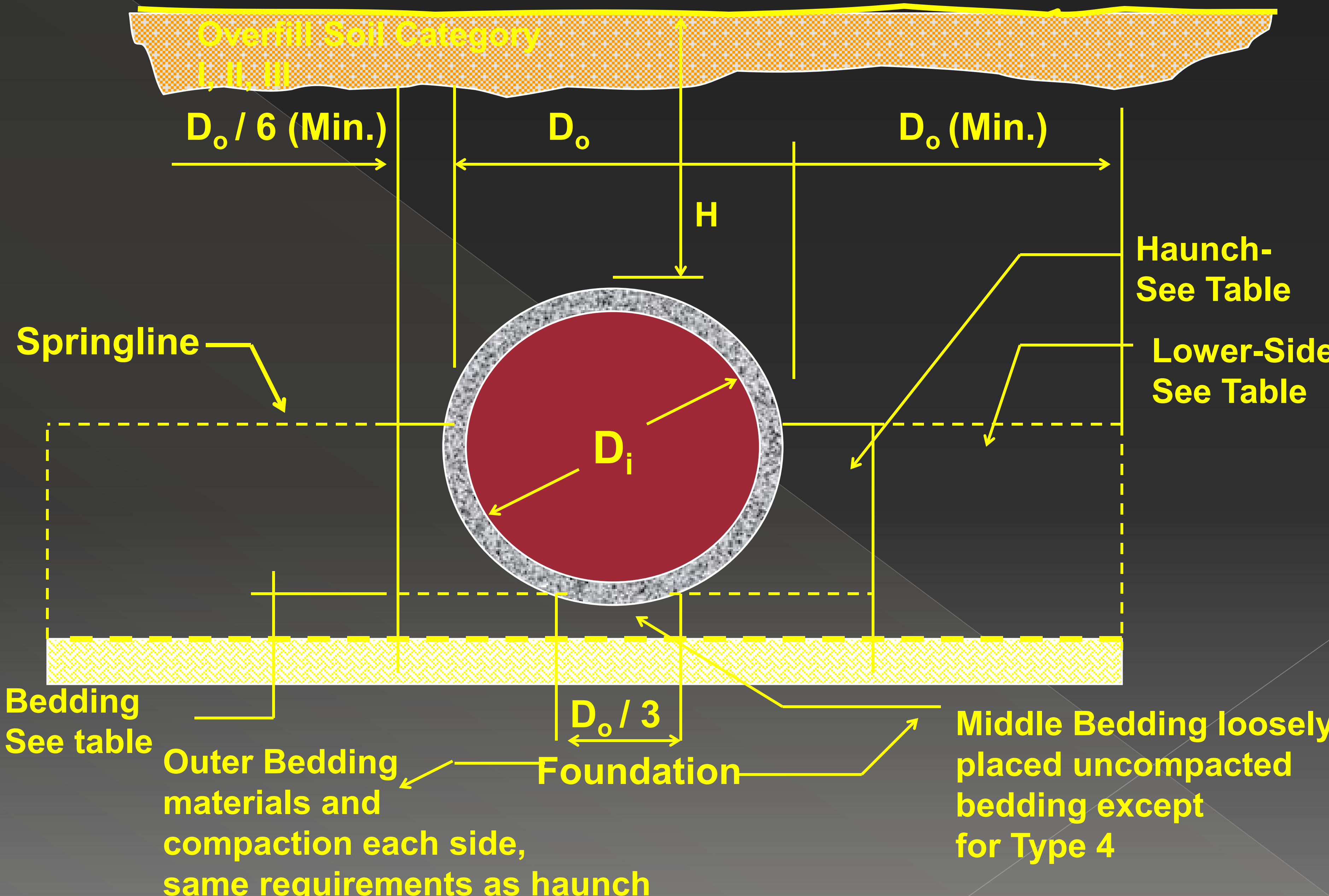
Standard Installations
Indirect Design

Standard Embankment Installation



Standard Installation Soils and Minimum Compaction Requirements

Installation Type	Bedding Thickness	Haunch and Outer Bedding	Lower Side
Type 1	D_o/24 minimum, not less than 3" (75 mm) If rock foundation, use D_o/12 minimum, not less than 6" (150 mm)	95% Category I	90% Category I, 95% Category II, or 100% Category III
Type 2	D_o/24 minimum, not less than 3" (75 mm) If rock foundation, use D_o/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	D_o/24 minimum, not less than 3" (75 mm) If rock foundation, use D_o/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 D_o/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

Representative Soil Types			Percent Compaction	
SIDD	USCS	AASHTO	Standard Proctor	Modified Proctor
Gravelly Sand (Category I)	SW, SP, GW, GP	A1, A3	100 95 90 85 80 61	95 90 85 80 75 59
Sandy Silt (Category II)	GM, SM, ML, Also GC, SC with less than 20% passing #200 sieve	A2, A4	100 95 90 85 80 49	95 90 85 80 75 46
Silty Clay (Category III)	CL, MH, GC, SC	A5, A6	100 95 90 85 80 45	90 85 80 75 70 40
	CH	A7	100 95 90 45	90 85 80 40

Delaware Backfill

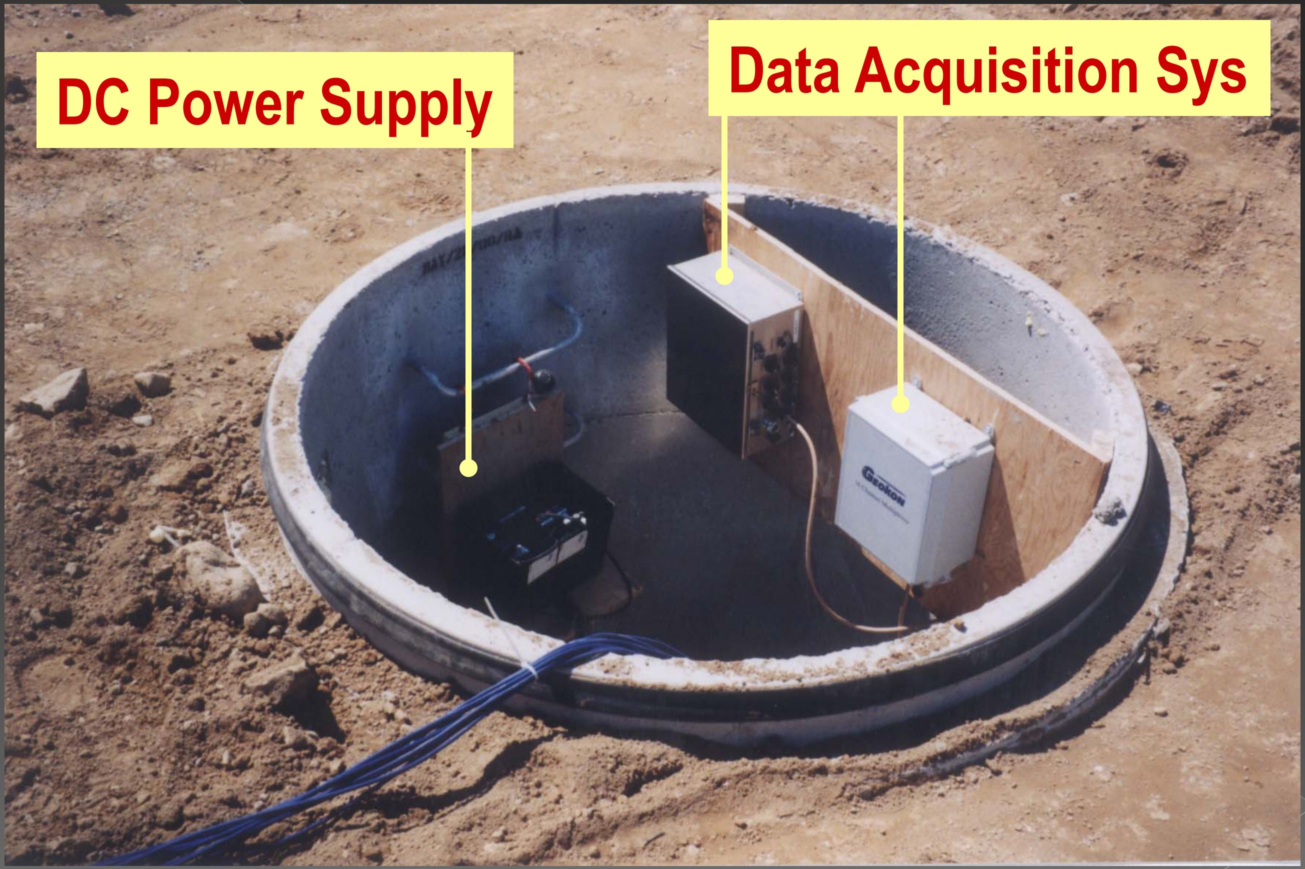
- 209.04 - “Borrow Type C (Backfill). This material shall have between 85 and 100% inclusive by dry weight, passing a 1” (25 mm) sieve and a maximum of 25% by dry weight, passing a No. 200 (75 µm) sieve.

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)."

