Standard Installations
Indirect Design
**Overfill Soil Category**

- Category I, II, III

- $D_o / 6$ (Min.)
- $D_o$
- $D_o$ (Min.)
- $H$

**Bedding**

- See table

**Foundation**

- $D_o / 3$

**Outer Bedding**

- materials and compaction each side, same requirements as haunch

**Middle Bedding** loosely placed uncompacted bedding except for Type 4

**Haunch**

- See Table

**Lower-Side**

- See Table

**Springline**

- Overfill Soil Category

**Do / 6 (Min.)**

**Do**

**Do (Min.)**
## Standard Installation Soils and Minimum Compaction Requirements

<table>
<thead>
<tr>
<th>Installation Type</th>
<th>Bedding Thickness</th>
<th>Haunch and Outer Bedding</th>
<th>Lower Side</th>
</tr>
</thead>
</table>
| Type 1            | D₀/24 minimum, not less than 3” (75 mm)  
                      If rock foundation, use D₀/12 minimum, not less than 6” (150 mm) | 95% Category I | 90% Category I, 95% Category II, or 100% Category III |
| Type 2            | D₀/24 minimum, not less than 3” (75 mm)  
                      If rock foundation, use D₀/12 minimum, not less than 6” (150 mm) | 90% Category I or 95% Category II | 85% Category I, 90% Category II, or 95% Category III |
| Type 3            | D₀/24 minimum, not less than 3” (75 mm)  
                      If rock foundation, use D₀/12 minimum, not less than 6” (150 mm) | 85% Category I, 90% Category II, or 95% Category III | 85% Category I, 90% Category II, or 95% Category III |
| Type 4            | No bedding required except if rock foundation, use D₀/12 minimum, not less than 6” (150 mm) | No compaction required, except if Category III, use 85% | No compaction required, except if Category III, use 85% |
## Soil Types

<table>
<thead>
<tr>
<th>SIDD</th>
<th>USCS</th>
<th>AASHTO</th>
<th>Standard Proctor</th>
<th>Modified Proctor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravelly Sand</td>
<td>SW, SP,</td>
<td>A1, A3</td>
<td>100</td>
<td>95</td>
</tr>
<tr>
<td>(Category I)</td>
<td>GW, GP</td>
<td></td>
<td>95</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>90</td>
<td>85</td>
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<td>85</td>
<td>80</td>
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<td></td>
<td>80</td>
<td>75</td>
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<td></td>
<td></td>
<td></td>
<td>61</td>
<td>59</td>
</tr>
<tr>
<td>Sandy Silt</td>
<td>GM, SM,</td>
<td>A2, A4</td>
<td>100</td>
<td>95</td>
</tr>
<tr>
<td>(Category II)</td>
<td>ML, Also GC, SC with less than 20% passing #200 sieve</td>
<td></td>
<td>95</td>
<td>90</td>
</tr>
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<td></td>
<td></td>
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<td>75</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>49</td>
<td>46</td>
</tr>
<tr>
<td>Silty Clay</td>
<td>CL, MH, GC, SC</td>
<td>A5, A6</td>
<td>100</td>
<td>90</td>
</tr>
<tr>
<td>(Category III)</td>
<td></td>
<td></td>
<td>95</td>
<td>85</td>
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<tr>
<td></td>
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<td></td>
<td>80</td>
<td>70</td>
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<td></td>
<td></td>
<td></td>
<td>45</td>
<td>40</td>
</tr>
<tr>
<td>CH</td>
<td>A7</td>
<td></td>
<td>100</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>95</td>
<td>85</td>
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<td>80</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>45</td>
<td>40</td>
</tr>
</tbody>
</table>
Delaware Backfill

- 209.04 - “Borrow Type C (Backfill). This material shall have between 85 and 100% inclusive by dry weight, passing a 1” (25 mm) sieve and a maximum of 25% by dry weight, passing a No. 200 (75 μm) sieve.
Delaware Backfill

208.04

“For these areas, (below the roadway or shoulders) backfill material shall be compacted to 95% or more of maximum density according to the requirements of subsection 202.05 (f).”

“For these areas, (locations other than the below the roadway and shoulders) backfill material shall be compacted to 90% or more of the maximum density according to the requirements of subsection 202.05 (f).”
Design and Installation

- Standard Installations
  - Developed by ASCE (15-93)
  - Adopted by AASHTO (Sections 16 & 27)
  - LRFD Section 12 and Section 27 of Construction Standard
SPIDA

Soil Pipe Interaction Design & Analysis
INCREASED PIPE DESIGN

INSTALLATION TYPE

INCREASED MATERIAL QUALITY

INSTALLATION QUALITY

PIPE STRENGTH

1 2 3 4
Figure 12.10.2.1-1—Heger Pressure Distribution and Arching Factors
\[ W_e = \text{prism load} \times \text{VAF} \]

Where:

*VAF = vertical arching factor as per Heger distribution*
<table>
<thead>
<tr>
<th>Installation Type</th>
<th>VAF</th>
<th>HAF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.35</td>
<td>0.45</td>
</tr>
<tr>
<td>2</td>
<td>1.40</td>
<td>0.40</td>
</tr>
<tr>
<td>3</td>
<td>1.40</td>
<td>0.37</td>
</tr>
<tr>
<td>4</td>
<td>1.45</td>
<td>0.30</td>
</tr>
</tbody>
</table>
Vertical Pressures
Soil Load

- \[ W_E = F_e \gamma_s B_c H \]
  - Pipe – Section 12.10.2.1-1
Table 12.10.2.1-3 Coefficients for use with Figure 1.

<table>
<thead>
<tr>
<th>Installation Type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{AF}$</td>
<td>1.35</td>
<td>1.40</td>
<td>1.40</td>
<td>1.45</td>
</tr>
<tr>
<td>$H_{AF}$</td>
<td>0.45</td>
<td>0.40</td>
<td>0.37</td>
<td>0.30</td>
</tr>
<tr>
<td>$A_{1}$</td>
<td>0.62</td>
<td>0.85</td>
<td>1.05</td>
<td>1.45</td>
</tr>
<tr>
<td>$A_{2}$</td>
<td>0.73</td>
<td>0.55</td>
<td>0.35</td>
<td>0.00</td>
</tr>
<tr>
<td>$A_{3}$</td>
<td>1.35</td>
<td>1.40</td>
<td>1.40</td>
<td>1.45</td>
</tr>
<tr>
<td>$A_{4}$</td>
<td>0.19</td>
<td>0.15</td>
<td>0.10</td>
<td>0.00</td>
</tr>
<tr>
<td>$A_{5}$</td>
<td>0.08</td>
<td>0.08</td>
<td>0.10</td>
<td>0.11</td>
</tr>
<tr>
<td>$A_{6}$</td>
<td>0.18</td>
<td>0.17</td>
<td>0.17</td>
<td>0.19</td>
</tr>
<tr>
<td>$a$</td>
<td>1.40</td>
<td>1.45</td>
<td>1.45</td>
<td>1.45</td>
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<tr>
<td>$b$</td>
<td>0.40</td>
<td>0.40</td>
<td>0.36</td>
<td>0.30</td>
</tr>
<tr>
<td>$c$</td>
<td>0.18</td>
<td>0.19</td>
<td>0.20</td>
<td>0.25</td>
</tr>
<tr>
<td>$e$</td>
<td>0.08</td>
<td>0.10</td>
<td>0.12</td>
<td>0.00</td>
</tr>
<tr>
<td>$f$</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>—</td>
</tr>
<tr>
<td>$u$</td>
<td>0.80</td>
<td>0.82</td>
<td>0.85</td>
<td>0.90</td>
</tr>
<tr>
<td>$v$</td>
<td>0.80</td>
<td>0.70</td>
<td>0.60</td>
<td>—</td>
</tr>
</tbody>
</table>
Basic Forms of Installation

