<table>
<thead>
<tr>
<th>Title:</th>
<th>Modification of F.4.2 and 5.11</th>
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<tr>
<td>Date:</td>
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| Contact: | Name: Larry Hiner  
Company: Chicago Bridge & Iron Company  
Phone: 815-439-6125  
E-mail: lhiner@CBI.com |
| Purpose: | Modification of F.4.2 eliminates redundancy and conflicts with 5.11.2 |
| Source: | Technical Inquiry from January 2007 |
| Revision: | 5 dated May 20, 2009 |
| Impact: | Minimal |
| Background: | Equation F.4.2 was revised and included in Edition 10 addendum 4 to account for load combinations. The formula however does not adequately account for the load combinations now in 5.11. See page 2 for derivation of F.4.2 to support the changes. This is essentially the same as provided by Bhana Mistry as comment on the previous ballot. |
| Proposal: | Modify F.4.2 formula to reflect the controlling formula in 5.11.2. Additionally, the 5.11.2 formulas are modified to clarify requirements. Some terminology clean up is made to agree with other agenda item work. |
| Rationale: | This agenda item clarifies requirements and eliminates conflicts. |
| Specific changes: | See changes starting on sheet 3 |
AGENDA ITEM 650-652 DERIVATION

API 650 CONTROLLING FORMULA IN 5.11.2
5.11.2 CORRECTED TO ACCOUNT FOR ROOF PLATE WEIGHT

\[ 0.6 \ M_w + M_p \leq \frac{M_D}{1.5} + M_{DLR} \]

\[ 0.6 \ M_w + \frac{\pi}{4} \ D^2 \ P_i \times \frac{D}{2} \leq \frac{D_{LS} \times D_{LZ}}{1.5} + D_{LR} \times \frac{D}{2} \]

\[ \frac{8}{\pi D^3} (0.6 \ M_w) + P_i \leq \frac{8}{\pi D^3} \times \frac{D_{LS} \times D}{3} + \frac{8}{\pi D^3} \times D_{LR} \times \frac{D}{2} \]

\[ \therefore \ P_i \leq \frac{8}{\pi D^3} \times \frac{D_{LS} \times D}{3} + \frac{8}{\pi D^3} \times D_{LR} \times \frac{D}{2} - \frac{8}{\pi D^3} (0.6 \ M_w) \]

\[ P_i \leq \frac{0.8488 \ D_{LS}}{D^2} + \frac{1.273 \ D_{LR}}{D^2} - \frac{1.5278 \ M_w}{D^3} \]

For SI

\[ P_i \leq \frac{0.0008488 \ D_{LS}}{D^2} + \frac{0.001273 \ D_{LR}}{D^2} - \frac{0.0015278 \ M_w}{D^3} \quad [\text{in kPa}] \]

For US Customary

WHERE 1 "H_2O = 5.2 \ PSF; RESULTS IN INCHES OF H_2O

\[ P_i \leq \frac{0.8488 \ D_{LS}}{5.2 \times D^2} + \frac{1.273 \ D_{LR}}{5.2 \times D^2} - \frac{1.5278 \ M_w}{5.2 \times D^3} \]

\[ P_i \leq \frac{0.1632 \ D_{LS}}{D^2} + \frac{0.245 \ D_{LR}}{D^2} - \frac{0.2938 \ M_w}{D^3} \]
5.11 WIND LOAD ON TANKS (OVERTURNING STABILITY)

5.11.1 Wind Pressure

Overturning stability shall be calculated using the wind pressures given in 5.2.1(k).

