Procedure 10-4: Lifting Loads and Forces

Effect of Lift Line Orientation to Lug

Initial Pick Point

Multipoint Lift

\( \theta_H \)

\( P_T \)

\( P_r \)

\( P_r \)

Single-Point Lift

Without spreader beam

With spreader beam

Erected Position

Multipoint Lift

\( \theta_v \)

\( P_L \)

\( P_r \)

\( L_2 \)

\( L_3 \)

\( L_1 \)

Single-Point Lift

Without spreader beam

With spreader beam
Force and Loading Diagrams

Free-Body Diagram

\[ P_T = P \cos \theta \]
\[ P_L = P \sin \theta \]
\[ l_1 = T \cos \theta \]
\[ l_2 = T \sin \theta \]

Top Head Lug

Side or Cone Lugs

Top Flange Lug

Trunnions
Loads

- **Overall load factor, $K_L$.**
  
  \[ K_L = K_i + K_s \]

- **Design lift weight, $W_L$.**
  
  \[ W_L = K_L W_E \]

- **Tailing load, $T$.**
  
  \[ T = \frac{W_L \cos \theta L_2}{\cos \theta L_1 + \sin \theta L_4} \]

At $\theta = 0$, initial pick point, vessel horizontal:

\[ T = \frac{W_L L_2}{L_1} \quad \text{and} \quad P = \frac{W_L L_3}{L_1} \quad \text{or} \quad P = W_L - T \]

At $\theta = 90^\circ$, vessel vertical:

\[ T = 0 \quad \text{and} \quad P = W_L \]

- **Calculate the loads for various lift angles, $\theta$.**

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<th>Loads $T$ and $P$</th>
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</tr>
<tr>
<td>80</td>
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<tr>
<td>90</td>
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Lift angles shown are suggested only to help find the worst case for loads $T$ and $P$.

- **Maximum transverse load per lug, $P_T$.**
  
  \[ P_T = \frac{P \cos \theta}{n_L} \]

- **Maximum longitudinal load per lug, $P_L$.**
  
  \[ P_L = \frac{P \sin \theta}{n_L} \]

- **Radial loads in shell due to sling angles, $\theta_v$ or $\theta_H$.**
  
  \[ P_r = P_T \tan \theta_H \quad \text{Vessel in horizontal} \]

\[ P_r = P_L \tan \theta_v \quad \text{Vessel in vertical} \]

- **Tailing loads, $f_L$ and $f_r$.**
  
  \[ f_L = T \cos \theta \]

\[ f_r = T \sin \theta \]

- **Longitudinal bending stress in vessel shell, $\sigma_b$.**
  
  \[ \sigma_b = \frac{4M}{\pi D_m^2 t} \]

Maximum moment occurs at initial pick, when $\theta = 0$. See cases 1 through 4 for maximum moment, $M$.

**Note**

If the tailing point is below the CG as is the case when a tailing frame or sled is used, the tail support could see the entire weight of the vessel as erection approaches $90^\circ$. 
Dimensions and Moments for Various Vessel Configurations

Case 1: Top Head Lug, Top Head Trunnion, or Top Head Flange

\[ M_1 = \frac{W_L L_3 L_2}{L_1} \]

Case 2: Side Lug or Side Trunnion

\[ w_5 = \frac{W_L}{L_5} \quad w_6 = \frac{W_L}{L_1} \]

\[ M_1 = \frac{w_5}{8L_1^2} (L_1 + L_4)^2 (L_1 - L_4)^2 \]

\[ M_2 = \frac{w_5 L_4^2}{2} \]

Case 3: Cone Lug or Trunnion

\[ w_5 = \frac{W_L}{L_4} \quad w_6 = \frac{W_L}{L_1} \]

\[ M_1 = \frac{w_6}{8L_1^2} (L_1 + L_4)^2 (L_1 - L_4)^2 \]

\[ M_2 = \frac{w_5 L_4^2}{2} \]

Case 4: Cone Lug or Trunnion with Intermediate Skirt Tail

\[ w_5 = \frac{W_L}{L_4} \quad w_6 = \frac{W_L}{L_1 + L_5} \]

\[ M_1 = \frac{w_6 L_5^2}{2} \]

\[ M_2 = \frac{w_5 L_4^2}{2} \]

\[ M_3 = \left( \frac{M_1 + M_3}{2} \right) - \frac{w_6 L_1^2}{8} \]
Find Lifting Loads at Any Lift Angle for a Symmetrical Horizontal Drum

Dimensions and Forces

Steam drum:
\[ WL = 600 \text{kips} \]
\[ L_1 = 80 \text{ ft} \]
\[ L_4 = 5 \text{ ft} \]
\[ \frac{L_1}{2L_4} = \frac{80}{10} = 8 \]

Free-Body Diagram

Curve is based on the following equation:
\[ \frac{P}{WL} = \frac{L_4}{L_1} (\tan \theta) + 0.5 \]

Results from curve

@ \( \theta = 15^\circ \) = 51.6%
@ \( \theta = 30^\circ \) = 53.6%
@ \( \theta = 45^\circ \) = 56.3%
@ \( \theta = 60^\circ \) = 60.8%
@ \( \theta = 75^\circ \) = 73.3%

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**Sample Problem**

**Case 1: \( L_3 > L_2 \)**

\[
L_1 = 280 + 2.833 + 1 = 283.83 \text{ ft}
\]

\[
L_2 = 283.83 - 162 = 121.83 \text{ ft}
\]

\[
L_3 = 161 + 1 = 162 \text{ ft}
\]

\[
L_4 = 10 \text{ ft}
\]

**Case 2: \( L_3 < L_2 \)**

\[
L_1 = 283.83 \text{ ft}
\]

\[
L_2 = 162 \text{ ft}
\]

\[
L_3 = 121.83 \text{ ft}
\]

\[
L_4 = 10 \text{ ft}
\]

### Loads \( T \) and \( P \)

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<th>( P )</th>
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Procedure 10-5: Design of Tail Beams, Lugs, and Base Ring Details

Design of Base Plate, Skirt, and Tail Beam

Base Ring-Stiffening Configuration

Loadings in Skirt and Base

Tail Beam Connection Details
Skirt Crippling Criteria with Tailing Beam

**Base Type 1: Base Ring Only**

\[ l_1 = N + 2t_r \]
\[ l_r = 16t_{ed} \]

**Base Type 2: Gussets Only**

\[ l_2 = N + 2t_r \]
\[ l_r = 16t_{ed} \]

**Base Type 3: w/Anchor Chairs**

\[ l_3 = N + 2t_r \]
\[ l_r = 0.55 \sqrt{D_{ed}t_{ed}} \]

**Base Type 4: w/Continuous Top Ring**

Note: \( N = 1 \) in. if a web stiffener is not used.

\[ l_4 = N + 2t_r \]
\[ l_r = (L_G - t_b) + 0.55 \sqrt{D_{ed}t_{ed}} \]
Base Ring Design Check

Type 4 base configuration shown. Alteration required for Type 1, 2, or 3

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<th>Y^2</th>
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\[
C_1 = \frac{\Sigma AY}{\Sigma A}
\]

\[
C_2 = W_B - C_1
\]

\[
I = \Sigma AY^2 + \Sigma I_o - C_1 \Sigma AY
\]

\[
R_B = \text{inside radius of base plate} + C_2
\]

**Internal Forces and Moments in the Skirt Base During Lifting**

To determine the stresses in the base ring as a result of the tailing load, the designer must find the coefficients K_r and K_T based on angle α as shown and the type of stiffening in the skirt/base ring configuration.

\[
M = K_r TR_B
\]

\[
T_1 = K_T T
\]
Skirt/Tail Beam Calculations

**Tail Beam**

- Tailing loads, \( f_L \) and \( f_r \).
  \[
  f_L = T \cos \theta \\
  f_r = T \sin \theta 
  \]

- Maximum bending moment, \( M_b \).
  \[
  M_b = x f_r + y f_L 
  \]

- Maximum bending stress, \( \sigma_b \).
  \[
  \sigma_b = \frac{M_b}{Z} 
  \]

**Tail Beam Bolts**

- Shear load, \( f_s \).
  \[
  f_s = \frac{0.5 f_r n}{n} 
  \]

- Shear stress, \( \tau \).
  \[
  \tau = \frac{f_s}{A_b} 
  \]

- Tension force, \( f_t \).