GROUND SURFACE

H

Trench

D_o

B_d

TOP OF EMBANKMENT

H

pB_C

D_o

Positive Projecting Embankment
Vertical Pressures

TRENCH
Soil-Structure Interaction Factor Pipe

“Standard installations for both embankments and trenches shall be designed for positive projection, embankment loading conditions where $F_e$ shall be taken as the vertical arching factor, VAF, specified in Table 12.10.2.1-3 for each type of standard installation.”
Concrete Pipe Indirect Design – 12.10.4.3
D-Load Equation

\[ D = \left( \frac{12}{S_i} \right) \left( \frac{W_E + W_F}{B_{FE}} + \frac{W_L}{B_{FLL}} \right) \]  

(12.10.4.3.1-1)

where:

- \( B_{FE} \) = earth load bedding factor specified in Article 12.10.4.3.2a or Article 12.10.4.3.2b
- \( B_{FLL} \) = live load bedding factor specified in Article 12.10.4.3.2c
- \( S_i \) = internal diameter of pipe (in.)
- \( W_E \) = total unfactored earth load specified in Article 12.10.2.1 (kip/ft)
- \( W_F \) = total unfactored fluid load in the pipe as specified in Article 12.10.2.2 (kip/ft)
- \( W_L \) = total unfactored live load on unit length pipe specified in Article 12.10.2.3 (kip/ft)
Bedding Factors
Di Bedding

See table

Do / 3

Foundation

Outer Bedding materials and compaction each side, same requirements as haunch

Middle Bedding loosely placed uncompacted bedding except for Type 4

Do / 6 (Min.)

H

Overfill Soil Category I, II, III

Do

D₀ (Min.)

Haunch- See Table

Lower-Side See Table

Springline

Bedding See table

Dᵢ

D₀ / 3

D₀
\[ M = 0.170 \ W_e \ r \]
\[ M = 0.318 \ P \ r \]
\[ \frac{W_e}{P} = 1.9 = B_f \]
D-Load

Supporting strength of a pipe loaded under three-edge bearing test conditions, expressed in pounds per linear foot per foot of inside diameter or horizontal span.

ASTM C-76  Class IV

$D_{0.01} = 2000$

$D_{ULT} = 3000$
Basic Bedding Factor Relationship

\[ B_f = \frac{M_{\text{TEST}}}{M_{\text{FIELD}}} \]  \hspace{1cm} (4.18)

where:
- \( B_f \) = bedding factor
- \( M_{\text{TEST}} \) = maximum moment in pipe wall under three-edge bearing test load, inch-pounds
- \( M_{\text{FIELD}} \) = maximum moment in pipe wall under field loads, inch-pounds
Bedding Factors

\[ B_f = ? \]
## Embankment Earth Load Bedding Factor

**Table 12.10.4.3.2a-1 Bedding Factors for Circular Pipe.**

<table>
<thead>
<tr>
<th>Pipe Diameter, in.</th>
<th>Standard Installations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type 1</td>
</tr>
<tr>
<td>12</td>
<td>4.4</td>
</tr>
<tr>
<td>24</td>
<td>4.2</td>
</tr>
<tr>
<td>36</td>
<td>4.0</td>
</tr>
<tr>
<td>72</td>
<td>3.8</td>
</tr>
<tr>
<td>144</td>
<td>3.6</td>
</tr>
</tbody>
</table>
Extra Safety Factor for Type 1 Installations

C12.5.5

The standard installations for direct design of concrete pipe were developed based on extensive parameter studies using the soil structure interaction program, SPIDA. Although past research validates that SPIDA soil structure models correlate well with field measurements, variability in culvert installation methods and materials suggests that the design for Type I installations be modified. This revision reduces soil structure interaction for Type I installations by ten percent until additional performance documentation on installation in the field is obtained.
Standard Installations D-load

\[ D = \left( \frac{12}{S_i} \right) \left( \frac{W_E + W_F}{B_{FE}} + \frac{W_L}{B_{FLL}} \right) \]  

(12.10.4.3.1-1)
### Table 3: Design Requirements for Class III Reinforced Concrete Pipe

*Note 1—See Section 5 for basis of acceptance specified by the owner.*

The strength test requirements in pounds-force per linear foot of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in pounds-force per linear foot per foot of diameter) to produce a 0.01-in. crack, or the D-loads to produce the 0.01-in. crack and the ultimate load as specified below, multiplied by the internal diameter of the pipe in feet.

<table>
<thead>
<tr>
<th>Internal Designated Diameter, in.</th>
<th>Wall Thicknesses, in.</th>
<th>Circular Reinforcement</th>
<th>Elliptical Reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Inner Cage</td>
<td>Outer Cage</td>
</tr>
<tr>
<td></td>
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</tr>
</tbody>
</table>
Recommended Design Specifications for Live Load Distribution to Buried Structures
Where are We Measuring From?
(C12.6.6.3)

Minimum Cover Orientation

\[ H_{\text{min}} = \text{minimum allowable cover dimension} \]

Note: The minimum cover dimension is not to be confused with the fill height used for calculation purposes, which shall be from the top of the pipe to the top of the surface, regardless of the pipe type or pavement type.
3.6.1.2.6a—General

For single-span culverts, the effects of live load may be neglected where the depth of fill is more than 8.0 ft. and exceeds the span length; for multiple span culverts, the effects may be neglected where the depth of fill exceeds the distance between inside faces of end walls.

Live load shall be distributed to the top slabs of flat top three-sided, or long-span concrete arch culverts, or concrete pipe with less than 2.0 ft of fill as specified in Article 4.6.2.10. Round concrete culverts with 1.0 ft or more but less than 2.0 ft of cover shall be designed for a depth of 1.0 ft. Round culverts with less than 1.0 ft of fill shall be analyzed with more comprehensive methods.

\[ E = 96 + 1.44S \quad (4.6.2.10.2-1) \]

E = Distribution width perpendicular to span in inches
S = Clear Span in feet
Less Than 2 Feet of Cover

\[ E_{\text{span}} = \text{Distribution width parallel to span in inches} \]

\[ E_{\text{span}} = L_T + LLDF(H) \]

\[ L_T = \text{length of contact area parallel to span (in)} \]
\[ LLDF = \text{live load distribution factor} \]
\[ H = \text{depth of fill} \]
Live Load Spread for Less Than 2 feet of Cover (single and (Perpendicular)
For Trucks Traveling Parallel to the Axis of the Pipe

\[ E = 96 + 1.44S \]  \hfill (4.6.2.10.2-1)

\( E = \) Distribution width perpendicular to span in inches
\( S = \) Clear Span in feet

Note: Equation 4.6.2.10.2-1 is for an axle load. with pipe, having much smaller spans than boxes a distribution for wheel loads is more appropriate.

