Steel Tank Structures

By Eric MacFarlane, SE, PE, LEED AP
Presentation Topics:

1. What is a Tank?
2. Tank Dimensional Characteristics.
3. Tank Operational Characteristics.
4. Tank Component Parts (Tank Anatomy).
5. Tank Materials.
6. How Tanks are constructed.
7. Types of Tanks.
8. Design of Tanks.
What is a Tank?

When I say “Tank” I don’t mean:
I do mean:
A site assembled, steel plate structure used to store a liquid product.

Image reference – cargotransfer.net
Per ASCE 7-05:
Storage Tank – A non-building structure not similar to a building. Design requirements per Chapter 15.7 and industry standards denoted in Chapter 23.
Tank Dimensional and General Characteristics
- Constructed from steel plate between 3/16” and 3” thick.
- Diameters from 15 feet to 300 feet.
- Heights from 8 feet to 200+ feet, where height is product height.
- Standpipe – tank with a height > its diameter.
- Reservoir – tank with a diameter > its height.
- Tanks are mostly round, not square. Square tanks require significant external stiffening.
- Roof types can include – self supported, internally framed, internally stiffened self supported, and floating.
- Tank shell is generally supported on a “ringwall concrete foundation.
- t/R ratio for a tank is less than a pop can. R=tank radius t=shell plate thick.
- Steel tanks can be buried, but stiffening for earth load is expensive.
- Tank plates often are supplied with a corrosion allowance.
- Freeboard – distance between top of product and top of shell plates. Distance can vary depending on internal process and height of seismic induced sloshing wave.

- Water tanks will have an overflow system to prevent overfilling.

- Chemical tanks will generally have level alarms to prevent overfilling.
Tank Operational Characteristics
- Used to store liquids like water, oil, Liquid Natural Gas, & liquid chemicals.
- Temperatures can be elevated (200+ F), atmospheric, or cryogenic (-150 F and colder).
- Pressures on tank can be atmospheric, vacuum, or elevated. For a “flat bottom tank” the internal or external pressure is generally less than 1 psi (aka 144 psf).
- Special processes – vacuum chambers, nuclear reactors, and wind tunnels.
Tank Anatomy – Product Envelope
The envelope of a steel tank is comprised of an assemblage of many kinds of individual steel plates, including:

- Bottom, Annular, Shell, Knuckle, and Roof Plates.
- Shell stiffeners – top angle and intermediate shell stiffeners.
Self Supporting Dome Roof Tank -
- Internally Framed Cone Roof Tank -

Roof framing. Generally W shapes arranged like spokes in a wheel.

Center column. Generally pipes and W shapes.
Internally Framed Knuckle Roof Tank -

- Knuckle
- Ringwall foundation supports shell
- Sand / soil support product

Image by – Cadwell Tanks
All tanks will have nozzles. This is a point where product is introduced or removed from the tank.

Nozzles can also be used for attaching vents (atmospheric or pressure release).

An opening for a nozzle will locally weaken the shell, thus reinforcing is required in the shell or pad plate, nozzle neck, and or via a nozzle flange.
Nozzles and Manways:

Image reference – API 650 Figure 5-7A
Nozzle location can be limited by:

- Proximity to other nozzles and manways.
- Product and internal pressure at nozzle location.
- Proximity to horizontal or vertical shell plate junction.
- Position relative to tank bottom or top of shell.
Tank Materials - Plates
Design Metal Temperature:

Image reference – API 650 Figure 4-2

Figure 4-2—Isothermal Lines of Lowest One-Day Mean Temperatures (°F)

°C = (°F – 32)/1.8
Design Metal Temperature:

Example – Determine the Design Metal Temperature for a tank in Santa Fe, NM.

