The Basics of API 650

National Institute for Storage Tank Management

2009 Aboveground Storage Tank Management Conference and Trade Show
September 11, 2009 - Houston, Texas

Presented By:
Mark Baker, P.E.
API Standard 650
Welded Tanks for Oil Storage

Addendum 1, November 2008
Scope

• Establishes minimum requirements for material, design, fabrication, erection, and testing for vertical, cylindrical, aboveground, closed- and open-top, welded carbon or stainless steel storage tanks in various sizes and capacities for internal pressures approximating atmospheric pressure (internal pressures not exceeding the weight of the roof plates)
Scope

• Applies only to tanks whose entire bottom is uniformly supported

• Tanks in non-refrigerated service that have a maximum design temperature of 93°C (200°F) or less.
• The Standard has requirements given in two alternate systems of units:
  – SI units, or
  – US Customary units.

• The Purchaser and Manufacturer shall mutually agree on the units that will be used.
<table>
<thead>
<tr>
<th>Appendix</th>
<th>Title</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Optional design basis for small tanks</td>
<td>Purchaser’s Option</td>
</tr>
<tr>
<td>B</td>
<td>Recommendations for design and construction of foundations for aboveground oil storage tanks</td>
<td>Recommendations</td>
</tr>
<tr>
<td>C</td>
<td>External floating roofs</td>
<td>Requirements</td>
</tr>
<tr>
<td>D</td>
<td>Technical inquiries</td>
<td>Required Procedures</td>
</tr>
<tr>
<td>E</td>
<td>Seismic design of storage tanks</td>
<td>Purchaser’s Option</td>
</tr>
<tr>
<td>F</td>
<td>Design of tanks for small internal pressures</td>
<td>Requirements</td>
</tr>
<tr>
<td>G</td>
<td>Structurally-supported aluminum dome roofs</td>
<td>Requirements</td>
</tr>
<tr>
<td>H</td>
<td>Internal floating roofs</td>
<td>Requirements</td>
</tr>
<tr>
<td>I</td>
<td>Undertank leak detection and subgrade protection</td>
<td>Purchaser’s Option</td>
</tr>
<tr>
<td>J</td>
<td>Shop-assembled storage tanks</td>
<td>Requirements</td>
</tr>
<tr>
<td>K</td>
<td>Sample application of the variable-design-point method to determine shell-plate thickness</td>
<td>Information</td>
</tr>
<tr>
<td>L</td>
<td>API Std 650 storage tank data sheets</td>
<td>Requirements</td>
</tr>
<tr>
<td>M</td>
<td>Requirements for tanks operating at elevated temperatures</td>
<td>Requirements</td>
</tr>
<tr>
<td>N</td>
<td>Use of new materials that are not identified</td>
<td>Requirements</td>
</tr>
<tr>
<td>O</td>
<td>Recommendation for under-bottom connections</td>
<td>Purchaser’s Option</td>
</tr>
<tr>
<td>P</td>
<td>Allowable external load on tank shell openings</td>
<td>Purchaser’s Option</td>
</tr>
<tr>
<td>R</td>
<td>Load combinations</td>
<td>Requirements</td>
</tr>
<tr>
<td>S</td>
<td>Austenitic stainless steel storage tanks</td>
<td>Requirements</td>
</tr>
<tr>
<td>T</td>
<td>NDE requirements summary</td>
<td>Requirements</td>
</tr>
<tr>
<td>U</td>
<td>Ultrasonic examination in lieu of radiography</td>
<td>Purchaser’s Option</td>
</tr>
<tr>
<td>V</td>
<td>Design of storage tanks for external pressure</td>
<td>Purchaser’s Option</td>
</tr>
<tr>
<td>W</td>
<td>Commercial and Documentation Recommendations</td>
<td>Recommendations</td>
</tr>
</tbody>
</table>
Limitations

a) The face of the first flange in bolted flanged connections, unless covers or blinds are provided as permitted in this Standard.

b) The first sealing surface for proprietary connections or fittings.

c) The first threaded joint on the pipe in a threaded connection to the tank shell.

d) The first circumferential joint in welding-end pipe connections if not welded to a flange.
Responsibilities

• The Manufacturer is responsible for complying with all provisions of this Standard.

