Testing Underground Steel Storage Tank for Buckling

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LAN
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Goal of Research Study

- Steel underground storage tank fabricators compete against non-metallic FRP tanks
- Underwriters Laboratories publishes separate standards for steel and FRP UST’s
- UL 1316 is strictly a performance testing standard for FRP tanks
- Claims have been inappropriately made that FRP tanks are stronger than steel tanks due to UL 1316 performance tests
- Steel tank industry wanted to test a steel tank to UL 1316
11 Water-Load Test
11.1 A tank shall be:
   a) Placed in a sand bed so that one-eighth of the tank diameter is buried, and
   b) Filled to capacity with water for 1 hour.

The tank shall not be damaged.

*11.1 revised April 2, 1996*

12 External Pressure Test
12.1 A tank shall be tested as described in 12.2. The tank shall not implode or otherwise be damaged.

12.2 The empty tank is to be installed in a test pit using the specified anchoring system and the specified backfill procedure. The pit is then to be filled with water to such a level that the tank is submerged to its maximum specified burial depth. The tank is to remain submerged for 24 hours. While the tank is still submerged, it is to be subjected for 1 minute to a partial internal vacuum so that the internal pressure on the tank is 5.3 inches of mercury (17.9 kPa) less than the external pressure imposed by the hydrostatic head.

*12.2 revised April 2, 1996*

13 Internal Pressure Test
13.1 A tank shall withstand without rupture for 1 minute an internal pressure as specified in Table 13.1.

<table>
<thead>
<tr>
<th>Maximum diameter of tank feet (m)</th>
<th>Applied pressure, Psi (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 (3.0) or less</td>
<td>25 (172)</td>
</tr>
<tr>
<td>More than 10</td>
<td>15 (103)</td>
</tr>
</tbody>
</table>
UL 58 Establishes Acceptable Steel Tank Wall Thicknesses Using the Roark Equation
No Credit is Given for Soil Stiffness

Roark Vacuum equation in a fluid environment:

\[
P_c = \frac{2E_s}{(1-v^2)} \left(\frac{t}{D}\right)^3
\]

<table>
<thead>
<tr>
<th>(P_c)</th>
<th>1.28 PSI</th>
</tr>
</thead>
</table>

Tank OD = 64”  \(t\) = 0.172”
Carbon Steel: ASTM A36
Fabrication Details were Agreed Upon by STI’s Technical Committee

Tank Built & Installed by Acterra Group
Steel UST to be Tested
Backfill Placed 7’ Atop Tank
Angular Backfill Compacted
Water Level Verified via Groundwater Well
Camera Placed Inside Tank to Provide Live 360 Degree View
No Tank Deformation with Water Table at Grade-Ready to Apply Vacuum
5.3” Hg Vacuum Applied per UL 1316
Tank Does Not Implose or Get Damaged
Vacuum Continued to be Applied

- Vacuum pump continued to pull vacuum
- Reached 16.5 Hg vacuum inside tank
- Camera continued to provide live views in all directions – video was recorded
- Around 10 PM, vacuum pumps were turned off to make sure the pumps could be used another day
- Vacuum displaced with atmospheric pressure
**Buckling Calculation**

Per AWWA M11 Pages 63 & 64

<table>
<thead>
<tr>
<th>Given</th>
<th>Equation &amp; Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank Size, D (D)</td>
<td>(q_a = \frac{1}{FS(32 \text{ } R_w \text{ } B' \text{ } E' \text{ } EI/D^3)^{0.5}})</td>
</tr>
<tr>
<td>Tank O.D., D(_y)</td>
<td></td>
</tr>
<tr>
<td>Tank Thickness, (t_y)</td>
<td></td>
</tr>
<tr>
<td>Fill Height, H</td>
<td></td>
</tr>
<tr>
<td>Height of Water, H(_w)</td>
<td>(R_w = 1 - .33 \text{ } H_w/H = 0.67)</td>
</tr>
<tr>
<td>Soil Modulus, E'</td>
<td></td>
</tr>
<tr>
<td>Soil Weight, (w_e)</td>
<td></td>
</tr>
</tbody>
</table>

Given values:
- Tank Size, \(D\): 64 Inches
- Tank O.D., \(D_y\): 64 Inches
- Tank Thickness, \(t_y\): 0.172 Inches
- Fill Height, \(H\): 7 Feet
- Height of Water, \(H_w\): 7 Feet
- Soil Modulus, \(E'\): 1,500 PSI
- Soil Weight, \(w_e\): 120 PCF

Equations:
- \(FS = \text{Factor of Safety} = 1\)
- \(R_w = 1 - .33 \text{ } H_w/H = 0.67\)
- \(B' = \frac{1}{(1+4e^{(-0.065H)})} = 0.283\)
- \(EI = E_s I_s = 12,721\)
Calculated Buckling Load per AWWA M11

<table>
<thead>
<tr>
<th>Buckling Resistance,</th>
<th>( q_a = )</th>
<th>21.1</th>
<th>PSI</th>
<th>(Allowable Buckling Load)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( j_w H_w + R_w W_c / D + P_v )</td>
<td>(&lt; q_a )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( j_w ) with ( H_w )</td>
<td>( 0.0361 )</td>
<td>Lbs./In.³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( W_c = )</td>
<td>( 4,480 )</td>
<td>Lbs./Ft.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( W_c = )</td>
<td>( 373 )</td>
<td>Lbs./In.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( P_v = )</td>
<td>( 16.5 )</td>
<td>In. Hg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( j_w H_w + R_w W_c / D + P_v )</td>
<td>( = 15.0 )</td>
<td>PSI</td>
<td>(Calculated Buckling Load)</td>
<td></td>
</tr>
</tbody>
</table>
Next day, tank was excavated
Tank Examined After Test
Post Test Tank Examination

- Tank did not implode or buckle
- Tank cylinder remained round without permanent deformation
- Tank heads deflected inward approximately 2”