**Note:** \( y_1 \) = mean skirt diameter or centerline of bolt group if a filler plate is used.

\[
  f_t = \frac{M_b}{y_1} 
  \]

**Skirt**

- Tension stress in bolts, \( \sigma_T \).
  \[
  \sigma_T = \frac{f_T}{N_b A_b} 
  \]

- Compressive force in skirt, \( f_c \).
  \[
  f_c = f_L + f_t 
  \]

- Skirt crippling is dependent on the base configuration and lengths \( l_1 \) through \( l_4 \).

  \( N = 1 \) in. if web stiffeners are not used
  \( N = \) width of top flange of tail beam if web stiffeners are used

- Compressive stress in skirt, \( \sigma_c \).
  \[
  \sigma_c = \frac{f_c}{t_{sk} l_n} 
  \]

- Check shear stress, \( \tau \), in base to skirt weld.
  \[
  \tau = \frac{f_r}{\pi D_{sk} \cdot 0.707 w_4} 
  \]

**Base Plate**

- Bending moment in base plate, \( M_b \).
  \[
  M_b = K_T R B 
  \]

- Find tangential force, \( T_t \).
  \[
  T_t = K_T T 
  \]

- Total combined stress, \( \sigma \).
  \[
  \sigma_T = \frac{M_b C_1}{I} + \frac{T_t}{A} \quad \text{(tension)} \\
  \sigma_C = \frac{-M_b C_2}{I} - \frac{T_t}{A} \quad \text{(compression)} 
  \]
Size Base Ring Stiffeners

F₁ = force in strut or tailing beam, lb
F₁ is (+) for tension and (−) for compression

- **Tension stress, σₜ.**
  \[ σₜ = \frac{F_n}{A_s} \]

- **Critical buckling stress per AISC, σ_cr.**
  \[ C_c = \sqrt{\frac{2\pi^2}{F_y}} \]
  \[ σ_{cr} = \frac{\left(1 - \frac{KL^2}{r/2C^2_c}\right)F_y}{(5/3) + \left(\frac{3KL_N/r}{8C_c} - \frac{(KL_N/r)^3}{8C_c^3}\right)} \]

- **Actual compressive stress, σ_c.**
  \[ σ_c = \frac{F_n}{A_s} \]

*Note:* Evaluate all struts as tension and compression members regardless of sign, because when the vessel is sitting on the ground, the loads are the reverse of the signs shown.

### Two Point

F₁ = (+)0.5T

### Three Point

F₁ = (+)0.453T
F₂ = (−)0.329T

### Parallel Beams/Struts

F₁ = (+)0.25T

### Four Point

F₁ = (+)0.5T
F₂ = (−)0.273T
F₃ = (+)0.273T
<table>
<thead>
<tr>
<th>Angle $\alpha$</th>
<th>One Point $K_r$ $K_T$</th>
<th>Two Point $K_r$ $K_T$</th>
<th>Three Point $K_r$ $K_T$</th>
<th>Four Point $K_r$ $K_T$</th>
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<td>0.2387 $-0.2387$</td>
<td>0.0795 $-0.2387$</td>
<td>$-0.0229$ 0.1651</td>
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<tr>
<td>160.00</td>
<td>0.0654 0.2053</td>
<td>$-0.0083$ 0.2908</td>
<td>$-0.0015$ $-0.0399$</td>
<td>0.0033 0.1089</td>
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<td>165.00</td>
<td>0.0715 0.2198</td>
<td>$-0.0225$ 0.2845</td>
<td>$-0.0028$ $-0.0484$</td>
<td>0.0015 0.1155</td>
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<tr>
<td>170.00</td>
<td>0.0760 0.2301</td>
<td>$-0.0398$ 0.2736</td>
<td>$-0.0041$ $-0.0569$</td>
<td>$-0.0012$ $-0.1188$</td>
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<tr>
<td>175.00</td>
<td>0.0787 0.2366</td>
<td>$-0.0587$ 0.2584</td>
<td>$-0.0046$ $-0.0597$</td>
<td>$-0.0048$ $-0.1188$</td>
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<tr>
<td>180.00</td>
<td>0.0796 0.2387</td>
<td>$-0.0795$ 0.2387</td>
<td>$-0.0051$ $-0.0626$</td>
<td>$-0.0093$ $-0.1156$</td>
</tr>
</tbody>
</table>
Values of Moment Coefficient, $K_r$, for Base Ring With Two Parallel Tail Beams or Internal Struts

Notes:

2. The curve shows moment coefficients at points C and D. The moment coefficients at point A and B are equal and opposite.
3. Positive moments put the inside of the vessel in circumferential tension.
4. The signs of coefficients are for hanging loads. For point support loads underneath the vessel, the signs of the coefficients should be reversed.
• **Uniform load,** \( p \).

\[ p = \frac{T}{R} \]

• **Moments in ring at points A and C.**

\[ M_A = -0.1271TR \]
\[ M_c = -0.0723TR \]

• **Tension/compression forces in ring at points A and C.**

\[ T_A = -0.6421T \]
\[ T_c = -1.2232T \]

• **Combined stress at point A, inside of ring.**

\[ \sigma_A = \frac{T_A}{A} + \frac{M_A}{Z_{in}} \]

• **Combined stress at point A, outside of ring.**

\[ \sigma_A = \frac{T_A}{A} - \frac{M_A}{Z_{out}} \]

• **Combined stress at point C, inside of ring.**

\[ \sigma_c = \frac{T_c}{A} + \frac{M_c}{Z_{in}} \]

• **Combined stress at point C, outside of ring.**

\[ \sigma_c = \frac{T_c}{A} - \frac{M_c}{Z_{out}} \]

*Note:* Assume that the choker is attached immediately at the base ring even though this may be impossible to achieve. Then use the properties of the base ring for A and Z.

Design of Tailing Lugs

Table 10-8
Dimensions for tailing lugs

<table>
<thead>
<tr>
<th>Tail Load (kips)</th>
<th>$t_L$</th>
<th>$t_p$</th>
<th>$E$</th>
<th>$R_o$</th>
<th>$R_p$</th>
<th>$D_1$</th>
<th>$e$</th>
</tr>
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<tbody>
<tr>
<td>&lt;10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>None required</td>
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<tr>
<td>10 to 20</td>
<td>0.75</td>
<td>NR</td>
<td>3</td>
<td>4</td>
<td>NR</td>
<td>2.375</td>
<td>NR</td>
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<tr>
<td>21 to 40</td>
<td>0.75</td>
<td>0.375</td>
<td>3</td>
<td>4</td>
<td>3.5</td>
<td>2.375</td>
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<td>3</td>
<td>4</td>
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<td>2.375</td>
<td>0.3125</td>
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<tr>
<td>71 to 100</td>
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<td>0.5</td>
<td>4</td>
<td>5</td>
<td>4.5</td>
<td>3.4375</td>
<td>0.3125</td>
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<tr>
<td>101 to 130</td>
<td>1.5</td>
<td>0.5</td>
<td>4</td>
<td>5</td>
<td>4.5</td>
<td>3.4375</td>
<td>0.3125</td>
</tr>
<tr>
<td>131 to 170</td>
<td>1.625</td>
<td>0.75</td>
<td>4</td>
<td>5</td>
<td>4.5</td>
<td>3.4375</td>
<td>0.375</td>
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<td>171 to 210</td>
<td>1.625</td>
<td>0.75</td>
<td>5</td>
<td>6</td>
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<td>4.5</td>
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<td>211 to 250</td>
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<td>0.75</td>
<td>5</td>
<td>6</td>
<td>5.5</td>
<td>4.5</td>
<td>0.4375</td>
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<tr>
<td>251 to 300</td>
<td>2.25</td>
<td>1</td>
<td>5</td>
<td>6</td>
<td>5.5</td>
<td>4.5</td>
<td>0.5</td>
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<tr>
<td>&gt;300</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Special design required</td>
<td></td>
</tr>
</tbody>
</table>
Formulas

The tailing lug is designed like all other lugs. The forces are determined from the tailing load, T, calculated per this procedure. The ideal position for the tailing lug is to be as close as possible to the base plate for stiffness and transmitting these loads through the base to the skirt. The option of using a tailing lug versus a tailing beam is the designer’s choice. Either can accommodate internal skirt rings, stiffeners, and struts.