\( E_{\text{wheel}} = 48 + 0.72S \)
Live Load Spread for Less Than 2 feet of Cover (Parallel)
Live Load Spread for Less Than 2 feet of Cover (single axle) (Perpendicular)

\[ E_{\text{span}} = l_t + \text{LLDF}(H) \]

(4.6.2.10.2-2)
Live Load Spread for Less Than 2 feet of Cover (single axle, Perpendicular)

\[ A_{LL} = l_w \cdot w_w \quad (3.6.1.2.6a-1) \]

\[ A_{LL} = E_{span} \cdot E \]

- \( A_{LL} = \) rectangular area at depth \( H \) (\( ft^2 \))
- \( l_w = \) live load patch length at depth \( H \) (\( ft \))
- \( w_w = \) live load patch width at depth \( h \) (\( ft \))
Where the depth of fill over round, nonconcrete culverts is greater than 1.0 ft, or when the depth of fill over flat top three-sided, or long-span concrete arch culverts, or concrete pipe is 2.0 ft or greater the live load shall be distributed to the structure as wheel loads, uniformly distributed over a rectangular area with sides equal to the dimension of the tire contact area specified in Article 3.6.1.2.5 increased by the live load distribution factors (LLDF) specified in Table 3.6.1.2.6a-1, and the provisions of Articles 3.6.1.2.6b and 3.6.1.2.6c. More precise methods of analysis may be used.
## Live Load Distribution Factors

### Table 3.6.1.2.6a-1—Live Load Distribution Factor (LLDF) for Buried Structures

<table>
<thead>
<tr>
<th>Structure Type</th>
<th>LLDF Transverse or Parallel to Span</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Pipe with fill depth 2 ft or greater</td>
<td>1.15 for diameter 2 ft or less</td>
</tr>
<tr>
<td></td>
<td>1.75 for diameters 8 ft or greater</td>
</tr>
<tr>
<td></td>
<td>Linearly interpolate for LLDF between these limits</td>
</tr>
<tr>
<td>All other culverts and buried structures</td>
<td>1.15</td>
</tr>
</tbody>
</table>
Traffic Perpendicular to Span

Figure S-1. Live load variation with depth for concrete box culverts (SDE refers to the proposed simplified design equations).
Figure 3.6.1.2.2-1—Characteristics of the Design Truck
Wheel and Axle Spacing

- \( s_w = \) wheel spacing, 6.0 ft.
- \( s_a = \) axle spacing (ft)
Interaction Depth for Tandem Axles (Perpendicular)

Plan View

Elevation View

$H_{\text{intd}}$

$l_{\text{ws}}$ when $H < H_{\text{intd}}$

$l_{\text{ws}}$ when $H > H_{\text{intd}}$

$s_a$

$l_{\text{wt}}$

$l_{\text{ws}}$

$PR_{\text{dist}} < 0$
Interaction Depth for Wheels *(Perpendicular)*

- **Sw**
- **W_{ws} for a single wheel**
- **W_{ws} for two wheels**

**Plan View**

- **Sw**

**Elevation View**

- **W_{ws} if H < H_{intw}**
- **W_{ws} if H > H_{intw}**
- **H_{intw}**
Interaction Depth

3.6.1.2.6b—Traffic Parallel to the Culvert Span

For live load distribution transverse to culvert spans, the wheel/axle load interaction depth $H_{int}$ shall be determined as:

$$H_{int} = \frac{s_w - \frac{w_t}{12} - 0.06D_i}{LLDF}$$

(3.6.1.2.6b-1)

$s_w = \text{wheel spacing, 6.0 ft}$

$w_t = \text{tire patch width, 20 in.}$

$D_i = \text{inside diameter or clear span of the culvert (in)}$
Interaction Depth – Distribution Transverse to Culvert Span

Where $H < H_{\text{int-t}}$

$$W_w = \frac{w_t}{12} + \text{LLDF}(H) + 0.06(D_i/12) \quad (3.6.1.2.6b-2)$$

Where $H \geq H_{\text{int-t}}$

$$W_w = \frac{w_t}{12} + s_w + \text{LLDF}(H) + 0.06(D_i/12) \quad (3.6.1.2.6b-3)$$
“For live load distribution parallel to culvert span, the wheel/axle load interaction depth $H_{int-p}$ shall be determined as:”

$$H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$$

(3.6.1.2.6b-4)

$s_a = \text{axle spacing (ft)}$

$l_t = \text{tire patch length, 10 (in)}$

$LLDF = \text{live load distribution factor}$
**Interaction Depth – Distribution Parallel to Culvert Span**

Where $H < H_{int-p}$

$$l_w = 1_t/12 + LLDF(H)$$  \hspace{1cm} (3.6.1.2.6b-5)

Where $H \geq H_{int-p}$

$$l_w = 1_t/12 + s_a + LLDF(H)$$  \hspace{1cm} (3.6.1.2.6b-6)
Pressure Area at the Top of the Pipe

\[ A_{LL} = l_w \cdot w_w \]  \hspace{1cm} (3.6.1.2.6a-1)
Pressure at the Top of the Pipe

\[ P_L = \frac{P \left(1 + \frac{IM}{100}\right)^m}{A_{LL}} \]

(3.6.1.2.6b-7)

\( P_L \) = live load vertical crown pressure (ksf)
\( P \) = live load applied at surface on all interacting wheels (kips)
\( IM \) = dynamic load allowance as specified in Article 3.6.2.2
\( m \) = multiple presence factor specified in Article 3.6.1.1.2
Dynamic Load Allowance

- LRFD – Dynamic Load Allowance (3.6.2.2)
  - $DLA = 0.33(1.0 - 0.125D_E)$
    - $D_E =$ Depth of cover (ft)
## Multiple Presence Factor

<table>
<thead>
<tr>
<th>Lanes</th>
<th>AASHTO STD</th>
<th>AASHTO LRFD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td>2</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>3</td>
<td>0.90</td>
<td>0.85</td>
</tr>
<tr>
<td>4</td>
<td>0.75</td>
<td>0.65</td>
</tr>
</tbody>
</table>

- **Design Code**: Lanes AASHTO STD & LRFD
For Concrete Pipe, Load must be in Terms of lbs/ft

\[ W_L = P_L \times L = \text{live load (lbs/ft)} \]

\[ L = \text{Smaller of } l_w \text{ or } D_o \]
D-Load Equation

\[ D = \left( \frac{12}{S_i} \right) \left( \frac{W_E + W_F}{B_{FE}} + \frac{W_L}{B_{FLL}} \right) \]  

(12.10.4.3.1-1)

\[ B_{FLL} = \text{Live Load Bedding Factor} \]
### Table 12.10.4.3.2c-1

<table>
<thead>
<tr>
<th>Pipe Diameter, in</th>
<th>Fill Height, ft</th>
<th>&lt; 2 ft</th>
<th>≥ 2 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>3.2</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>3.2</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>3.2</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>30 and larger</td>
<td>2.2</td>
<td>2.2</td>
<td></td>
</tr>
</tbody>
</table>
EXAMPLE 1

- Embankment Condition
  - Pipe Size = 36” I.D., 44” = 3.67 ft. - \( D_0 \)
  - Fill Height = \( H = 5 \) ft.
  - Soil Unit Weight = \( w = 120 \text{ lbs/ft}^3 \)
  - Check Type 2 and Type 3 Installations
1. Determine Earth Load
2. Determine Live Load
3. Select Bedding
4. Determine Bedding Factor
5. Application of Factor of Safety
6. Selection of Pipe Strength
Determine Earth Load

- Soil Prism Load:
  - \( PL = w H D_o \)
  - \( PL = (120 \text{ lbs/ft}^3)(5 \text{ ft.})(3.67 \text{ ft.}) \)
  - \( PL = 2202 \text{ lbs/ft} \)

- \( W = VAF \times PL \) (AASHTO Equation 12.10.2.1-1)
  - Type 2
    - \( W = (1.40)(2202 \text{ lbs/ft}) \)
    - \( W = 3083 \text{ lbs/ft} \)
  - Type 3
    - \( W = (1.40)(2202 \text{ lbs/ft}) \)
    - \( W = 3083 \text{ lbs/ft} \)
The unfactored earth load, $W_E$, shall be determined as:

$$W_E = F_e w B_c H$$  \hspace{1cm} \text{(12.10.2.1-1)}

where:

- $W_E = \text{unfactored earth load (kip/ft)}$
- $F_e = \text{soil-structure interaction factor for the specified installation as defined herein}$
- $B_c = \text{out-to-out horizontal dimension of pipe (ft)}$
- $H = \text{height of fill over pipe (ft)}$
- $w = \text{unit weight of soil (pcf)}$
Table 12.10.2.1-3 Coefficients for use with Figure 1.