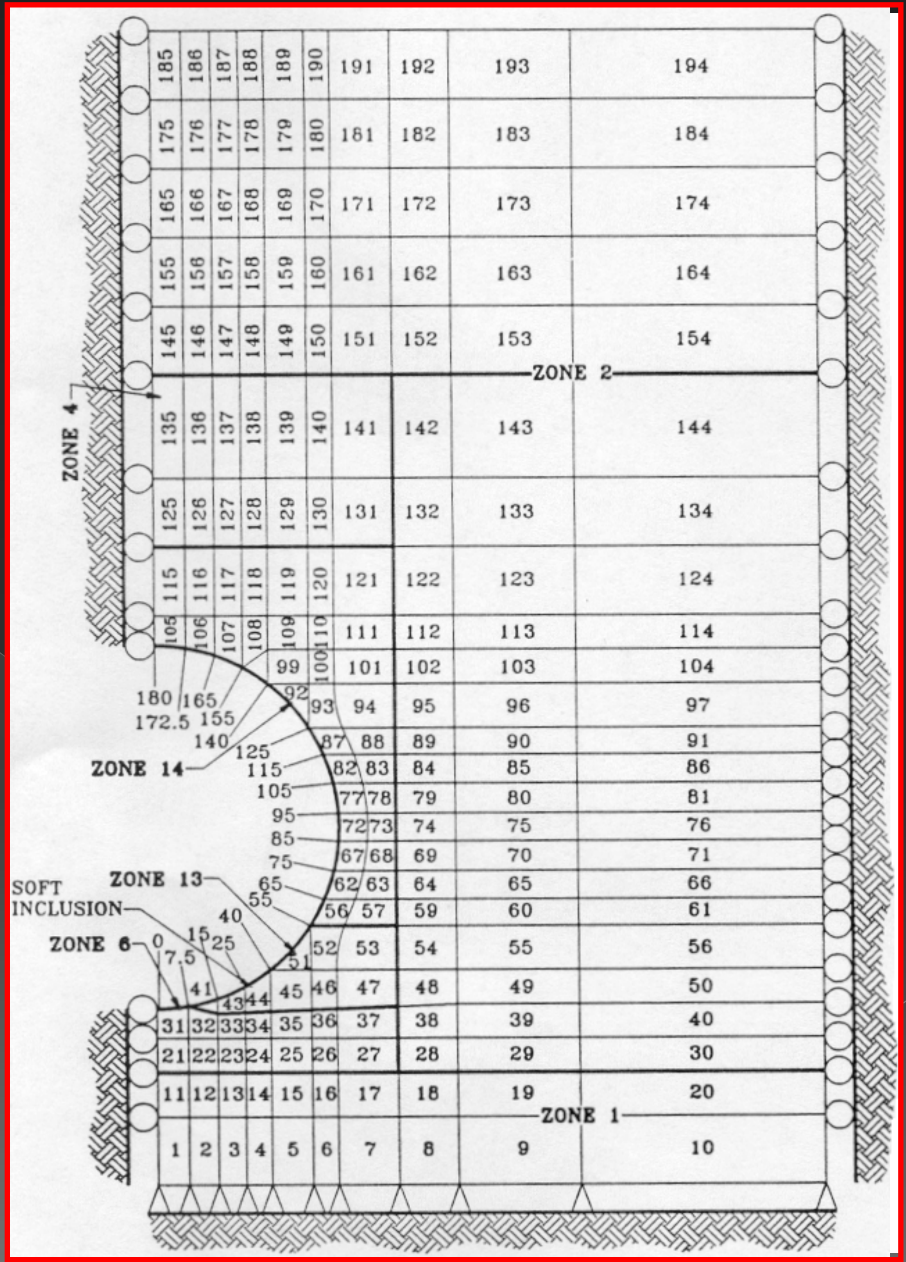
Design and Installation

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

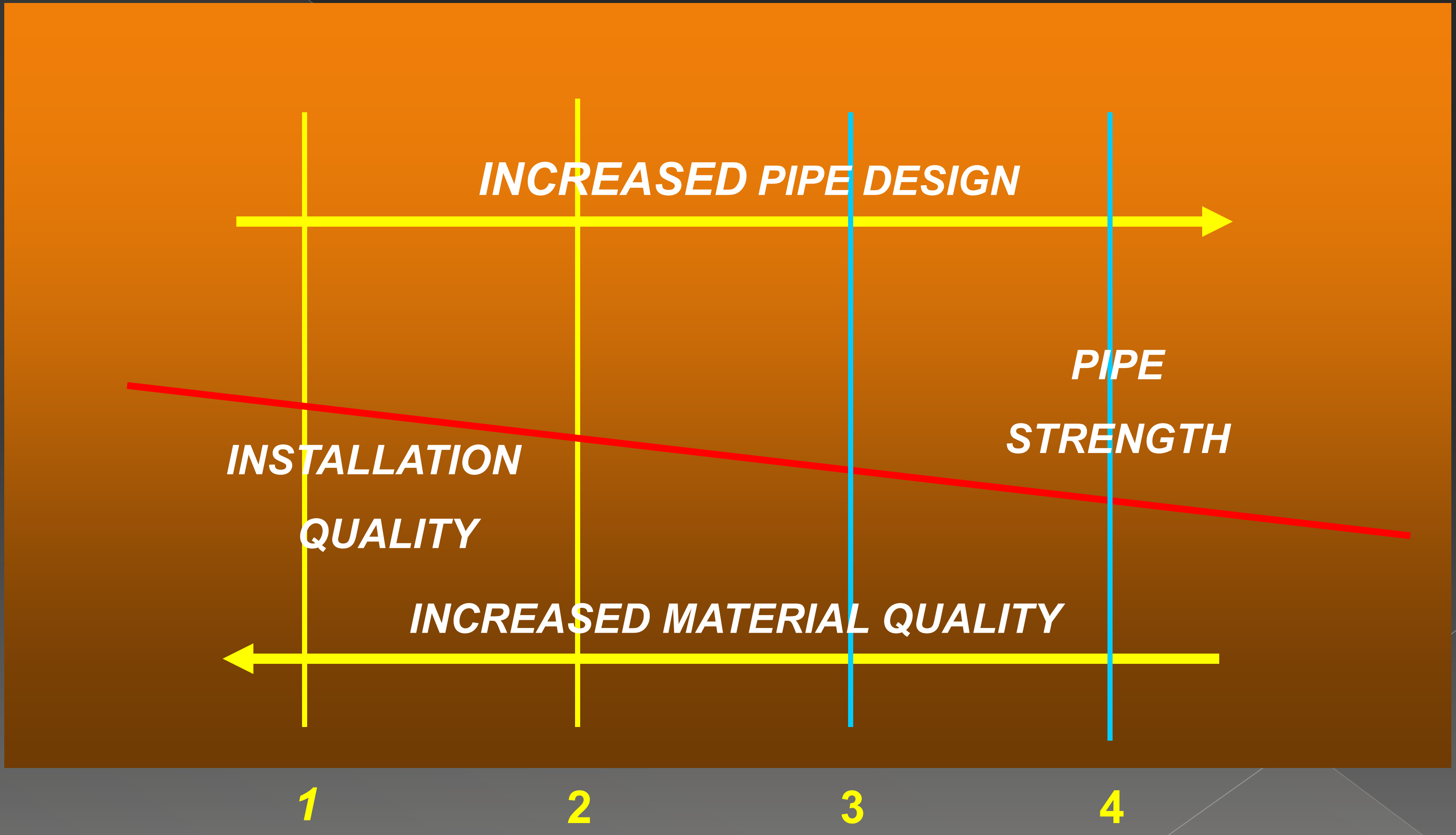

DC Power Supply
Data Acquisition Sys

SPIDA

Soil
Pipe
Interaction
Design &
Analysis



INSTALLATION TYPE



Pipe Pressure Distribution

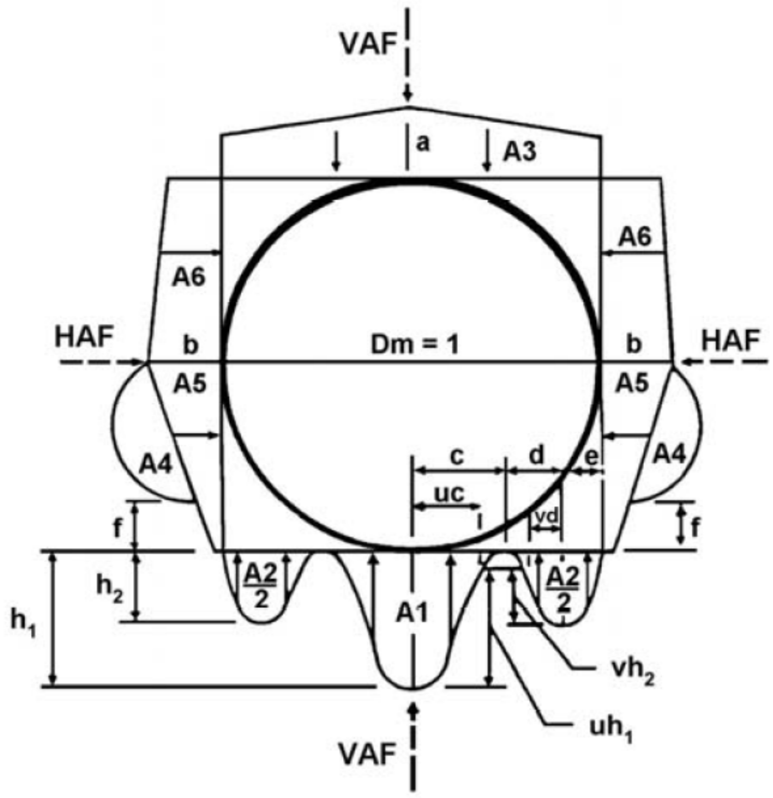
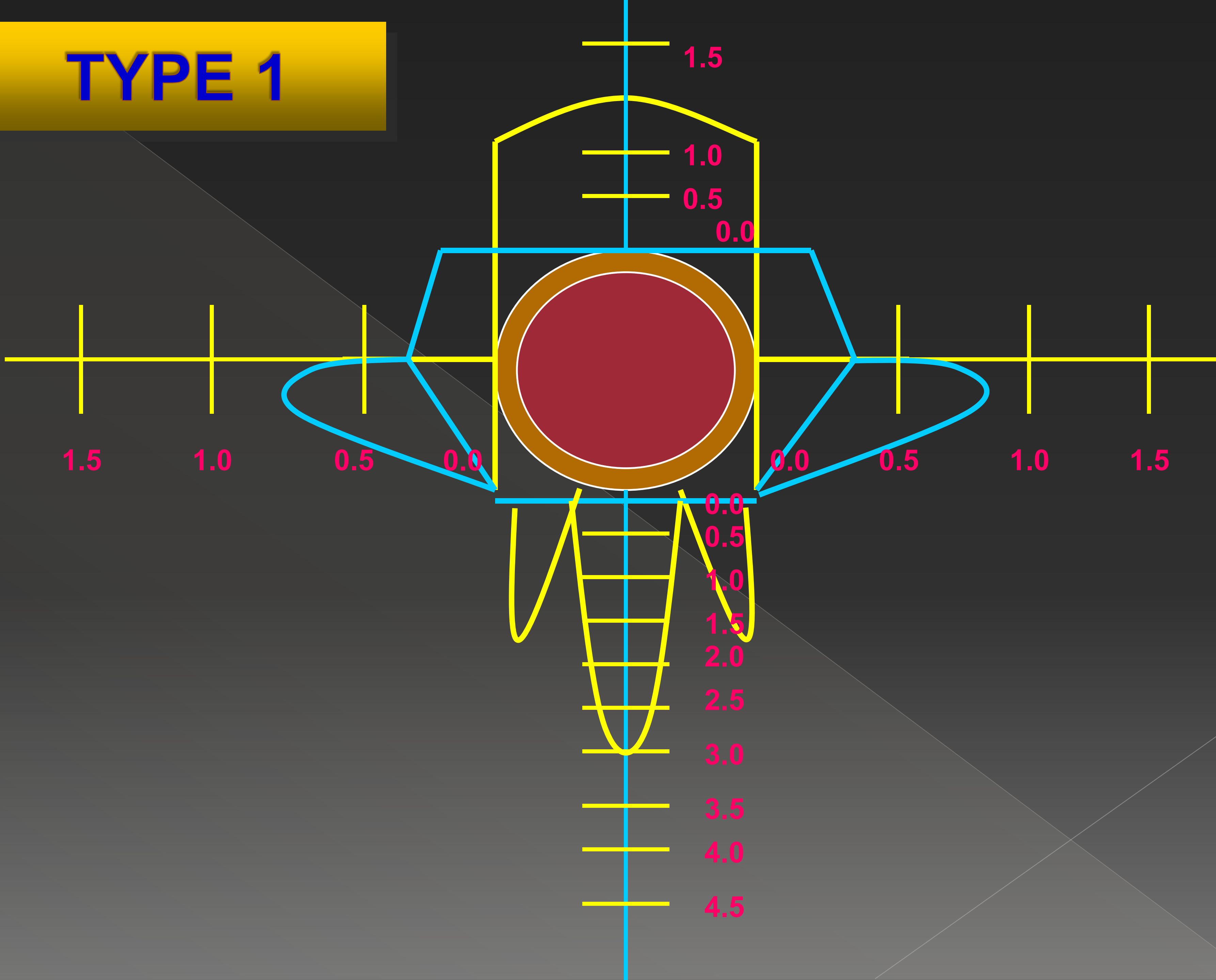
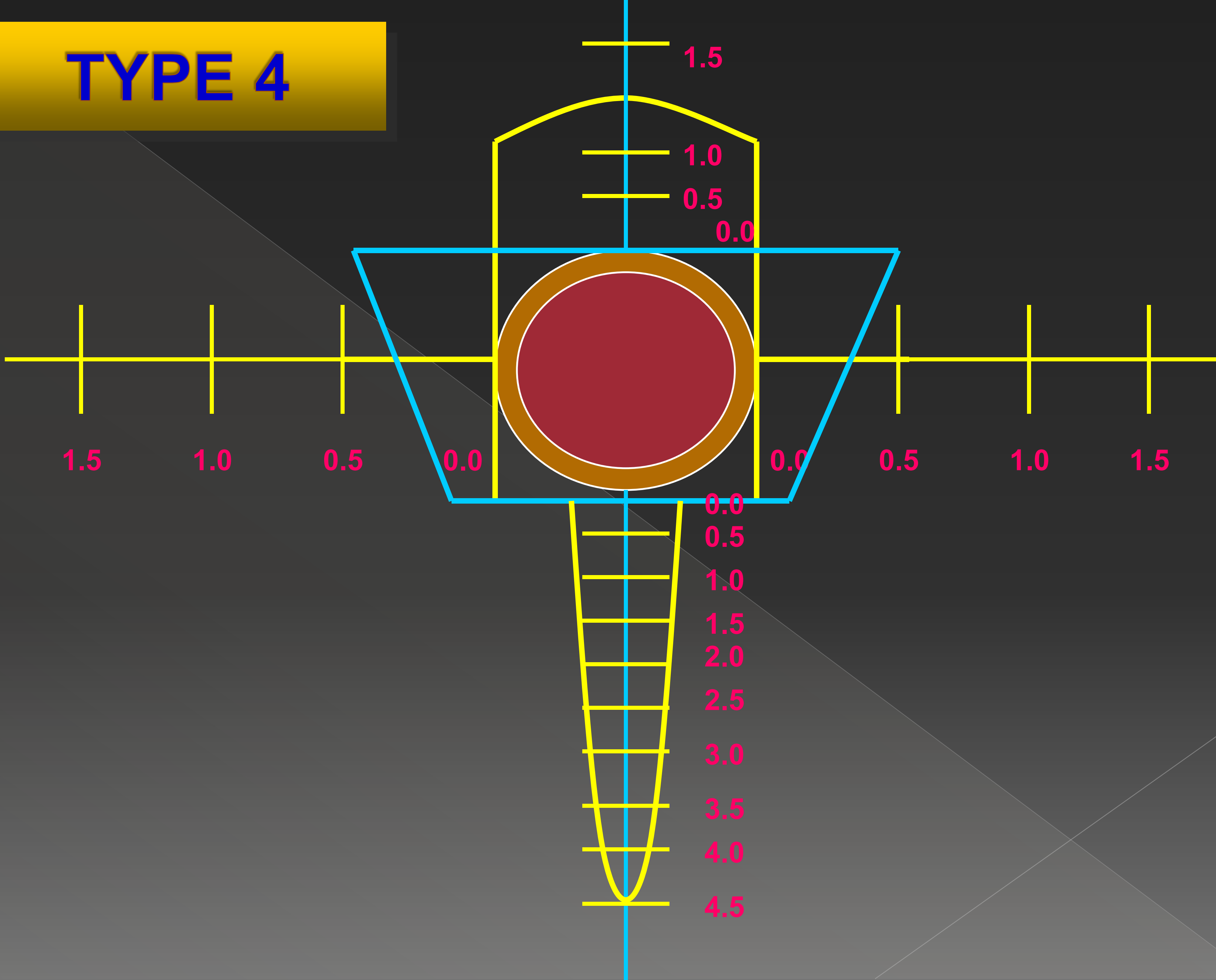


Figure 12.10.2.1-1—Heger Pressure Distribution and Arching Factors

TYPE 1

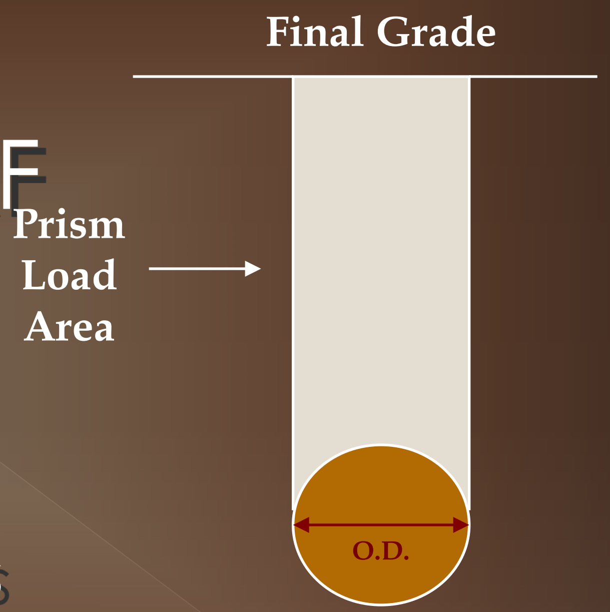


TYPE 4



Calculation of Earth Load

W_e = prism load x VAF

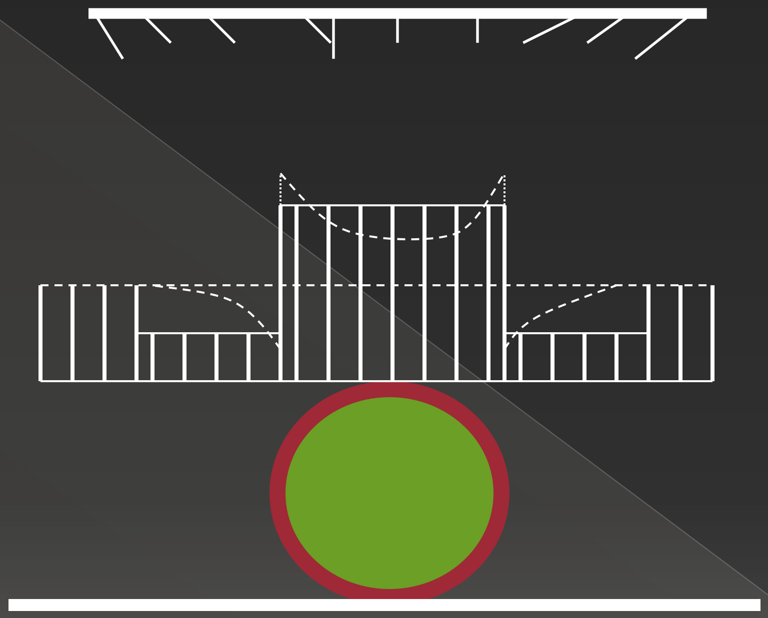


Where :
VAF = vertical arching factor as per Heger distribution

ARCHING FACTORS

Installation Type	VAF	HAF
1	1.35	0.45
2	1.40	0.40
3	1.40	0.37
4	1.45	0.30

Vertical Pressures



Soil Load

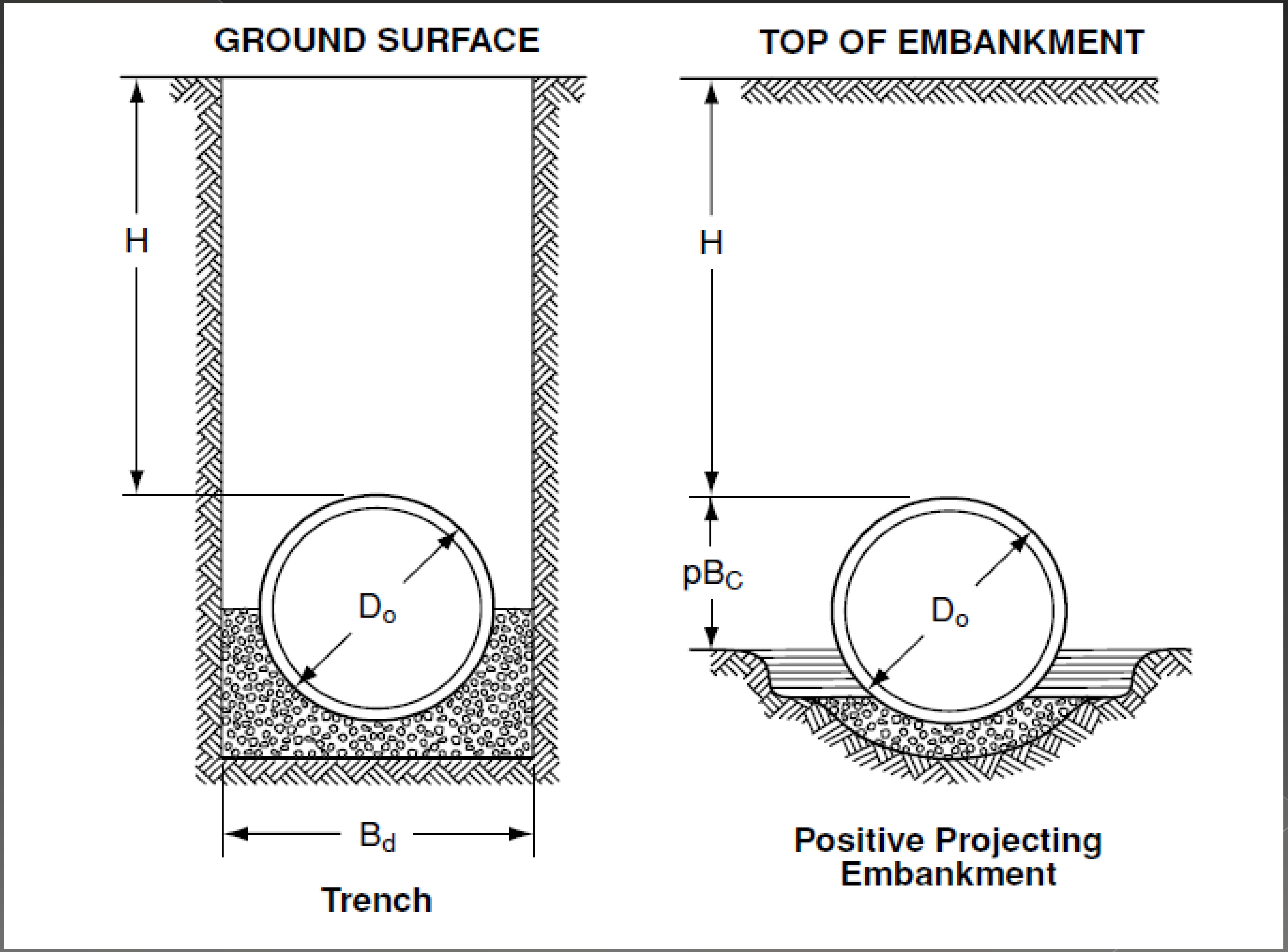
- $W_E = F_e \gamma_s B_c H$
  - Pipe – Section 12.10.2.1-1