Design as follows:

- **Area required at pin hole, \( A_r \).**
  \[
  A_r = \frac{T}{F_s}
  \]

- **Area available at pin hole, \( A_a \).**
  \[
  A_a = (At_L)-(D_1t_L)
  \]

- **Bending moment in lug, \( M_b \).**
  \[
  M_b = f_L E
  \]

- **Section modulus of lug, \( Z \).**
  \[
  Z = \frac{t_L A^2}{6}
  \]

- **Bending stress in lug, \( \sigma_b \).**
  \[
  \sigma_b = \frac{M_b}{Z}
  \]

- **Area required at pin hole for bearing, \( A_r \).**
  \[
  A_r = \frac{T}{F_p}
  \]

- **Area available at pin hole for bearing, \( A_a \).**
  \[
  A_a = D_2 t_L
  \]

*Note: Substitute \( t_L + 2t_p \) for \( t_L \) in the preceding equations if pad eyes are used.*
Procedure 10-6: Design of Top Head and Cone Lifting Lugs

Design of Top Head/Cone Lug

**Dimensions**

\[ N_T = \frac{B^2}{A + 2B} \]

\[ L_T = E + B - N_T \]

\[ \theta_1 = \arctan \left( \frac{2L_1}{A} \right) \]

\[ L_2 = \frac{L_1}{\sin \theta_1} \]

\[ \theta_2 = \arcsin \left( \frac{R_3}{L_2} \right) \]

\[ \theta_3 = \theta_1 + \theta_2 \]

\[ L_3 = \frac{R_3}{\sin \theta_3} \]

\[ L_4 = 0.5A - \frac{L_1 - 0.5D_3}{\tan \theta_3} \]

\[ L_5 = 0.5A - \frac{L_1 - C}{\tan \theta_3} \]
Lug

- Maximum bending moment in lug, \( M_L \).
  \[ M_L = PE \]
- Section modulus, lug, \( Z \).
  \[ Z = \frac{A^2t_L}{6} \]
- Bending stress, lug, \( \sigma_b \).
  \[ \sigma_b = \frac{M_L}{Z} \]
- Thickness of lug required, \( t_L \).
  \[ t_L = \frac{6M_L}{A^2F_b} \]
- Tension at edge of pad, \( \sigma_T \).
  \[ \sigma_T = \frac{P_L}{2L_4t_L} \]
- Net section at pin hole, \( A_p \).
  \[ A_p = 2L_3t_L + 2t_p(D_3 - D_1) \]
- Shear stress at pin hole, \( \tau \).
  \[ \tau = \frac{P_L}{A_p} \]
- Net section at top of lug, \( A_n \).
  \[ A_n = t_L\left( R_3 - \frac{D_1}{2} \right) + 2t_p\left( \frac{D_3 - D_1}{2} \right) \]
- Shear stress at top of lug, \( \tau \).
  \[ \tau = \frac{P_T}{A_n} \]
- Pin bearing stress, \( \sigma_p \).
  \[ \sigma_p = \frac{P_T}{D_3(t_L + 2t_p)} \]

Check Welds

- Polar moment of inertia, \( J_w \).
  \[ \text{Re-pad: } J_w = \frac{(A_1 + L_6)^3}{6} \]
  \[ \text{Lug: } J_w = \frac{(A + 2B)^3}{12} - \frac{B^2(A + B)^2}{(A + 2B)} \]
- Moment, \( M_1 \).
  \[ M_1 = L_T P_T \]

Lug Weld

- Find loads on welds.
- Transverse shear due to \( P_T \), \( f_1 \).
  \[ f_1 = \frac{P_T}{A + 2B} \]
- Transverse shear due to \( M_1 \), \( f_2 \).
  \[ f_2 = \frac{M_1(B - N_T)}{J_w} \]
- Longitudinal shear due to \( M_1 \), \( f_3 \).
  \[ f_3 = \frac{M_1B}{J_w} \]
- Combined shear load, \( f_r \).
  \[ f_r = \sqrt{(f_1 + f_2)^2 + f_3^2} \]
Size of weld required, \( w_1 \).

\[
w_1 = \frac{f_r}{0.707F_s}
\]

Note: If \( w_1 \) exceeds the shell plate thickness, then a re-pad must be used.

**Re-pad Weld**

- **Moment, \( M_2 \).**

\[
M_2 = P_T(E + 0.5L_6)
\]

- **Transverse shear due to \( P_T \), \( f_1 \).**

\[
f_1 = \frac{P_T}{2A_1 + 2L_6}
\]

- **Transverse shear due to \( M_2 \), \( f_2 \).**

\[
f_2 = \frac{0.5M_2L_6}{J_w}
\]

- **Longitudinal shear due to \( M_2 \), \( f_3 \).**

\[
f_3 = \frac{M_2L_6}{J_w}
\]

- **Combined shear load, \( f_r \).**

\[
f_r = \sqrt{(f_1 + f_2)^2 + f_3^2}
\]

- **Size of weld required, \( w_2 \).**

\[
w_2 = \frac{f_r}{0.707F_s}
\]

**Pad Eye Weld**

- **Unit shear load on pad, \( f_4 \).**

\[
f_4 = \frac{P_Tt_p\pi D_2}{2t_p + t_L}
\]

- **Size of weld required, \( w_3 \).**

\[
w_3 = \frac{f_4}{0.707F_s}
\]

**Top Head Lug for Large Loads**

- **Pad eye**
- **Cutout for additional welding**
- **Re-pad**
Table 10-9
Dimensions for top head or cone lugs

<table>
<thead>
<tr>
<th>Type</th>
<th>Note</th>
<th>Total Erection Weight (tons)</th>
<th>Shackles Size (tons)</th>
<th>Lug Thickness t_L</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>E</th>
<th>R₃</th>
<th>W₁</th>
<th>Gusset Thickness t₃</th>
<th>Pads</th>
<th>Lift Hole Dia D₁</th>
<th>Lug Matt. Min. Yield (psi)</th>
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<td>36-in. to 48-in. Inside Diameter</td>
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</tr>
<tr>
<td>1-A</td>
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<td>0–30</td>
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</tr>
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<td>9</td>
<td>15</td>
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<tr>
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<td>30</td>
<td>18</td>
<td>12</td>
<td>34</td>
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<td>1½</td>
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Notes:
1. For 75-ton shackle, increase lift hole to 3.375
2. For 150-ton shackle, increase lift hole to 4.375
3. For 450-ton shackle, increase lift hole to 5.375
Procedure 10-7: Design of Flange Lugs
Table 10-10
Flange lug dimensions

<table>
<thead>
<tr>
<th>Load Capacity (tons)</th>
<th>D₁</th>
<th>t_L</th>
<th>t_b</th>
<th>A</th>
<th>B</th>
<th>G</th>
<th>H</th>
<th>E</th>
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<tbody>
<tr>
<td>50</td>
<td>3.38</td>
<td>2</td>
<td>2</td>
<td>8</td>
<td>11</td>
<td>12</td>
<td>30</td>
<td>9</td>
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<tr>
<td>100</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>14</td>
<td>12</td>
<td>24</td>
<td>36</td>
<td>9</td>
</tr>
<tr>
<td>200</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>18</td>
<td>14</td>
<td>30</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>400</td>
<td>8</td>
<td>5</td>
<td>5</td>
<td>20</td>
<td>16</td>
<td>36</td>
<td>46</td>
<td>11</td>
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<tr>
<td>600</td>
<td>9</td>
<td>6</td>
<td>6</td>
<td>24</td>
<td>22</td>
<td>40</td>
<td>58</td>
<td>16</td>
</tr>
<tr>
<td>800</td>
<td>10</td>
<td>9</td>
<td>7</td>
<td>28</td>
<td>24</td>
<td>42</td>
<td>60</td>
<td>17</td>
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Table 10-11
Bolt properties