<table>
<thead>
<tr>
<th>Installation Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>( V_{AF} )</td>
</tr>
<tr>
<td>( H_{AF} )</td>
</tr>
<tr>
<td>( A1 )</td>
</tr>
<tr>
<td>( A2 )</td>
</tr>
<tr>
<td>( A3 )</td>
</tr>
<tr>
<td>( A4 )</td>
</tr>
<tr>
<td>( A5 )</td>
</tr>
<tr>
<td>( A6 )</td>
</tr>
<tr>
<td>( a )</td>
</tr>
<tr>
<td>( b )</td>
</tr>
<tr>
<td>( c )</td>
</tr>
<tr>
<td>( e )</td>
</tr>
<tr>
<td>( f )</td>
</tr>
<tr>
<td>( u )</td>
</tr>
<tr>
<td>( v )</td>
</tr>
</tbody>
</table>
Determine Fluid load

- $\gamma_w = 62.4$ pcf
- ID = 3 ft
- $W_f = \gamma_w \times \pi \times (\text{ID}/2)^2$
- $W_f = 441$ lbs/ft
3.6.1.2.6a

“For single-span culverts, the effects of live load may be neglected where the depth of fill is more than 8.0 ft. and exceeds the span length;”
3.6.1.2.6b—Traffic Parallel to the Culvert Span

For live load distribution transverse to culvert spans, the wheel/axle load interaction depth $H_{int-t}$ shall be determined as:

$$H_{int-t} = \frac{s_v - \frac{w_c}{12} - \frac{0.06D_c}{12}}{LLDF}$$

(3.6.1.2.6b-1)
## Live Load Distribution Factor

### Table 3.6.1.2.6a-1—Live Load Distribution Factor (LLDF) for Buried Structures

<table>
<thead>
<tr>
<th>Structure Type</th>
<th>LLDF Transverse or Parallel to Span</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Pipe with fill depth 2 ft or greater</td>
<td>1.15 for diameter 2 ft or less</td>
</tr>
<tr>
<td></td>
<td>1.75 for diameters 8 ft or greater</td>
</tr>
<tr>
<td></td>
<td>Linearly interpolate for LLDF between these limits</td>
</tr>
<tr>
<td>All other culverts and buried structures</td>
<td>1.15</td>
</tr>
</tbody>
</table>

\[
LLDF = 1.15 + \frac{(3 \text{ ft} - 2 \text{ ft})}{(8 \text{ ft} - 2 \text{ ft})} (1.75 - 1.15)
\]

\[
LLDF = 1.25
\]
3.6.1.2.6b—Traffic Parallel to the Culvert Span

For live load distribution transverse to culvert spans, the wheel/axle load interaction depth $H_{int-t}$ shall be determined as:

$$H_{int-t} = \frac{s_w - \frac{w_t - 0.06D_t}{12}}{12}$$

(3.6.1.2.6b-1)

$$H_{int-t} = 6 \text{ ft.} - \frac{(20''/12) - (0.06 \times 36'')/12}{1.25}$$

$$H_{int-t} = 3.32 \text{ ft}$$
Interaction Depth for Wheels (Perpendicular)

Plan View

Elevation View

W_{ws} for a single wheel

W_{ws} for two wheels

W_{ws} if H < H_{intw}

W_{ws} if H > H_{intw}

H_{intw}
"For live load distribution parallel to culvert span, the wheel/axle load Interaction depth $H_{\text{int-p}}$ shall be determined as:

$$H_{\text{int-p}} = \frac{s_a - \frac{1_t}{12}}{\text{LLDF}}$$

(3.6.1.2.6b-4)

$$H_{\text{int-p}} = \frac{4 \text{ ft} - (10''/12)}{1.25}$$

$$H_{\text{int-p}} = 2.53 \text{ ft}$$
Interaction Depth for Tandem Axles (Perpendicular)

Plan View

Elevation View

\[ PR_{\text{dist}} \leq 0 \]

- \( S_a \)
- \( l_{wt} \)
- \( l_{ws} \)

- \( H_{\text{intd}} \)
- \( l_{ws} \text{ when } H < H_{\text{intd}} \)
- \( l_{ws} \text{ when } H > H_{\text{intd}} \)
Pressure at top of Pipe

For The Single Axle (HS20)

Where $H \geq H_{\text{int-t}}$

$$W_w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06\left(\frac{D_i}{12}\right) \quad (3.6.1.2.6b-3)$$

$$W_w = \frac{20”}{12} + 6 \text{ ft} + 1.25*5 \text{ ft} + 0.06*3 \text{ ft}$$

$$W_w = 14.1 \text{ ft}$$

Where $H < H_{\text{int-p}}$

$$l_w = \frac{l_t}{12} + LLDF(H) \quad (3.6.1.2.6b-5)$$

$$l_w = \frac{10”}{12} + 1.25*5 \text{ ft.}$$

$$l_w = 7.1 \text{ ft}$$

$$A_{LL} = 14.1 \text{ ft} \times 7.1 \text{ ft} = 100 \text{ ft}^2$$
Pressure at top of Pipe

For The Tandem Axles

Where $H \geq H_{\text{int-t}}$

$$W_w = \frac{w_t}{12} + s_w + \text{LLDF}(H) + 0.06(D_i/12) \quad (3.6.1.2.6b-3)$$

$$W_w = \frac{20”}{12} + 6\text{ ft} + 1.25*5\text{ ft} + 0.06*3\text{ ft}$$

$$W_w = 14.1\text{ ft}$$

Where $H > H_{\text{int-p}}$

$$l_w = \frac{l_t}{12} + s_a + \text{LLDF}(H) \quad (3.6.1.2.6b-5)$$

$$l_w = \frac{10”}{12} + 4\text{ ft} + 1.25*5\text{ ft.}$$

$$l_w = 11.1\text{ ft}$$

$$A_{LL} = 14.1\text{ ft} \times 11.1\text{ ft} = 156.5\text{ ft}^2$$
\[ P_L = \frac{P \left(1 + \frac{IM}{100}\right)}{A_{LL}} \]  

\((3.6.1.2.6b-7)\)

**Load \( P \)**

For the single axle – \( P = 16 \text{ kips} \times 2 \text{ wheel loads} \)

\( P = 32 \text{ kips} \)

For the tandem axle – \( P = 12.5 \text{ kips} \times 4 \text{ wheel loads} \)

\( P = 50 \text{ kips} \)
Pressure at top of Pipe

\[
P_L = \frac{P \left(1 + \frac{IM}{100}\right)^m}{A_{LL}}
\]

