Alternate-Type Supports

Pipe and Vessel Share Load to Reduce Load on Vessel Shell

Inverted Support, Large Lines with Spring Hangers

All Welded Integral Construction for Overhead Vapor Lines
Notes

1. Allowable deflection brackets should be limited to L/360.
2. Kneebracing should be used only if absolutely necessary.
3. Pipe support should be placed as close as possible to the nozzle to which it attaches. This limits the effect of differential temperature between the pipe and the vessel. If the line is colder than the vessel, the nozzle will tend to pick up the line. For the reverse situation (pipe hotter than vessel), the line tends to go into compression and adds load to the support.
4. The nozzle and the pipe support will share support of the overall line weight. Each will share the load in proportion to its respective stiffness. The procedure is to design the pipe support for the entire load, which is conservative. However, be aware that as the pipe support deflects, more of the load is transferred to the nozzle.
5. The pipe is normally supported by trunnions welded to the pipe. The trunnions can be shimmed to accommodate differences in elevation between the trunnions and the supports.
6. Design/selection of pipe supports:
   • Make preliminary selection of support type based on the sizing in the table.
   • Check allowable bolt loads per chart.
   • Check shell stresses via the applicable local load procedure.
7. The order of preference for overstressed supports, shells, or bolts is as follows:
   • Go to the next largest type of support.
   • If the loads in the bolts exceed that allowable, change the material or size of the bolts.
   • If the brackets are overstressed, increase the bracket size.
8. Use “high-temperature brackets” for kneebraced pipe supports or platform brackets when the design temperature of the vessel exceeds 650°F. This sliding support is utilized for hot, insulated vessels where the support steel is cold. This sliding support prevents the support from dipping as the vessel clips grow apart due to linear thermal expansion of the vessel while the kneebrace remains cold. This condition becomes more pronounced as the vessel becomes hotter and the distance between clips becomes greater.
10. Vessel clip thickness should be ⅜ in. for standard clips up to 650°F. Above 650°F, clips should be ½ in. thick.
11. Bolt holes for Type 1, 2, or 3 supports should be 13/16-in.-diameter holes for ¾-in.-diameter bolts.
Procedure 9-5: Shear Loads in Bolted Connections

Cases of Bolted Connections

**Case 1**

\( n \) = no. of fasteners in a vertical row  
\( m \) = no. of fasteners in a horizontal row = 2  
\( I_p \) = polar moment of inertia about c.g. of fastener group: \( I_x + I_y \)  
\[
I_x = 2 \left[ \frac{nb^2(n^2 - 1)}{12} \right]
\]
\[
I_y = n \left[ \frac{mD^2(m^2 - 1)}{12} \right]
\]

\[
f_x = \frac{(F \ell)(n - 1)b}{2I_p}
\]
\[
f_y = \frac{F}{mn} + \frac{F \ell D}{2I_p}
\]
\[
f_r = \sqrt{f_x^2 + f_y^2}
\]

**Case 2**

\[
f_x = \frac{F \ell}{e}
\]
\[
f_y = \frac{F}{2}
\]
\[
f_r = \sqrt{f_x^2 + f_y^2}
\]

**Case 3**

\[
f = \frac{F \ell}{e}
\]

Table 9-9
Allowable loads, in kips

<table>
<thead>
<tr>
<th>Material</th>
<th>Size</th>
<th>⅜ in.</th>
<th>⅝ in.</th>
<th>⅞ in.</th>
<th>1 in.</th>
<th>1 ¼ in.</th>
<th>1 ½ in.</th>
<th>1 ¾ in.</th>
<th>2 in.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Double</td>
<td>7.36</td>
<td>10.60</td>
<td>14.40</td>
<td>18.80</td>
<td>23.80</td>
<td>29.40</td>
<td>35.60</td>
<td>42.40</td>
</tr>
<tr>
<td>A-325</td>
<td>Single</td>
<td>7.36</td>
<td>10.60</td>
<td>14.40</td>
<td>18.80</td>
<td>23.80</td>
<td>29.40</td>
<td>35.60</td>
<td>42.40</td>
</tr>
<tr>
<td></td>
<td>Double</td>
<td>14.70</td>
<td>21.20</td>
<td>28.80</td>
<td>37.60</td>
<td>47.70</td>
<td>58.90</td>
<td>71.20</td>
<td>84.80</td>
</tr>
</tbody>
</table>

Values from AISC.

**Figure 9-16.** Longitudinal clip with double row of \( n \) bolts.

**Figure 9-17.** Longitudinal clip with two bolts.

**Figure 9-18.** Circumferential clip with two bolts.
Case 4

\[ f_x = x_n \left[ \frac{F_l}{2(x_1^2 + x_2^2 + \ldots + x_n^2)} \right] \]

\[ f_y = \frac{F}{n} \]

\[ f_r = \sqrt{f_x^2 + f_y^2} \]

Figure 9-19. Longitudinal clip with single row of n bolts.

Case 5

\[ f_x = \frac{F_l}{2b} \]

\[ f_y = \frac{F ld}{2(b^2 + d^2)} \]

\[ f_r = \sqrt{f_x^2 + f_y^2} \]

Figure 9-20. Circumferential clip with four bolts.

Shear Loads in Bolted Connections

Shear loads in bolted connections are classified as either “Friction Type” or “Bearing Type”. A brief definition is as follows:

**Friction Type Connection**

A friction type connection is one in which the sole purpose of the bolts is to provide adequate tension such that the two plates being joined will not slip. In this manner the bolts are not technically in shear, but solely in tension. High strength bolts must be used for friction type connections. The following factors are critical to the joint functioning as designed;

a. The condition of the surface finish of the plates being joined on the contacting surfaces.
   1. Uncoated (Class A, B or C)
   2. Hot dipped galvanized and roughened (Class D)
   3. Blast cleaned, zinc rich paint (Class E or F)
   4. Blast cleaned, metalized zinc or alum (Class G or H)
   5. Contact surfaces are coated (Class I)

b. The tightness of the joint based on;
   1. Snug Tightened
   2. Pre-tensioned
   3. Slip Critical

c. Size of hole relative to bolt size. Dimensions given in Table J3.3.
   1. STD: Standard round holes
   2. OVS: Oversize round holes
   3. SSL: Short slotted holes
   4. LSL: Long Slotted holes

**Bearing Type Connection**

A bearing type connection is one in which the bolts are in shear because there is not significant enough friction in the joint to prevent slip. There are two major classifications of bearing type connections;

a. Connections with threads in shear plane (Type N)

b. Connections without threads in shear plane (Type X)

The following bolt hole/slot types may be used with a bearing type connection;

a. STD: Standard round holes, \( d + 1/16" \)

b. NSL: Long Slotted holes

Paint is acceptable for all types of bearing connections.

The cost to install friction type connections is variable depending on the degree of labor required to produce the joint. In general, the relative costs of each type of joint is as follows (from cheapest to most expensive):

a. Snug tightened (X): 1.0
b. Pre-tensioned (X): 1.2
c. Snug tightened (N): 1.3
d. Pre-tensioned (N): 1.6
e. Slip Critical (N or X): 3.1
The definition of a “bulk storage container” can be quite subjective. The terms “bunkers,” “hoppers,” and “bins” are commonly used. This procedure is written specifically for cylindrical containers of liquid or bulk material with or without small internal pressures.

There is no set of standards that primarily applies to bins and since they are rarely designed for pressures greater than 15 psi, they do not require code stamps. They can, however, be designed, constructed, and inspected in accordance with certain sections of the ASME Code or combinations of codes.

When determining the structural requirements for bins, the horizontal and vertical force components on the bin walls must be computed. A simple but generally incorrect design method is to assume that the bin is filled with a fluid of the same density as the actual contents and then calculate the “equivalent” hydrostatic pressures. While this is correct for liquids, it is wrong for solid materials. All solid materials tend to bridge or arch, and this arch creates two force components on the bin walls. The vertical component on the bin wall reduces the weight load on the material below, and pressures do not build up with the depth as much as in the case of liquids. Consequently, the hoop stresses caused by granular or powdered solids are much lower than for liquids of the same density. However, friction between the shell wall and the granular material can cause high longitudinal loads and even longitudinal buckling. These loads must be carefully considered in the case of a “deep bin.”