<table>
<thead>
<tr>
<th>Bolt Size</th>
<th>A_b</th>
<th>A_s</th>
<th>T_b</th>
</tr>
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<tbody>
<tr>
<td>0.5–13</td>
<td>0.196</td>
<td>0.112</td>
<td>12</td>
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<tr>
<td>0.625–11</td>
<td>0.307</td>
<td>0.199</td>
<td>19</td>
</tr>
<tr>
<td>0.75–10</td>
<td>0.442</td>
<td>0.309</td>
<td>28</td>
</tr>
<tr>
<td>0.875–9</td>
<td>0.601</td>
<td>0.446</td>
<td>39</td>
</tr>
<tr>
<td>1–8</td>
<td>0.785</td>
<td>0.605</td>
<td>51</td>
</tr>
<tr>
<td>1.125–8</td>
<td>0.994</td>
<td>0.79</td>
<td>56</td>
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<td>1.227</td>
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<td>71</td>
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<td>1.375–8</td>
<td>1.485</td>
<td>1.233</td>
<td>85</td>
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<tr>
<td>1.5–8</td>
<td>1.767</td>
<td>1.492</td>
<td>103</td>
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<tr>
<td>1.75–8</td>
<td>2.405</td>
<td>2.082</td>
<td>182</td>
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<td>2–8</td>
<td>3.142</td>
<td>2.771</td>
<td>243</td>
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<td>3.976</td>
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<td>9.62</td>
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<td>11.04</td>
<td>10.34</td>
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<td>4–8</td>
<td>12.57</td>
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<td>910</td>
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Table 10-12
Values of S_u

<table>
<thead>
<tr>
<th>Bolt Dia, d_b</th>
<th>Material</th>
<th>S_u (ksi)</th>
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<tbody>
<tr>
<td>&lt; 1</td>
<td>A-325</td>
<td>120</td>
</tr>
<tr>
<td>1.125–1.5</td>
<td>A-325</td>
<td>105</td>
</tr>
<tr>
<td>1.625–2.5</td>
<td>A-193-B7</td>
<td>125</td>
</tr>
<tr>
<td>2.625–4</td>
<td>A-193-B7</td>
<td>110</td>
</tr>
</tbody>
</table>
Top Flange Lug

\[ P_L = P \sin \theta \]
\[ P_T = P \cos \theta \]
\[ P_E = \frac{P_L}{A} + \frac{3P_T e}{A^2} \]
\[ M_1 = P_T B \]
\[ M_2 = P_T (B + J) \]
\[ M_3 = P_T e \]
\[ M_u = X_n \cos \alpha_n N_b \]
\[ M_s = \frac{M_u M_1}{\sum M_u} \]
\[ X_n = R_b \cos \alpha_n \]
\[ y_n = R_b \sin \alpha_n \]

Side Flange Lug

\[ F_n = \frac{M_u}{X_n N_b} \]
\[ f_s = \frac{P_T}{N} \]
\[ \sigma_T = \frac{F_n}{A_s} \]
\[ F_s = 15 \text{ ksi } \left( 1 - \frac{\sigma_T A_b}{T_b} \right) \]
\[ A_s = 0.7854 (d - 0.1218)^2 \]
\[ \tau = \frac{f_s}{A_s} < F_s \]
\[ T_b = 0.75 u A_s \]
\[ 0.6 F_y < F_T < 40 \text{ ksi} \]
**Design Process**

1. Determine loads
2. Check of lug:
   a. Shear at pin hole.
   b. Bending of lug.
   c. Bearing at pin hole.
3. Check of base plate.
4. Check of nozzle flange.
5. Check of flange bolting.
6. Check of local load at nozzle to head or shell junction.

**Step 1: Determine loads.**
- Determine loads $P_T$ and $P_L$ for various lift angles, $\theta$.
- Determine uniform loads $w_1$ and $w_2$ for various angles, $\theta$.
- Using $w_1$ and $w_2$, solve for worst case of combined load, $P_E$.
- Determine worst-case bending moment in lug, $M_3$.

**Step 2: Check of lug.**

a. Shear at pin hole:
   - *Area required, $A_r$.*
     \[
     A_r = \frac{P_E}{F_s}
     \]
   - *Area available at pin hole, $A_a$.*
     \[
     A_a = (A_{tL}) - (D_1 t_L)
     \]

b. Bending of lug due to $M_3$:
   - *Section modulus, $Z$.*
     \[
     Z = \frac{t_L A^2}{6}
     \]
   - *Bending stress, lug, $\sigma_b$.*
     \[
     \sigma_b = \frac{M_3}{Z}
     \]

c. Bearing at pin hole:
   - *Bearing required at pin hole $A_r$.*
     \[
     A_r = \frac{P_E}{F_p}
     \]
   - *Bearing available, $A_a$.*
     \[
     A_a = D_2 t_L
     \]

**Maximum Tension in Lug**

\[
\begin{align*}
  w_1 &= \frac{3P_T e}{A^2} \\
  w_2 &= \frac{P_L}{A} \\
  w &= w_1 + w_2 \\
  P_E &= wA
\end{align*}
\]

**Check of Nozzle Flange**

- *Unit load, $w$.*
  \[
  w = \frac{P_E}{\pi B_c}
  \]
- *Bending moment, $M$.*
  \[
  M = wh_D
  \]
- *Bending stress, $\sigma_{br}$.*
  \[
  \sigma_b = \frac{6M}{t^2}
  \]
Bolt Loads for Rectangular Lugs

**Design of Full Circular Base Plate for Lug**

- If a full circular plate is used in lieu of a rectangular plate, the following evaluation may be used.

**Unit load on bolt circle, w.**

\[ w = \frac{P_e}{\pi B_c} \]

**Edge distance from point of load, \( h_p \).**

\[ h_p = \frac{B_c - t_L}{2} \]

**Bending moment, \( M \).**

\[ M = w h_p \]

**Bending stress, \( \sigma_b \).**

\[ \sigma_b = \frac{6M}{t_b^3} \]

- Check bolting same as rectangular flange.
Design of Lug Base Plate


- **Uniform load,** $w$.
  \[ w = \frac{P_E}{A} \]

- **End reaction,** $R_1$.
  \[ R_1 = \frac{wA}{2} \]

- **Edge moment,** $M_a$.
  \[ M_a = \frac{wA}{24B_c} \left[ \frac{24R_c^3}{B_c} - 6(B + A)A^2 + \frac{3A^3}{B_c} + 4A^2 \right] - 24R_c^2 \]

- **Moment at midspan,** $M_x$.
  \[ M_x = M_a + R_1R_c - \frac{wA}{2} \left[ \frac{(R_c - b)^2}{A} \right] \]

- **Thickness required,** $t_b$.
  \[ t_b = \sqrt{\frac{6M_x}{GF_b}} \]
Check of Bolts

Case 1: Bolts on Centerline

Case 2: Bolts Straddle Centerline

<table>
<thead>
<tr>
<th>Bolt</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Bolt</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a_n)</td>
<td>(x_n)</td>
<td>(y_n)</td>
<td>(N_b)</td>
<td>(M_u)</td>
<td>(M_s)</td>
<td>(F_n)</td>
<td>(\sigma_T)</td>
<td>(F_s)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Sample Problem: Top Flange Lug

Given

\[ L_1 = 90 \text{ ft} \]
\[ L_2 = 50 \text{ ft} \]
\[ L_3 = 40 \text{ ft} \]
\[ L_4 = 9.5 \text{ ft} \]
\[ F_y \text{ bolting} = 75 \text{ ksi} \]
\[ F_y \text{ lug} = 36 \text{ ksi} \]
\[ F_y \text{ flange} = 36 \text{ ksi} \]
\[ F_s = 0.4(36) = 14.4 \text{ ksi} \]
\[ F_T = 0.6(36) = 21.6 \text{ ksi} \]
\[ F_b = 0.66(36) = 23.76 \text{ ksi} \]
\[ W_L = 1200 \text{ kips} \]
\[ B_c = 54 \text{ in.} \]
\[ R_c = 27 \text{ in.} \]
\[ B = 22 \text{ in.} \]
\[ t_b = 6 \text{ in.} \]
\[ t_L = 6 \text{ in.} \]
\[ t_f = 11 \text{ in.} \]
\[ D_1 = 9 \text{ in.} \]

Bolt size = 3-1/4-8 UNC
\[ A_b = 8.3 \text{ in.}^2 \]
\[ A_s = 7.686 \text{ in.}^2 \]
\[ T_b = 592 \text{ kips} \]
\[ S_u = 110 \text{ ksi} \]
\[ e = 16 \text{ in.} \]
\[ G = 40 \text{ in.} \]
\[ A = 24 \text{ in.} \]
\[ h_D = 9.5 \text{ in.} \]
\[ b = 0.5(B_c - A) \]

Results
\[ P_T \text{ max} = 537 \text{ kips} @ \theta = 10^\circ \]
\[ P_L \text{ max} = 1200 \text{ kips} @ \theta = 90^\circ \]
\[ P_E \text{ max} = 1277 \text{ kips} @ \theta = 40^\circ \]
\[ \sigma_T \text{ bolt, max} = 20.11 \text{ ksi} \leq 40 \text{ ksi} \]
\[ \tau \text{ bolt, max} = 6.98 \text{ ksi} \leq 10.77 \text{ ksi} \]
### Step 1: Determine loads.