5.11.2 Unanchored Tanks

Unanchored tanks shall satisfy both of the following uplift criteria:

1. \( 0.6M_o + M_{pi} < M_{DL} / 1.5 \)

2. \( M_o + (M_{pi} + M_{p}) / 2 < M_{DL} \)

where

- \( M_o \) = overturning moment about the shell-to-bottom joint from horizontal plus vertical wind pressure,
- \( M_{pi} \) = moment about the shell-to-bottom joint from design internal pressure,
- \( M_{p} \) = moment about the shell-to-bottom joint from the weight of the shell and roof supported by the shell, that is not attached to roof plate,
- \( M_{DL} \) = moment about the shell-to-bottom joint from the weight of the shell and roof supported by the shell, that is not attached to roof plate.

In SI units:

\[ w_L = 59t_b \sqrt{FbyH} \text{ (N/m)} \]

In US Customary units

\[ w_L = 4.67t_b \sqrt{FbyH} \text{ (lbf/ft)} \]

where

- \( Fby \) = minimum specified yield stress of the bottom plate under the shell MPa (lbf/in.\(^2\)),
- \( H \) = design liquid height, m (ft),
- \( D \) = tank diameter, m (ft),
- \( t_b \) = required thickness (not including corrosion allowance) of the bottom plate under the shell mm (in.) that is used to resist wind overturning. The bottom plate shall have the following restrictions:
  1. The thickness, \( t_b \), used to calculate \( w_L \) shall not exceed the first shell course thickness less any shell corrosion allowance.
  2. When the bottom plate under the shell is thicker due to wind overturning than the remainder of the tank bottom, the minimum projection of the supplied thicker annular ring inside the tank wall, \( L_b \), shall be the greater of 450 mm (18 in.) or \( L_b \), however, need not be more than 0.035D.

In SI units:

\[ L_b = 0.0291t_b \sqrt{FbyH} \leq 0.035D \text{ (m)} \]

In US Customary units

\[ L_b = 0.365t_b \sqrt{FbyH} \leq 0.035D \text{ (ft)} \]
5.11.3 Anchored Tanks

When the requirements of 5.11.2 cannot be satisfied, anchor the tank per requirements of 5.12.

\[
\tau_b = \frac{4M_{ulw}}{W} \text{ in lbf/ln ft}
\]

where:
- \( \tau_b \) = design tension load per anchor (lbfl/ln ft),
- \( d \) = diameter of the anchor circle (m) (ft),
- \( N \) = number of anchors,
- \( W \) = weight of the shell plus roof supported by the shell less 0.4 times the uplift from internal pressure.

![Diagram of Overturning Check for Unanchored Tanks]

Figure 5-27—Overturning Check for Unanchored Tanks

5.11.4 Sliding Friction

Unless otherwise required, tanks that may be subject to sliding due to wind shall use a maximum allowable sliding friction of 0.40 multiplied by the force against the tank bottom.

5.12 TANK ANCHORAGE

5.12.1 When a tank is required to be anchored per 5.11, Appendix E, Appendix F, or when a tank is anchored for any other reason, the following minimum requirements shall be met.

5.12.2 Anchorage shall be provided to resist each of the uplift load cases listed in Tables 5-21a and 5-21b. The load per anchor shall be:

\[
t_b = \frac{U}{N}
\]

where
- \( t_b \) = load per anchor,
- \( U \) = net uplift load per Tables 5-21a and 5-21b,
- \( N \) = number of anchors (a minimum of 4 is required),
APPENDIX F—DESIGN OF TANKS FOR SMALL INTERNAL PRESSURES

F.1 Scope

F.1.1 The maximum internal pressure for closed-top API Std 650 tanks may be increased to the maximum internal pressure permitted when the additional requirements of this appendix are met. This appendix applies to the storage of nonrefrigerated liquids (see also API Std 620, Appendices Q and R). For maximum design temperatures above 93°C (200°F), see Appendix M.

F.1.2 When the internal pressure multiplied by the cross-sectional area of the nominal tank diameter does not exceed the nominal weight of the metal in the shell, roof, and any framing supported by the shell or roof, see the design requirements in F.3 through F.6. Overturning stability with respect to seismic conditions shall be determined independently of internal pressure uplift. Seismic design shall meet the requirements of Appendix E.