• Inspection by the Purchaser’s inspector does not negate the Manufacturer’s obligation to provide quality control and inspection necessary to ensure such compliance.
Design

Tank Capacity

Maximum capacity: 
_______ m³ (bbl)

Overfill protection level requirement:
_______ m³ (bbl) or _______ mm (in.)

Networking capacity:
_______ m³ (bbl)

Minimum operating volume remaining in the tank:
_______ m³ (bbl) or _______ mm (in.)

Figure 5-4—Storage Tank Volumes and Levels
Special Considerations

• Foundation
  – The adequacy of the foundation is the responsibility of the Purchaser

• Corrosion Allowance
  – Guidance to the Purchaser for considering corrosion allowance

• Service Conditions
  – The Purchaser specify any special requirements as required by anticipated service conditions.
• Provides considerations for the design and construction of foundations.

• Outline good practices

• Precautions to be considered

• Tolerances for levelness of the final foundation
Tank Bottoms
• **Shell Design**
  
  – Shell designed on the basis that the tank is filled to level H with a specific gravity (SG) product value furnished by the customer.

  – Manufacturer must furnish a drawing that lists:
    - Required shell t (include CA) for both product and hydrotest
    - Nominal thickness used
    - Material specification
    - Allowable stresses
Design Metal Temperature

- 8°C (15°F) above the lowest 1-day mean
Design

Material Group Selection

Notes:
1. The Group II and Group V lines coincide at thicknesses less than 12.5 mm (1/2 in.).
2. The Group III and Group IIIA lines coincide at thicknesses less than 12.5 mm (1/2 in.).
3. The materials in each group are listed in Table 2-3.
4. This figure is not applicable to controlled-rolled plates (see 2.2.7.4).
5. Use the Group IIA and Group VIA curves for pipe and flanges (see 2.5.5.2 and 2.5.5.3).

Figure 2-1—Minimum Permissible Design Metal Temperature for Materials Used in Tank Shells Without Impact Testing
Shell Design

$S_d$ and $S_t$ is selected from the table of permissible materials and allowable stresses is API Std 650
Shell Design

One foot Method

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

Where -

\( t_d \) = thickness (in)
\( G \) = specific gravity
\( D \) = diameter (ft)
\( H \) = height (ft)
\( S_d \) = product design stress (psi)
\( CA \) = corrosion allowance
\( S_t \) = test design stress

- use max of \( t_d \) or \( t_t \)
- \( S_d \) and \( S_t \) per Table 3-2
- add internal pressure to \( H \)
- must use min “t” per 5.6.1.1
- must check for wind buckling

Not allowed for shells with diameters greater than 60m (200 ft).
Shell Design

• Shells with diameters greater than 60m (200 feet)
  
  – Variable Design-Point Method
    • See Appendix K
  
  – Elastic Analysis (Finite Element Analysis)
## Shell Design

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Minimum Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\leq 15\text{m (50')}$</td>
<td>5mm (3/16 in)</td>
</tr>
<tr>
<td>$15\text{m} &lt; D \leq 36\text{m}$</td>
<td>6mm (1/4 in)</td>
</tr>
<tr>
<td>$50' &lt; D \leq 120'$</td>
<td>6mm (1/4 in)</td>
</tr>
<tr>
<td>$36\text{m} &lt; D \leq 60\text{m}$</td>
<td>8mm (5/16 in)</td>
</tr>
<tr>
<td>$120' &lt; D \leq 200'$</td>
<td>8mm (5/16 in)</td>
</tr>
<tr>
<td>$&gt; 60\text{m (200')}$</td>
<td>10mm (3/8 in)</td>
</tr>
</tbody>
</table>
Wind Girders

\[ Z = 0.0001 \ D^2 \ H_2 \]