<table>
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<tr>
<th>( \theta )</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
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<tbody>
<tr>
<td>( T_g )</td>
<td>666</td>
<td>654</td>
<td>642</td>
<td>629</td>
<td>613</td>
<td>592</td>
<td>564</td>
<td>517</td>
<td>417</td>
<td>0</td>
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<tr>
<td>( P_o )</td>
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<td>546</td>
<td>558</td>
<td>571</td>
<td>587</td>
<td>608</td>
<td>636</td>
<td>683</td>
<td>783</td>
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<tr>
<td>( P_r )</td>
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<td>537</td>
<td>525</td>
<td>494</td>
<td>450</td>
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<td>234</td>
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<tr>
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<td>191</td>
<td>286</td>
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<td>465</td>
<td>551</td>
<td>642</td>
<td>771</td>
<td>1200</td>
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<td>7.96</td>
<td>11.92</td>
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<td>19.38</td>
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<td>26.75</td>
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<td>50</td>
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<tr>
<td>( w_C )</td>
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<td>44.75</td>
<td>43.75</td>
<td>41.16</td>
<td>37.5</td>
<td>32.58</td>
<td>26.5</td>
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<td>11.33</td>
<td>0</td>
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<tr>
<td>( w )</td>
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<td>48.71</td>
<td>51.71</td>
<td>53.08</td>
<td>53.21</td>
<td>51.96</td>
<td>49.46</td>
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<td>43.46</td>
<td>50</td>
</tr>
<tr>
<td>( P_E )</td>
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<td>1169</td>
<td>1241</td>
<td>1274</td>
<td>1277</td>
<td>1247</td>
<td>1187</td>
<td>1110</td>
<td>1043</td>
<td>1200</td>
</tr>
<tr>
<td>( M_l )</td>
<td>11,748</td>
<td>11,814</td>
<td>11,550</td>
<td>10,868</td>
<td>9900</td>
<td>8602</td>
<td>6996</td>
<td>5148</td>
<td>2992</td>
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<tr>
<td>( f_n ), bolts (10)</td>
<td>53.4</td>
<td>53.7</td>
<td>52.5</td>
<td>49.4</td>
<td>45</td>
<td>39.1</td>
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<td>23.4</td>
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<td>( f_n ), bolts (12)</td>
<td>44.5</td>
<td>44.75</td>
<td>43.75</td>
<td>41.16</td>
<td>37.5</td>
<td>32.6</td>
<td>26.5</td>
<td>19.5</td>
<td>11.33</td>
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<tr>
<td>( T ), bolts (10)</td>
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<td>6.98</td>
<td>6.83</td>
<td>6.42</td>
<td>5.85</td>
<td>5.08</td>
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</table>

### Step 2: Check bolts for tension load.

#### Case 1: \( N = 10 \) Bolts

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<tr>
<th>( \alpha_n )</th>
<th>0</th>
<th>15</th>
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<th>7.5</th>
<th>22.5</th>
<th>37.5</th>
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</thead>
<tbody>
<tr>
<td>( \cos \alpha_n )</td>
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<td>0.866</td>
<td>0.923</td>
<td>0.793</td>
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<tr>
<td>( X_n )</td>
<td>0</td>
<td>7</td>
<td>13.5</td>
<td>3.52</td>
<td>10.33</td>
<td>16.44</td>
</tr>
<tr>
<td>( N_n )</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>( M_{u} )</td>
<td>0</td>
<td>27.05</td>
<td>46.76</td>
<td>( \Sigma = 73.81 )</td>
<td>13.95</td>
<td>38.13</td>
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<tr>
<td>( M_{K} )</td>
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<td>7484</td>
<td>( \Sigma = 11,814 )</td>
<td>1581</td>
<td>4322</td>
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<tr>
<td>( F_{K} )</td>
<td>0</td>
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<td>138.6</td>
<td>112.3</td>
<td>104.6</td>
<td>89.9</td>
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<tr>
<td>( \sigma_{T} )</td>
<td>20.11</td>
<td>18.03</td>
<td>14.61</td>
<td>13.61</td>
<td>11.7</td>
<td></td>
</tr>
<tr>
<td>( F_{S} )</td>
<td>10.77</td>
<td>11.21</td>
<td>11.93</td>
<td>12.13</td>
<td>12.53</td>
<td></td>
</tr>
</tbody>
</table>
1.0 Check Lug

a. Shear at pin hole:
   - Area required, $A_r$.
     $$ A_r = \frac{P_E}{F_s} = \frac{1277}{14.4} = 88.68 \text{ in.}^2 $$
   - Area available at pin hole, $A_a$.
     $$ A_a = (A_{t_L}) - (D_1t_L) = (24 \cdot 6) - (9 \cdot 6) = 90 \text{ in.}^2 $$

b. Bending of lug due to $M_3$:
   - Maximum moment, $M_3$.
     $$ M_3 = P_T e = 537(16) = 8592 \text{ in.} - \text{kips} $$
   - Section modulus, $Z$.
     $$ Z = \frac{t_{u}A^2}{6} = \frac{(6 \cdot 24^2)}{6} = 576 \text{ in.}^3 $$
   - Bending stress, lug, $\sigma_b$.
     $$ \sigma_b = \frac{M_3}{Z} = \frac{8592}{576} = 14.91 \text{ ksi} $$
   - Thickness required, $t_L$.
     $$ t_L = \frac{6M}{F_bA^2} = \frac{6 \cdot 8592}{23.76(24^2)} = 3.76 \text{ in.} $$

c. Bearing at pin hole:
   - Bearing required at pin hole, $A_r$.
     $$ A_r = \frac{P_E}{F_p} = \frac{1277}{32.4} = 39.41 \text{ in.}^2 $$
   - Bearing available, $A_a$.
     $$ A_a = D_2t_L = 8 \cdot 6 = 48 \text{ in.}^2 $$

2.0 Check Lug Base Plate

- Uniform load, $w$.
  $$ w = \frac{P_E}{A} = \frac{1277}{24} = 53.2 \text{ kips in.} $$
- End reaction, $R_1$.
  $$ R_1 = \frac{P_E}{2} = \frac{1277}{2} = 638.5 \text{ kips} $$

- Edge moment, $M_a$.
  $$ M_a = \frac{wA}{24B_c} \left[ \frac{24R_3^3}{B_c} - \frac{6(b + A)A^2}{B_c} + \frac{3A^3}{B_c} + 4A^2 \right] $$
  $$ M_a = 0.985(8748 - 2496 + 768 + 2304 - 17,496) $$
  $$ = -8049 \text{ in.} - \text{kips} $$

- Moment at mid, $M_x$.
  $$ M_x = M_a + R_1R_c \frac{wA}{2} \left[ \frac{(R_c - b)^2}{A} \right] $$
  $$ M_x = -8049 + 17,240 - 3831 $$
  $$ = 5360 \text{ in.} - \text{kips} $$

- Section modulus, $Z$.
  $$ Z = \frac{(t_bG)}{6} = \frac{(6^2 \cdot 40)}{6} = 240 \text{ in.}^3 $$

- Bending stress, $\sigma_b$.
  $$ \sigma_b = \frac{M_x}{Z} = \frac{5360}{240} = 22.33 \text{ ksi} $$

- Allowable bending stress, $F_b$.
  $$ F_b = 0.66F_y = 0.66(36) = 23.76 \text{ ksi} $$

3.0 Check of Vessel Flange

- Unit load, $w$.
  $$ w = \frac{P_E}{\pi B_c} = \frac{1277}{\pi 54} = 7.52 \text{ kips in.} $$

- Bending moment, $M_b$.
  $$ M_b = wh_D = 7.52(9.2) = 69.25 \text{ in.} - \text{kips} $$

- Bending stress, $\sigma_b$.
  $$ \sigma_b = \frac{6M_b}{t_f^2} = \frac{6(69.25)}{11.25^2} = 3.28 \text{ ksi} $$
Top Flange Lugs—Alternate Construction