In a “shallow bin,” the contents will be entirely supported by the bin bottom. In a “deep bin” or “silo,” the support will be shared, partly by the bottom and partly by the bin walls due to friction and arching of material.

**Notation**

- \( A \) = cross-sectional area of bin, \( \text{ft}^2 \)
- \( A_r \) = area of reinforcement required, \( \text{in.}^2 \)
- \( A_a \) = area of reinforcement available, \( \text{in.}^2 \)
- \( A_s \) = cross-sectional area of strut, \( \text{in.}^2 \)
- \( e \) = common log 2.7183
- C.A. = corrosion allowance, in.
- \( E \) = joint efficiency, 0.35–1.0
- \( F \) = summation of all vertical downward forces, lb
- \( F_a \) = allowable compressive stress, psi
- \( f \) = vertical reactions at support points, lb
- \( h_i \) = depth of contents to point of evaluation, ft
- \( K_1, K_2 \) = Rankine factors, ratio of lateral to vertical pressure
- \( M \) = overturning moment, \( \text{ft} \cdot \text{lb} \)
- \( N \) = number of supports
- \( P \) = internal pressure, psi
- \( p_n \) = pressure normal to surface of cone, psf
- \( p_v \) = vertical pressure of contents, psf
- \( p_h \) = horizontal pressure on bin walls, psf
- \( Q \) = total circumferential force, lb
- \( R_h \) = hydraulic radius of bin, ft
- \( S \) = allowable tension stress, psi
- \( T_1, T_{1s} \) = longitudinal force, lb/ft
- \( T_2, T_{2s} \) = circumferential force, lb/ft
- \( G \) = specific gravity of contents
- \( \theta \) = angle of repose of contents, degrees
- \( \phi \) = angle of filling, angle of surcharge, friction angle. Equal to \( \theta \) for free filling or 0 if filled flush, degrees
- \( \beta \) = angle of rupture, degrees
- \( \mu \) = friction coefficient, material on material
- \( \mu' \) = friction coefficient, material on bin wall
- \( \Delta h \) = height of filling peak, depth of emptying crater, ft
- \( C_s \) = a function of the area of shell that acts with strut to \( A_s \)

**Weights**

- \( W \) = total weight of bin contents, lb
- \( w \) = density of contents, lb/\( \text{cu ft} \)
- \( W_T \) = total weight of bin and contents, lb
- \( W_c \) = weight of cone and lining below elevation under consideration, lb
- \( W_R \) = D.L. + L.L. of roof plus applied loads, lb (include weight of any installed plant equipment)
- \( W_s \) = weight of shell and lining (cylindrical portion only), lb
- \( W_1 \) = \( W + W_c \)
- \( W_2 \) = weight of contents in cylindrical portion of bin, lb, \( = \pi R^2 H w \)
- \( W_3 \) = load caused by vertical pressure of contents, lb, \( = p_v \pi R^2 \)
\[
W_4 = \text{portion of bin contents carried by bin walls due to friction, lb,}= W_2 - W_3
\]
\[
W_5 = W_R + W_4 + W_s
\]
\[
W_6 = W_T - W_c - W_{cl}
\]
\[
W_7 = \text{weight of bin below point of supports plus total weight of contents, lb}
\]
\[
W_{c1} = \text{weight of contents in bottom, lb}
\]

Bins

1. Determine if bin is "deep" or "shallow." The distinction between deep and shallow bins is as follows:
   - In a shallow bin the plane of rupture emerges from the top of the bin.
   - In a deep bin the plane of rupture intersects the opposite bin wall below both the top of the bin and/or the maximum depth of contents.

2. Determine angle \(\beta\).

\[
\tan \beta = \mu + \sqrt{\mu + 1 + \mu'^2 - \mu' \mu}
\]

If \(\mu\) and \(\mu'\) are unknown, compute \(\beta\) as follows:

\[
\beta = \frac{90 + \theta}{2}
\]

and \(h = D \tan \beta\).

If \(h\) is smaller than the straight side of the bin and below the design depth of the contents, the bin is assumed to be "deep" and the silo theory applies. If \(h\) is larger than
the straight side of the bin or greater than the design depth of the contents, then the bin should be designed as “shallow.” This design procedure is also known as the “sliding wedge” method.

**Liquid-Filled Elevated Tanks**

![Diagram of liquid-filled elevated tank]

**Figure 9-23.** Dimensions and loads for a liquid-filled elevated tank.

- **Shell (API 650 & AWWA D100).**
  
  \[ t = \frac{2.6DHG}{SE} + \text{C.A.} \]

  For A-36 material:
  
  API 650: \( S = 21,000 \text{ psi} \)
  
  AWWA D100: \( S = 15,000 \text{ psi} \)

- **Conical bottom (Wozniak).**
  
  At spring line,
  
  \[ T_1 = \frac{wR}{2 \sin \alpha} \left( H + \frac{R \tan \alpha}{3} \right) \]
  \[ T_2 = \frac{wRH}{\sin \alpha} \]

  At any elevation below spring line,
  
  \[ T_1 = \frac{w}{2 \sin \alpha} \left( R - \frac{h_c}{\tan \alpha} \right) \left( H + \frac{2h_c}{3} + \frac{R \tan \alpha}{3} \right) \]
  \[ T_2 = \frac{wh_i}{\sin \alpha} \left( R - \frac{h_c}{\tan \alpha} \right) \]

  \[ t_c = \frac{(T_1 \text{ or } T_2)}{12SE \sin \alpha} + \text{C.A.} \]

- **Spherical bottom (Wozniak).**
  
  At spring line,
  
  \[ T_1 = wR_3 \left[ \frac{H}{2} + \frac{R_3}{3} \right] \]
  \[ T_2 = wR_3 \left[ \frac{H}{2} - \frac{R_3}{3} \right] \]

  At bottom (max. stress),
  
  \[ T_1 = T_2 = \frac{wh_iR_3}{2} \]
  \[ t_s = \frac{(T_1 \text{ or } T_2)}{12SE} + \text{C.A.} \]

- **Ring compression at junction (Wozniak).**
  
  \[ Q = \frac{R^2w}{2 \tan \alpha} \left( H + \frac{R \tan \alpha}{3} \right) \]

**Shallow, Granular- or Powder-Filled Bin**

![Diagram of shallow bin]

**Figure 9-24.** Dimensions and forces for a shallow bin.

- **Cylindrical Shell (Lambert).**
  
  \[ p_v = wh_i = \text{maximum at depth } H \]
  
  \[ K = K_1 \text{ or } K_2 \]
  
  \[ P_h = p_vK \cos \phi \]
  
  \[ T_1 = \text{compression only—from weight of shell, roof, and wind loads} \]
Hoop tension, $T_2$, will govern design of shell for shallow bins

$$T_2 = p_h R$$
$$t = \frac{T_2}{12SE} + \text{C.A.}$$

- **Conical bottom (Ketchum).**

  $p_v = \text{wh}_i$

  Maximum at depth $H = \text{wth}_i$

  $$p_h = \frac{p_v \sin^2(\alpha + \theta)}{\sin^3\alpha \left[ 1 + \sin \frac{\theta}{\sin \alpha} \right]^2}$$

