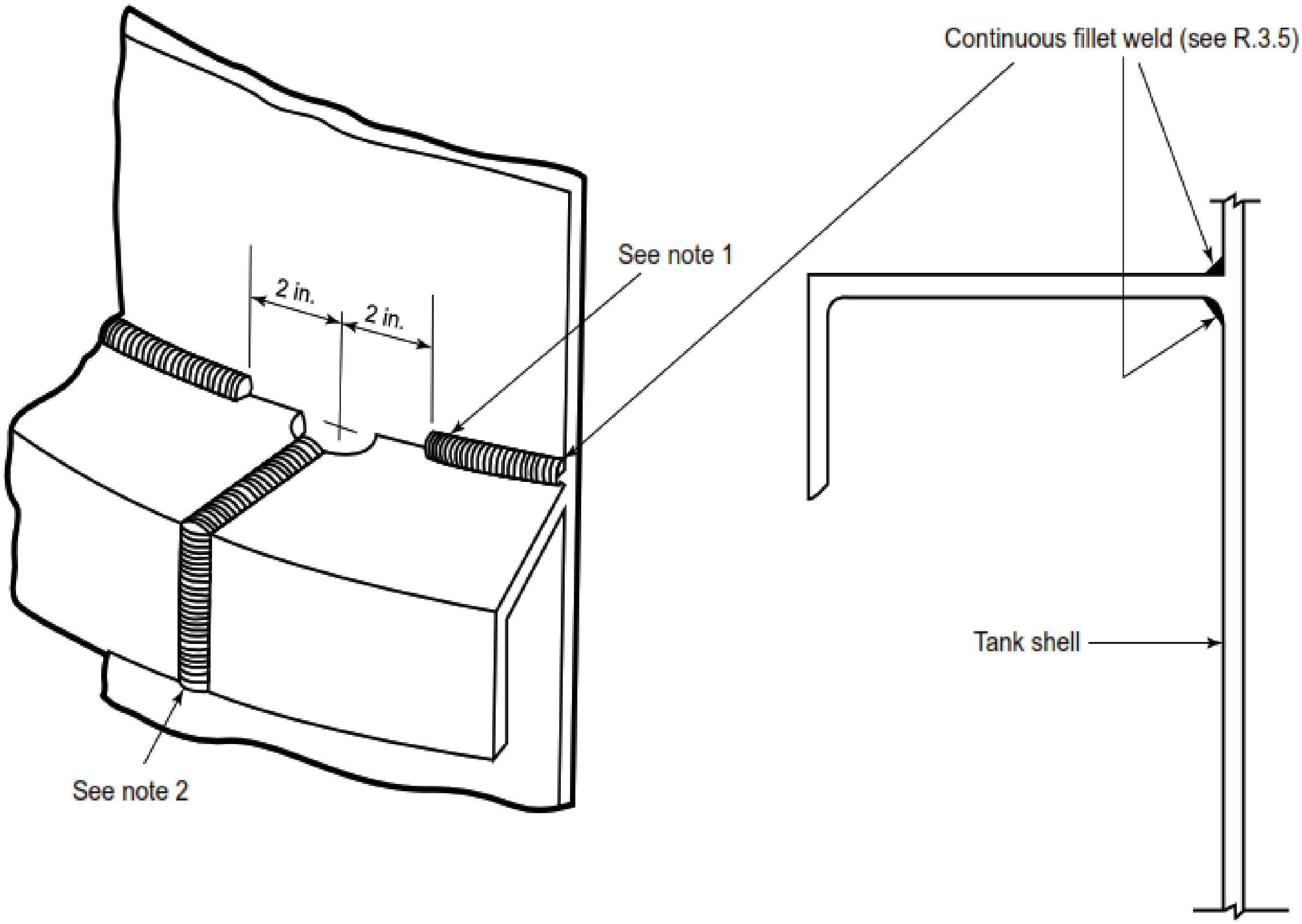
b) ΔT1 (n1 operating cycles)

c) ΔT2 (n2 cycles)

d) Δ~~PG~~ PI + ΔT1 (n1 operating cycles)

e) Δ~~PG~~ PI + ΔT2 (n2 cycles)

This has nothing to do with this agenda item, but I found the error below while searching for “vacuum”. Looking at sections R.3.5.4 & R.3.6.4 it is obvious the figure should be referring to R.3.6.4



NOTE 1 See ~~R.3.5.4~~ R.3.6.4 for alternative fillet-weld termination details.
NOTE 2 Backing strips are permitted on stiffening-ring junction welds.

R.3.5.4 The plates of the first shell course shall be attached to the annular bottom plates by welds as required by 5.9.5 except when a full penetration weld is used or required (see R.5.1.1).

R.3.6.4 All fillet welds shall consist of a minimum of two passes. The ends of the fillet welds shall be 2 in. from the rat hole (see Figure R-1), and these welds shall be deposited by starting 2 in. from the rat hole and welding away from the rat hole. An acceptable alternative to stopping fillet welds 2 in. short of the rat hole would be to weld continuously through the rat hole from one side of the stiffener to the opposite side. All craters in fillet welds shall be repaired by back welding.