50-Ton Capacity

400-Ton Capacity

200-Ton Capacity

600-Ton Capacity
Procedure 10-8: Design of Trunnions

Lug Dimensions

Type 1: Trunnion and Fixed Lug

Type 2: Trunnion and Rotating Lug

Type 3: Trunnion Only

Dimensions for Trunnion
**Type 1: Trunnion and Fixed Lug**

There are four checks to be performed:

1. Check lug.
2. Check trunnion.
3. Check welds.
4. Check vessel shell.

**Check Lug**

Transverse (vessel horizontal)

\[ M = P_T E \quad \text{and} \quad Z = \frac{4R_t^2 t_L}{6} \]

Therefore,

\[ t_L = \frac{1.5P_T E}{R_t^2 F_b} \]

Longitudinal (vessel vertical)

- **Cross-sectional area at pin hole, \( A_p \).**
  \[ A_p = 213t_L + 2t_p(D_3 - D_1) \]

- **Cross-sectional area at top of lug, \( A_n \).**
  \[ A_n = t_L \left( R_T - \frac{D_1}{2} \right) + 2t_p \left( \frac{D_3 - D_1}{2} \right) \]

- **Shear stress, \( \tau \).**
  \[ \tau = \frac{P_L}{A_p} \quad \text{or} \quad \tau = \frac{P_L}{A_n} \]

- **Pin bearing stress, \( \sigma_p \).**
  \[ \sigma_p = \frac{P_L}{D_2(t_L + 2t_p)} \]

**Check Trunnion**

- **Longitudinal moment, \( M_L \) (vessel vertical).**
  \[ M_L = P_L e \]

- **Torsional moment, \( M_T \) (vessel horizontal).**
  \[ M_T = P_T E \]

- **Bending stress, \( \sigma_b \).**
  \[ \sigma_b = \frac{M_L}{Z} \]

- **Torsional shear stress, \( \tau_T \).**
  \[ \tau_T = \frac{M_T R_n}{2\pi R_n t_0} \]

**Check Welds**

- **Section modulus of weld, \( S_w \).**
  \[ S_w = \frac{\pi R_n^2}{2} \]

- **Polar moment of inertia, \( J_w \).**
  \[ J_w = 2\pi R_n^3 \]

- **Shear stress in weld due to bending moment, \( f_s \).**
  \[ f_s = \frac{M_T}{S_w} \]

- **Torsional shear stress in weld, \( \tau_T \).**
  \[ \tau_T = \frac{M_T R_n}{J_w} \]

- **Size of welds required, \( w_1 \) and \( w_2 \).**
  \[ w_1 > \text{thickness of end plate} \]
  \[ w_2 = \text{width of combined groove and fillet welds} \]
  \[ w_2 = \frac{f_s}{F_s} > \frac{3}{8} \text{in.} \]

**Type 2: Trunnion and Rotating Lug**

- **Net section at Section A-A, \( A_p \).**
  \[ A_p = 213t_L + 2t_p(D_3 - D_1) \]
• Shear stress at pin hole, $\tau$.

$$\tau = \frac{P_L}{A_p}$$

• Net section at Section B-B, $A_n$

$$A_n = 2t_L(R_o - R_i)$$

• Shear stress at trunnion, $\tau$.

$$\tau = \frac{P_L}{A_n}$$

• Minimum bearing contact angle for lug at trunnion, $\theta_B$

$$\theta_B = \frac{(15.9P_L)}{R_n t_L F_p}$$

• Pin hole bearing stress, $\sigma_p$.

$$\sigma_p = \frac{P_L}{D_3(t_L + 2t_p)}$$

Check Welds

• Longitudinal moment, $M_L$ (vessel vertical).

$$M_L = P_L e$$

• Section modulus of weld, $S_w$.

$$S_w = \pi R_n^2$$

• Shear stress in weld due to bending moment, $f_s$.

$$f_s = \frac{M_L}{S_w}$$

• Size of welds required, $w_1$ and $w_2$.

$w_1 >$ thickness of end plate

$w_2 =$ width of combined groove and fillet welds

$$w_2 = \frac{f_s}{F_s} > \frac{3}{8} \text{ in.}$$

Type 3: Trunnion Only

Vessel Vertical

• Longitudinal moment, $M_L$.

$$M_L = P_L e$$

• Bending stress in trunnion, $\sigma_b$.

$$\sigma_b = \frac{M_L}{Z}$$

Vessel Horizontal

• Circumferential moment, $M_c$.

$$M_c = P_T e$$

• Bending stress in trunnion, $\sigma_b$.

$$\sigma_b = \frac{M_c}{Z}$$

Check Welds

• Longitudinal moment, $M_L$ (vessel vertical).

$$M_L = P_L e$$

• Section modulus of weld, $S_w$.

$$S_w = \pi R_n^2$$

• Shear stress in weld due to bending moment, $f_s$.

$$f_s = \frac{M_L}{S_w}$$

• Size of welds required, $w_1$ and $w_2$.

$w_1 >$ thickness of end plate

$w_2 =$ width of combined groove and fillet welds

$$w_2 = \frac{f_s}{F_s} > \frac{3}{8} \text{ in.}$$
### Table 10-13
Dimensions of trunnions

<table>
<thead>
<tr>
<th>Allowable Load, Tons</th>
<th>Pipe Size &quot;A&quot;</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>M</th>
<th>N</th>
<th>T</th>
<th>W</th>
<th>Weight, Lbs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4&quot; Std</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>8.5</td>
<td>8</td>
<td>-</td>
<td>0.5</td>
<td>0.25</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>6&quot; Std</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>10.5</td>
<td>12</td>
<td>-</td>
<td>0.5</td>
<td>0.25</td>
<td>55</td>
</tr>
<tr>
<td>3</td>
<td>8&quot; Std</td>
<td>6</td>
<td>0.625</td>
<td>8</td>
<td>12.5</td>
<td>15</td>
<td>4</td>
<td>0.5</td>
<td>0.375</td>
<td>90</td>
</tr>
<tr>
<td>4</td>
<td>10&quot; Std</td>
<td>6</td>
<td>0.625</td>
<td>8</td>
<td>15</td>
<td>18</td>
<td>4</td>
<td>0.75</td>
<td>0.375</td>
<td>150</td>
</tr>
<tr>
<td>5</td>
<td>12&quot; Sch 80</td>
<td>6</td>
<td>0.75</td>
<td>8</td>
<td>17</td>
<td>21</td>
<td>4</td>
<td>0.75</td>
<td>0.375</td>
<td>240</td>
</tr>
<tr>
<td>6</td>
<td>12&quot; Sch 80</td>
<td>6</td>
<td>0.75</td>
<td>8</td>
<td>17</td>
<td>21</td>
<td>4</td>
<td>0.75</td>
<td>0.5</td>
<td>240</td>
</tr>
<tr>
<td>7</td>
<td>14&quot; Sch 80</td>
<td>6</td>
<td>0.75</td>
<td>8</td>
<td>18</td>
<td>24</td>
<td>8</td>
<td>1</td>
<td>0.5</td>
<td>375</td>
</tr>
<tr>
<td>8</td>
<td>14&quot; Sch 80</td>
<td>7</td>
<td>0.875</td>
<td>8</td>
<td>18</td>
<td>24</td>
<td>8</td>
<td>1</td>
<td>0.625</td>
<td>400</td>
</tr>
<tr>
<td>9</td>
<td>16&quot; Sch 80</td>
<td>7</td>
<td>0.875</td>
<td>8</td>
<td>25</td>
<td>27</td>
<td>8</td>
<td>1</td>
<td>0.625</td>
<td>625</td>
</tr>
<tr>
<td>10</td>
<td>16&quot; Sch 80</td>
<td>7</td>
<td>0.875</td>
<td>8</td>
<td>25</td>
<td>27</td>
<td>8</td>
<td>1.125</td>
<td>0.875</td>
<td>660</td>
</tr>
<tr>
<td>11</td>
<td>18&quot; Sch 80</td>
<td>7</td>
<td>0.875</td>
<td>8</td>
<td>27</td>
<td>30</td>
<td>12</td>
<td>1.125</td>
<td>0.875</td>
<td>850</td>
</tr>
<tr>
<td>12</td>
<td>18&quot; Sch 80</td>
<td>8</td>
<td>0.875</td>
<td>8</td>
<td>27</td>
<td>30</td>
<td>12</td>
<td>1.125</td>
<td>1</td>
<td>875</td>
</tr>
<tr>
<td>13</td>
<td>20&quot; Sch 80</td>
<td>8</td>
<td>0.875</td>
<td>8</td>
<td>30</td>
<td>36</td>
<td>16</td>
<td>1.25</td>
<td>1</td>
<td>1000</td>
</tr>
<tr>
<td>14</td>
<td>24&quot; Sch 80</td>
<td>8</td>
<td>1</td>
<td>10</td>
<td>34</td>
<td>36</td>
<td>16</td>
<td>1.25</td>
<td>1.125</td>
<td>1440</td>
</tr>
<tr>
<td>15</td>
<td>24&quot; Sch 80</td>
<td>8</td>
<td>1</td>
<td>10</td>
<td>34</td>
<td>40</td>
<td>20</td>
<td>1.375</td>
<td>1.125</td>
<td>1675</td>
</tr>
<tr>
<td>16</td>
<td>30&quot; x 1.25&quot;</td>
<td>10</td>
<td>1.25</td>
<td>12</td>
<td>42</td>
<td>48</td>
<td>20</td>
<td>1.375</td>
<td>1.375</td>
<td>2400</td>
</tr>
<tr>
<td>17</td>
<td>36&quot; x 1.25&quot;</td>
<td>10</td>
<td>1.25</td>
<td>12</td>
<td>48</td>
<td>60</td>
<td>24</td>
<td>1.5</td>
<td>1.375</td>
<td>3600</td>
</tr>
</tbody>
</table>