AASHTO LRFD 12.10.2.1

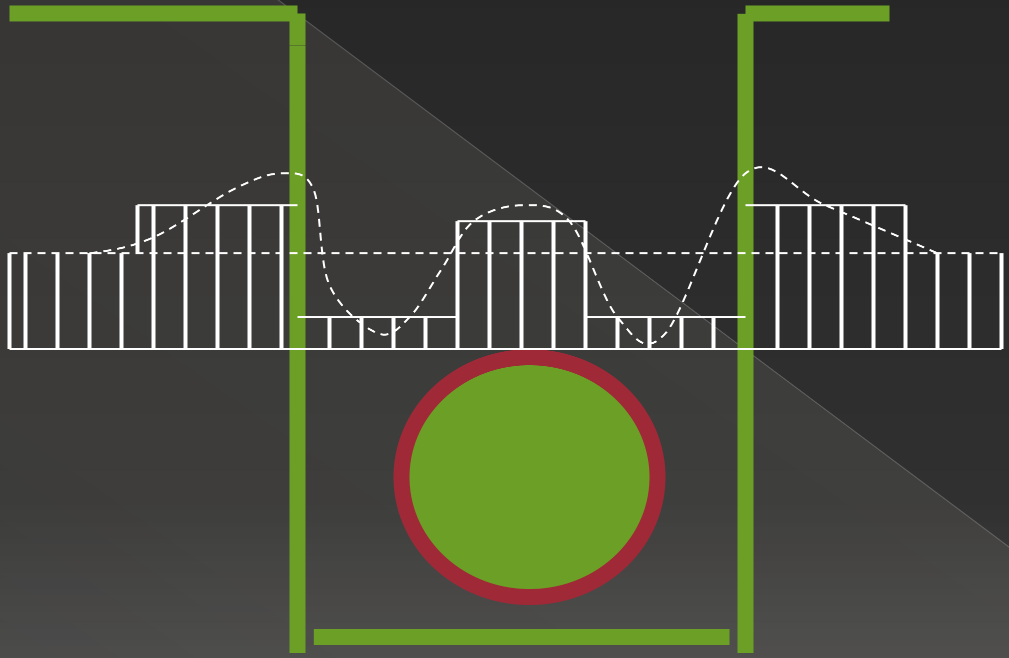
Table 12.10.2.1-3 Coefficients for use with Figure 1.

	Installation Type			
	1	2	3	4
VAF	1.35	1.40	1.40	1.45
HAF	0.45	0.40	0.37	0.30
A1	0.62	0.85	1.05	1.45
A2	0.73	0.55	0.35	0.00
A3	1.35	1.40	1.40	1.45
A4	0.19	0.15	0.10	0.00
A5	0.08	0.08	0.10	0.11
A6	0.18	0.17	0.17	0.19
a	1.40	1.45	1.45	1.45
b	0.40	0.40	0.36	0.30
c	0.18	0.19	0.20	0.25
e	0.08	0.10	0.12	0.00
f	0.05	0.05	0.05	—
u	0.80	0.82	0.85	0.90
v	0.80	0.70	0.60	—

Basic Forms of Installation



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

$$D = \left(\frac{12}{S_i}\right)\left(\frac{W_E + W_F}{B_{FE}} + \frac{W_L}{B_{FLL}}\right) \qquad (12.10.4.3.1\text{-}1)$$

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.)

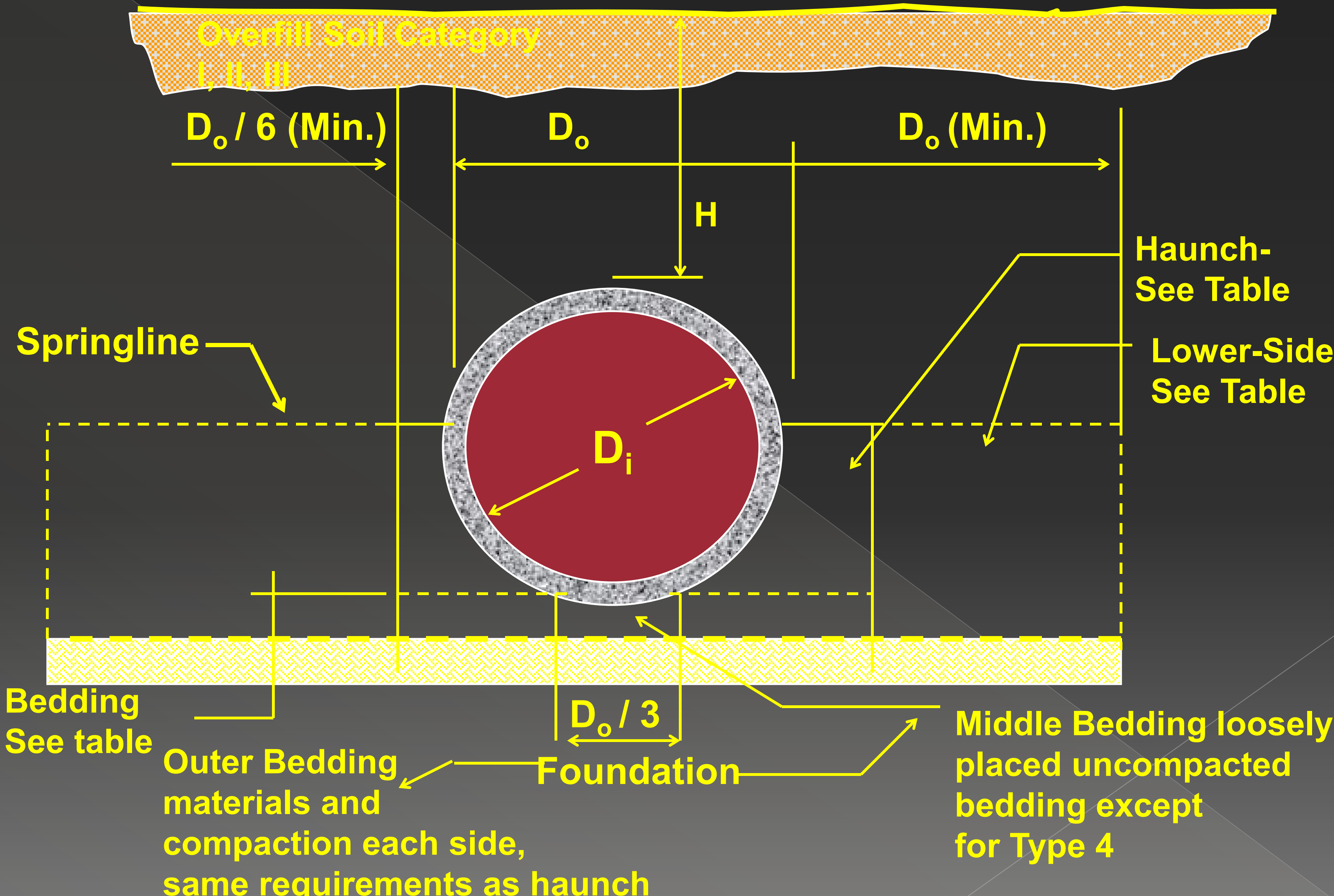
W_E = total unfactored earth load specified in Article 12.10.2.1 (kip/ft)

W_F = total unfactored fluid load in the pipe as specified in Article 12.10.2.2 (kip/ft)

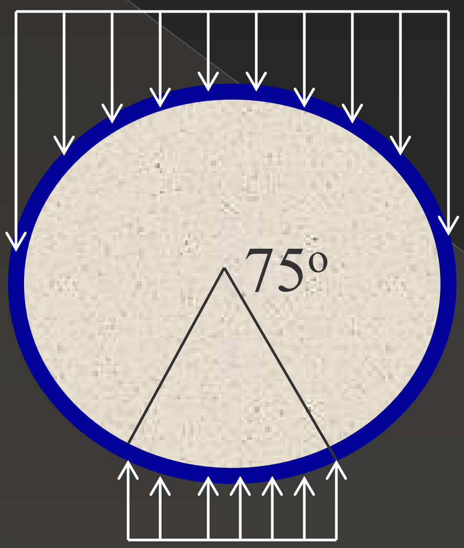
W_L = total unfactored live load on unit length pipe specified in Article 12.10.2.3 (kip/ft)

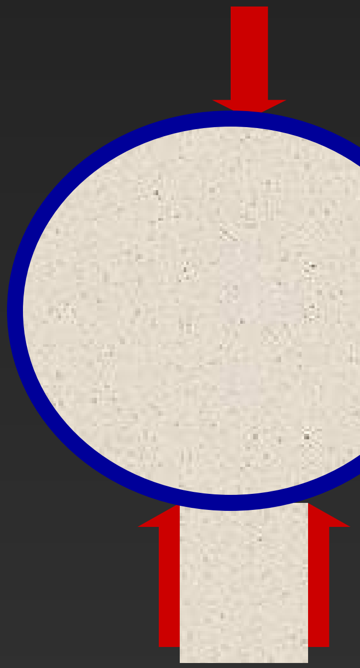
Bedding Factors

Standard Embankment Installation



Bedding Factors





$M = 0.170\ W_e\ r$

$M = 0.318\ P\ r$

$W_e / P = 1.9 = B_f$

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

$$B_f = \frac{M_{TEST}}{M_{FIELD}} \qquad (4.18)$$

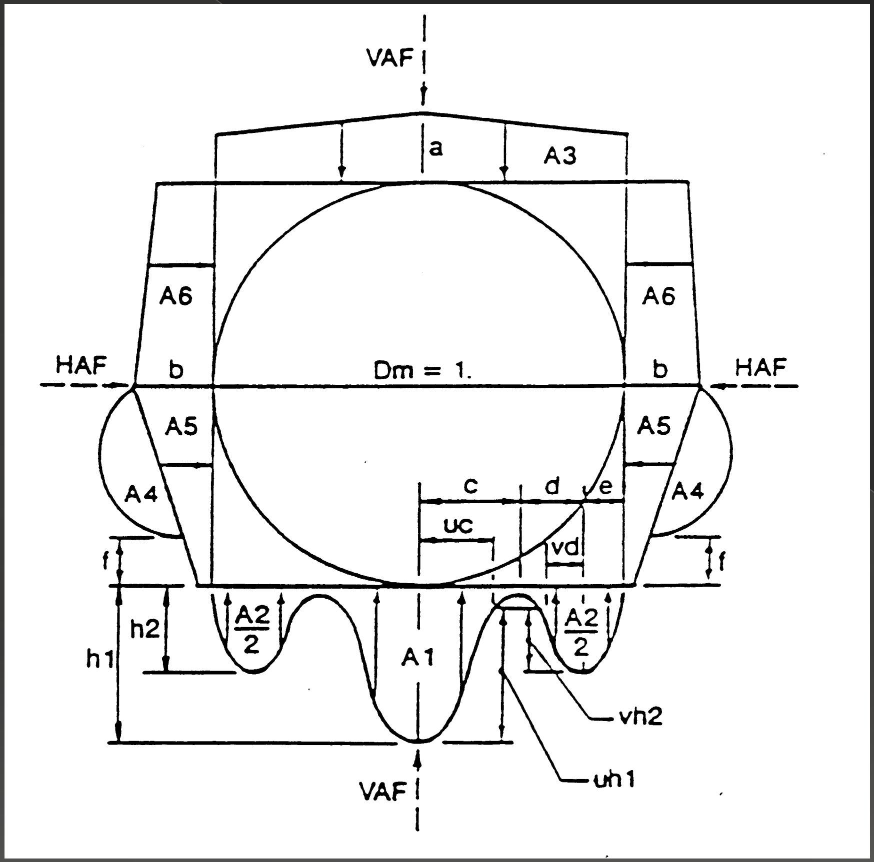
where:

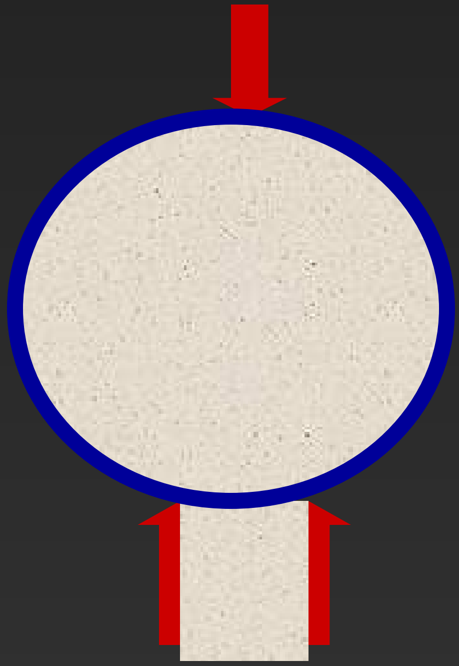
B_f = bedding factor

M_{TEST} = maximum moment in pipe wall under three-edge bearing test load, inch-pounds

M_{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.

Pipe Diameter, in.	Standard Installations			
	Type 1	Type 2	Type 3	Type 4
12	4.4	3.2	2.5	1.7
24	4.2	3.0	2.4	1.7
36	4.0	2.9	2.3	1.7
72	3.8	2.8	2.2	1.7
144	3.6	2.8	2.2	1.7

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

$$D = \left(\frac{12}{S_i}\right)\left(\frac{W_E + W_F}{B_{FE}} + \frac{W_L}{B_{FLL}}\right) \qquad (12.10.4.3.1\text{-}1)$$

ASTM C 76

C76 – 10

TABLE 3 Design Requirements for Class III Reinforced Concrete Pipe[A]

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.