  $$W_1 = W + W_c$$

  $$T_1 = \frac{W_1}{2\pi R_1 \sin \alpha}$$

  $$T_2 = \frac{p_h R_1}{\sin \alpha}$$

  $$t_c = \frac{T_1 \text{ or } T_2}{12SE} + \text{C.A.}$$

- **Spherical bottom (Ketchum).**

  $$T_1 = T_2 = \frac{W_1}{2\pi R_1 \sin^2 \alpha'}$$

  Note: At $\alpha' = 90^\circ$, $\sin^2 \alpha' = 1$

  $$t_s = \frac{T_1}{12SE} + \text{C.A.}$$

- **Ring compression (Wozniak).**

  $$Q = T_1 R \cos \alpha$$

**Deep Bins (Silo)—Granular/Powder Filled**

- **Shell (Lambert).**

  Hydraulic radius

  $$R_h = \frac{R}{2}$$

- **Pressures on bin walls, $p_v$ and $p_h$.**

  $$K = K_1 \text{ or } K_2$$

  $$\left( \frac{\text{wh}_i}{R_h} \right)$$

  $$e = \text{common log} \ 2.7183$$

  $$p_v = \frac{wR_h}{\mu K} \left[ 1 - e^{\left( \frac{\text{wh}_i}{R_h} \right)} \right]$$

  $$p_h = p_v K$$

- **Weights.**

  $$W_2 = \pi R^2 \text{Hw}$$

  $$W_3 = p_v \pi R^2$$

  $$W_4 = W_2 - W_3$$

  $$W_5 = W_4 + W_R + W_s$$

  $$W_R =$$

  $$W_s =$$

- **Forces.**

  $$T_1 = -\frac{W_5}{\pi D} - \frac{48M}{\pi D}$$

  $$T_2 = p_h R$$

  Note: For thin, circular steel bins, longitudinal compression will govern. The shell will fail by buckling from vertical drag rather than bursting due to hoop tension.

- **Maximum allowable compressive stress (Boardman formula).**

  $$F_a = 2 \times 10^6 \left( \frac{1}{R} \right) \left( 1 - \frac{100t}{3R} \right)$$

  $$F_a = 10,000 \ \text{psi maximum}$$

- **Thickness required shell, $t$.**

  $$t = \frac{T}{12F_a}$$
• Conical bottom (Ketchum).

Note: Design bottoms to support full load of contents. Vibration will cause lack of side-wall friction.

At spring line,

\[ p_v = wH \]

\[ p_n = \frac{p_v \sin^2(\alpha + \theta)}{\sin^3\left(\frac{1 + \sin \theta}{\sin \alpha}\right)^2} \]

\[ W_1 = W + W_c \]

\[ T_1 = \frac{W_1}{2\pi R \sin \alpha} \]

\[ T_2 = \frac{p_n R}{\sin \alpha} \]

\[ t = \frac{(T_1 \text{ or } T_2)}{12SE} + \text{C.A.} \]

• Spherical bottom (Ketchum).

At spring line,

\[ T_1 = T_2 = \frac{W_1}{2\pi R^3} \]

\[ t = \frac{T_1}{12SE} + \text{C.A.} \]

• Ring compression (Wozniak).

\[ Q = T_1 R \cos \alpha \]

Bins and Tanks with Small Internal Pressures

• Pressures.

\[ P_1 = \text{pressure due to gas pressure} \]

\[ P_2 = \text{pressure due to static head of liquid} \]

\[ P_3 = \frac{wH}{144} \]

\[ P_3 = \frac{wHK \cos \phi}{144} \]

\[ P = \text{total pressure} \]

\[ P = P_1 + P_2 \]

or

\[ P_1 + P_3 = \]

• Shell (API 620).

\[ F = W_T \]

\[ W_6 = W_T - W_c - W_{ci} \]

\[ A = \pi R^2 \]

\[ T_{1s} = \frac{R}{2} \left( P + \frac{-W_6 + F}{A} \right) \]

\[ T_{2s} = PR \]

\[ t = \frac{(T_{1s} \text{ or } T_{2s})}{SE} + \text{C.A.} \]

• Conical bottom (API 620).

\[ T_1 = \frac{R}{2 \cos \alpha} \left( P + \frac{-W_6 + F}{A} \right) \]

\[ T_2 = \frac{PR}{\sin \alpha} \]

\[ t_c = \frac{(T_1 \text{ or } T_2)}{SE} + \text{C.A.} \]

• Ring compression at spring line, Q (API 620).

\[ W_h = 0.6 \sqrt{R_2(t_c - \text{C.A.})} \]

\[ W_c = 0.6 \sqrt{R(t - \text{C.A.})} \]

\[ Q = T_2 W_h + T_{2s} W_c - T_1 R_2 \cos \alpha \]

Design of Compression Ring

Per API 620 the horizontal projection of the compression ring juncture shall have a width in a radial direction not less than 0.015 R. The compression ring may be used as a balcony girder (walkway) providing it is at least 3 ft-0 in. wide.

\[ R_2 = \frac{R}{\sin \alpha} \]

\[ W_h = 0.6 \sqrt{R_2(t_c - \text{C.A.})} \]

\[ W_c = 0.6 \sqrt{R(t - \text{C.A.})} \]

\[ Q = \text{from applicable case} = \]
$A_r = \frac{Q}{S}$

$A_a = W_c t + W_h t_c$

- **Additional area required.**

$A_r - A_a = \text{Struts}$

Struts are utilized to offset unfavorable high local stresses in the shell immediately above lugs when either lugs or rings are used to support the bin. These high localized stresses may cause local buckling or deformation if struts are not used.

- **Height of struts required, } q.**

$q = \frac{\pi R}{N}$

- **Strut cross-sectional area required, } A_s.**

$A_s = \frac{f C_s}{S}$

where $f = \frac{W_7 R_f + 2 M}{NR_f}$

$W_7 = \text{weight of bin below point of supports plus total weight of contents, lb}$

The total cross-sectional area of single or double struts may be computed by this procedure. To determine $C_s$ assume a value of $A_s$ and a corresponding value of $C_s$ from Figure 9-27. Substitute this value of $C_s$ into the area equation and compute the area required. Repeat this procedure until the proposed $A_s$ and calculated $A_s$ are in agreement.

**Figure 9-25.** Dimensions at junction of cone and cylinder.

**Figure 9-26.** Dimensions and arrangement of single and double struts.

**Figure 9-27.** Graph of function $C_s$. 
Figure 9-28. Typical support arrangements for bins and elevated tanks.
Supports

Bins may be supported in a variety of ways. Since the bottom cone-cylinder intersection normally requires a compression ring, it is common practice to combine the supports with this ring. This will take advantage of the local stiffness and is convenient for the support design.

Table 9-10
Material properties

<table>
<thead>
<tr>
<th>Material</th>
<th>Density w</th>
<th>Angle of Repose θ</th>
<th>Contents on Contents μ</th>
<th>μ'</th>
<th>φ</th>
<th>μ'</th>
<th>φ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland cement</td>
<td>90</td>
<td>39°</td>
<td>0.32</td>
<td>0.93</td>
<td>0.54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal (bituminous)</td>
<td>45–55</td>
<td>35°</td>
<td>0.70</td>
<td>0.59</td>
<td>25</td>
<td>0.70</td>
<td>35</td>
</tr>
<tr>
<td>Coal (anthracite)</td>
<td>52</td>
<td>27°</td>
<td>0.51</td>
<td>0.45</td>
<td>22</td>
<td>0.51</td>
<td>27</td>
</tr>
<tr>
<td>Coke (dry)</td>
<td>28</td>
<td>30°</td>
<td>0.58</td>
<td>0.55</td>
<td>20</td>
<td>0.84</td>
<td>20</td>
</tr>
<tr>
<td>Sand</td>
<td>90–110</td>
<td>30°–35°</td>
<td>0.67</td>
<td>0.60</td>
<td>20</td>
<td>0.58</td>
<td>30</td>
</tr>
<tr>
<td>Wheat</td>
<td>50–53</td>
<td>25°–28°</td>
<td>0.47</td>
<td>0.41</td>
<td>0.44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td>45</td>
<td>40°</td>
<td>0.84</td>
<td>0.70</td>
<td>25</td>
<td>0.70</td>
<td>35</td>
</tr>
<tr>
<td>Clay—dry, fine</td>
<td>100–120</td>
<td>35°</td>
<td>0.70</td>
<td>0.70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stone, crushed</td>
<td>100–110</td>
<td>32°–39°</td>
<td>0.70</td>
<td>0.70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bauxite ore</td>
<td>85</td>
<td>35°</td>
<td>0.70</td>
<td>0.70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn</td>
<td>44</td>
<td>27.5°</td>
<td>0.52</td>
<td>0.37</td>
<td>0.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peas</td>
<td>50</td>
<td>25°</td>
<td>0.47</td>
<td>0.37</td>
<td>0.44</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If μ' is unknown it may be estimated as follows:
- Mean particle diameter <0.002 in., tan⁻¹ μ' = θ.
- Mean particle diameter >0.008 in., tan⁻¹ μ' = 0.75 θ.