**Notes:**

1. Do not use re-pads for cyclic service
2. $B = D - .125$
3. $K = \text{Pipe Wall Thk}$
4. Dimensions are given for reference only. All loadings and stress shall be checked prior to use.

---

![TYPE 1](image1)

![TYPE 2](image2)
Procedure 10-9: Local Loads in Shell Due to Erection Forces

**Fixed Lug Trunnion**

- Maximum longitudinal moment, $M_X$.
  \[ M_X = P_L e \]
- Maximum circumferential moment, $M_C$.
  \[ M_C = P_T e \]
- Maximum torsional moment, $M_T$.
  \[ M_T = P_T E \]
- Loads for any given lift angle, $\theta$.
  \[ P_L = 0.5P \sin \theta \]
  \[ P_T = 0.5P \cos \theta \]

**Rotating Trunnion**

- Maximum longitudinal moment, $M_X$.
  \[ M_X = P_L e \]
- Maximum circumferential moment, $M_C$.
  \[ M_C = P_T e \]
- Loads for any given lift angle, $\theta$.
  \[ P_L = 0.5P \sin \theta \]
  \[ P_T = 0.5P \cos \theta \]

**Trunnion—No Lug**

- Maximum longitudinal moment, $M_X$.
  \[ M_X = P_L e \]
- Maximum circumferential moment, $M_C$.
  \[ M_C = P_T e \]
- Loads for any given lift angle, $\theta$.
  \[ P_L = 0.5P \sin \theta \]
  \[ P_T = 0.5P \cos \theta \]
Notes:

1. Optional internal pipe. Remove after erection.
2. Radial load, $P_r$, is the axial load in the internal pipe stiffener if used in lieu of radial load in shell.
3. Circumferential ring stiffeners are optional at these elevations.

- **Circumferential moment, $M_c$.**
  \[ M_c = P_T e \]

- **Longitudinal moment, $M_x$.**
  \[ M_x = P_L e \]

- **Load on weld group, $f$.**
  \[ f = \frac{P_T E}{L_T} \]

- **Radial loads, $P_r$ and $P_a$.**
  \[ P_r = P_L e \]
  \[ P_a = P_L \sin \phi \]

- **Loads, $P_T$ and $P_L$.**
  \[ P_T = P \cos \theta \]
  \[ P_L = P \sin \theta \]
• Moment on flange, $M$.
  
  \[ M = P_T B \]

• Moment on head, $M$.
  
  \[ M = P_T (B + J) \]

• Moment on vessel, $M$.
  
  \[ M = P_T G \]

• Radial load on head and nozzle = $P_L$.

Side Flange Lug

• Loads, $P_T$ and $P_L$.
  
  \[ PL = P \cos \theta \]
  \[ PT = P \sin \theta \]

• Moment on flange, $M$.
  
  \[ M = P_T B \]

• Longitudinal moment on shell, $M_x$.
  
  \[ M = P_T (B + J) \]

• Radial load on shell and nozzle = $P_T$. 
Procedure 10-10: Miscellaneous

Figure 10-7. Fundamental handling operations. Reprinted by permission of the Babcock and Wilcox Company, a McDermott Company.
Figure 10-8. Loads on wire rope for various sheave configurations.
Table 10-14
Forged Steel Shackles

<table>
<thead>
<tr>
<th>Size D (in.)</th>
<th>Safe Load (lb)</th>
<th>D (min)</th>
<th>A</th>
<th>Tolerance A Dim.</th>
<th>B</th>
<th>B (min)</th>
<th>C</th>
<th>G</th>
<th>Tolerance C and G Dim.</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>⅛</td>
<td>1,050</td>
<td>11/32</td>
<td>21/32</td>
<td>± 3/32</td>
<td>7/16</td>
<td>29/64</td>
<td>1 7/16</td>
<td>1/16</td>
<td>± 3/32</td>
<td>1/16</td>
<td>1 3/16</td>
</tr>
<tr>
<td>⅛</td>
<td>1,450</td>
<td>29/64</td>
<td>33/64</td>
<td>± 3/32</td>
<td>9/16</td>
<td>29/64</td>
<td>1 15/16</td>
<td>1/16</td>
<td>± 3/32</td>
<td>1/16</td>
<td>1 3/16</td>
</tr>
<tr>
<td>⅛</td>
<td>1,900</td>
<td>29/64</td>
<td>1 3/16</td>
<td>± 3/32</td>
<td>9/16</td>
<td>1 3/16</td>
<td>1/16</td>
<td>± 3/32</td>
<td>1 3/16</td>
<td>1/16</td>
<td>1 3/16</td>
</tr>
<tr>
<td>⅛</td>
<td>2,950</td>
<td>9/16</td>
<td>1 5/16</td>
<td>± 3/32</td>
<td>¼</td>
<td>43/64</td>
<td>2 1/16</td>
<td>2</td>
<td>± 3/32</td>
<td>1/16</td>
<td>1 3/16</td>
</tr>
<tr>
<td>⅛</td>
<td>4,250</td>
<td>43/64</td>
<td>1 3/16</td>
<td>± 3/32</td>
<td>¼</td>
<td>29/64</td>
<td>2 2/16</td>
<td>2</td>
<td>± 3/32</td>
<td>1/16</td>
<td>1 3/16</td>
</tr>
<tr>
<td>1</td>
<td>7,550</td>
<td>67/64</td>
<td>1 1/16</td>
<td>± 3/32</td>
<td>1 3/16</td>
<td>1 3/16</td>
<td>3 3/16</td>
<td>3 3/16</td>
<td>± 3/32</td>
<td>2 3/16</td>
<td>2 3/16</td>
</tr>
<tr>
<td>1 ⅛</td>
<td>8,900</td>
<td>1 1/2</td>
<td>1 3/16</td>
<td>± 3/32</td>
<td>1 1/4</td>
<td>1 3/16</td>
<td>4 3/16</td>
<td>3 3/16</td>
<td>± 3/32</td>
<td>2 3/16</td>
<td>2 3/16</td>
</tr>
<tr>
<td>1 ⅛</td>
<td>11,000</td>
<td>1 1/4</td>
<td>2 1/4</td>
<td>± 3/32</td>
<td>1 3/16</td>
<td>1 3/16</td>
<td>4 3/16</td>
<td>3 3/16</td>
<td>± 3/32</td>
<td>3</td>
<td>3 3/16</td>
</tr>
<tr>
<td>1 ⅛</td>
<td>13,300</td>
<td>1 3/16</td>
<td>2 3/16</td>
<td>± 3/32</td>
<td>1 1/4</td>
<td>1 3/16</td>
<td>5 4/16</td>
<td>3 3/16</td>
<td>± 3/32</td>
<td>3 3/16</td>
<td>3 3/16</td>
</tr>
<tr>
<td>1 ⅛</td>
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<td>1 3/16</td>
<td>2 3/16</td>
<td>± 3/32</td>
<td>1 1/4</td>
<td>1 3/16</td>
<td>5 4/16</td>
<td>4 3/16</td>
<td>± 3/32</td>
<td>3 3/16</td>
<td>3 3/16</td>
</tr>
</tbody>
</table>