Where:

- \( Z \) = Required section Modulus (in\(^3\))
- \( D \) = Nominal Tank Diameter
- \( H_2 \) = Height of the tank, incl. Freeboard (ft)

Based on 120 MPH 3 sec gust
**Intermediate Wind Girders**

Where

\[ H_1 = 600,000t \sqrt{\left(\frac{t}{D}\right)^3 \left(\frac{120}{V}\right)^2} \]

\[ W_{tr} = W \sqrt{\left(\frac{t_{\text{uniform}}}{t_{\text{actual}}}\right)^5} \]

*Where*

- \( H_1 \) = vertical distance (ft) between intermediate wind girder and top angle or top wind girder
- \( t \) = as ordered thickness (in) of the top shell course
- \( D \) = nominal tank diameter (ft)

If the Transformed shell height is > \( H_1 \) then an intermediate wind girder is required.
Shell Openings

One 6 mm (1/4") telltale hole in reinforcing plate, on horizontal centerline

Alternative circular shape (see Note 8)

Symmetrical about C

D0/2 (see Note 8)

L (see Note 8)

Arc dimension = W/2

Reinforcing pad shall be shaped to suit tank curvature

500 mm (20") and 600 mm (24") manhole: 750 mm (30") OD x 750 mm (30") ID x 3 mm (1/8") thickness

750 mm (30") manhole: 885 mm (35 9/16") OD x 750 mm (30") ID x 3 mm (1/8") thickness

900 mm (36") manhole: 1035 mm (41 3/8") OD x 900 mm (36") ID x 3 mm (1/8") thickness

125 mm (5") minimum

32 mm (1 1/4")

Rounded corners (150 mm [6"] minimum radius)

6 mm (1/4") rod

10 mm-diameter (1/8") rod

See Figure 3-7B

75 mm (3")

150 mm (6")

See details

(See Note 7)
Roof Design

- Roofs
  - Fixed roofs
    - Roofs and structure designed to support load combinations in Appendix R.
    - Roof Plates minimum of 5mm (3/16” or 7 gauge) sheet
      - Self supported roof plates may require thicker plate.
      - Supported cone roof plates shall not be attached to the supporting members unless the underside is to be painted.
Fixed Roof Design

Cone Roof
Fixed Roof Design
Dome Roof

Minimum thickness = \[
\frac{r_r}{200\sqrt{\frac{T}{45}}} + \text{C.A.} \geq \frac{3}{16} \text{ in.}
\]

Maximum thickness = 1/2 in., exclusive of corrosion allowance.

where

\( D \) = nominal diameter of the tank shell (ft),

\( T \) = greater of load combinations (e)(1) and (e)(2) of Appendix R (lbf/ft\(^2\)),

\( r \) = roof radius (ft).
Umbrella Roof

• Minimum radius = 0.8D (unless otherwise specified by the Purchaser)
• Maximum radius = 1.2D
Wind Load

• Provides a set of rules for evaluating the uplift or overturning stability of a tank

• If the design does not satisfy the uplift requirements
  – Increase shell weight
  – Provide anchorage
Erection of Tanks

• API 650 provides rules and tolerances for erecting tanks

• Rules for welding
  – Welding Procedure Specifications
  – Procedure Qualification Records
  – Section IX of the ASME Code
Erection of Tanks

- Welding of tank bottom
- Welding of tank shell
The standard provides details for the minimum testing to be performed to ensure quality workmanship of the tank.