Table 9-11
Rankine factors K₁ and K₂

<table>
<thead>
<tr>
<th>θ</th>
<th>K₁</th>
<th>K₂, no surcharge</th>
<th>K₂, with surcharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>10°</td>
<td>0.7041</td>
<td>1.0000</td>
<td></td>
</tr>
<tr>
<td>12°</td>
<td>0.6558</td>
<td>0.7919</td>
<td></td>
</tr>
<tr>
<td>15°</td>
<td>0.5888</td>
<td>0.6738</td>
<td>1.0000</td>
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<tr>
<td>17°</td>
<td>0.5475</td>
<td>0.6144</td>
<td>0.7532</td>
</tr>
<tr>
<td>20°</td>
<td>0.4903</td>
<td>0.5394</td>
<td>0.6241</td>
</tr>
<tr>
<td>22°</td>
<td>0.4549</td>
<td>0.4958</td>
<td>0.5620</td>
</tr>
<tr>
<td>25°</td>
<td>0.4059</td>
<td>0.4376</td>
<td>0.4860</td>
</tr>
<tr>
<td>27°</td>
<td>0.3755</td>
<td>0.4195</td>
<td>0.4428</td>
</tr>
<tr>
<td>30°</td>
<td>0.3333</td>
<td>0.3549</td>
<td>0.3743</td>
</tr>
<tr>
<td>35°</td>
<td>0.2709</td>
<td>0.2861</td>
<td>0.3073</td>
</tr>
<tr>
<td>40°</td>
<td>0.2174</td>
<td>0.2282</td>
<td>0.2429</td>
</tr>
<tr>
<td>45°</td>
<td>0.1716</td>
<td>0.1792</td>
<td>0.1896</td>
</tr>
</tbody>
</table>


K₁ = \frac{p_h}{p_r} = \frac{1 - \sin \theta}{1 + \sin \theta}

K₂, no surcharge

K₂, with surcharge

K₂ = \frac{\cos \phi - \sqrt{\cos^2 \phi \cos^2 \theta}}{\cos \phi + \sqrt{\cos^2 \phi \cos^2 \theta}}
Notes

1. Rankine factors $K_1$ and $K_2$ are ratios of horizontal to vertical pressures. These factors take into account the distribution of forces based on the filling and emptying properties of the material. If the filling angle is different from the angle of repose, then $K_2$ is used. Remember, even if the material is not heaped to begin with, a crater will develop when emptying. The heaping, filling peak, and emptying crater all affect the distribution of forces.

2. Supports for bins should be designed by an appropriate design procedure. See Chapter 4.

3. In order to assist in the flow of material, the cone angle should be as steep as possible. An angle of $45^\circ$ can be considered as minimum, $50^\circ$–$60^\circ$ preferred.

4. While roofs are not addressed in this procedure, their design loads must be considered since they are translated to the shell and supports. As a minimum, allow 25 psf dead load and 50–75 psf live load plus the weight of any installed plant equipment (mixers, conveyors, etc.).

5. Purging, fluidizing techniques, and general vibration can cause loss of friction between the bin wall and the contents. Therefore its effect must be considered or ignored in accordance with the worst situation: in general, added to longitudinal loads and ignored for circumferential loads.

6. Surcharge: Most bunkers will be surcharged as a result of the normal filling process. If the surcharge is taken into account, the horizontal pressures will be overestimated for average bins. It is therefore more economical to assume the material to be flat and level at the mean height of the surcharge and to design accordingly. Where the bin is very wide in relation to the depth of contents the effects of surcharging need to be considered.

Procedure 9-7: Field-Fabricated Spheres

A sphere is the most efficient pressure vessel because it offers the maximum volume for the least surface area and the required thickness of a sphere is one-half the thickness of a cylinder of the same diameter. The stresses in a sphere are equal in each of the major axes, ignoring the effects of supports. In terms of weight, the proportions are similar. When compared with a cylindrical vessel, for a given volume, a sphere would weigh approximately only half as much. However, spheres are more expensive to fabricate, so they aren’t used extensively until larger sizes. In the larger sizes, the higher costs of fabrication are balanced out by larger volumes.

Spheres are typically utilized as “storage” vessels rather than “process” vessels. Spheres are economical for the storage of volatile liquids and gases under pressure, the design pressure being based on some marginal allowance above the vapor pressure of the contents. Spheres are also used for cryogenic applications for the storage of liquefied gases.

Products Stored

- Volatile liquids and gases: propane, butane, and natural gas.
- Cryogenic: oxygen, nitrogen, hydrogen, ethylene, helium, and argon.

Codes of Construction

Spheres are built according to ASME, Section VIII, Division 1 or 2, API 620 or BS 5500. In the United States, ASME, Section VIII, Division 1 is the most commonly used code of construction. Internationally spheres are often designed to a higher stress basis upon agreement between the user and the jurisdictional authorities. Spheres below 15 psig design pressure are designed and built to API 620.

The allowable stresses for the design of the supports is based on either AWWA D100 or AISC.

Materials of Construction (MOC)

Typical materials are carbon steel, usually SA-516-70. High-strength steels are commonly used as well (SA-537, Class 1 and 2, and SA-738, Grade B). SA-516-60 may be used to eliminate the need for PWHT in wet H2S service. For cryogenic applications, the full range of materials has been utilized, from the low-nickel steels, stainless steels, and higher alloys. Spheres of aluminum have also been fabricated.

Liquified gases such as ethylene, oxygen, nitrogen, and hydrogen are typically stored in double-wall spheres, where the inner tank is suspended from the outer tank by
straps or cables and the annular space between the tanks is filled with insulation. The outer tank is not subjected to the freezing temperatures and is thus designed as a standard carbon steel sphere.

**Size, Thickness, and Capacity Range**

Standard sizes range from 1000 barrels to 50,000 barrels in capacity. This relates in size from about 20 feet to 82 feet in diameter. Larger spheres have been built but are considered special designs. In general, thicknesses are limited to 1.5 in. to preclude the requirement for PWHT, however PWHT can be accomplished, even on very large spheres.

**Supports**

Above approximately 20 feet in diameter, spheres are generally supported on legs or columns evenly spaced around the circumference. The legs are attached at or near the equator. The plates in this zone of leg attachment may be required to be thicker, to compensate for the additional loads imposed on the shell by the supports. An internal stiffening ring or ring girder is often used at the junction of the centerline of columns and the shell to take up the loads imposed by the legs.

The quantity of legs will vary. For gas-filled spheres, assume one leg every third plate, assuming 10-feet-wide plates. For liquid-filled spheres, assume one leg every other plate.

Legs can be either cross-braced or sway-braced. Of the two bracing methods, sway-bracing is the more common. Sway-bracing is for tension-only members. Cross-bracing is used for tension and compression members. When used, cross-bracing is usually pinned at the center to reduce the sizes of the members in compression.

Smaller spheres, less than 20 feet in diameter, can be supported on a skirt. The diameter of the supporting skirt should be \(0.7 \times \text{the sphere diameter}\).

**Heat Treatment**

Carbon steel spheres above 1.5-in. thickness must be PWHT per ASME Code. Other alloys should be checked for thickness requirements. Spheres are often stress relieved for process reasons. Spheres made of high-strength carbon steel in wet H\(_2\)S service should be stress relieved regardless of thickness. When PWHT is required, the following precautions should be taken:

- a. Loosen cross-bracing to allow for expansion.
- b. Jack out columns to keep them level during heating and cooling.
- c. Scaffold the entire vessel.
- d. Weld thermocouple wires to shell external surface to monitor and record temperature.
- e. Typically, internally fire it.
- f. Monitor heat/cooling rate and differential temperature.