Notes:
For shackles with safe loads greater than the maximum shown, use Crosby–Laughlin (The Crosby Group, Div. of American Hoist & Derrick Co, Tulsa, OK 74101), Skookum (Skookum Co., Inc., Portland, OR 97203), or equal with an ultimate strength at least 5 times the safe working load.
Allowable loads are lower than OSHA requirements tabulated in Section 1926.251, Table H-19.
Figure 10-9. Wire rope end configurations.
### Table 10-15
Material transportation and lifting

<table>
<thead>
<tr>
<th>Material-Handling System</th>
<th>Description</th>
<th>Capacity t (t_m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Transport: Flatbed trailers</td>
<td>Bed dimension 8 × 40 ft (2.4 × 12.2 m)—deck height 60 in. (1524 mm) used to transport materials from storage to staging area.</td>
<td>20 (18)</td>
</tr>
<tr>
<td>Extendable trailers</td>
<td>Bed dimension up to 8 × 60 ft (2.4 × 18.3 m)—deck height 60 in. (1524 mm) used to transport materials from storage to staging area.</td>
<td>15 (14)</td>
</tr>
<tr>
<td>Lowboy and dropdeck Crawler</td>
<td>Bed dimension up to 8 × 40 ft (2.4 × 12.2 m)—deck height of 24 in. (610 mm) used to transport materials from storage to staging area.</td>
<td>60 (54)</td>
</tr>
<tr>
<td>Straddle carrier</td>
<td>Specially designed mechanism for handling heavy loads; Lampson crawler transporter, for an example of the Lampson design.</td>
<td>700 (635)</td>
</tr>
<tr>
<td>Rail</td>
<td>Track utilized to transport materials to installed location. Continuous track allows material in-stallation directly from delivery car.</td>
<td>as designed</td>
</tr>
<tr>
<td>Roller and track</td>
<td>Steel machinery rollers located relative to component center of gravity handle the load. Rollers traverse the web of a channel welded to top flange of structural member below.</td>
<td>2000 (1814)</td>
</tr>
<tr>
<td>Plate and slide</td>
<td>Sliding steel plates. Coefficient of friction—0.4 steel on steel, 0.09 greased steel on steel, 0.04 Teflon on steel. Sliding plate transport for movement of 1200 t (1089 t_m) vessel.</td>
<td>as designed</td>
</tr>
<tr>
<td>Air bearings or air pallets</td>
<td>Utilizes film of air between flexible diaphragm and flat horizontal surface. Air flow 3 to 200 ft³/min (0.001 to 0.09 m³/s). 1 lb (4.5 N) lateral force per 1000 lb (454 kg) vertical load.</td>
<td>75 (68)</td>
</tr>
<tr>
<td>High line</td>
<td>Taut cable guideway anchored between two points and fitted with inverted sheave and hook.</td>
<td>5 (4.5)</td>
</tr>
<tr>
<td>Lifting: Chain hoist</td>
<td>Chain operated geared hoist for manual load handling capability. Standard lift heights 8 to 12 ft (2.4 to 3.7 m).</td>
<td>25 (23)</td>
</tr>
<tr>
<td>Hydraulic rough terrain cranes</td>
<td>Telescopic boom mounted on rubber tired self-propelled carrier.</td>
<td>90 (82)</td>
</tr>
<tr>
<td>Hydraulic truck cranes</td>
<td>Telescopic boom mounted on rubber tired independent carrier.</td>
<td>450 (408)</td>
</tr>
<tr>
<td>Lattice boom truck cranes</td>
<td>Lattice boom mounted on rubber tired independent carrier.</td>
<td>800 (726)</td>
</tr>
<tr>
<td>Lattice boom crawler cranes</td>
<td>Lattice boom mounted on self-propelled crawlers.</td>
<td>2200 (1996)</td>
</tr>
<tr>
<td>Fixed position crawler cranes</td>
<td>Lattice boom mounted on self-propelled crawlers and equipped with specifically designed attachments and counterweights.</td>
<td>750 (680)</td>
</tr>
<tr>
<td>Tower gantry cranes</td>
<td>Tower mounted lattice boom gantry for operation above work site.</td>
<td>230 (209)</td>
</tr>
<tr>
<td>Guy derrick</td>
<td>Boom attached to mast supported by wire rope guys. Attached to existing building steel with load lines operated from independent hoist. Swing angle 360 deg (6.28 rad).</td>
<td>600 (544)</td>
</tr>
<tr>
<td>Chicago boom</td>
<td>Boom mounted to existing structure which acts as mast, and to which is attached boom of approximately 100 ft (30.5 m) length. Swing angle is 100 deg (1.75 rad).</td>
<td>function of support structure</td>
</tr>
<tr>
<td>Stiff leg derrick</td>
<td>Boom attached to mast supported by two rigid diagonal legs and horizontal sills. Horizontal angle between each leg and sill combination ranges from 60 to 90 deg (1.05 to 1.57 rad); swing angle from 270 to 300 deg (4.71 to 5.24 rad).</td>
<td>700 (635)</td>
</tr>
<tr>
<td>Monorail</td>
<td>High capacity load blocks suspended from trolleys which traverse monorail beams suspended from boiler support steel. Provides capability to lift and move loads within boiler cavity.</td>
<td>400 (363)</td>
</tr>
<tr>
<td>Jacking systems</td>
<td>Custom designed hydraulic or mechanical system for high capacity special lifts.</td>
<td>as specified</td>
</tr>
</tbody>
</table>

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Notes

1. This procedure is for the design of the vessel and the lifting attachments only. It is not intended to define rigging or crane requirements.
2. Lifting attachments may remain on the vessel after erection unless there is some process- or interference-related issue that would necessitate their removal.
3. Load and impact factors must be used for moving loads. It is recommended that a 25% impact factor and a minimum load factor of 1.5 be used. The combined load and impact factor should be 1.5–2.0.
4. Allowable stress compression should be 0.6Fy for structural attachments and ASME Factor “B” times 1.33 for the vessel shell.
5. Vessel shipping orientation should be established such that a line through the lifting lugs is parallel to grade if possible. This prevents the vessel from having to be “rolled” to the correct orientation for loading and offloading operations.
6. If a spreader beam is not used, the minimum sling angle shall be 30° from the horizontal position. At 30°, the tension in each sling is equal to the total design load. Thus a load factor of 2 is mandatory for these cases. This requires that each lug be designed for the full load.
7. Vessels should never be lifted by a nozzle or other small attachments unless specifically designed to do so.
8. All local loads in vessel shell or head resulting from loadings imposed during erection of the vessel shall be analyzed using a suitable local load procedure.
9. Tailing attachment shall be designed such that they may be unbolted without having to get under the load while it is suspended. As an alternative, the vessel must be set down at grade before a person can get under the base ring to unbolt the tailing beam. Be advised that the base and skirt may not be designed for point support if cribbing is used to build up the base for access.
10. A tailing lug, as opposed to a tailing beam, allows the load to be disconnected from the vessel without a person’s getting under a suspended load to unhook.
11. This procedure assumes that the pin diameter is no less than ¼ in. less than the hole diameter. If the pin diameter is greater than ¼ in. smaller than the hole diameter, then the bearing stresses in the lug at the contact point are increased dramatically due to the stress concentration effect.
12. Internal struts in the skirt or base plate are required only if the base/skirt configuration is overstressed.
13. If bearing or shear stresses are exceeded in the lug, add pad eyes.
14. Trunnions may be used as tailing devices as long as the resulting local loads in the skirt are analyzed.
15. Do not use less than Schedule 40 pipe for trunnions.
16. Specific notes for trunnions:
   a. Type 1, fixed lug: Normal use but generally for small to medium vessels (less than 100 tons).
   b. Type 2, rotating lug: Best use is when multiple vessels are to be lifted with the same lug. The lug may be removed by removing the end plate and sliding the lug off. Then the lug is reinstalled on the next vessel. For heavier loads, an internal sleeve should be attached to the lug to increase the bearing area on the trunnion.
   c. Type 3, trunnion only: No size limitation or weight limitation. The cable and trunnions should be lubricated prior to lifting to prevent the cables from binding. The bend radius of the cables may govern the diameter of the trunnion. Check with erection contractor.