D-load to produce a 0.01-in. crack	1350
D-load to produce the ultimate load	2000

Internal Designated Diameter, in.	Reinforcement, in.^{2}/linear ft of pipe wall											
	Wall A				Wall B				Wall C			
	Concrete Strength, 4000 psi				Concrete Strength, 4000 psi				Concrete Strength, 4000 psi			
	Wall Thicknesses, in.	Circular Reinforcement[B] Inner Cage	Circular Reinforcement[B] Outer Cage	Elliptical Reinforcement[C]	Wall Thicknesses, in.	Circular Reinforcement[B] Inner Cage	Circular Reinforcement[B] Outer Cage	Elliptical Reinforcement[C]	Wall Thicknesses, in.	Circular Reinforcement[B] Inner Cage	Circular Reinforcement[B] Outer Cage	Elliptical Reinforcement[C]
12	1¾	0.07[D]	. . .	. . .	2	0.07[D]	. . .	. . .	2¾	0.07[D]	. . .	. . .
15	1⅞	0.07[D]	. . .	. . .	2¼	0.07[D]	. . .	. . .	3	0.07[D]	. . .	. . .
18	2	0.07[D]	. . .	0.07[D]	2½	0.07[D]	. . .	0.07[D]	3¼	0.07[D]	. . .	0.07[D]
21	2¼	0.14	. . .	0.11	2¾	0.07[D]	. . .	0.07[D]	3½	0.07[D]	. . .	0.07[D]
24	2½	0.17	. . .	0.14	3	0.07[D]	. . .	0.07[D]	3¾	0.07	. . .	0.07[D]
27	2⅝	0.18	. . .	0.16	3¼	0.16	. . .	0.14	4	0.08	. . .	0.07[D]
30	2¾	0.19	. . .	0.18	3½	0.18	. . .	0.15	4¼	0.10	. . .	0.08
33	2⅞	0.21	. . .	0.20	3¾	0.20	. . .	0.17	4½	0.12	. . .	0.10
36	3	0.21	0.13	0.23	4 [E]	0.17	0.10	0.19	4¾[E]	0.08	0.07	0.09
42	3½	0.25	0.15	0.28	4½	0.21	0.13	0.23	5¼	0.12	0.07	0.13
48	4	0.32	0.19	0.35	5	0.24	0.14	0.27	5¾	0.16	0.10	0.18
54	4½	0.38	0.23	0.42	5½	0.29	0.17	0.32	6¼	0.21	0.13	0.23
60	5	0.44	0.26	0.49	6	0.34	0.20	0.38	6¾	0.25	0.15	0.28
66	5½	0.50	0.30	0.55	6½	0.41	0.25	0.46	7¼	0.31	0.19	0.34
72	6	0.57	0.34	0.63	7	0.49	0.29	0.54	7¾	0.36	0.22	0.40

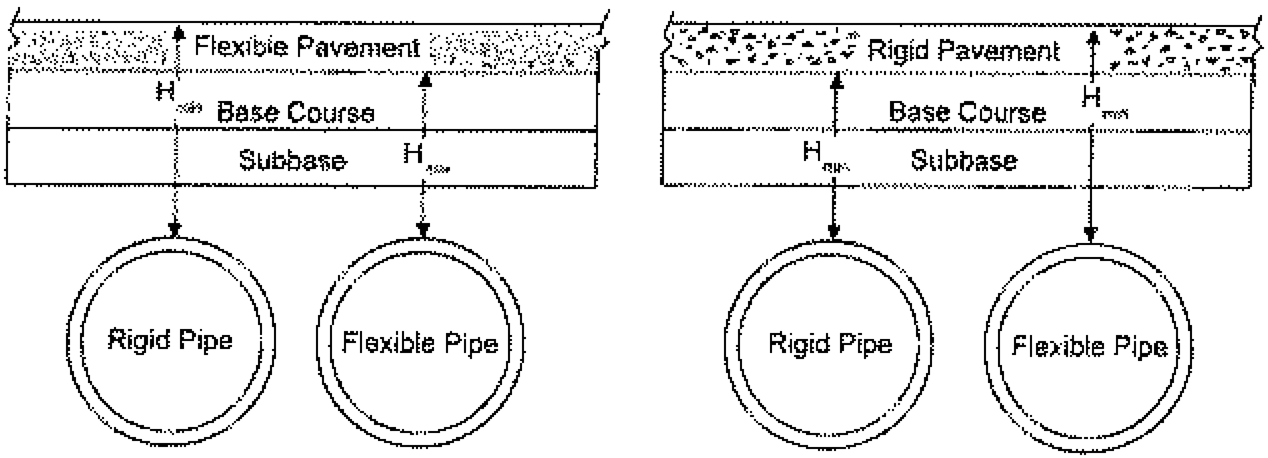
AASHTO LIVE LOAD DESIGN

The Latest

The Latest NCHRP Live Load Research, 2010

Where are We Measuring From? (C12.6.6.3)

Minimum Cover Orientation



H_{min} = 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.

Less Than 2 Feet of Cover

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.

$$\mathbf{E = 96 + 1.44S} \qquad (4.6.2.10.2\text{-}1)$$

E = Distribution width perpendicular to span in inches

S = Clear Span in feet

Less Than 2 Feet of Cover

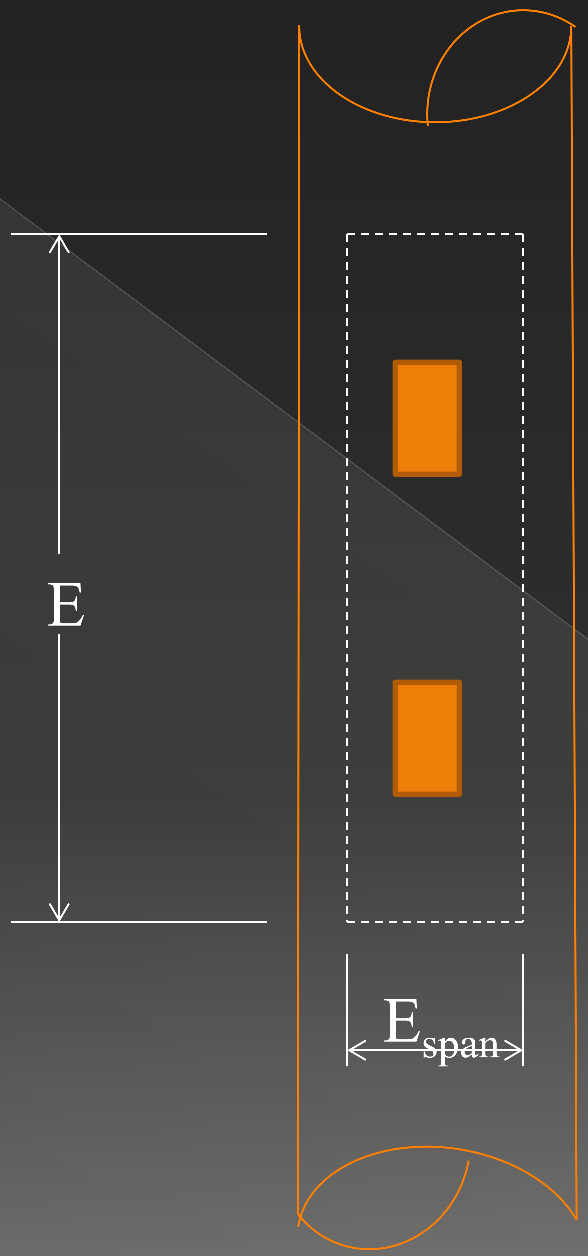
E_{span} = Distribution width parallel to span in inches

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

L_T = length of contact area parallel to span (in)
LLDF = live load distribution factor
H = depth of fill

Live Load Spread for Less Than 2 feet of Cover (single a

(Perpendicular)



For Trucks Traveling Parallel to the Axis of the Pipe

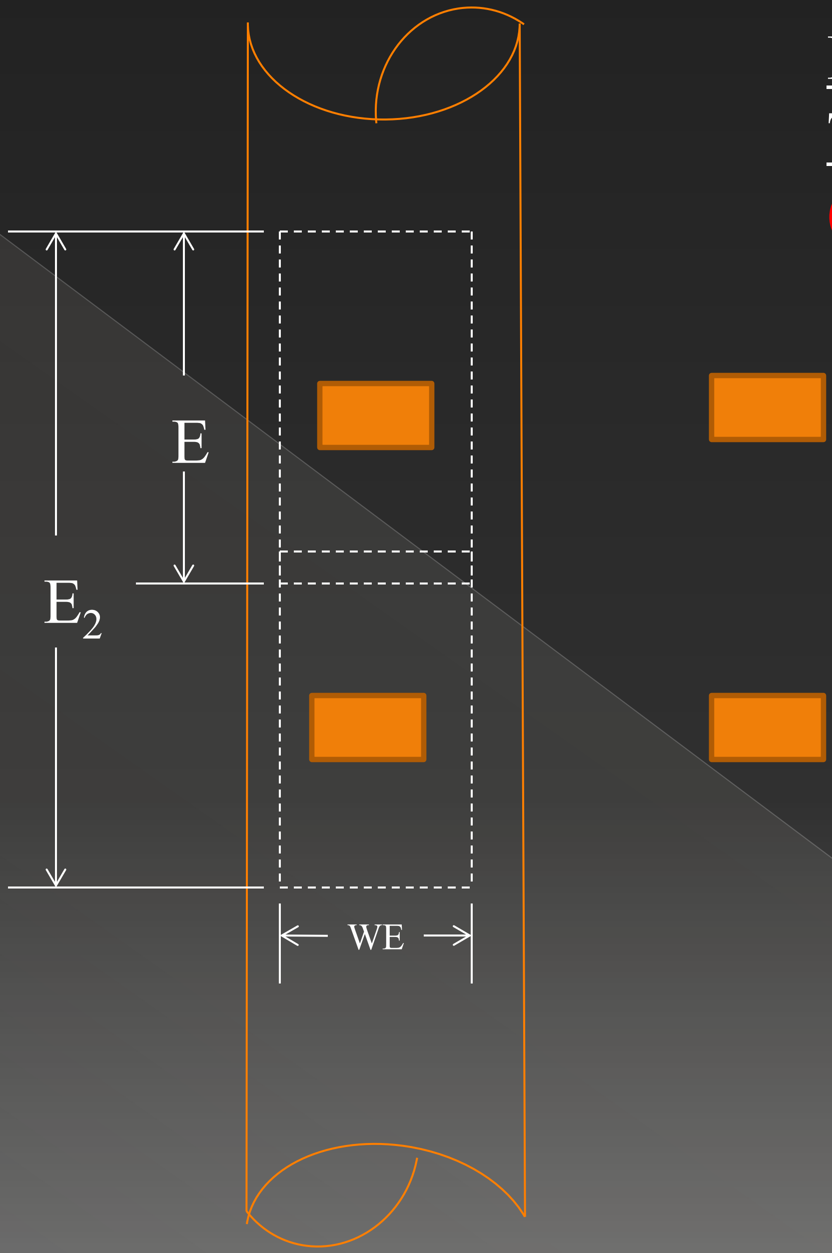
$$E = 96 + 1.44S \qquad (4.6.2.10.2\text{-}1)$$

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

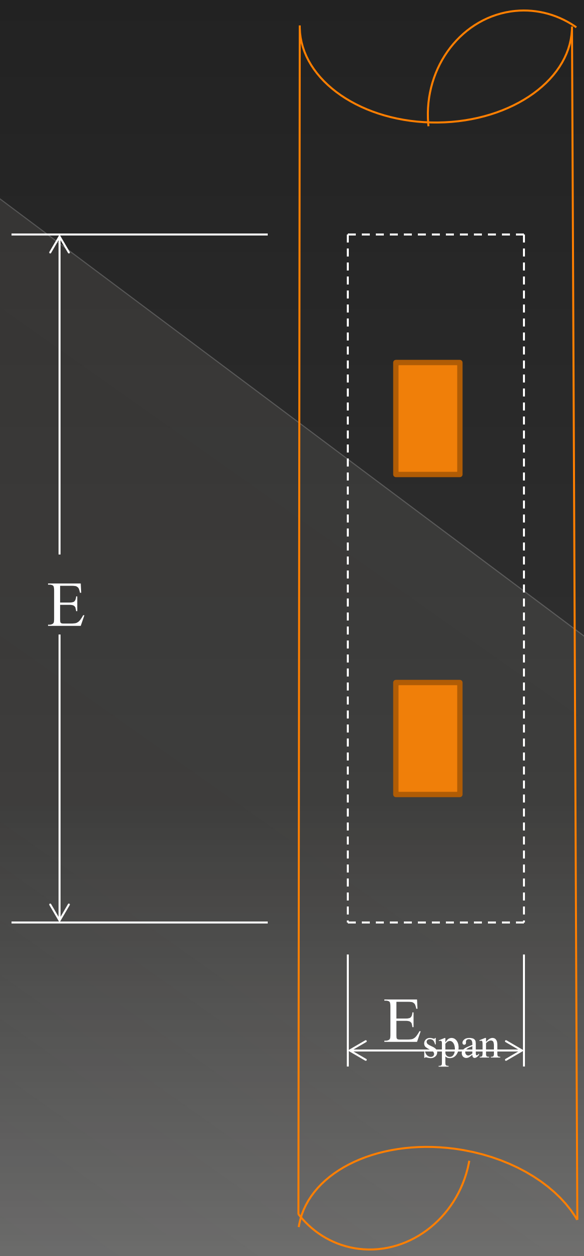
Note: Equation 4.6.2.10.2-1 is for an axle load.
with pipe, having much smaller spans than boxes
a distribution for wheel loads is more appropriate.

$$E_{wheel} = 48 + 0.72S$$

Live Load Spread for Less Than 2 feet of Cover (Parallel)



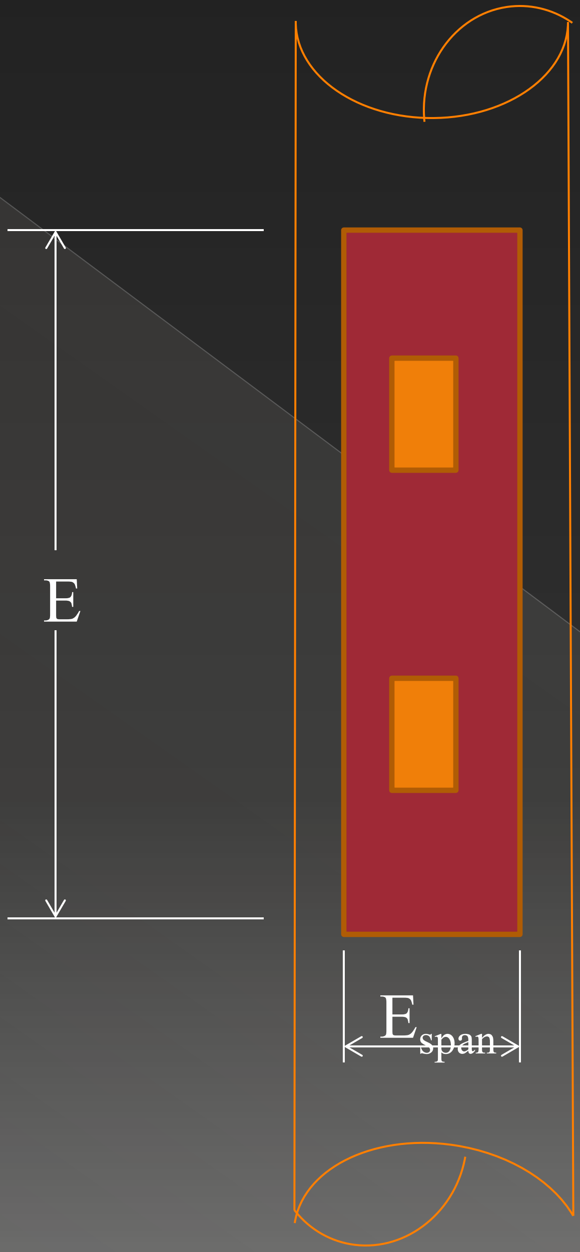
Live Load Spread for Less Than 2 feet of Cover (single axle (Perpendicular)



$$E_{span} = l_t + LLDF(H)$$

(4.6.2.10.2-2)

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



$$A_{LL} = l_w \, w_w \quad (3.6.1.2.6a\text{-}1)$$

$$A_{LL} = E_{span} * E$$

A_{LL} = rectangular area at depth H (ft²)

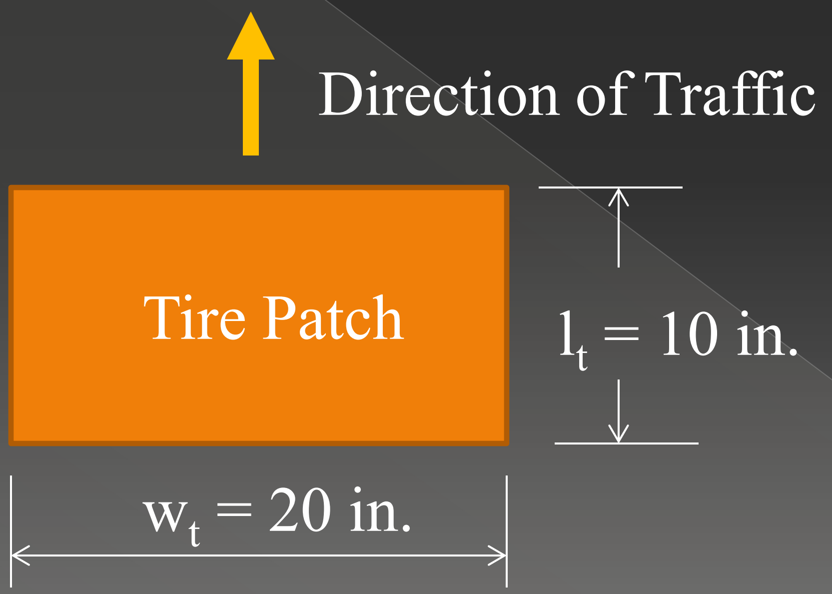
l_w = live load patch length at depth H (ft)

w_w = live load patch width at depth h (ft)

2 Feet or More

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.