**Accessories**

Accessories should include a spiral stairway and a top platform to access instruments, relief valves, and vents. Manways should be used on both the top and bottom of the sphere. Nozzles should be kept as close as practical to the center of the sphere to minimize platforming requirements.

**Methods of Fabrication**

Field-fabricated spheres are made in one of two methods. Smaller spheres can be made by the expanded cube, soccer ball method, while larger ones are made by the orange peel method. The orange peel method consists of petals and cap plates top and bottom.

Typically all shell pieces are pressed and trimmed in the shop and assembled to the maximum shipping sizes allowable. Often, the top portion of the posts are fit up and welded in the shop to their respective petals.

**Field Hydrotests**

Typically the bracing on the support columns is not tightened fully until the hydrotest. While the sphere is full of water and the legs are at their maximum compression, the bracing is tightened so that once the sphere is emptied, all of the bracing goes into tension and there is the assurance that they remain in tension during service.

Settlement between the legs must be monitored during hydrotest to detect any uneven settlement between the posts. Any uneven settlement of over \(\frac{1}{2}\) in. between any pair of adjacent legs can cause distortion and damage to the sphere. Foundation requirements should take this requirement into consideration.

**Notes**

1. Spheres that operate either hot or cold will expand or contract differentially with respect to the support
columns or posts. The moment and shear forces resulting from this differential expansion must be accounted for in the design of the legs.

2. The minimum clearance between the bottom of the vessel and grade is 2 ft 6 in.

3. The weights shown in the tables include the weight of the sphere with an allowance for thinning (1/16 in.) and corrosion (1/8 in.) plus plate overtolerance. A clearance of 3 ft was assumed between the bottom of the sphere and the bottom of the base plate. The weights include columns, base plates, and bracing, plus a spiral stairway and top platform. Column weights were estimated from the quantities and sizes listed in the table.

4. For estimating purposes, the following percentages of the sphere shell weight should be added for the various categories:
   - Columns and base plates: 6–14%. For thicker, heavier spheres, the lower percentage should be used. For larger, thinner spheres, the higher percentage should be used.
   - Sway rods/bracing: 1–9%. Use the lower value for wind only and higher values where seismic governs. The highest value should be used for the highest seismic area.
   - Stairway, platform, and nozzles: 2–5%. Apply the lower value for minimal requirements and the higher where the requirements are more stringent.

**Notation**

- A = surface area, sq ft
- d = OD of column legs, in.
- D = diameter, ft
- \(D_m\) = mean vessel diameter, ft
- E = joint efficiency
- \(E_m\) = modulus of elasticity, psi
- N = number of support columns
- n = number of equal volumes
- P = internal pressure, psig
- \(P_a\) = maximum allowable external pressure, psi
- \(P_m\) = MAWP, psig
- R = radius, ft
- \(R_c\) = radius, corroded, in
- S = allowable stress, psi
- t = thickness, new, in.
- \(t_c\) = thickness, corroded, in.
- \(t_p\) = thickness of pipe leg, in.
- \(t_{rv}\) = thickness required for full vacuum, in.
- V = volume, cu ft
- W = weight, lb
- w = unit weight of plate, psf

**Conversion Factors**

- 7.481 gallons/cu ft
- 0.1781 barrels/cu ft
- 5.614 cu ft/barrel
- 35.31 cu ft/cu meter
- 6.29 barrels/cu meter
- 42 gallons/barrel

**Formulas**

\[
V = \frac{\pi D^3}{6} \quad \text{or} \quad V = \frac{4\pi R^3}{3}
\]

\[
V_n = \frac{\pi D^3}{6n} \quad \text{or} \quad V_n = \frac{4\pi R^3}{3n}
\]

\[
V_1 = \frac{\pi h_1^2}{3} (3R - h_1)
\]

\[
V_2 = \frac{\pi h_1}{6} (3r_1^2 + 3r_2^2 + h_2^2)
\]

\[
D = \sqrt{\frac{6V}{\pi}}
\]

\[
A = \pi D^2 \quad \text{or} \quad A = 4\pi R^2
\]

\[
A_n = \pi D_n^2 \quad \text{or} \quad A_n = 2\pi R_n^2
\]

\[
r_1 = \sqrt{2Rh_1 - h_1^2}
\]

\[
r_2 = \sqrt{R^2 - h_2^3}
\]

\[
\sin \alpha = \frac{r_1}{R} \alpha
\]

\[
W = \pi D_m^2 w
\]

\[
P_m = \frac{2SE_{lc}}{R_i + 0.2t_c}
\]

\[
P_a = \frac{0.0625E_m}{\left(\frac{R_c}{t_c}\right)^2}
\]

\[
t_c = \frac{PR_c}{2SE - 0.2P} \quad \text{(Division 1)}
\]

\[
t_c = R_c \left(e^{0.5P/SE} - 1\right) \quad \text{(Division 2)}
\]
Typical Leg Attachment

Dimensional Data

Liquid Level in a Sphere
Table 9-12  
Dimensions for “n” quantity of equal volumes

<table>
<thead>
<tr>
<th>Figure</th>
<th>n</th>
<th>$V_n$</th>
<th>$r_1$</th>
<th>$r_2$</th>
<th>$h_1$</th>
<th>$h_2$</th>
<th>$h_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
<td>$\frac{\pi D^3}{18}$</td>
<td>0.487D</td>
<td>—</td>
<td>0.387D</td>
<td>0.226D</td>
<td>—</td>
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<tr>
<td></td>
<td>4</td>
<td>$\frac{\pi D^3}{24}$</td>
<td>0.469D</td>
<td>—</td>
<td>0.326D</td>
<td>0.174D</td>
<td>—</td>
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<tr>
<td></td>
<td>5</td>
<td>$\frac{\pi D^3}{30}$</td>
<td>0.453D</td>
<td>0.496D</td>
<td>0.287D</td>
<td>0.146D</td>
<td>0.067D</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>$\frac{\pi D^3}{36}$</td>
<td>0.436D</td>
<td>0.487D</td>
<td>0.254D</td>
<td>0.133D</td>
<td>0.113D</td>
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</tbody>
</table>

Table 9-13  
Volumes and surface areas for various depths of liquid

<table>
<thead>
<tr>
<th>$h_4$</th>
<th>$h_5$</th>
<th>$\alpha$</th>
<th>$r_1$</th>
<th>$V_5$</th>
<th>$V_4$</th>
<th>$A_5$</th>
<th>$A_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05D</td>
<td>0.45D</td>
<td>25.84</td>
<td>0.218D</td>
<td>0.0038D$^3$</td>
<td>0.2580D$^3$</td>
<td>0.1571D$^2$</td>
<td>1.4137D$^2$</td>
</tr>
<tr>
<td>0.10D</td>
<td>0.40D</td>
<td>36.87</td>
<td>0.300D</td>
<td>0.0147D$^3$</td>
<td>0.2471D$^3$</td>
<td>0.3142D$^2$</td>
<td>1.2567D$^2$</td>
</tr>
<tr>
<td>0.15D</td>
<td>0.35D</td>
<td>45.57</td>
<td>0.357D</td>
<td>0.0318D$^3$</td>
<td>0.2300D$^3$</td>
<td>0.4712D$^2$</td>
<td>1.1000D$^2$</td>
</tr>
<tr>
<td>0.20D</td>
<td>0.30D</td>
<td>53.13</td>
<td>0.400D</td>
<td>0.0545D$^3$</td>
<td>0.2073D$^3$</td>
<td>0.6283D$^2$</td>
<td>0.9425D$^2$</td>
</tr>
<tr>
<td>0.25D</td>
<td>0.25D</td>
<td>60.0</td>
<td>0.433D</td>
<td>0.0818D$^3$</td>
<td>0.1800D$^3$</td>
<td>0.7854D$^2$</td>
<td>0.7854D$^2$</td>
</tr>
<tr>
<td>0.30D</td>
<td>0.20D</td>
<td>66.42</td>
<td>0.458D</td>
<td>0.1131D$^3$</td>
<td>0.1487D$^3$</td>
<td>0.9425D$^2$</td>
<td>0.6283D$^2$</td>
</tr>
<tr>
<td>0.35D</td>
<td>0.15D</td>
<td>72.54</td>
<td>0.477D</td>
<td>0.1475D$^3$</td>
<td>0.1143D$^3$</td>
<td>1.1000D$^2$</td>
<td>0.4712D$^2$</td>
</tr>
<tr>
<td>0.40D</td>
<td>0.10D</td>
<td>78.46</td>
<td>0.490D</td>
<td>0.1843D$^3$</td>
<td>0.0775D$^3$</td>
<td>1.2567D$^2$</td>
<td>0.3141D$^2$</td>
</tr>
<tr>
<td>0.45D</td>
<td>0.05D</td>
<td>84.26</td>
<td>0.498D</td>
<td>0.2227D$^3$</td>
<td>0.0391D$^3$</td>
<td>1.4137D$^2$</td>
<td>0.1571D$^2$</td>
</tr>
<tr>
<td>0.50D</td>
<td>0D</td>
<td>90.0</td>
<td>0.500D</td>
<td>0.2618D$^3$</td>
<td>0D$^3$</td>
<td>1.5708D$^2$</td>
<td>0D$^2$</td>
</tr>
</tbody>
</table>
Types of Spheres