(3.6.1.2.6b-7)

\[
IM = 33 \times [1 - 0.125 \times (H)]
\]

\[
IM = 33 \times [1 - 0.125 \times (5)]
\]

IM = 12.375

m = 1.2 for a single lane
Pressure at top of Pipe

\[ P_L = \frac{P \left(1 + \frac{IM}{100}\right)}{A_{LL}} \quad \text{(3.6.1.2.6b-7)} \]

\[ P_{Ls} = \frac{32000 \text{ lbs} \left(1 + \frac{12.375}{100}\right)}{100 \text{ ft}^2} \quad \text{(1.2)} \]

\[ P_{Lt} = \frac{50000 \text{ lbs} \left(1 + \frac{12.375}{100}\right)}{156.5 \text{ ft}^2} \quad \text{(1.2)} \]

\[ = 431.5 \text{ psf} \]

\[ = 430.8 \text{ psf} \]
Live Load on the Pipe

- Outside Diameter = 3.67 lbs/ft
- Spread length for Single Axle
  \[ l_w = 7.1 \text{ ft} \]
- Spread length for Tandem Axles
  \[ l_w = 11.1 \text{ ft} \]
- Live load = O.D. \times P_L
  \[ W_L = 3.67 \text{ ft} \times 431.5 \text{ psf} = 1583.6 \text{ lbs/ft} \]
For Concrete Pipe, Load must be in Terms of lbs/ft

\[ W_L = P_L \times L = \text{live load (lbs/ft)} \]

\[ L = \text{Smaller of } l_w \text{ or } D_o \]
Recap of Loads

- **Type 2**
  - $W_E = 3083$ lbs/ft
  - $W_F = 441$ lbs/ft
  - $W_L = 1583.6$ lbs/ft

- **Type 3**
  - $W_E = 3083$ lbs/ft
  - $W_F = 441$ lbs/ft
  - $W_L = 1583.6$ lbs/ft
We will compare Type 2 and Type 3 installations.
Standard Installations D-load

\[ D = \left( \frac{12}{S_i} \right) \left( \frac{W_E + W_F}{B_{FE}} \frac{W_L}{B_{FLL}} \right) \]  

(12.10.4.3.1-1)
## Embankment Bedding Factors

Table 12.10.4.3.2a-1 Bedding Factors for Circular Pipe.

<table>
<thead>
<tr>
<th>Pipe Diameter, in.</th>
<th>Standard Installations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type 1</td>
</tr>
<tr>
<td>12</td>
<td>4.4</td>
</tr>
<tr>
<td>24</td>
<td>4.2</td>
</tr>
<tr>
<td>36</td>
<td>4.0</td>
</tr>
<tr>
<td>72</td>
<td>3.8</td>
</tr>
<tr>
<td>144</td>
<td>3.6</td>
</tr>
</tbody>
</table>
Earth Load Bedding Factor

- Earth Load Bedding Factors for Embankment Condition (Table 12.10.4.3.2a-1)
  - Type 2, $B_{FE} = 2.9$
  - Type 3, $B_{FE} = 2.3$
## Table 12.10.4.3.2c-1

<table>
<thead>
<tr>
<th>Pipe Diameter, in</th>
<th>Fill Height, ft</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 2 ft</td>
<td>≥ 2 ft</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>3.2</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>3.2</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>3.2</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>30 and larger</td>
<td>2.2</td>
<td>2.2</td>
<td></td>
</tr>
</tbody>
</table>

Type 2, \(B_{FLL} = 2.2\)

Type 3, \(B_{FLL} = 2.2\)
Find D-load

\[
D = \left( \frac{12}{S_i} \right) \left( \frac{W_E + W_F}{B_{FE}} + \frac{W_L}{B_{FLL}} \right)
\]

(12.10.4.3.1-1)
Application of Factor of Safety

- Design is based on 0.01 inch crack, so use a factor of safety of 1.0.
SELECTION OF PIPE STRENGTH FOR A TYPE 2 INSTALLATION

\[ D_{0.01} = \left[ \frac{3,083 \text{ lbs/ft}}{2.9} + \frac{441 \text{ lbs/ft}}{2.2} \right] x \frac{1.0}{3 \text{ ft}} + 2.2 \]

\[ D_{0.01} = 645 \text{ lbs/linear ft/ft of diameter} \]
SELECTION OF PIPE STRENGTH FOR A TYPE 3 INSTALLATION

\[ D_{0.01} = \left( \frac{3,083 \text{ lbs/ft} + 441 \text{ lbs/ft}}{2.3} \right) + \frac{1584 \text{ lbs/ft}}{2.2} \times \frac{1.0}{3 \text{ ft}} \]

\[ D_{0.01} = 751 \text{ lbs/linear ft/ft of diameter} \]
Class I - $D_{0.01} = 800$ lbs/ft/ft
Class II - $D_{0.01} = 1000$ lbs/ft/ft
Class III - $D_{0.01} = 1350$ lbs/ft/ft
Class IV - $D_{0.01} = 2000$ lbs/ft/ft
Class V - $D_{0.01} = 3000$ lbs/ft/ft
Elliptical Pipe Design
Elliptical Pipe Installations

HORIZONTAL ELLIPTICAL PIPE

Overfill - SW, ML, or CL

H

BC (Min.)

BC

BC (Min.)

Haunch - See Table 27.5.2.2-1

Lower Side - See Table 27.5.2.2-1

Spring Line

Bedding - See Table 27.5.2.2-1

Outer Bedding material and compaction each side. Same requirements as haunch

BC

Middle Bedding loosely placed uncompacted bedding except for Type 4

BC

BC

BC

BC

BC

BC

BC

BC

BC

BC

BC
## Elliptical Pipe Installations

<table>
<thead>
<tr>
<th>Installation Type</th>
<th>Bedding Thickness</th>
<th>Haunch and Outer Bedding</th>
<th>Lower Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>For soil foundation, $B_c/24.0$ in. minimum, not less than 3.0 in. For rock foundation, use $B_c/12.0$ in. minimum, not less than 6.0 in.</td>
<td>95% SW</td>
<td>90% SW, 95% ML or 100% CL</td>
</tr>
<tr>
<td>Type 2—Installations are available for horizontal elliptical, vertical elliptical and arch pipe</td>
<td>For soil foundation, $B_c/24.0$ in. minimum, not less than 3.0 in. For rock foundation, use $B_c/12.0$ in. minimum, not less than 6.0 in.</td>
<td>90% SW or 95% ML</td>
<td>85% SW, 90% ML or 95% CL</td>
</tr>
<tr>
<td>Type 3—Installations are available for horizontal elliptical, vertical elliptical and arch pipe</td>
<td>For soil foundation, $B_c/24.0$ in. minimum, not less than 3.0 in. For rock foundation, use $B_c/12.0$ in. minimum, not less than 6.0 in.</td>
<td>85% SW, 90% ML or 95% CL</td>
<td>85% SW, 90% ML or 95% CL</td>
</tr>
<tr>
<td>Type 4</td>
<td>For soil foundation, no bedding required. For rock foundation, use $B_c/12.0$ in. minimum, not less than 6.0 in.</td>
<td>No compaction required, except if CL, use 85% CL</td>
<td>No compaction required, except if CL, use 85% CL</td>
</tr>
</tbody>
</table>

Table 27.5.2.2-1 Standard Embankment Installation Soils and Minimum Compaction Requirements.
Find D-load

\[ D = \left( \frac{12}{S_i} \right) \left( \frac{W_E + W_F}{B_{FE}} + \frac{W_L}{B_{FLL}} \right) \]  

(12.10.4.3.1-1)
Soil Load

- $W_E = F_e \gamma_s B_c H$
  - Pipe – Section 12.10.2.1-1
### Table 12.10.2.1-3 Coefficients for use with Figure 1.