Article 3.6.1.2.5



Live Load Distribution Factors

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

Structure Type	LLDF Transverse or Parallel to Span
Concrete Pipe with fill depth 2 ft or greater	1.15 for diameter 2 ft or less 1.75 for diameters 8 ft or greater Linearly interpolate for LLDF between these limits
All other culverts and buried structures	1.15

Traffic Perpendicular to Span

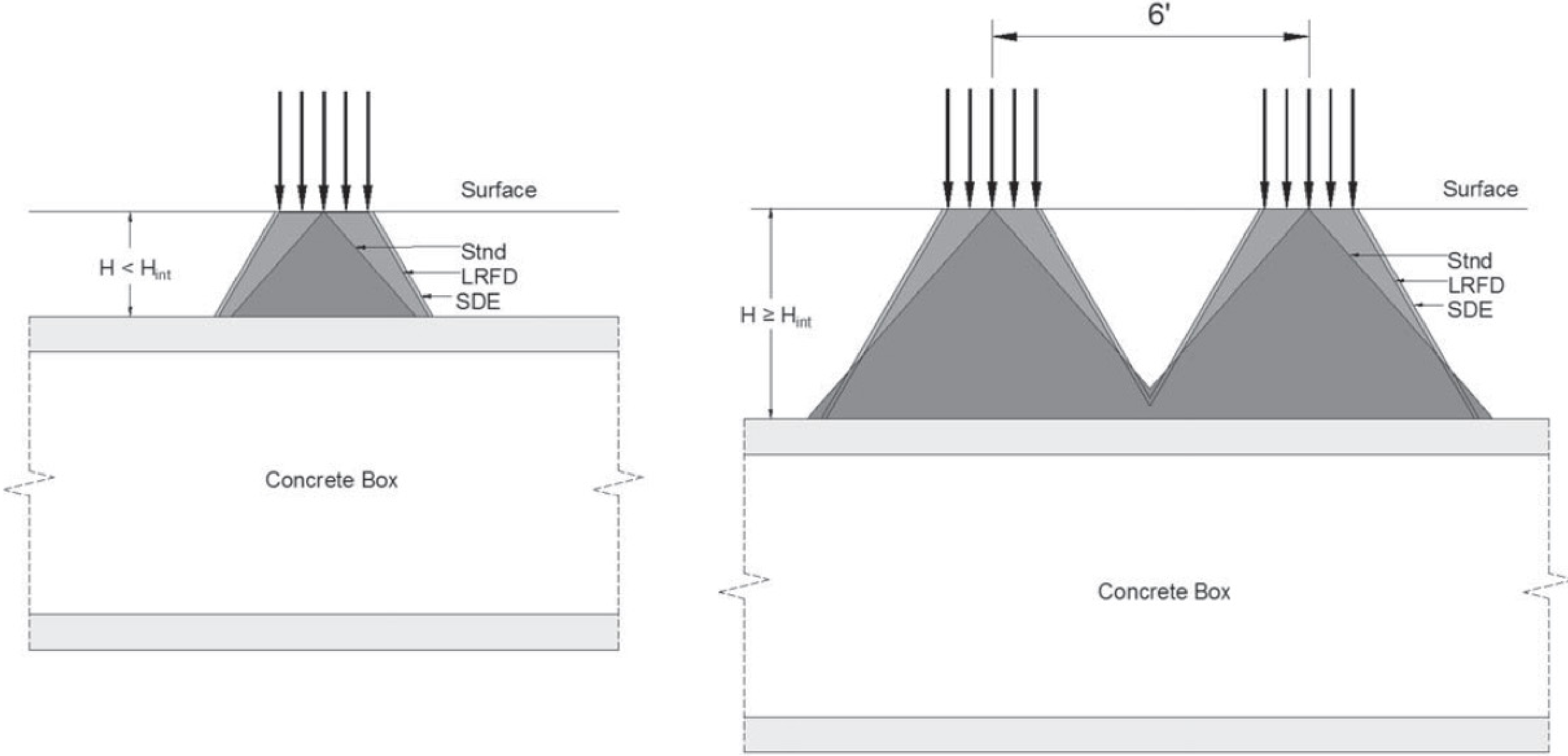


Figure S-1. Live load variation with depth for concrete box culverts (SDE refers to the proposed simplified design equations).

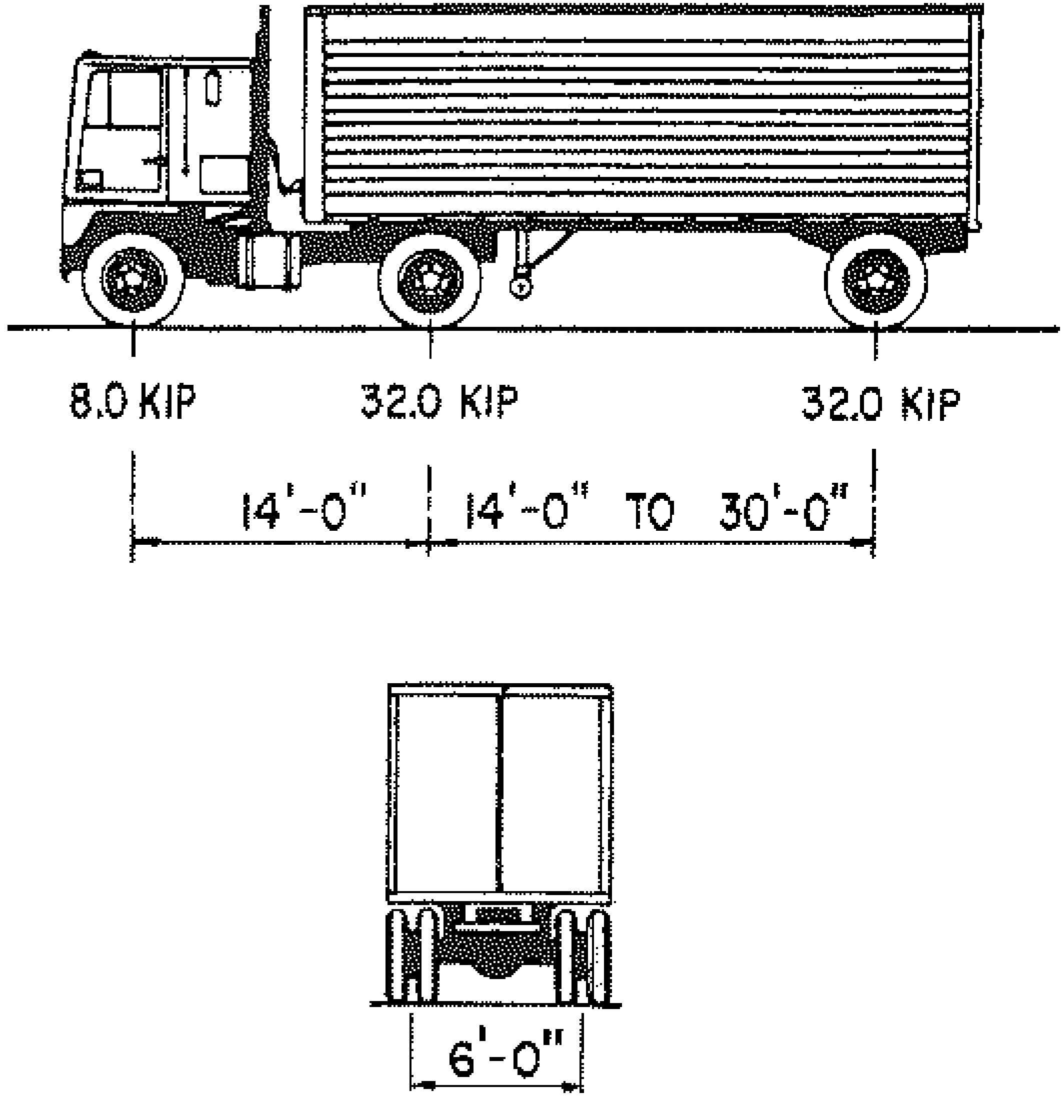
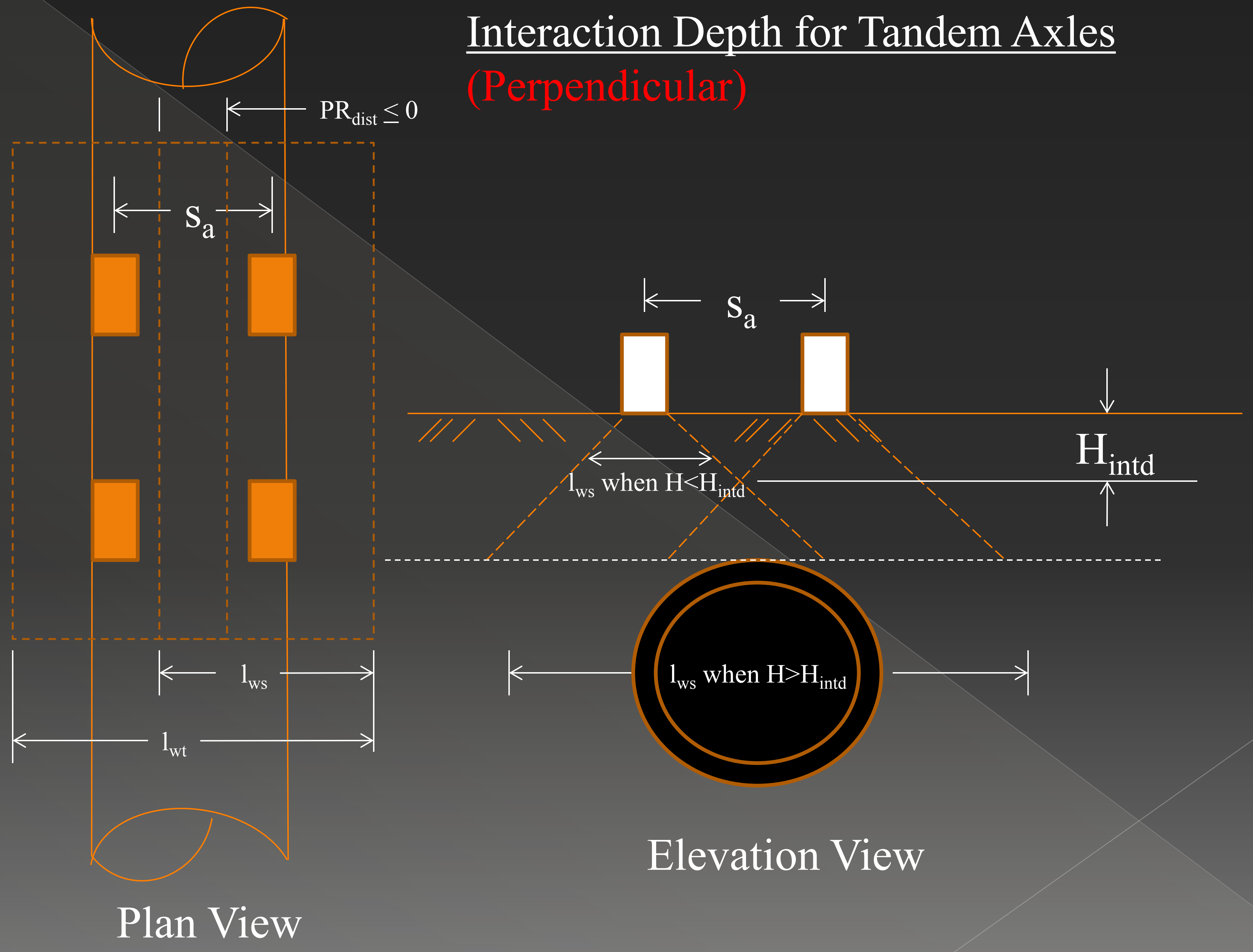


Figure 3.6.1.2.2-1—Characteristics of the Design Truck

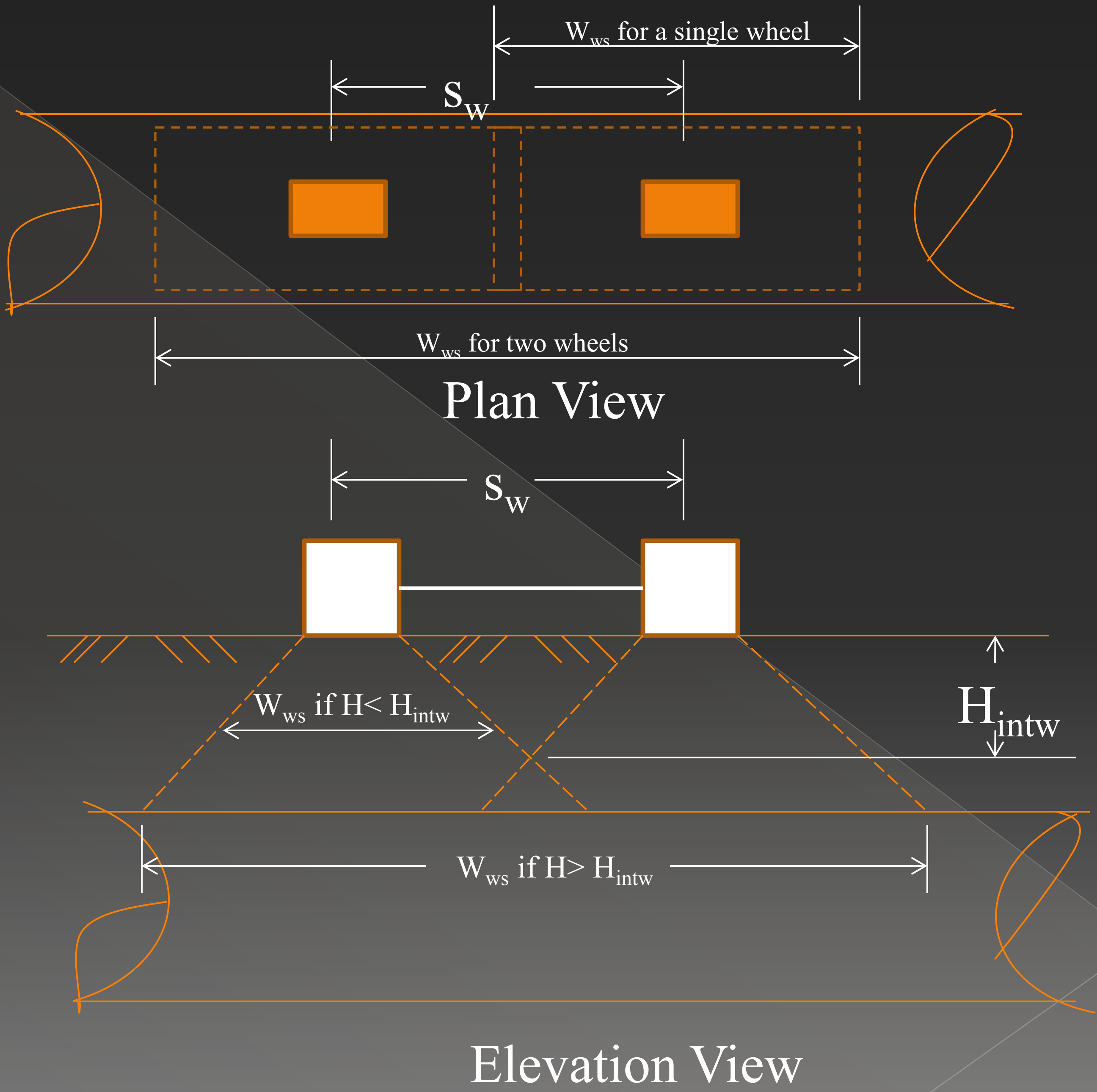
Wheel and Axle Spacing

- s_w = wheel spacing, 6.0 ft.
- s_a = axle spacing (ft)

Interaction Depth for Tandem Axles (Perpendicular)



Interaction Depth for Wheels (Perpendicular)



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-t} shall be determined as:

$$H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06D_i}{12}}{LLDF} \qquad (3.6.1.2.6b\text{-}1)$$

s_w = wheel spacing, 6.0 ft
w_t = tire patch width, 20 in.
D_i = inside diameter or clear span of the culvert (in)