Expanded Cube, Square Segment, or Soccer Ball Type
- Small spheres only
- Sizes less than about 20 feet in diameter
- Volumes less than 750 bbls

Partial Soccer Ball Type
- Combines orange peel and soccer ball types
- Sizes 30 to 62 feet in diameter
- Volumes 2200 to 22,000 bbls

Meridian, Orange Peel, or Watermelon Type (3-Course Version)
- Consists of crown plates and petal plates
- Sizes 20 to 32 feet in diameter
- Volumes 750 to 3000 bbls

Meridian, Orange Peel, or Watermelon Type (5-Course Version)
- Consists of crown plates and petal plates
- Sizes up to 62 feet in diameter
- Volumes to 22,000 bbls
Table 9-14

Data for 50-psig sphere

<table>
<thead>
<tr>
<th>D</th>
<th>t</th>
<th>bbl nom</th>
<th>bbls</th>
<th>ft³</th>
<th>A</th>
<th>W</th>
<th>N</th>
<th>d</th>
<th>t_p</th>
<th>P_a</th>
<th>t_rv</th>
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</thead>
<tbody>
<tr>
<td>20 ft-0 in.</td>
<td>0.3125</td>
<td>750</td>
<td>746</td>
<td>4188</td>
<td>1256</td>
<td>23.5</td>
<td>4</td>
<td>16</td>
<td>0.25</td>
<td>4.4</td>
<td>0.5</td>
</tr>
<tr>
<td>22 ft-3 in.</td>
<td>0.375</td>
<td>1000</td>
<td>1027</td>
<td>5767</td>
<td>1555</td>
<td>32.8</td>
<td>4</td>
<td>16</td>
<td>0.25</td>
<td>6.32</td>
<td>0.5625</td>
</tr>
<tr>
<td>25 ft-0 in.</td>
<td>0.375</td>
<td>1500</td>
<td>1457</td>
<td>8181</td>
<td>1963</td>
<td>41</td>
<td>4</td>
<td>16</td>
<td>0.25</td>
<td>5.01</td>
<td>0.5625</td>
</tr>
<tr>
<td>25 ft-6 in.</td>
<td>0.375</td>
<td>1500</td>
<td>1546</td>
<td>8662</td>
<td>2043</td>
<td>42.7</td>
<td>4</td>
<td>16</td>
<td>0.25</td>
<td>4.82</td>
<td>0.5625</td>
</tr>
<tr>
<td>28 ft-0 in.</td>
<td>0.375</td>
<td>2000</td>
<td>2047</td>
<td>11494</td>
<td>2463</td>
<td>52.2</td>
<td>5</td>
<td>16</td>
<td>0.25</td>
<td>4</td>
<td>0.625</td>
</tr>
<tr>
<td>30 ft-3 in.</td>
<td>0.4375</td>
<td>2500</td>
<td>2581</td>
<td>14494</td>
<td>2875</td>
<td>68.8</td>
<td>5</td>
<td>16</td>
<td>0.25</td>
<td>5.35</td>
<td>0.6875</td>
</tr>
<tr>
<td>32 ft-0 in.</td>
<td>0.4375</td>
<td>3000</td>
<td>3055</td>
<td>17157</td>
<td>3217</td>
<td>78</td>
<td>6</td>
<td>18</td>
<td>0.25</td>
<td>4.78</td>
<td>0.6875</td>
</tr>
<tr>
<td>35 ft-0 in.</td>
<td>0.4375</td>
<td>3000</td>
<td>3998</td>
<td>22449</td>
<td>3848</td>
<td>93.4</td>
<td>6</td>
<td>18</td>
<td>0.25</td>
<td>4</td>
<td>0.75</td>
</tr>
<tr>
<td>35 ft-3 in.</td>
<td>0.4375</td>
<td>4000</td>
<td>4084</td>
<td>22934</td>
<td>3904</td>
<td>94.7</td>
<td>6</td>
<td>20</td>
<td>0.25</td>
<td>2.52</td>
<td>0.75</td>
</tr>
<tr>
<td>38 ft-0 in.</td>
<td>0.5</td>
<td>5000</td>
<td>5116</td>
<td>28731</td>
<td>4536</td>
<td>123</td>
<td>6</td>
<td>22</td>
<td>0.25</td>
<td>4.88</td>
<td>0.8125</td>
</tr>
<tr>
<td>40 ft-0 in.</td>
<td>0.5</td>
<td>6000</td>
<td>5968</td>
<td>33510</td>
<td>5027</td>
<td>138</td>
<td>6</td>
<td>22</td>
<td>0.25</td>
<td>4.41</td>
<td>0.8125</td>
</tr>
<tr>
<td>40 ft-6 in.</td>
<td>0.5</td>
<td>6000</td>
<td>6195</td>
<td>34783</td>
<td>5153</td>
<td>142.3</td>
<td>7</td>
<td>24</td>
<td>0.25</td>
<td>4</td>
<td>0.875</td>
</tr>
<tr>
<td>43 ft-6 in.</td>
<td>0.5625</td>
<td>7500</td>
<td>7676</td>
<td>43099</td>
<td>5945</td>
<td>181</td>
<td>7</td>
<td>24</td>
<td>0.29</td>
<td>5.07</td>
<td>0.875</td>
</tr>
<tr>
<td>45 ft-0 in.</td>
<td>0.5625</td>
<td>8500</td>
<td>8497</td>
<td>47713</td>
<td>6362</td>
<td>193.6</td>
<td>7</td>
<td>24</td>
<td>0.29</td>
<td>4.74</td>
<td>0.9375</td>
</tr>
<tr>
<td>48 ft-0 in.</td>
<td>0.5625</td>
<td>10,000</td>
<td>10,313</td>
<td>57906</td>
<td>7238</td>
<td>222.2</td>
<td>8</td>
<td>28</td>
<td>0.3</td>
<td>4.17</td>
<td>1</td>
</tr>
<tr>
<td>50 ft-0 in.</td>
<td>0.625</td>
<td>11,500</td>
<td>11,656</td>
<td>65450</td>
<td>7854</td>
<td>269.4</td>
<td>8</td>
<td>28</td>
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<tr>
<td>51 ft-0 in.</td>
<td>0.625</td>
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<td>12,370</td>
<td>69456</td>
<td>8171</td>
<td>280.2</td>
<td>9</td>
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<td>0.29</td>
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<tr>
<td>54 ft-9 in.</td>
<td>0.625</td>
<td>15,000</td>
<td>15,304</td>
<td>85931</td>
<td>9417</td>
<td>326.8</td>
<td>9</td>
<td>32</td>
<td>0.344</td>
<td>4.18</td>
<td>1.0625</td>
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<tr>
<td>55 ft-0 in.</td>
<td>0.625</td>
<td>15,000</td>
<td>15,515</td>
<td>87114</td>
<td>9503</td>
<td>330.6</td>
<td>9</td>
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<td>0.344</td>
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<tr>
<td>60 ft-0 in.</td>
<td>0.6875</td>
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<td>20,142</td>
<td>113097</td>
<td>11,310</td>
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<td>32</td>
<td>0.344</td>
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<td>1.1875</td>
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<td>20,650</td>
<td>115948</td>
<td>11,500</td>
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<td>10</td>
<td>34</td>
<td>0.38</td>
<td>4.34</td>
<td>1.1875</td>
</tr>
<tr>
<td>62 ft-0 in.</td>
<td>0.6875</td>
<td>22,000</td>
<td>22,225</td>
<td>124788</td>
<td>12,076</td>
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<td>4.13</td>
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<tr>
<td>65 ft-0 in.</td>
<td>0.75</td>
<td>25,000</td>
<td>25,610</td>
<td>143793</td>
<td>13,273</td>
<td>551.5</td>
<td>11</td>
<td>36</td>
<td>0.406</td>
<td>4.64</td>
<td>1.25</td>
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<tr>
<td>69 ft-0 in.</td>
<td>0.75</td>
<td>30,000</td>
<td>30,634</td>
<td>172007</td>
<td>14,957</td>
<td>629.2</td>
<td>11</td>
<td>40</td>
<td>0.438</td>
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<td>1.375</td>
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<tr>
<td>76 ft-0 in.</td>
<td>0.8125</td>
<td>40,000</td>
<td>40,936</td>
<td>229847</td>
<td>18,146</td>
<td>874.1</td>
<td>12</td>
<td>42</td>
<td>0.503</td>
<td>4.11</td>
<td>1.5</td>
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<tr>
<td>81 ft-10 in.</td>
<td>0.875</td>
<td>50,000</td>
<td>51,104</td>
<td>286939</td>
<td>21,038</td>
<td>1105</td>
<td>13</td>
<td>42</td>
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<td>87 ft-0 in.</td>
<td>0.9375</td>
<td>60,000</td>
<td>61,407</td>
<td>344791</td>
<td>23,779</td>
<td>1460</td>
<td>14</td>
<td>48</td>
<td>0.75</td>
<td>4.38</td>
<td>1.75</td>
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</table>