Lowest One Day Mean Temp – 0F.
DMT = 0 + 15 F per API 650 section 3.0
DMT = 15 F

DMT limitations apply to shell, nozzle, and bottom plates in contact with the shell.
Selecting Shell Material:

Image reference – API 650 Figure 4-1b
Shell, nozzle, and bottom plates in contact with the shell:

**Table 4-4b—(USC) Material Groups (See Figure 4-1b and Note 1 Below)**

<table>
<thead>
<tr>
<th>Group I</th>
<th>Group II</th>
<th>Group III</th>
<th>Group IIIA</th>
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<tbody>
<tr>
<td>As Rolled, Semi-killed</td>
<td>As Rolled, Killed or Semi-killed</td>
<td>As Rolled, Killed Fine-Grain Practice</td>
<td>Normalized, Killed Fine-Grain Practice</td>
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<tr>
<td>Material</td>
<td>Notes</td>
<td>Material</td>
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<tr>
<td>A 283 C</td>
<td>2</td>
<td>A 131 B</td>
<td>7</td>
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<td>A 285 C</td>
<td>2</td>
<td>A 36</td>
<td>2, 6</td>
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<td>2</td>
<td>G40.21-38W</td>
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<tr>
<td>A 36</td>
<td>2, 3</td>
<td>Grade 250</td>
<td>5, 8</td>
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<td>3, 5</td>
<td>Grade 250</td>
<td>5, 9</td>
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<tr>
<th>Group IV</th>
<th>Group IVA</th>
<th>Group V</th>
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<tbody>
<tr>
<td>As Rolled, Killed Fine-Grain Practice</td>
<td>As Rolled, Killed Fine-Grain Practice</td>
<td>Normalized, Killed Fine-Grain Practice</td>
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<tr>
<td>Material</td>
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<tr>
<td>A 573-65</td>
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<td>A 662 C</td>
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<td>A 573-70</td>
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<td>A 573-70</td>
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<tr>
<td>A 516-65</td>
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<td>A 516-65</td>
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<tr>
<td>A 516-70</td>
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<td>G40.21-44W</td>
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<td>G40.21-50W</td>
<td>9, 11</td>
<td>G40.21-50W</td>
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<td>A 662 B</td>
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<td>G40.21-50W</td>
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<td>E 275</td>
<td>4, 9</td>
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<td>E 355</td>
<td>9</td>
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<tr>
<td>Grade 275</td>
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<th>Group VI</th>
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<tbody>
<tr>
<td>Normalized or Quenched and Tempered, Killed Fine-Grain Practice Reduced Carbon</td>
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<tr>
<td>Material</td>
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<tr>
<td>--------</td>
</tr>
<tr>
<td>A 131 EH 36</td>
</tr>
<tr>
<td>A 633 C</td>
</tr>
<tr>
<td>A 633 D</td>
</tr>
<tr>
<td>A 537 Class 1</td>
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<tr>
<td>A 537 Class 2</td>
</tr>
<tr>
<td>A 678 A</td>
</tr>
<tr>
<td>A 678 B</td>
</tr>
<tr>
<td>A 737 B</td>
</tr>
<tr>
<td>A 841, Grade A, Class 1</td>
</tr>
<tr>
<td>A 841, Grade B, Class 2</td>
</tr>
</tbody>
</table>

Image reference – API 650 Table 4-4b
Other Materials:

- Bottom Plates – A36.
- Roof Plates – A36 for internally framed, possibly higher strength for self supporting roof tanks.
- Structural shapes – A36, A992 and A500.
- Annular plates are typically the same as the shell material.
Tank Construction
Tank Construction:

- Shell plates are welded, not bolted.
- Horizontal shell to shell welds are done with an automatic welder.
- Vertical shell to shell welds can be automatic or hand welded.
- Shell, roof, and bottom plate welds are ground by hand to facilitate painting.
- Site assembled by automatic and hand welding.
Tank Construction:

- **NDE**: nondestructive examination of shell welds by magnetic particle, vacuum box, or x-ray testing.
- **Hydro-test**: site test where by a tank is filled with water prior to placement in operation and inspected for leaking.
- “Thicker” shell and roof plates can be pre-rolled or dished in the shop (spherical tanks)
- Nozzles are shop fabricated and field installed in shell, roof and bottom plates.
- Roofs can be constructed on internal framing (permanent or temporary).
Tank Construction:

- Roofs for dome and umbrella roof tanks can be built on temporary framing which is supported on the tank bottom. And then “air raised” into their final placement. Air pressure is introduced at tank manways and the roof is mechanically sealed at the shell perimeter to facilitate this process.