Interaction Depth – Distribution Transverse to Culvert Span

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

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

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

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

Interaction Dept Parallel

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

$$H_{int\text{-}p} = \frac{s_a - \frac{l_t}{12}}{LLDF} \qquad (3.6.1.2.6b\text{-}4)$$

s_a = axle spacing (ft)
l_t = tire patch length, 10 (in)
LLDF = live load distribution factor

Interaction Depth – Distribution Parallel to Culvert Span

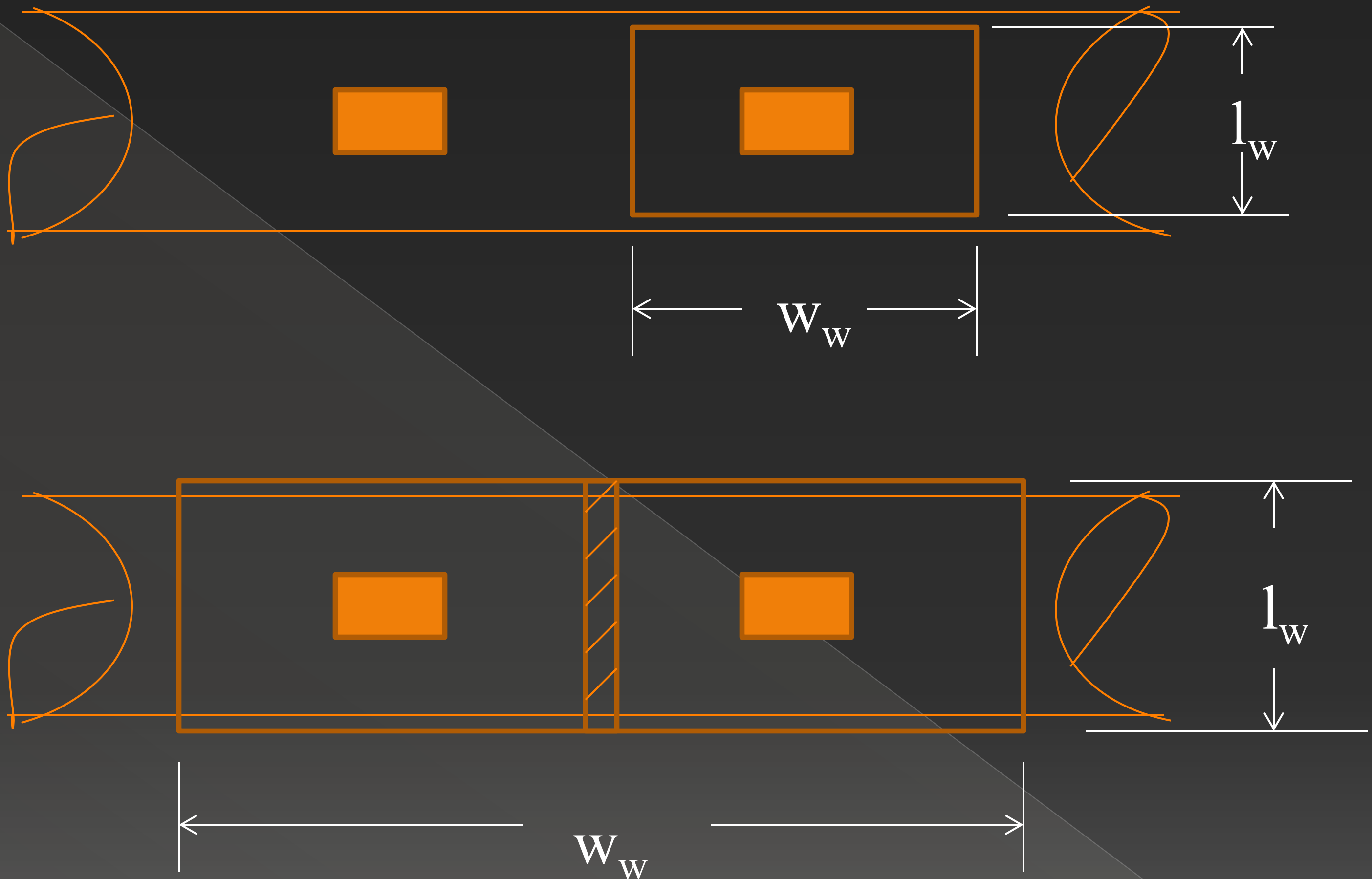
Where $H < H_{int\text{-}p}$

$l_w = l_t/12 + LLDF(H)$ (3.6.1.2.6b-5)

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

$l_w = l_t/12 + s_a + LLDF(H)$ (3.6.1.2.6b-6)

Pressure Area at the Top of the Pipe



Plan View

$$A_{LL} = l_w \, w_w \qquad (3.6.1.2.6a\text{-}1)$$

Pressure at the Top of the Pipe

$$P_L = \frac{P\left(1 + \frac{IM}{100}\right)(m)}{A_{LL}} \qquad (3.6.1.2.6b\text{-}7)$$

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

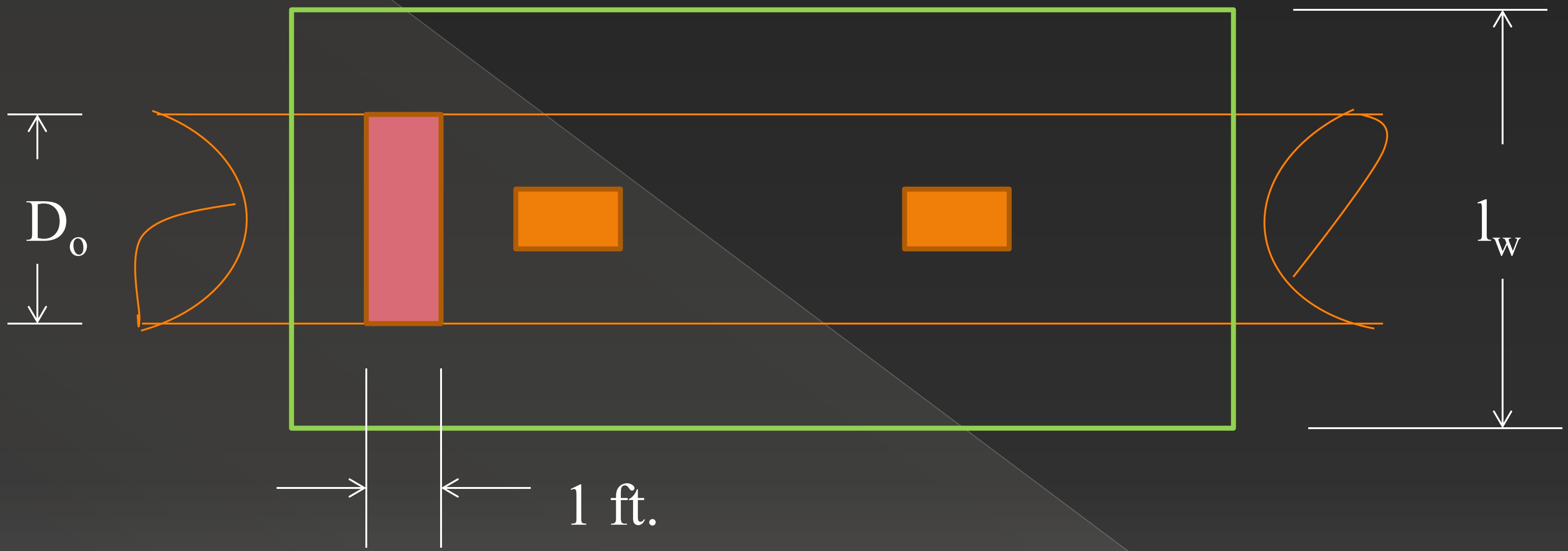
Dynamic Load Allowance

- 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

	Design Code	
Lanes	**AASHTO STD**	**AASHTO LRFD**
1	**1.0**	**1.2**
2	**1.0**	**1.0**
3	**0.90**	**0.85**
4	**0.75**	**0.65**

For Concrete Pipe, Load must be in Terms of lbs/ft



$W_L = P_L * L$ = live load (lbs/ft)

L = Smaller of l_w or D_o

D-Load Equation

$$D = \left(\frac{12}{S_i}\right)\left(\frac{W_E + W_F}{B_{FE}} + \frac{W_L}{B_{FLL}}\right) \qquad (12.10.4.3.1\text{-}1)$$

B_{FLL} = Live Load Bedding Factor

Live Load Bedding Factors

Table 12.10.4.3.2c-1

Pipe Diameter, in	Fill Height, ft	
	< 2 ft	≥ 2 ft
12	3.2	2.4
18	3.2	2.4
24	3.2	2.4
30 and larger	2.2	2.2

STANDARD INSTALLATIONS

Design Examples

EXAMPLE 1

- Embankment Condition
  - Pipe Size = 36" I.D., 44" = 3.67 ft. - D_o
  - Fill Height = H = 5 ft.
  - Soil Unit Weight = w = 120 lbs/ft^3
  - Check Type 2 and Type 3 Installations

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

- Soil Prism Load:
  - **PL = w H D_o**
  - PL = (120 lbs/ft^3)(5 ft.)(3.67 ft.)
  - PL = 2202 lbs/ft
  - **W = VAF x PL (AASHTO Equation 12.10.2.1-1)**

Type 2	Type 3
W = (1.40)(2202 lbs/ft)	W = (1.40)(2202 lbs/ft)
W = 3083 lbs/ft	**W = 3083 lbs/ft**

AASHTO LRFD Bridge Design Specifications, Section 12

The unfactored earth load, W_E, shall be determined as:

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

where:

W_E = unfactored earth load (kip/ft)
F_e = soil-structure interaction factor for the specified installation as defined herein
B_c = out-to-out horizontal dimension of pipe (ft)
H = height of fill over pipe (ft)
w = unit weight of soil (pcf)

AASHTO LRFD 12.10.2.1

Table 12.10.2.1-3 Coefficients for use with Figure 1.

	Installation Type			
	1	2	3	4
VAF	1.35	1.40	1.40	1.45
HAF	0.45	0.40	0.37	0.30
A1	0.62	0.85	1.05	1.45
A2	0.73	0.55	0.35	0.00
A3	1.35	1.40	1.40	1.45
A4	0.19	0.15	0.10	0.00
A5	0.08	0.08	0.10	0.11
A6	0.18	0.17	0.17	0.19
a	1.40	1.45	1.45	1.45
b	0.40	0.40	0.36	0.30
c	0.18	0.19	0.20	0.25
e	0.08	0.10	0.12	0.00
f	0.05	0.05	0.05	—
u	0.80	0.82	0.85	0.90
v	0.80	0.70	0.60	—

Determine Fluid load

- γ_w = 62.4 pcf
- ID = 3 ft
- $W_f = \gamma_w \times \pi \times (ID/2)^2$
- W_f = 441 lbs/ft

DETERMINE LIVE LOAD

- 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;"

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-t} shall be determined as:

$$H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06 D_i}{12}}{LLDF} \qquad (3.6.1.2.6b\text{-}1)$$

Live Load Distribution Factor

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

Structure Type	LLDF Transverse or Parallel to Span
Concrete Pipe with fill depth 2 ft or greater	1.15 for diameter 2 ft or less 1.75 for diameters 8 ft or greater Linearly interpolate for LLDF between these limits
All other culverts and buried structures	1.15

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

$$\text{LLDF} = 1.25$$

Interaction Depth

3.6.1.2.6b—Traffic Parallel to the Culvert Span

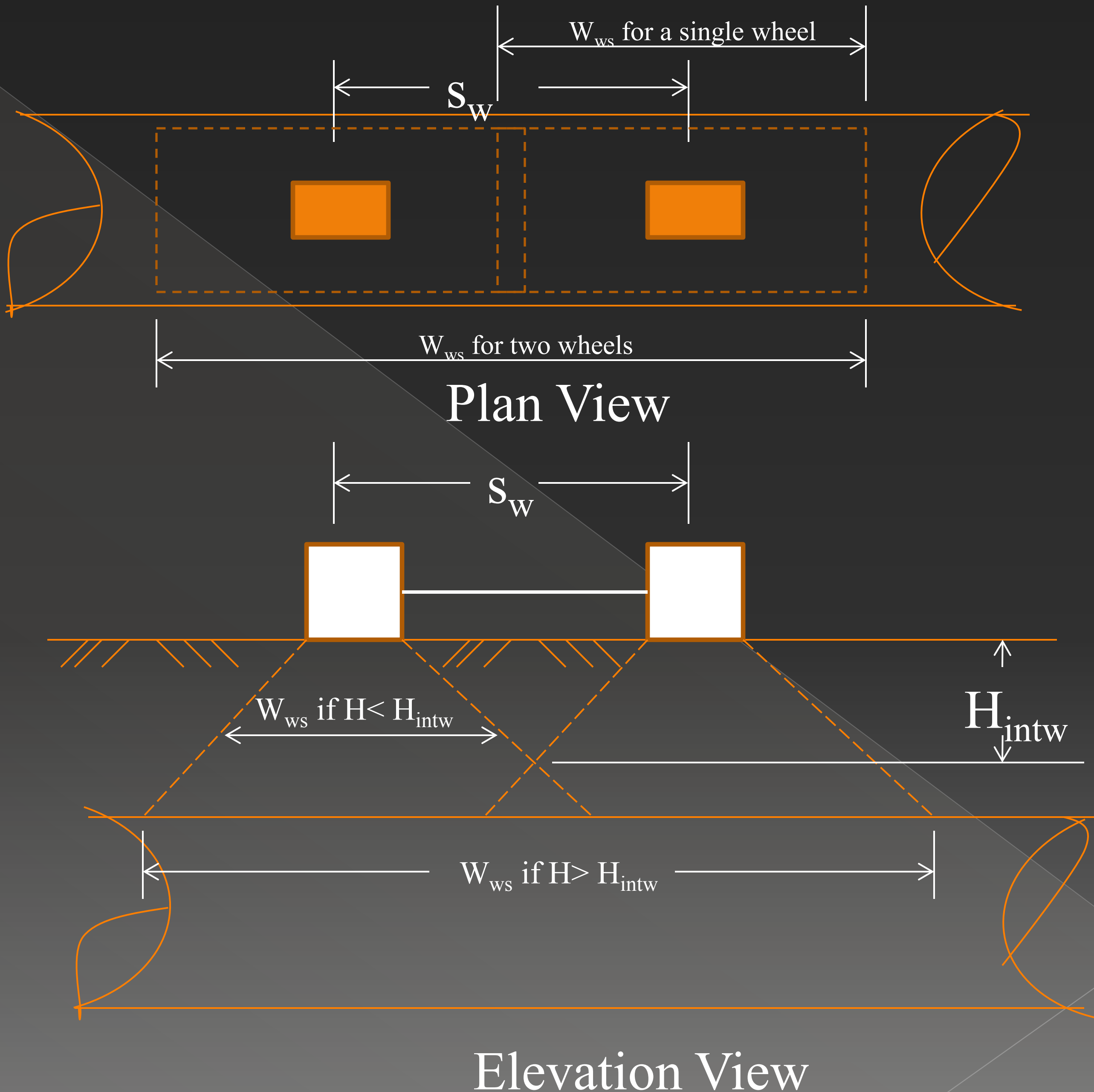
For live load distribution transverse to culvert spans, the wheel/axle load interaction depth H_{int-t} shall be determined as:

$$H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06D_i}{12}}{LLDF} \qquad (3.6.1.2.6b\text{-}1)$$

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

$$H_{int-t} = 3.32\text{ ft}$$

Interaction Depth for Wheels (Perpendicular)