Note: Values are based on the following:
1. Material SA-516-70, $S = 20,000$ psi.
2. Joint efficiency, $E = 0.85$.
3. Corrosion allowance, $c.a. = 0.125$. 
### Table 9-15
Weights of spheres, kips

<table>
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<tr>
<th>Dia. (ft)</th>
<th>Thickness (in.)</th>
<th>0.375</th>
<th>0.4375</th>
<th>0.5</th>
<th>0.5625</th>
<th>0.625</th>
<th>0.6875</th>
<th>0.75</th>
<th>0.8125</th>
<th>0.875</th>
<th>0.9375</th>
<th>1</th>
<th>1.125</th>
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<tr>
<td>20 ft-0 in.</td>
<td>26.8</td>
<td>30</td>
<td>[33.3]</td>
<td>36.5</td>
<td>39.8</td>
<td>43</td>
<td>46.3</td>
<td>49.5</td>
<td>52.7</td>
<td>55.9</td>
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<tr>
<td>22 ft-6 in.</td>
<td>32.8</td>
<td>36.8</td>
<td>[40.9]</td>
<td>49</td>
<td>53.1</td>
<td>57.2</td>
<td>61.2</td>
<td>65.3</td>
<td>69.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25 ft-0 in.</td>
<td>41</td>
<td>46</td>
<td>51</td>
<td>[56]</td>
<td>61</td>
<td>66.1</td>
<td>71.1</td>
<td>76.1</td>
<td>81.1</td>
<td>86</td>
<td></td>
<td></td>
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<tr>
<td>27 ft-6 in.</td>
<td>48</td>
<td>54.1</td>
<td>60.1</td>
<td>66.2</td>
<td>[72.3]</td>
<td>78.3</td>
<td>84.4</td>
<td>90.4</td>
<td>96.5</td>
<td>103</td>
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<tr>
<td>30 ft-0 in.</td>
<td>60</td>
<td>66</td>
<td>73.2</td>
<td>80.4</td>
<td>87.6</td>
<td>[94.8]</td>
<td>102</td>
<td>109</td>
<td>117</td>
<td>124</td>
<td>131</td>
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<tr>
<td>32 ft-6 in.</td>
<td>71.5</td>
<td>80</td>
<td>88.5</td>
<td>97</td>
<td>105</td>
<td>[114]</td>
<td>122</td>
<td>131</td>
<td>139</td>
<td>148</td>
<td>156</td>
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<td></td>
</tr>
<tr>
<td>35 ft-0 in.</td>
<td>81.1</td>
<td>93.4</td>
<td>103</td>
<td>113</td>
<td>123</td>
<td>133</td>
<td>[143]</td>
<td>152</td>
<td>162</td>
<td>172</td>
<td>182</td>
<td>202</td>
<td></td>
</tr>
<tr>
<td>37 ft-6 in.</td>
<td>98.3</td>
<td>110</td>
<td>121</td>
<td>132</td>
<td>143</td>
<td>155</td>
<td>166</td>
<td>[177]</td>
<td>189</td>
<td>200</td>
<td>211</td>
<td>234</td>
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<tr>
<td>40 ft-0 in.</td>
<td>105</td>
<td>122</td>
<td>[138]</td>
<td>151</td>
<td>164</td>
<td>177</td>
<td>189</td>
<td>[202]</td>
<td>215</td>
<td>228</td>
<td>241</td>
<td>266</td>
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<tr>
<td>42 ft-6 in.</td>
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<td>143</td>
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<td>187</td>
<td>201</td>
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<tr>
<td>45 ft-0 in.</td>
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<td>177</td>
<td>194</td>
<td>210</td>
<td>226</td>
<td>242</td>
<td>259</td>
<td>275</td>
<td>[291]</td>
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<td>340</td>
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<tr>
<td>47 ft-6 in.</td>
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<td>179</td>
<td>197</td>
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<td>233</td>
<td>251</td>
<td>269</td>
<td>287</td>
<td>305</td>
<td>324</td>
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<td>378</td>
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<tr>
<td>50 ft-0 in.</td>
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<td>229</td>
<td>249</td>
<td>269</td>
<td>289</td>
<td>309</td>
<td>330</td>
<td>350</td>
<td>370</td>
<td>[390]</td>
<td>430</td>
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<tr>
<td>52 ft-6 in.</td>
<td>234</td>
<td>256</td>
<td>278</td>
<td>300</td>
<td>322</td>
<td>344</td>
<td>366</td>
<td>388</td>
<td>411</td>
<td>433</td>
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<tr>
<td>55 ft-0 in.</td>
<td>282</td>
<td>306</td>
<td>[331]</td>
<td>355</td>
<td>379</td>
<td>403</td>
<td>428</td>
<td>452</td>
<td>476</td>
<td>[525]</td>
<td></td>
<td></td>
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<tr>
<td>57 ft-6 in.</td>
<td>313</td>
<td>340</td>
<td>366</td>
<td>393</td>
<td>419</td>
<td>446</td>
<td>472</td>
<td>499</td>
<td>525</td>
<td>578</td>
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</tr>
<tr>
<td>60 ft-0 in.</td>
<td>373</td>
<td>402</td>
<td>431</td>
<td>462</td>
<td>493</td>
<td>525</td>
<td>556</td>
<td>587</td>
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<td>650</td>
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<tr>
<td>62 ft-6 in.</td>
<td>399</td>
<td>431</td>
<td>462</td>
<td>[482]</td>
<td>525</td>
<td>556</td>
<td>587</td>
<td>619</td>
<td>650</td>
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<tr>
<td>65 ft-0 in.</td>
<td>484</td>
<td>518</td>
<td>552</td>
<td>585</td>
<td>619</td>
<td>653</td>
<td>687</td>
<td>755</td>
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<tr>
<td>69 ft-0 in.</td>
<td>553</td>
<td>591</td>
<td>629</td>
<td>667</td>
<td>706</td>
<td>744</td>
<td>782</td>
<td>858</td>
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<tr>
<td>76 ft-0 in.</td>
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<td>828</td>
<td>874</td>
<td>920</td>
<td>967</td>
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<tr>
<td>81 ft-10 in.</td>
<td>944</td>
<td>998</td>
<td>1051</td>
<td>[1105]</td>
<td>1159</td>
<td>1212</td>
<td>1320</td>
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<tr>
<td>87 ft-0 in.</td>
<td>1278</td>
<td>1339</td>
<td>1400</td>
<td>[1460]</td>
<td>1521</td>
<td>1642</td>
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</table>