- Shell plates are generally erected in sections 10’ x 20’ to 40’ x design shell thickness.
Ringwall foundation placement:

Image reference S.C.C.I Tanks at weldedsteeltanks.com
Tank Construction:

Shell Erection
Tank Construction:

Cylindrical tank plate erection -

Temporary connections to stabilize shell prior to welding shell joints

Image reference dodsal.com
Tank Construction:

Automatic shell welder -

Image reference ptadelconst.com.au
Tank Construction:

Spherical tank plate erection -

Image reference english.pv.vn
Dome roof air-raising:

Check out “Tank Roof Air Raising” on YouTube
Dated 9-28-2010
Dome roof air-raising:

Roof partially raised
Dome roof air-raising:

Roof almost in place
Dome roof air-raising:

Placing temporary connections
Types of Tanks
Supported Roof Storage Tanks

Image by – visualphotos.com
Internal Roof Framing

Image reference  S.C.C.I Tanks at weldedsteeltanks.com
Elevated Water Storage Tanks
(AWWA D100)

Image by – Cadwell Tanks
Composite Elevated Tank – Steel containment on a concrete pedestal
Composite Elevated Tank – Construction sequence:
“Floating Roof Tank Farm”

Image reference – heatingoil.com
Open Top Floating Roof Tank (API 650)

- Deck Legs support the roof when the tank is empty.
Rim Seal:

A rim seal is attached to the edge of the steel floating roof. It should allow the roof to move and prevent product vapor from escaping. Thus, theoretically eliminating the potential for a fire. As seals degrade, fire can become a risk.
What can happen if a rim seal fails?

Claricone – Potable Water treatment (AWWA D100)

Image reference - CBI
Egg Shaped Digester – Waste water treatment (API 620)

Image reference
- CBI
ASME – horizontal high pressure blimp

Reference - www.totalenergy.com
ASME – high pressure sphere

- Leg to shell attachment - stress concentration
- Product envelope
- Lateral system

Image by – Flickr.com
Tank Design (Abbreviated)
Codes:

1. American Petroleum Institute – API 650
   - Petroleum and chemical storage
2. American Petroleum Institute – API 620
   - Low temperature storage
3. American Petroleum Institute – API 653
   - Maintenance and repair
4. American Water Works Association – AWWA D100
   - Water storage
Codes:

5. American Society of Mechanical Engineers – ASME Division I and II
   - Cryogenic and high pressure storage
Design Loads:

1. Internal Product – hydrostatic pressure
2. Internal Pressure – pressure or vacuum relative to external atmospheric pressure
3. Snow
4. Earthquake
5. Blast due to adjacent tank explosion, etc.
6. Fire due to product or adjacent tank
7. Hydro-test
8. Live on roof and platforms
9. Impact
## Minimum Shell Plate Thickness:

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Nominal Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 50</td>
<td>3/16</td>
</tr>
<tr>
<td>50 to &lt; 120</td>
<td>1/4</td>
</tr>
<tr>
<td>120 to &lt; 200</td>
<td>5/16</td>
</tr>
<tr>
<td>&gt; 200</td>
<td>3/8</td>
</tr>
</tbody>
</table>

Reference – API 650 section 5.6.1.1.
Shell Design for Product Pressure:

1. One Foot Method – API 650, 5.6.3:
   Calculation of shell plate thickness at one foot above the bottom of each shell course.

\[ t_d = \frac{2.6D(H-1)G}{S_d} + CA \]
\[ t_t = \frac{2.6D(H-1)}{S_t} \]

Reference – API 650 section 5.6.3.2.