Interaction Dept Parallel

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

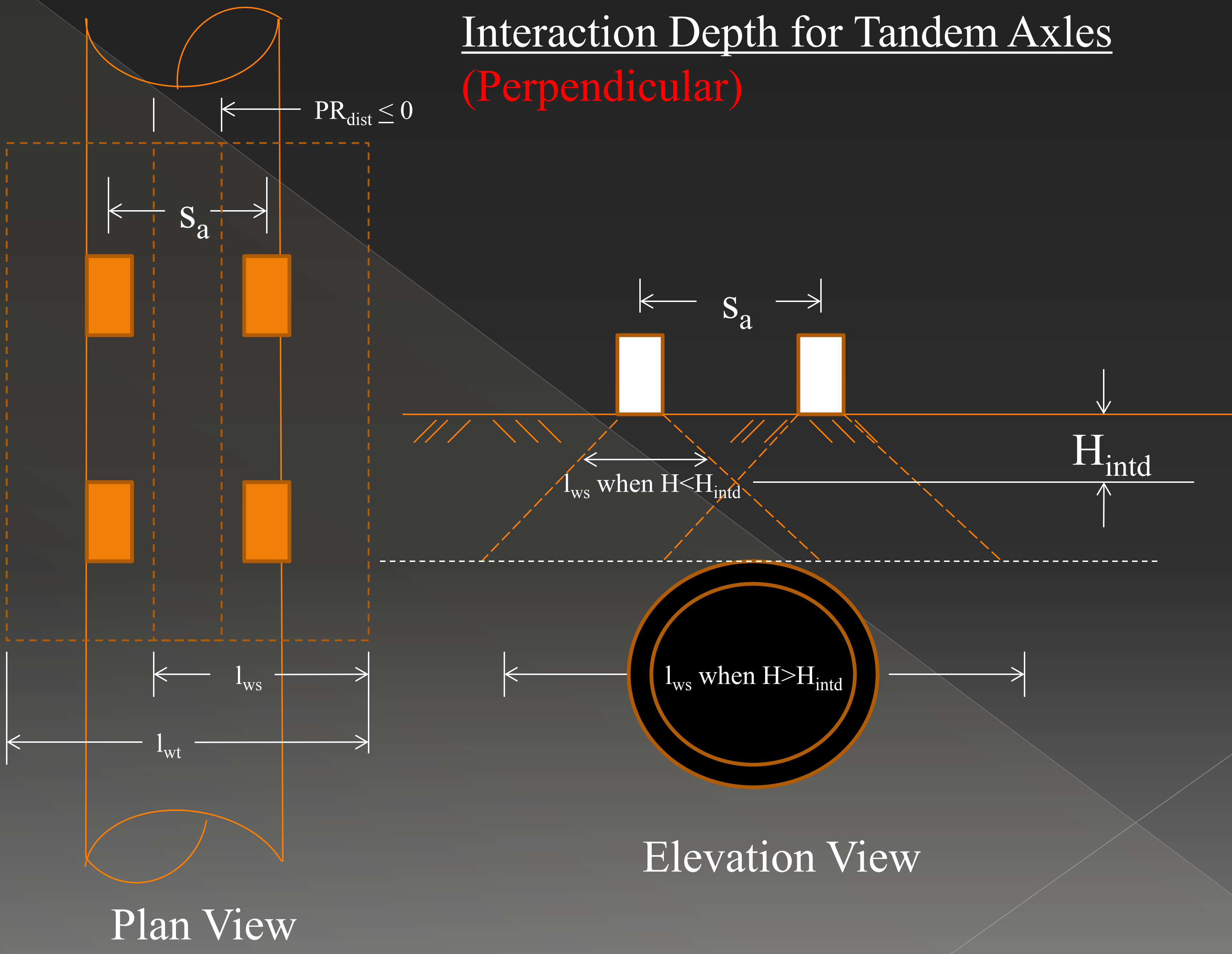
$$H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF} \qquad (3.6.1.2.6b\text{-}4)$$

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

$$H_{int-p} = 2.53\ ft$$

Interaction Depth for Tandem Axles

(Perpendicular)



Pressure at top of Pipe

For The Single Axle (HS20)

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

$W_w = w_t/12 + s_w + LLDF(H) + 0.06(D_i/12)$ (3.6.1.2.6b-3)

$W_w = (20''/12) + 6\text{ ft} + 1.25*5\text{ ft} + 0.06*3\text{ ft}$

$W_w = 14.1\text{ ft}$

Where $H < H_{int-p}$

$l_w = l_t/12 + LLDF(H)$ (3.6.1.2.6b-5)

$l_w = 10''/12 + 1.25*5\text{ ft.}$

$l_w = 7.1\text{ ft}$

$A_{LL} = 14.1\text{ ft} \times 7.1\text{ ft} = 100\text{ ft}^2$

Pressure at top of Pipe

For The Tandem Axles

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

$W_w = w_t/12 + s_w + LLDF(H) + 0.06(D_i/12)$ (3.6.1.2.6b-3)

$$W_w = (20''/12) + 6\text{ ft} + 1.25*5\text{ ft} + 0.06*3\text{ ft}$$

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

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

$l_w = l_t/12 + s_a + LLDF(H)$ (3.6.1.2.6b-5)

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

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

$A_{LL} = 14.1\text{ ft} \times 11.1\text{ ft} = 156.5\text{ ft}^2$

Pressure at top of Pipe

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

(3.6.1.2.6b-7)

Load P

For the single axle – P = 16 kips x 2 wheel loads

P = 32 kips

For the tandem axle – P = 12.5 kips x 4 wheel loads

P = 50 kips

Pressure at top of Pipe

$$P_L = \frac{P\left(1 + \frac{IM}{100}\right)(m)}{A_{LL}} \qquad (3.6.1.2.6b\text{-}7)$$

$IM = 33*[1 – 0.125 (H)]$

$IM = 33*[1 – 0.125 (5)]$

$IM = 12.375$

$m = 1.2$ for a single lane

Pressure at top of Pipe

$$P_L = \frac{P\left(1 + \frac{IM}{100}\right)(m)}{A_{LL}} \qquad (3.6.1.2.6b\text{-}7)$$

$$P_{Ls} = \frac{32000\ \text{lbs}\left(1 + \frac{12.375}{100}\right)(1.2)}{100\ \text{ft}^2} = 431.5\ \text{psf}$$

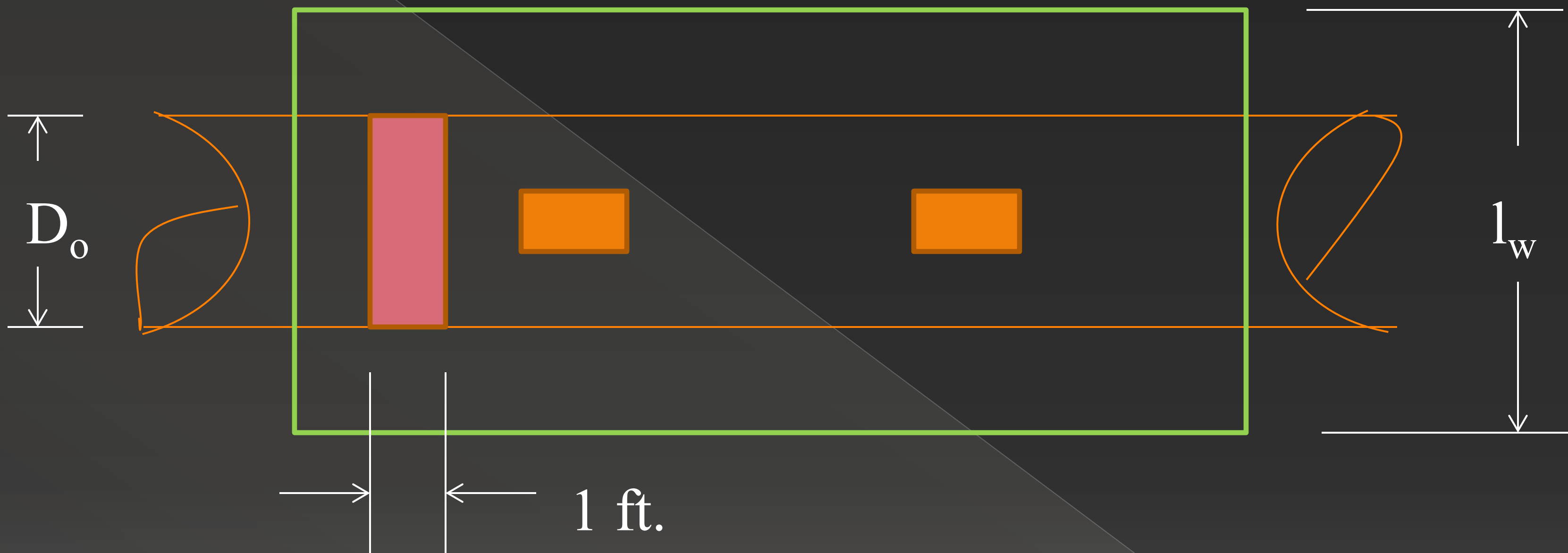
$$P_{Lt} = \frac{50000\ \text{lbs}\left(1 + \frac{12.375}{100}\right)(1.2)}{156.5\ \text{ft}^2} = 430.8\ \text{psf}$$

Live Load on the Pipe

- Outside Diameter = 3.67 lbs/ft
- Spread length for Single Axle
  - l_w = 7.1 ft
- Spread length for Tandem Axles
  - l_w = 11.1 ft

- Live load = O.D. x P_L
  - W_L = 3.67 ft x 431.5 psf = 1583.6 lbs/ft

For Concrete Pipe, Load must be in Terms of lbs/ft



$W_L = P_L * L$ = live load (lbs/ft)

L = Smaller of l_w 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

SELECTION OF BEDDING

- We will compare Type 2 and Type 3 installations.

Standard Installations D-load

$$D = \left(\frac{12}{S_i}\right)\left(\frac{W_E + W_F}{B_{FE}} + \frac{W_L}{B_{FLL}}\right) \qquad (12.10.4.3.1\text{-}1)$$

Embankment Bedding Factors

Table 12.10.4.3.2a-1 Bedding Factors for Circular Pipe.

Pipe Diameter, in.	Standard Installations			
	Type 1	Type 2	Type 3	Type 4
12	4.4	3.2	2.5	1.7
24	4.2	3.0	2.4	1.7
36	4.0	2.9	2.3	1.7
72	3.8	2.8	2.2	1.7
144	3.6	2.8	2.2	1.7

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**

Live Load Bedding Factor

Table 12.10.4.3.2c-1

Pipe Diameter, in	Fill Height, ft	
	< 2 ft	≥ 2 ft
12	3.2	2.4
18	3.2	2.4
24	3.2	2.4
30 and larger	2.2	2.2

Type 2, $B_{FLL} = 2.2$
Type 3, $B_{FLL} = 2.2$

Find D-load

$$D = \left(\frac{12}{S_i}\right)\left(\frac{W_E + W_F}{B_{FE}} + \frac{W_L}{B_{FLL}}\right) \qquad (12.10.4.3.1\text{-}1)$$

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

$$D_{0.01} = \left[\frac{3{,}083 \text{ lbs/ft} + 441 \text{ lbs/ft}}{2.9} + \frac{1584 \text{ lbs/ft}}{2.2} \right] \times \frac{1.0}{3 \text{ ft}}$$

$D_{0.01}$ = 645 lbs/linear ft/ft of diameter

SELECTION OF PIPE STRENGTH FOR A TYPE 3 INSTALLATION

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

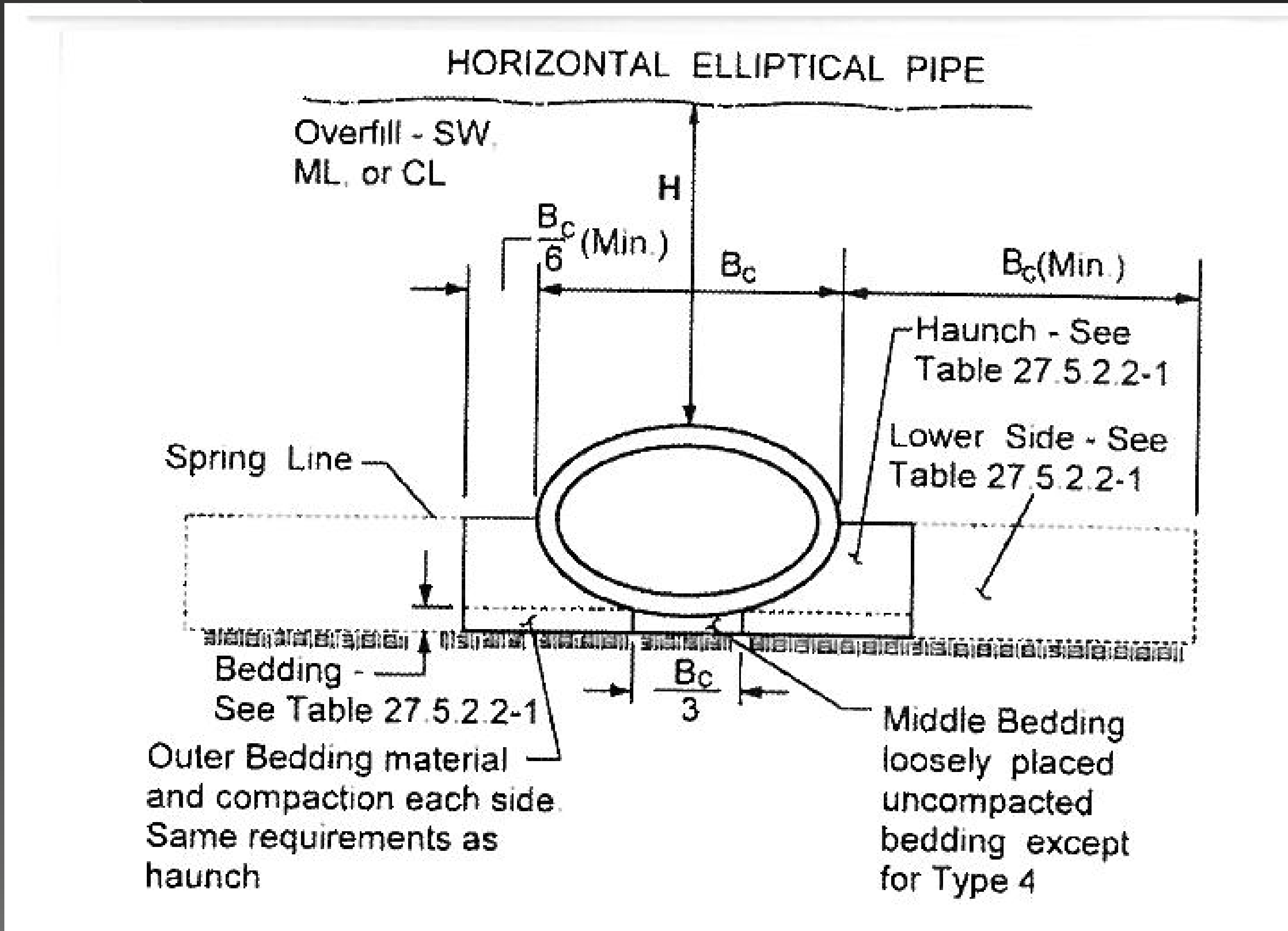
$D_{0.01}$ = 751 lbs/linear ft/ft of diameter

ASTM C 76 PIPE CLASSES

- 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



Elliptical Pipe Installations

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

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

Find D-load

$$D = \left(\frac{12}{S_i}\right)\left(\frac{W_E + W_F}{B_{FE}} + \frac{W_L}{B_{FLL}}\right) \qquad (12.10.4.3.1\text{-}1)$$

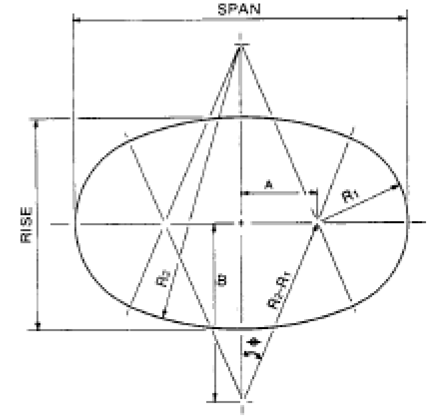
Soil Load

- $W_E = F_e \gamma_s B_c H$
  - Pipe – Section 12.10.2.1-1

AASHTO LRFD 12.10.2.1

Table 12.10.2.1-3 Coefficients for use with Figure 1.