Notes:
1. Values that are underlined indicate 50-psig internal pressure design.
2. Values in brackets [ ] indicate full vacuum design.
Figure 9-29. Weight of sphere.
Related Equipment

**Weight of Installed Sphere vs. Diameter for Different Internal Pressures**

- Shell Material: SA-516-70
- Allowable Stress: 20,000 psi
- Pressure: Variable 50-300 psig
- Not calculated for vacuum conditions
- Gas ONLY spheres, not liquid-loaded
- Includes weights of Column, Base Plates, Sway Rods, Bracing, Stairways, Platforms, & Nozzles
- Loads and Dimensions are for estimating purposes only, not for final design of foundation piers
- Joint Efficiency: 0.85 for plate thickness < 1.25"
- Joint Efficiency: 1.00 for plate thickness > 1.25"
- Division 1 for plate thickness < 2"
- Division 2 for plate thickness > 2"
- Corrosion Allowance: 0.125 in
- 10% additional thickness for thinning allowance during rolling
- 3% additional thickness to account for thicker plates around equator
- Nominal Plate thickness chosen by:
  - 0.118" Plate increments up to 1 1/8"
  - 0.125" Plate increments above 1 1/8"
- Plate weight accounts for mill overtolerance

---

**Graph Details**

- Weight, kips vs. Diameter, ft
- Internal Pressure, psig

---

- 50, 100, 150, 200, 250, 300 psig lines

---

Graph showing weight vs. diameter for spheres under different internal pressures.
### SPHERE DATA SHEET

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<th>EQUIPMENT NAME:</th>
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<tr>
<td>H</td>
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<td>Shell</td>
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<tr>
<td>Design Pressure - External</td>
<td>Columns</td>
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<td>Design Temperature - Internal</td>
<td>Column Bracing</td>
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<td>Design Temperature - External</td>
<td>Flanges</td>
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<td>MDMT</td>
<td>Nozzle Necks- Pipe</td>
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<tr>
<td>Specific Gravity</td>
<td>Bolting</td>
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<td>Capacity</td>
<td>Gaskets</td>
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<td>Joint Efficiency</td>
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<td>Wind</td>
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<td>Structural</td>
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**Nomenclature**

- $A_b = \text{Area, brace, in}^2$
- $A_c = \text{Area, column, in}^2$
- $A_{cr} = \text{Area required, column}$
- $A_s = \text{Area, shell, in}^2$
- $A_g = \text{Area, girder, in}^2$
- $A_T = \text{Area, total, in}^2$
- $A_{br} = \text{Area, brace, required, in}^2$
- $A_{sn} = \text{Surface area of shell section, Ft}^2$
- $A_{cn} = \text{Cross sectional area, Ft}^2$
- $C_a = \text{Corrosion allowance, in}$
- $D_c = \text{Centerline diameter of columns, Ft}$
- $\delta_c = \text{Inside diameter of column, in}$
- $E = \text{Joint efficiency}$
- $E_m = \text{Modulus of elasticity, PSI}$
- $f = \text{Maximum force in brace, Lbs}$
- $f_a = \text{Axial stress, compression, PSI}$
- $f_T = \text{Tension stress, PSI}$
- $F_a = \text{Allowable axial stress, PSI}$
- $F_b = \text{Allowable stress, bending, PSI}$
- $F_c = \text{Allowable stress, compression, PSI}$
- $F_D = \text{Axial load on column due to dead weight, Lbs}$
- $F_L = \text{Axial load on column due to live load, ie. wind or seismic, lbs}$
- $F_T = \text{Allowable stress, tension, psi}$
- $F_y = \text{Yield strength of material at temperature, PSI}$
- $g = \text{Acceleration due to gravity, 386 in/sec}^2$
- $I_b = \text{Moment of inertia, bracing, in}^4$
- $I_r = \text{Required moment of inertia, in}^4$
- $I_g = \text{Moment of inertia, girder, in}^4$
- $I_s = \text{Moment of inertia, shell, in}^4$
- $I_T = \text{Moment of inertia, combined shell and girder total, in}^4$
- $I_c = \text{Moment of inertia, column, in}^4$
- $k = \text{End connection coefficient, columns}$
- $L' = \text{Theoretical length of shell resisting loads, in}$
- $M_o = \text{Overtwisting moment, Ft-Lbs}$
- $M_B = \text{Internal bending moment in girder section between columns due to horizontal force, in-Lbs}$
- $M_C = \text{Internal bending moment in girder section between columns due to vertical force, in-Lbs}$
- $M_P = \text{Internal bending moment in post plate at column due to vertical force, in-Lbs}$
- $M_S = \text{Internal bending moment in post plate between columns due to vertical force, in-Lbs}$
- $N = \text{Number of columns}$
- $n = \text{Number of active rods per panel use 1 for sway bracing; 2 for cross bracing}$
- $n' = \text{Factor for cross bracing, use 1 for unpinned, 2 for pinned at center}$
- $P = \text{Internal pressure, PSIG}$
- $P_x = \text{External pressure, PSIG}$
- $P_h = \text{Pressure due to static head of liquid, PSI}$
- $P_n = \text{Total pressure at a given elevation, n, PSI}$
- $Q = \text{Maximum axial force in column, Lbs}$
- $R = \text{Inside radius, corroded, Ft}$
- $r = \text{Inside radius, corroded, in}$
- $r_c = \text{Radius of gyration, column, in}$
- $r_b = \text{Radius of gyration, brace, in}$
- $r_o = \text{Outside radius of sphere, in}$
- $r_g = \text{Radius of gyration, girder, in}$
- $S = \text{Allowable stress, shell, PSI}$
- $S_C = \text{Combined stress, compression, PSI}$
- $S_g = \text{Specific gravity, contents}$
- $S_r = \text{Slenderness ratio}$
- $S_T = \text{Combined stress, tension, PSI}$
- $T = \text{Period of vibration, Sec’s}$
- $T' = \text{Greater of T1 or T2, Lbs / in}$
- $T_1 = \text{Meridional load, Lb/in}$
- $T_2 = \text{Latitudinal load, Lb/in}$
- $t = \text{Thickness, sphere, in}$
- $t_c = \text{Thickness, column, in}$
- $t_r = \text{Thickness required, shell, in}$
- $V = \text{Base shear, Lbs}$
- $V_S = \text{Volume, Ft}^3$
- $V_{sn} = \text{Partial volumes of section, Ft}^3$
- $V_h = \text{Horizontal force per column, Lbs}$
- $W_o = \text{Weight, operating, Lbs}$
- $W_w = \text{Weight, water, Lbs}$
- $W_p = \text{Weight, product, Lbs}$
- $W_s = \text{Weight, steel, Lbs}$
- $w = \text{Unit weight of liquid, PCF}$
- $Z_g = \text{Section modulus, girder, in}^3$
- $Z_s = \text{Section modulus, shell, in}^3$
- $Z_T = \text{Section modulus, combined shell and girder, in}^3$
- $\Delta L = \text{Change in length of brace, in}$
- $\delta = \text{Lateral deflection of sphere, in}$
### Summary of loads at support locations

<table>
<thead>
<tr>
<th>QTY of Columns</th>
<th>LEG No.</th>
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<th>Vertical (Q)</th>
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