F.1.3 Internal pressures that exceed the weight of the shell, roof, and framing but do not exceed 18 kPa (2½ lb/ft²) gauge when the shell is anchored to a counterbalancing weight, such as a concrete ringwall, are covered in F.7.

F.1.4 Tanks designed according to this appendix shall comply with all the applicable rules of this Standard unless the rules are superseded by the requirements of F.7.

F.1.5 The tank nameplate (see Figure 10-1) shall indicate whether the tank has been designed in accordance with F.1.2 or F.1.3.

F.1.6 Figure F-1 is provided to aid in the determination of the applicability of various sections of this appendix.

F.2 Venting (Deleted)

F.3 Roof Details

The details of the roof-to-shell junction shall be in accordance with Figure F-2, in which the participating area resisting the compressive force is shaded with diagonal lines.

F.4 Maximum Design Pressure and Test Procedure

F.4.1 The maximum design pressure, $P$, for a tank that has been constructed or that has had its design details established may be calculated from the following equation (subject to the limitations of $P_{\text{max}}$ in F.4.2):

\[
P = \frac{AF_y \tan \theta}{200D^2} + 0.00127 \frac{\text{DLE}}{D^2}
\]

where

- $P =$ internal design pressure (kPa),
- $A =$ area resisting the compressive force, as illustrated in Figure F-1 (mm$^2$),
- $F_y =$ lowest minimum specified yield strength of the materials in the roof-to-shell junction (MPa),
- $\theta =$ angle between the roof and a horizontal plane at the roof-to-shell junction (degrees),
- $\tan \theta =$ slope of the roof, expressed as a decimal quantity,
- $D =$ tank diameter (m),
- $t_n =$ nominal roof thickness (mm).

DLE: nominal weight of roof plate plus any attached structural (N)
In US Customary units:

\[ P = \left( \frac{0.962}{D^2} \right) (A_F) \tan \theta + \frac{0.245 \text{ DLR}}{D^2} \]

where

- \( P \) = internal design pressure (in. of water),
- \( A \) = area resisting the compressive force, as illustrated in Figure F-2 (in.\(^2\)),
- \( F_y \) = lowest minimum specified yield strength of the materials in the roof-to-shell junction (lb/in.\(^2\)),
- \( \theta \) = angle between the roof and a horizontal plane at the roof-to-shell junction (degrees),
- \( \tan \theta \) = slope of the roof, expressed as a decimal quantity,
- \( D \) = tank diameter (ft),
- \( \text{DLR} \) = nominal weight of roof plate plus any attached structural material (lb).

**F.4.2** The maximum design pressure, limited by uplift at the base of the shell, shall not exceed the value calculated from the following equation unless further limited by F.4.3.

In SI units:

\[ P_{\text{max}} = \frac{0.00127D^2}{D^2} + \frac{0.000597 \text{ DLR}}{D^2} - \frac{0.00153 M_w}{D^3} \]

where

- \( P_{\text{max}} \) = maximum design internal pressure (kPa),
- \( D_{\text{LS}} \) = total weight of the shell and any framing (but not roof plates) supported by the shell and roof (N),
- \( M \) = wind moment (N-m).

In US Customary units:

\[ P_{\text{max}} = \frac{0.245 \text{ DLR}}{D^2} + \frac{0.1632 D_{\text{LS}}}{D^2} - \frac{0.245 \text{ DLR}}{D^2} - \frac{0.2938 M_{\text{w}}}{D^3} \]

where

- \( P_{\text{max}} \) = maximum design internal pressure (in. of water),
- \( D_{\text{LS}} \) = total weight of the shell and any framing (but not roof plates) supported by the shell and roof (lb),
- \( M \) = wind moment (ft-lbf).