<table>
<thead>
<tr>
<th>Installation Type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAF</td>
<td>1.35</td>
<td>1.40</td>
<td>1.40</td>
<td>1.45</td>
</tr>
<tr>
<td>HAF</td>
<td>0.45</td>
<td>0.40</td>
<td>0.37</td>
<td>0.30</td>
</tr>
<tr>
<td>A1</td>
<td>0.62</td>
<td>0.85</td>
<td>1.05</td>
<td>1.45</td>
</tr>
<tr>
<td>A2</td>
<td>0.73</td>
<td>0.55</td>
<td>0.35</td>
<td>0.00</td>
</tr>
<tr>
<td>A3</td>
<td>1.35</td>
<td>1.40</td>
<td>1.40</td>
<td>1.45</td>
</tr>
<tr>
<td>A4</td>
<td>0.19</td>
<td>0.15</td>
<td>0.10</td>
<td>0.00</td>
</tr>
<tr>
<td>A5</td>
<td>0.08</td>
<td>0.08</td>
<td>0.10</td>
<td>0.11</td>
</tr>
<tr>
<td>A6</td>
<td>0.18</td>
<td>0.17</td>
<td>0.17</td>
<td>0.19</td>
</tr>
<tr>
<td>a</td>
<td>1.40</td>
<td>1.45</td>
<td>1.45</td>
<td>1.45</td>
</tr>
<tr>
<td>b</td>
<td>0.40</td>
<td>0.40</td>
<td>0.36</td>
<td>0.30</td>
</tr>
<tr>
<td>c</td>
<td>0.18</td>
<td>0.19</td>
<td>0.20</td>
<td>0.25</td>
</tr>
<tr>
<td>e</td>
<td>0.08</td>
<td>0.10</td>
<td>0.12</td>
<td>0.00</td>
</tr>
<tr>
<td>f</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>—</td>
</tr>
<tr>
<td>u</td>
<td>0.80</td>
<td>0.82</td>
<td>0.85</td>
<td>0.90</td>
</tr>
<tr>
<td>v</td>
<td>0.80</td>
<td>0.70</td>
<td>0.60</td>
<td>—</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>18</td>
<td>1.83</td>
<td>14½</td>
<td>22½</td>
<td>5½</td>
</tr>
<tr>
<td>24</td>
<td>3.28</td>
<td>19½</td>
<td>30½</td>
<td>6½</td>
</tr>
<tr>
<td>27</td>
<td>4.12</td>
<td>21½</td>
<td>34</td>
<td>7½</td>
</tr>
<tr>
<td>30</td>
<td>5.10</td>
<td>24</td>
<td>37½</td>
<td>8½</td>
</tr>
<tr>
<td>33</td>
<td>6.33</td>
<td>26½</td>
<td>42</td>
<td>9½</td>
</tr>
<tr>
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<td>7.36</td>
<td>28½</td>
<td>45½</td>
<td>10½</td>
</tr>
<tr>
<td>39</td>
<td>8.78</td>
<td>31½</td>
<td>49½</td>
<td>11½</td>
</tr>
<tr>
<td>42</td>
<td>10.2</td>
<td>34</td>
<td>53½</td>
<td>12½</td>
</tr>
<tr>
<td>48</td>
<td>12.9</td>
<td>38½</td>
<td>60</td>
<td>13½</td>
</tr>
<tr>
<td>54</td>
<td>16.7</td>
<td>43½</td>
<td>68</td>
<td>15½</td>
</tr>
<tr>
<td>60</td>
<td>20.5</td>
<td>48½</td>
<td>75½</td>
<td>17</td>
</tr>
<tr>
<td>66</td>
<td>24.8</td>
<td>53</td>
<td>83</td>
<td>18½</td>
</tr>
<tr>
<td>72</td>
<td>29.4</td>
<td>57½</td>
<td>90½</td>
<td>20½</td>
</tr>
<tr>
<td>78</td>
<td>34.6</td>
<td>62½</td>
<td>98</td>
<td>22</td>
</tr>
<tr>
<td>84</td>
<td>40.1</td>
<td>67½</td>
<td>106½</td>
<td>23½</td>
</tr>
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<td>90</td>
<td>46.1</td>
<td>72½</td>
<td>113</td>
<td>25½</td>
</tr>
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<td>96</td>
<td>52.4</td>
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<td>120½</td>
<td>27</td>
</tr>
<tr>
<td>102</td>
<td>59.1</td>
<td>82</td>
<td>128</td>
<td>28½</td>
</tr>
<tr>
<td>108</td>
<td>66.4</td>
<td>87</td>
<td>135½</td>
<td>30½</td>
</tr>
<tr>
<td>114</td>
<td>73.9</td>
<td>91½</td>
<td>143</td>
<td>32</td>
</tr>
<tr>
<td>120</td>
<td>82.1</td>
<td>96½</td>
<td>150½</td>
<td>33½</td>
</tr>
<tr>
<td>132</td>
<td>99.2</td>
<td>108½</td>
<td>165½</td>
<td>37</td>
</tr>
<tr>
<td>144</td>
<td>118</td>
<td>116</td>
<td>180½</td>
<td>40½</td>
</tr>
</tbody>
</table>

Note: Rise, span, and radii are fixed; other dimensions and angles are calculated.

Fig. 5 Cross-Sectional Shape of Elliptical Pipe
## Flow Area Per ASTM C 507

<table>
<thead>
<tr>
<th>Approximate Equivalent Round Size, in.</th>
<th>Full Flow Water Area, ft³</th>
<th>Rise, in.</th>
<th>Span, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>K 18</td>
<td>1.83</td>
<td>14 1/4</td>
<td>22 3/4</td>
</tr>
<tr>
<td>24</td>
<td>3.28</td>
<td>19 1/4</td>
<td>30 1/4</td>
</tr>
<tr>
<td>27</td>
<td>4.12</td>
<td>21 1/2</td>
<td>34</td>
</tr>
<tr>
<td>30</td>
<td>5.10</td>
<td>24</td>
<td>37 3/4</td>
</tr>
<tr>
<td>33</td>
<td>6.33</td>
<td>26 3/4</td>
<td>42</td>
</tr>
<tr>
<td>36</td>
<td>7.36</td>
<td>28 3/4</td>
<td>45 1/2</td>
</tr>
<tr>
<td>39</td>
<td>8.78</td>
<td>31 1/2</td>
<td>49 1/2</td>
</tr>
<tr>
<td>42</td>
<td>10.2</td>
<td>34</td>
<td>53 1/4</td>
</tr>
</tbody>
</table>
Live Load
Bedding Factors
The bedding factor for installation of arch and elliptical pipe shall be taken as:

\[
B_{FE} = \frac{C_A}{C_N - xq}
\]  

(12.10.4.3.2b-1)

where:

- \( C_A \) = constant corresponding to the shape of the pipe, as specified in Table 12.10.4.3.2b-1
- \( C_N \) = parameter that is a function of the distribution of the vertical load and vertical reaction, as specified in Table 12.10.4.3.2b-1
- \( x \) = parameter that is a function of the area of the vertical projection of the pipe over which lateral pressure is effective, as specified in Table 12.10.4.3.2b-1
- \( q \) = ratio of the total lateral pressure to the total vertical fill load specified herein

Design values for \( C_A, C_N, \) and \( x \) are listed in Table 12.10.4.3.2b-1.