- **Shell-to-Bottom weld**
  - Magnetic particle
  - Liquid penetrant
  - High flash-point oil
  - Leak test
  - Alternative pressure test
Inspection Testing

• Testing of the bottom
  – Visual
  – Vacuum box
  – Tracer gas

• Testing of the shell
  – Radiographic inspection
  – Ultrasonic inspection
  – Magnetic particle of root pass
• Testing of the Roof
  – Gas tight roofs
    • Internal air pressure ≤ weight of roof plates
    • Vacuum box testing of weld seams
  – Non gas tight roofs
    • Visual inspection of weld seams
Inspection Testing

- Testing of Penetrations
- Hydrostatic testing requirements
## Marking

**API STANDARD 650**

<table>
<thead>
<tr>
<th>APPENDIX</th>
<th>YEAR COMPLETED</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDITION</td>
<td>ADDENDUM NO.</td>
</tr>
<tr>
<td>NOMINAL DIAMETER</td>
<td>NOMINAL HEIGHT</td>
</tr>
<tr>
<td>MAXIMUM CAPACITY</td>
<td>DESIGN LIQUID LEVEL</td>
</tr>
<tr>
<td>DESIGN SPECIFIC GRAVITY</td>
<td>DESIGN METAL TEMP.</td>
</tr>
<tr>
<td>DESIGN PRESSURE</td>
<td>MAXIMUM DESIGN TEMP.</td>
</tr>
<tr>
<td>MANUFACTURER’S SERIAL NO.</td>
<td>PARTIAL STRESS RELIEF</td>
</tr>
<tr>
<td>FABRICATED BY</td>
<td>PURCHASER’S TANK NO.</td>
</tr>
<tr>
<td>ERECTED BY</td>
<td></td>
</tr>
</tbody>
</table>

**API STD 650 STORAGE TANK**

- **API APPENDIX**: "E"
- **API REVISION**: ADD. 4
- **API EDITION**: 9TH
- **TANK NO.**: #1
- **YEAR BUILT**: 1999
- **DESIGN SPECIFIC GRAVITY**: 0.76
- **POST WELD HEAT TREATMENT**: NO
- **MAXIMUM OPERATING TEMP.**: 180°F
- **DESIGN PRESSURE**: 0 PSI
- **DESIGN LIQUID HEIGHT**: 45~8 1/4"
- **NOMINAL CAPACITY**: 70,000 BBLs
- **NOMINAL HEIGHT**: 48~5 1/4"

**Material**

- **RING**
  - #1 & 2
  - #3 THRU 6
- **MATERIAL**
  - A36 MOD
  - A36

**Fabrication**

- **FABRICATED BY**: CBI CONSTRUCTORS
- **ERECTED BY**: CBI CONSTRUCTORS
• Optional Design Basis for Small Tanks
  – Maximum shell thickness of 13mm (1/2”)
  – Only applicable to lower strength materials
  – Design equations are simplified
  – Inspection requirements can be reduced
  – Provides a table of typical sizes, capacities, and shell plate thicknesses
Appendices

Shop Assembled Storage Tanks
Appendices

- Stainless Steel Tanks
- This appendix covers materials, design, fabrication, erection, and testing requirements for austenitic stainless steel storage tanks constructed of material grades 304, 304L, 316, 316L, 317, and 317L.
Appendices

• Aluminum Tanks
  – Imported from ASME B96.1 Welded Aluminum Alloy Storage Tanks
  – ASME B96.1 has been withdrawn
Appendices

External Floating Roofs
Appendices

Internal Floating Roofs

INTERNAL FLOATING ROOF
(REVERSE SLOPE PONTOON ROOF)
Appendices

Internal Floating Roofs
Appendices
Appendices

Cable suspended floating
Appendices

Perimeter Venting
• Spaced 10m (32 ft)
• Minimum 4
• Area - 0.2 m² (2 ft²)

Shell Circulation Vents
• Can be used instead
Appendices

Aluminum Domes
Aluminum Domes

• With integral tension ring
  – Dome resists all forces
  – Supports slide radial direction

• Without tension ring
  – Tank resists all forces
  – Dome is fixed to the tank
Seismic Design
Appendices

Requirements for Tanks Operating at Elevated Temperatures 260°C (500°F)
• Design for external pressure
  – Applicable to pressures up to 6.9 KPa (1.0 PSI)
Appendices

• Design for Internal Pressures
  – Covers from Atmospheric up to 18 KPa (2.5 PSI)
Thank You