**F.4.3** As top angle size and roof slope decrease and tank diameter increases, the design pressure permitted by F.4.1 and F.4.2 approaches the failure pressure of F.6 for the roof-to-shell junction. In order to provide a safe margin between the maximum operating pressure and the calculated failure pressure, a suggested further limitation on the maximum design pressure for tanks with a weak roof-to-shell attachment (frangible joint) is:

\[ P_{\text{max}} \leq 0.8 P_f \]

**F.4.4** When the entire tank is completed, it shall be filled with water to the top angle or the design liquid level, and the design internal air pressure shall be applied to the enclosed space above the water level and held for 15 minutes. The air pressure shall then be reduced to one-half the design pressure, and all welded joints above the liquid level shall be checked for leaks by means of a soap film, linseed oil, or another suitable material. Tank vents shall be tested during or after this test.
F.5 Required Compression Area at the Roof-to-Shell Junction

- **F.5.1** Where the maximum design pressure has already been established (not higher than that permitted by F.4.2 or F.4.3), the total required compression area at the roof-to-shell junction calculated from the following equation:

  In SI units:

  \[ A = \frac{200D^2(P_r - 0.08P_t)}{F_y(tan\theta)} \]

  where

  \[ A = \text{total required compression area at the roof-to-shell junction (mm}^2\text{),} \]

  \[ P_r = \text{design internal pressure (kPa).} \]

  \[ D_r = \text{nominal weight of roof plate plus any attached structural (N).} \]

  In US Customary units:

  \[ A = \frac{D^2(P_r - 0.08P_t)}{0.962F_y(tan\theta)} \]

  where

  \[ A = \text{total required compression area at the roof-to-shell junction (in.}^2\text{),} \]

  \[ P_r = \text{design internal pressure (in. of water).} \]

  \[ D_r = \text{nominal weight of roof plate plus any attached structural (lb).} \]

  A is based on the nominal material thickness less any corrosion allowance.

- **F.5.2** For self-supporting roofs, the compression area shall not be less than the cross-sectional area calculated in 5.10.5 and 5.10.6.

F.6 Calculated Failure Pressure

Failure of the roof-to-shell junction can be expected to occur when the stress in the compression ring area reaches the yield point. On this basis, an approximate formula for the pressure at which failure of the top compression ring is expected (using conservative effective areas) to occur can be expressed in terms of the design pressure permitted by F.4.1, as follows:

In SI units:

\[ P_f = 1.6P - 0.047t_h \]

where

\[ P_f = \text{calculated minimum failure pressure (kPa).} \]

In US Customary units:

\[ P_f = 1.6P - 4.8t_h \]

where

\[ P_f = \text{calculated minimum failure pressure (in. of water).} \]

Note: Experience with actual failures indicates that buckling of the roof-to-shell junction is localized and probably occurs when the yield point of the material is exceeded in the compression area.

F.7 Anchored Tanks with Design Pressures up to 18 kPa (21/2 lbf/in.\(^2\)) Gauge

- **F.7.1** In calculating shell thickness for Appendix F tanks that are to be anchored to resist uplift due to internal pressure, and when selecting shell manhole thicknesses in Tables 5-3a and 5-3b and flush-type cleanout fitting thicknesses in Tables 5-10a and 5-10b, \( H \) shall be increased by the quantity \( P(9.8G) [P(12G)] \) —where \( H \) is the design liquid height, in m (ft), \( P \) is the design pressure kPa (in. of water), and \( G \) is the design specific gravity.
G.4.3 INTERNAL PRESSURE
Unless otherwise specified by the Purchaser, the internal design pressure shall not exceed the
weight of the roof. In no case shall the maximum-internal design pressure exceed 2.2 kPa (9 in. of
water). When the design pressure, $P_{\text{max}}$, for a tank with an aluminum dome roof is being
calculated, the weight of the roof, including structure, shall be used for the $DL_{\text{R}}$ term in F.4.2.
and / or shall be taken as zero.