### Table 12.10.4.3.2b-1—Design Values of Parameters in Bedding Factor Equation

<table>
<thead>
<tr>
<th>Pipe Shape</th>
<th>( C_A )</th>
<th>Installation Type</th>
<th>( C_N )</th>
<th>Projection Ratio, ( p )</th>
<th>( x )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Elliptical and Arch</td>
<td>1.337</td>
<td>2</td>
<td>0.630</td>
<td>0.9</td>
<td>0.421</td>
</tr>
<tr>
<td>Vertical Elliptical</td>
<td>1.021</td>
<td>2</td>
<td>0.516</td>
<td>0.9</td>
<td>0.718</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.615</td>
<td>0.5</td>
<td>0.457</td>
</tr>
</tbody>
</table>

The value of the parameter \( q \) is taken as:

- For arch and horizontal elliptical pipe:
  \[
  q = 0.23 \frac{P}{F_e} \left( \frac{B}{H} \right) \left( 1 + 0.35 \frac{B}{H} \right)
  \]  
  (12.10.4.3.2b-2)

- For vertical elliptical pipe:
  \[
  q = 0.48 \frac{P}{F_e} \left( \frac{B}{H} \right) \left( 1 + 0.73 \frac{B}{H} \right)
  \]  
  (12.10.4.3.2b-3)

where:

\( p = \) projection ratio, ratio of the vertical distance between the outside top of the pipe, and the ground of bedding surface to the outside vertical height of the pipe.
Bedding Factor Equation

\[ B_{FE} = \frac{C_A}{C_N - xq} \]  \hspace{1cm} (12.10.4.3.2b-1)

where:

\[ C_A = \text{constant corresponding to the shape of the pipe, as specified in Table 12.10.4.3.2b-1} \]

\[ C_N = \text{parameter that is a function of the distribution of the vertical load and vertical reaction, as specified in Table 12.10.4.3.2b-1} \]

\[ = \text{parameter that is a function of the area of the vertical projection of the pipe over which lateral pressure is effective, as specified in Table 12.10.4.3.2b-1} \]

\[ = \text{ratio of the total lateral pressure to the total vertical fill load specified herein} \]
Bedding Factor Per AASHTO

The bedding factor for installation of arch and elliptical pipe shall be taken as:

\[ B_{FE} = \frac{C_A}{C_N - xq} \]  

(12.10.4.3.2b-1)

Table 12.10.4.3.2b-1—Design Values of Parameters in Bedding Factor Equation

<table>
<thead>
<tr>
<th>Pipe Shape</th>
<th>( C_A )</th>
<th>Installation Type</th>
<th>( C_N )</th>
<th>Projection Ratio, ( p )</th>
<th>( x )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>1.337</td>
<td>2</td>
<td>0.630</td>
<td>0.9</td>
<td>0.421</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.763</td>
<td>0.7</td>
<td>0.369</td>
</tr>
<tr>
<td>Elliptical and</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical</td>
<td>1.021</td>
<td>2</td>
<td>0.516</td>
<td>0.9</td>
<td>0.718</td>
</tr>
<tr>
<td>Elliptical</td>
<td></td>
<td>3</td>
<td>0.615</td>
<td>0.7</td>
<td>0.639</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
For arch and horizontal elliptical pipe:

\[ q = 0.23 \frac{P}{F_e} \left( 1 + 0.35 \frac{B_c}{H} \right) \]  

(12.10.4.3.2b-2)

\[ F_e = 1.4 \]
The bedding factor for installation of arch and elliptical pipe shall be taken as:

\[ B_{FE} = \frac{C_A}{C_N - xq} \]  

(12.10.4.3.2b-1)
Live Load Bedding Factors

Table 12.10.4.3.2c-1

<table>
<thead>
<tr>
<th>Pipe Diameter, in</th>
<th>Fill Height, ft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 2 ft</td>
</tr>
<tr>
<td>12</td>
<td>3.2</td>
</tr>
<tr>
<td>18</td>
<td>3.2</td>
</tr>
<tr>
<td>24</td>
<td>3.2</td>
</tr>
<tr>
<td>30 and larger</td>
<td>2.2</td>
</tr>
</tbody>
</table>
EXAMPLE 2

- 34 x 53 horizontal elliptical pipe
- Positive projecting embankment condition
- Type 2 Installation
- 1 foot of cover
- Soil unit weight of 120 lbs/ft³
STEPS

1. Determine Earth Load
2. Determine Live Load
3. Select Bedding
4. Determine Bedding Factor
5. Application of Factor of Safety
6. Selection of Pipe Strength
Determine Earth Load

- Wall thickness = 5 in. (from ASTM C 507)
- Outside Span $B_c = 53$ in + 2 (5 in.) = 5.25 ft
- Soil Prism Load:
  - $PL = w \, H \, B_c$
  - $PL = (120 \, \text{lbs/ft}^3)(1\, \text{ft.})(5.25 \, \text{ft.})$
  - $PL = 630 \, \text{lbs/ft}$

- $W = VAF \times PL$ (AASHTO Equation 12.10.2.1-1)
  - Type 2
  - $W = (1.40)(630 \, \text{lbs/ft})$
  - $W = 882 \, \text{lbs/ft}$
Determine Fluid Load

- \( \gamma_w = 62.4 \text{ pcf} \)
- \( A = 10.2 \text{ ft} \)
- \( W_f = \gamma_w \times A \)
- \( W_f = 636 \text{ lbs/ft} \)
# Flow Area Per ASTM C 507

<table>
<thead>
<tr>
<th>Approximate Equivalent Round Size, in. K</th>
<th>Full Flow Water Area, ft(^3)</th>
<th>Rise, in.</th>
<th>Span, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>1.83</td>
<td>14(\frac{1}{4})</td>
<td>22(\frac{3}{4})</td>
</tr>
<tr>
<td>24</td>
<td>3.28</td>
<td>19(\frac{1}{4})</td>
<td>30(\frac{1}{4})</td>
</tr>
<tr>
<td>27</td>
<td>4.12</td>
<td>21(\frac{1}{2})</td>
<td>34</td>
</tr>
<tr>
<td>30</td>
<td>5.10</td>
<td>24</td>
<td>37(\frac{3}{4})</td>
</tr>
<tr>
<td>33</td>
<td>6.33</td>
<td>26(\frac{3}{4})</td>
<td>42</td>
</tr>
<tr>
<td>36</td>
<td>7.36</td>
<td>28(\frac{3}{4})</td>
<td>45(\frac{1}{2})</td>
</tr>
<tr>
<td>39</td>
<td>8.78</td>
<td>31(\frac{1}{2})</td>
<td>49(\frac{1}{2})</td>
</tr>
<tr>
<td>42</td>
<td>10.2</td>
<td>34</td>
<td>53(\frac{1}{4})</td>
</tr>
</tbody>
</table>
Elliptical Concrete Pipe

Roughness Coefficient (n): 0.012

Pipe Diameter (in.): 42 in. - 34 in. x 53 in.