- \( t_d \) = design shell thickness, in mm,
- \( t_t \) = hydrostatic test shell thickness, in mm,
- \( D \) = nominal tank diameter, in m (see 5.6.1.1, Note 1),
- \( H \) = design liquid level, in m,
- \( G \) = design specific gravity of the liquid to be stored, as specified by the Purchaser,
- \( CA \) = corrosion allowance, in mm, as specified by the Purchaser (see 5.3.2),
- \( S_d \) = allowable stress for the design condition, in MPa (see 5.6.2.1),
- \( S_t \) = allowable stress for the hydrostatic test condition, in MPa (see 5.6.2.2).
Shell Design for Product Pressure:

2. Variable Point Method – API 650, 5.6.4:
   Calculation of shell plate thickness at variable distances above the bottom of each shell course.

   Method is more efficient and results in calculated stresses close to actual circumferential shell stresses due to product load.

   See API 650 Section 5.6.4
Shell Wind Stiffeners:

Tank shells must be stiffened to prevent buckling from wind loading. API 650 requires top of shell and intermediate wind stiffeners for this purpose.

The required stiffener properties are dependent on the 3 second gust wind velocity, tank diameter, and shell plate thickness.

See API 650 section 5.9 for formulation.
Shell Wind stiffeners:

Reference FreeFoto.com
Top Wind Girder Details:

Reference API 650 Figure 5-24.
Earthquake Load on Tanks:

2010 Earthquake in Port Au Prince, Haiti

Image reference FEMA and Eduardo Fierro of BFP Engineers
Earthquake Load on Tanks:

1964 Earthquake in Anchorage Alaska

Image reference FEMA and PEER – Steinbrugge Collection
Earthquake Load on Tanks:

2010 Earthquake in Port Au Prince, Haiti

Image reference FEMA and Eduardo Fierro of BFP Engineers
Earthquake Loads:

Reference API 650 Appendix E

Loads are determined from a design spectra constructed based on the earthquake hazard at the site.

Accelerations are determined based on a two mode, dynamic model. These modes are known as the impulsive (rigid) and convective (sloshing) modes.
Earthquake Loads:

Impulsive spectral acceleration:

\[ A_i = 2.5Q \left( \frac{I}{R_{wi}} \right) S_{a0}^* \]

Reference API 650 Section E.4.6.2.

Q – 2/3 to 1.0

I – importance factor

R_{wi} – impulsive response modification factor

S_{a0}^* – 5% damped, MCE spectral acceleration at the zero period.
Earthquake Loads:

Convective spectral acceleration:

\[ A_c = QK \left( \frac{I}{R_{wc}} \right) S_a^* < A_i \]

Q – 2/3 to 1.0.
I – importance factor.
R_{wc} – convective response modification factor.
S_a^* – 5% damped, MCE spectral acceleration at the convective mass period.
K – factor to adjust spectral acceleration from 5% damping to 0.5% damping.

Reference API 650 Section E.4.6.2.
Horizontal Seismic Forces:

**Impulsive:**

\[ V_i = A_i \times W_i \]

\[ W_i = \frac{\tanh\left(0.866 \frac{D}{H}\right)}{0.866 \frac{D}{H}} W_p \]

When \( D/H > 1.333 \)

Otherwise

**Convective:**

\[ V_c = A_c \times W_c \]

\[ W_c = 0.230 \frac{D}{H} \tanh\left(\frac{3.67H}{D}\right) W_p \]

Reference API 650 Section E.5 & 6.
Vertical Seismic Forces:

Vertical acceleration of a liquid product will act to increase the hoop tension forces in the shell plate.

Impulsive hoop tension:

\[ N_i = 4.5A_i GDH \left( \frac{Y}{H} - 0.5 \left( \frac{Y}{H} \right)^2 \right) \tanh \left( 0.866 \frac{D}{H} \right) \]

When \( D/H > 1.333 \)

\[ N_i = 1.39A_i GD^2 \]

Otherwise

Convective hoop tension:

\[ N_c = \frac{0.98A_c GD^2 \cosh \left[ \frac{3.68(H-Y)}{D} \right]}{\cosh \left[ \frac{3.68H}{D} \right]} \]

Reference API 650 Section E.6.1.4
Design Base Shear:

By SRSS:

\[ V = \sqrt{V_i^2 + V_c^2} \]

Reference API 650 Section E.6.1.

By Direct Sum:

\[ V = V_i + V_c \]

Reference API 650 Section E.6.1.
QUESTIONS???