Pipe Slope (%): 0.1 0.001 ft/ft

Flow Depth (%): 100

Result

Pipe Flow = Q = 36.05 ft³/sec
Area of Flow = A = 10.14 ft²
Velocity of Flow = V = 3.55 ft/sec
DETERMINE LIVE LOAD
\( E_{\text{span}} = \text{Distribution width parallel to span in inches} \)

\( E_{\text{span}} = L_T + \text{LLDF}(H) \)

\( L_T = \text{length of contact area parallel to span (in)} \)
\( \text{LLDF} = \text{live load distribution factor} \)
\( H = \text{depth of fill} \)
3.6.1.2.6a—General

For single-span culverts, the effects of live load may be neglected where the depth of fill is more than 8.0 ft. and exceeds the span length; for multiple span culverts, the effects may be neglected where the depth of fill exceeds the distance between inside faces of end walls.

Live load shall be distributed to the top slabs of flat top three-sided, or long-span concrete arch culverts, or concrete pipe with less than 2.0 ft of fill as specified in Article 4.6.2.10. Round concrete culverts with 1.0 ft or more but less than 2.0 ft of cover shall be designed for a depth of 1.0 ft. Round culverts with less than 1.0 ft of fill shall be analyzed with more comprehensive methods.

\[ E = 96 + 1.44S \quad (4.6.2.10.2-1) \]

E = Distribution width perpendicular to span in inches
S = Clear Span in feet
Less Than 2 Feet of Cover

\[ E_{\text{span}} = \text{Distribution width parallel to span in inches} \]

\[ E_{\text{span}} = L_T + \text{LLDF}(H) \]

\[ L_T = \text{length of contact area parallel to span (in)} \]
\[ \text{LLDF} = \text{live load distribution factor} \]
\[ H = \text{depth of fill} \]
Live Load Spread for Less Than 2 feet of Cover (single and perpendicular)
Live Load Width

- $E = 96 + 1.44 \frac{53}{12}$
- $E = 102.36 \text{ inches} = 8.53 \text{ ft.}$

Live Load Length

- $\text{LLDF} = 1.39$
- $E = 10''/12 + 1 \text{ ft} \times 1.39$
- $E = 2.22 \text{ ft.}$
Area of Pressure on Top of Pipe

- $A_{LL} = E \times E_{span}$
- $A_{LL} = 8.53 \text{ ft} \times 2.22 \text{ ft}$
- $A_{LL} = 18.94 \text{ ft}^2$

- $P = 32,000 \text{ lbs}$
- $M = 1.2$
Pressure at top of Pipe

\[ P \left(1 + \frac{IM}{100}\right) (m) \]

\[ P_L = \frac{IM}{A_{LL}} \]

(3.6.1.2.6b-7)

\[ IM = 33 \times [1 - 0.125 \times (H)] \]

\[ IM = 33 \times [1 - 0.125 \times (1)] \]

\[ IM = 28.88 \]
Pressure at top of Pipe

\[ P_L = \frac{P \left( 1 + \frac{IM}{100} \right)^{(m)}}{A_{LL}} \]  

(3.6.1.2.6b-7)

\[ P_L = \frac{32000 \text{ lbs} \left( 1 + \frac{28.88}{100} \right)}{18.94 \text{ ft}^2} \]  

(1.2)

\[ P_L = 2,613 \text{ psf} \]
Live Load

- OD = 5.25 ft.
- $E_{\text{span}} = 2.22$ ft
- $E_{\text{span}} < \text{OD}$, so use Espan for live load calculation

- $W_{\text{LL}} = 2.22 \text{ ft} \times 2613 \text{ psf}$
- $W_{\text{LL}} = 5,801 \text{ lbs/ft}$
Recap of Loads

- **Type 2**
  - $W_E = 882 \text{ lbs/ft}$
  - $W_F = 636 \text{ lbs/ft}$
  - $W_L = 5801 \text{ lbs/ft}$
Determination of Bedding Factors
Bedding Factor Per AASHTO

The bedding factor for installation of arch and elliptical pipe shall be taken as:

$$B_{FE} = \frac{C_A}{C_N - xq}$$

(12.10.4.3.2b-1)

<table>
<thead>
<tr>
<th>Pipe Shape</th>
<th>$C_A$</th>
<th>Installation Type</th>
<th>$C_N$</th>
<th>Projection Ratio, $p$</th>
<th>$x$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>1.337</td>
<td>2</td>
<td>0.630</td>
<td>0.9</td>
<td>0.421</td>
</tr>
<tr>
<td>Elliptical</td>
<td></td>
<td>3</td>
<td>0.763</td>
<td>0.7</td>
<td>0.369</td>
</tr>
<tr>
<td>Arch</td>
<td></td>
<td>2</td>
<td>0.516</td>
<td>0.9</td>
<td>0.718</td>
</tr>
<tr>
<td>Vertical</td>
<td></td>
<td>3</td>
<td>0.615</td>
<td>0.5</td>
<td>0.457</td>
</tr>
<tr>
<td>Elliptical</td>
<td>1.021</td>
<td>2</td>
<td>0.511</td>
<td>0.7</td>
<td>0.639</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.615</td>
<td>0.5</td>
<td>0.238</td>
</tr>
</tbody>
</table>
Horizontal Elliptical Bedding Factor

For arch and horizontal elliptical pipe:

\[ q = 0.23 \frac{p}{F_e} \left( 1 + 0.35p \frac{B_c}{H} \right) \]  

(12.10.4.3.2b-2)

- \( F_e = 1.4 \)
- \( p = 0.7 \)
- \( B_c = 5.25 \text{ ft.} \)
- \( H = 1 \text{ ft.} \)
- \( q = 0.263 \)
Earth Load Bedding Factor

\[ B_{FE} = \frac{C_A}{C_N - xq} \]

\[ C_A = 1.337 \]
\[ C_N = 0.630 \]
\[ x = 0.369 \]
\[ q = 0.263 \]

\[ B_{FE} = \frac{1.337}{0.630 - 0.369 \times 0.263} \]

\[ B_{FE} = 2.5 \]
## Live Load Bedding Factor

### Table 12.10.4.3.2c-1

<table>
<thead>
<tr>
<th>Pipe Diameter, in</th>
<th>Fill Height, ft</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 2 ft</td>
<td>≥ 2 ft</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>3.2</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>3.2</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>3.2</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>30 and larger</td>
<td>2.2</td>
<td>2.2</td>
<td></td>
</tr>
</tbody>
</table>

$B_{FLL} = 2.2$
Find D-load

\[ D = \left( \frac{12}{S_i} \right) \left( \frac{W_E + W_F}{B_{FE}} + \frac{W_L}{B_{FLL}} \right) \]

(12.10.4.3.1-1)
Application of Factor of Safety

- Design is based on 0.01 inch crack, so use a factor of safety of 1.0.
SELECTION OF ELLIPTICAL PIPE STRENGTH FOR A TYPE 2 INSTALLATION

\[ D_{0.01} = \left( \frac{882 \text{ lbs/ft} + 636 \text{ lbs/ft}}{2.5} \right) + \left( \frac{5801 \text{ lbs/ft}}{2.2} \right) \times \frac{12}{53 \text{ in.}} \]

\[ D_{0.01} = 735 \text{ lbs/linear ft/ft of diameter} \]
Elliptical Pipe Classes (ASTM C 507)

- Class HE-A - 600 lbs/ft/ft
- Class HE-1 - 800 lbs/ft/ft
- Class HE-II - 1000 lbs/ft/ft
- Class HE-III - 1350 lbs/ft/ft
- Class HE-IV - 2000 lbs/ft/ft
Tandem Axle Live Load

25 kips 4 ft 25 kips

Diagram showing two 25 kip loads spaced 4 feet apart.
The End