	Installation Type			
	1	2	3	4
VAF	1.35	1.40	1.40	1.45
HAF	0.45	0.40	0.37	0.30
A1	0.62	0.85	1.05	1.45
A2	0.73	0.55	0.35	0.00
A3	1.35	1.40	1.40	1.45
A4	0.19	0.15	0.10	0.00
A5	0.08	0.08	0.10	0.11
A6	0.18	0.17	0.17	0.19
a	1.40	1.45	1.45	1.45
b	0.40	0.40	0.36	0.30
c	0.18	0.19	0.20	0.25
e	0.08	0.10	0.12	0.00
f	0.05	0.05	0.05	—
u	0.80	0.82	0.85	0.90
v	0.80	0.70	0.60	—



SYMMETRICAL ABOUT AXES

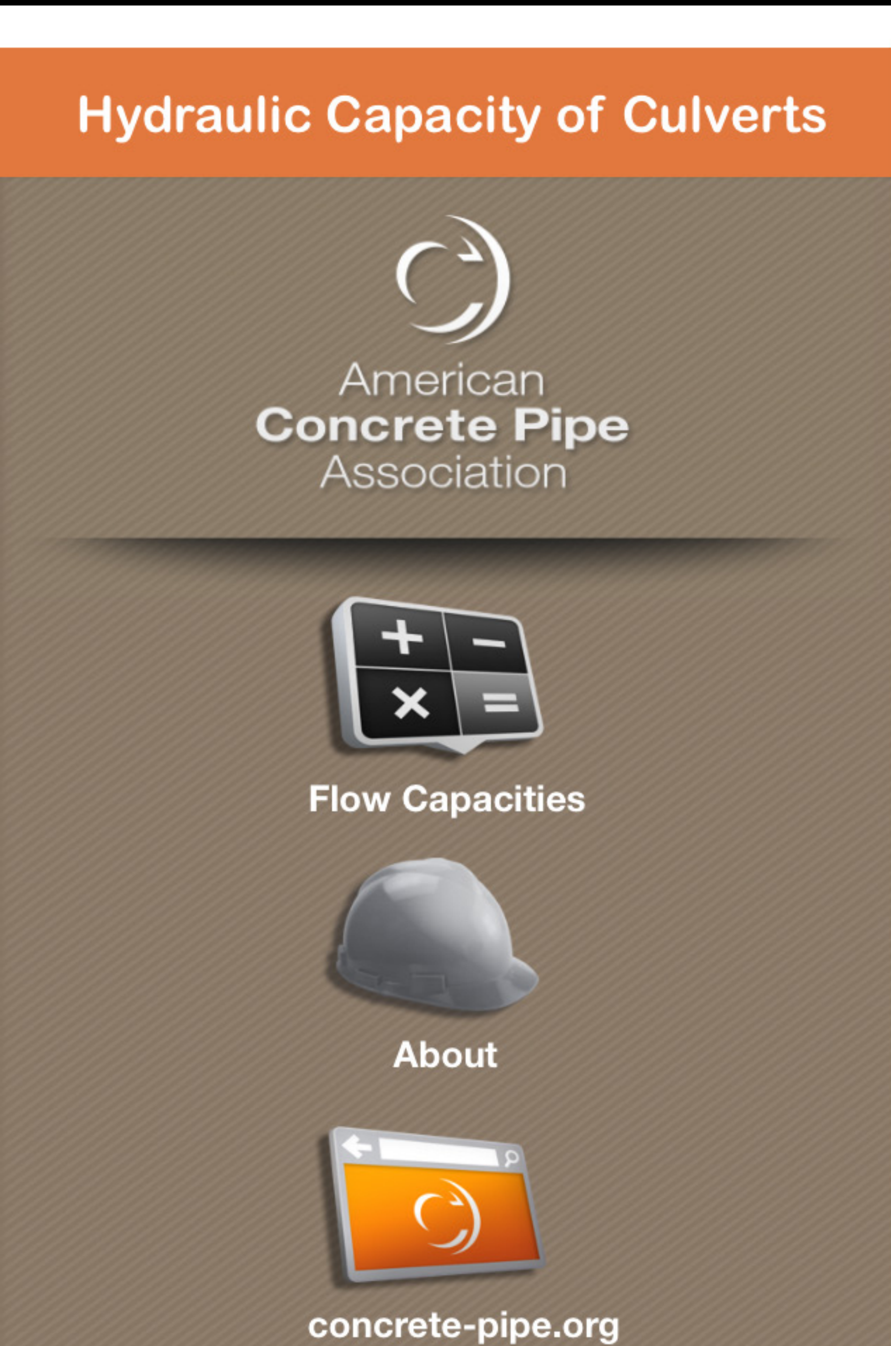
Approximate Equivalent Round Size, in. K	Full Flow Water Area, ft^2	Rise, in.	Span, in.	*A*, in.	*B*, in.	R_1, in.	R_2, in.	θ Degrees
18	1.83	14¼	22¾	5⅝	12⅞	6	20	22.6
24	3.28	19¼	30¼	6⅞	16⅝	8¼	26¼	22.6
27	4.12	21½	34	7¾	18½	9¼	29¼	22.6
30	5.10	24	37¾	8⅝	20¾	10¼	32¾	22.6
33	6.33	26¾	42	9½	22⅞	11½	36¼	22.6
36	7.36	28¾	45½	10½	24⅞	12¼	39¼	22.6
39	8.78	31½	49½	11¼	27	13½	42¾	22.6
42	10.2	34	53¼	12⅛	29	14½	46	22.6
48	12.9	38¼	60	13½	32⅝	16½	51½	22.6
54	16.7	43½	68	15¼	36¾	18¾	58½	22.6
60	20.5	48¼	75½	17	40⅞	20¾	65	22.6
66	24.8	53	83	18¾	45	22¾	71½	22.6
72	29.4	57¾	90½	20½	49⅛	24¾	78	22.6
78	34.6	62¾	98	22	53⅛	27	84½	22.6
84	40.1	67½	105½	23¾	57	29	90¾	22.6
90	46.1	72½	113	25½	61	31	97¼	22.6
96	52.4	77¼	120½	27	65⅛	33¼	103¾	22.6
102	59.1	82	128	28¾	69	35¼	110	22.6
108	66.4	87	135½	30¼	72¾	37½	116¼	22.6
114	73.9	91¾	143	32	76⅞	39½	122¾	22.6
120	82.1	96¾	150¾	33⅞	80⅞	41½	129¼	22.7
132	99.2	106½	165½	37	88¾	45¾	142	22.6
144	118	116	180¾	40⅝	96¾	50	154¾	22.6

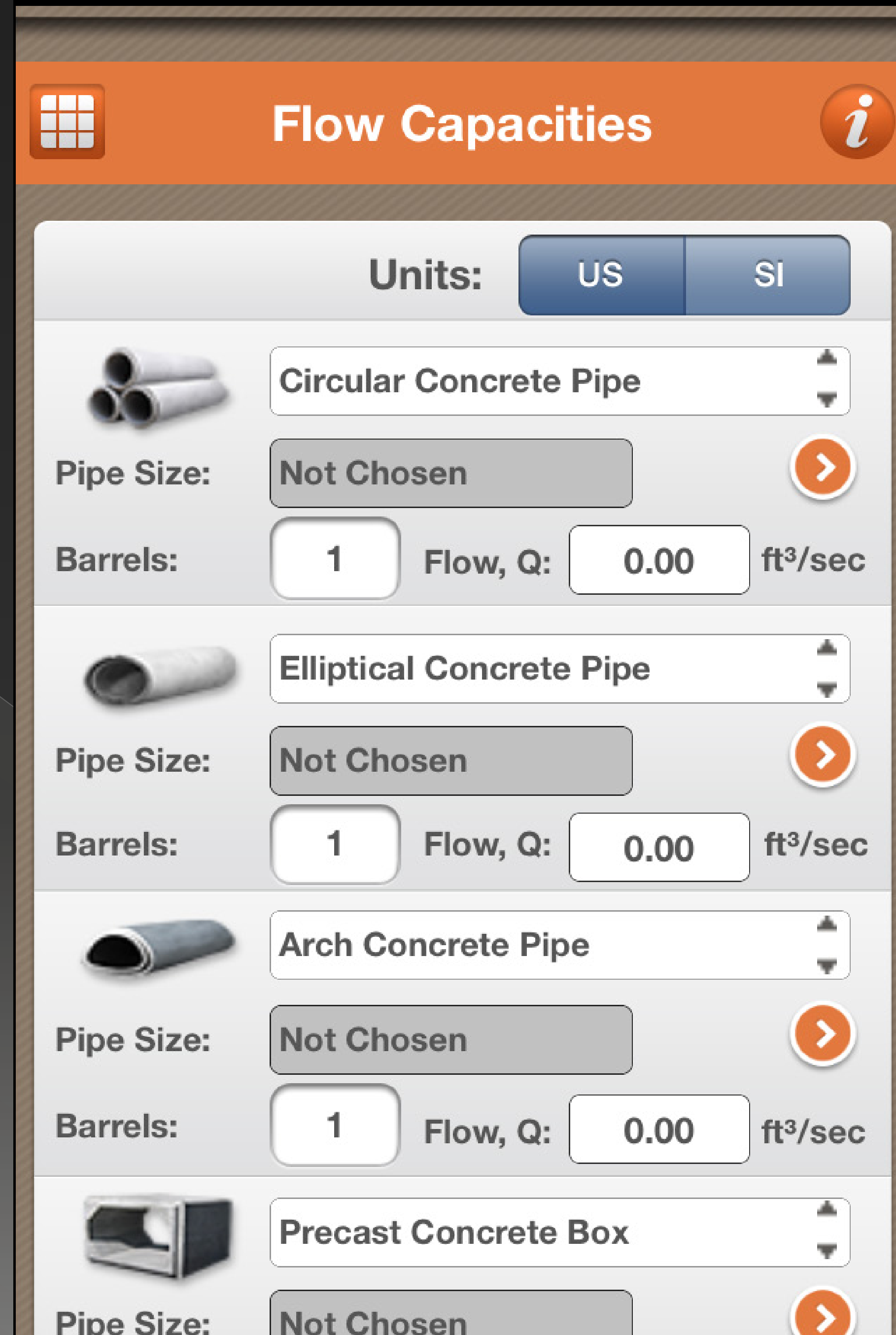
NOTE 1—Rise, span, and radii are fixed; other dimensions and angles are calculated.

FIG. 5 Cross-Sectional Shape of Elliptical Pipe

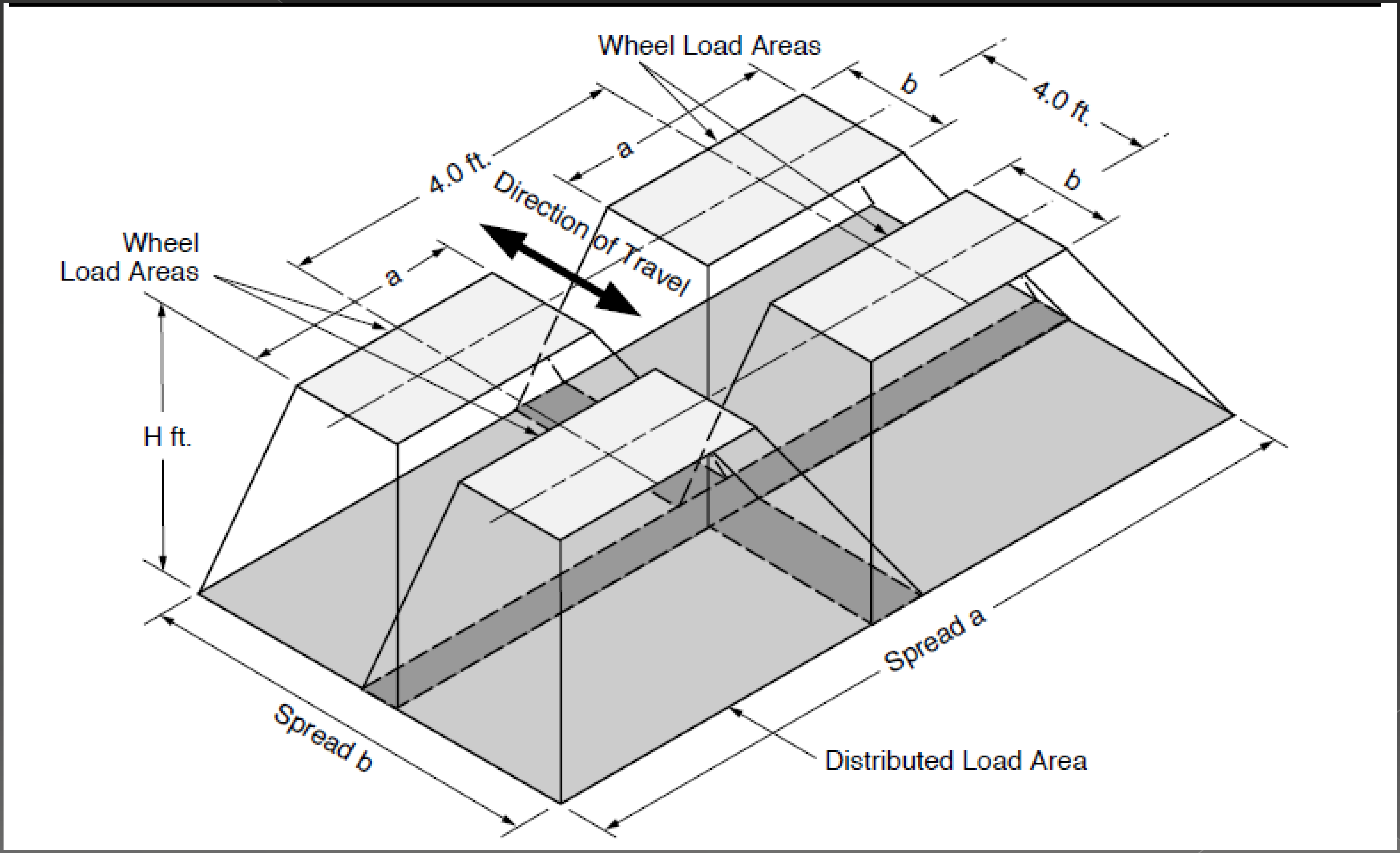
Flow Area Per ASTM C 507

Approximate Equivalent Round Size, in. K	Full Flow Water Area, ft^3	Rise, in.	Span, in.
18	1.83	14¼	22¾
24	3.28	19¼	30¼
27	4.12	21½	34
30	5.10	24	37¾
33	6.33	26¾	42
36	7.36	28¾	45½
39	8.78	31½	49½
42	10.2	34	53¼


Hydraulic Capacity of Culverts
American
Concrete Pipe
Association
Flow Capacities
About
concrete-pipe.org


Flow Capacities
Units:
US
SI
Circular Concrete Pipe
Pipe Size:
Not Chosen
Barrels:
1
Flow, Q:
0.00
ft³/sec
Elliptical Concrete Pipe
Pipe Size:
Not Chosen
Barrels:
1
Flow, Q:
0.00
ft³/sec
Arch Concrete Pipe
Pipe Size:
Not Chosen
Barrels:
1
Flow, Q:
0.00
ft³/sec
Precast Concrete Box
Pipe Size:
Not Chosen

Live Load



Wheel Load Areas
4.0 ft.
a
b
4.0 ft.
b
Direction of Travel
Wheel
Load Areas
a
H ft.
Spread a
Spread b
Distributed Load Area

Bedding Factors

Not the Same Earth Load Bedding Factor As Circular Pipe

12.10.4.3.2b—Earth Load Bedding Factor for Arch and Elliptical Pipe

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

$$B_{FE} = \frac{C_A}{C_N - xq} \qquad (12.10.4.3.2b\text{-}1)$$

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

= 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

= 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

Pipe Shape	C_A	Installation Type	C_N	Projection Ratio, p	x
Horizontal Elliptical and Arch	1.337	2	0.630	0.9	0.421
				0.7	0.369
		3	0.763	0.5	0.268
				0.3	0.148
Vertical Elliptical	1.021	2	0.516	0.9	0.718
				0.7	0.639
		3	0.615	0.5	0.457
				0.3	0.238

The value of the parameter q is taken as:

- For arch and horizontal elliptical pipe:

$$q = 0.23\frac{p}{F_e}\left(1 + 0.35p\frac{B_c}{H}\right) \qquad (12.10.4.3.2b\text{-}2)$$

- For vertical elliptical pipe:

$$q = 0.48\frac{p}{F_e}\left(1 + 0.73p\frac{B_c}{H}\right) \qquad (12.10.4.3.2b\text{-}3)$$

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

$$B_{FE} = \frac{C_A}{C_N - xq} \qquad (12.10.4.3.2b\text{-}1)$$

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

= 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

= 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:

$$B_{FE} = \frac{C_A}{C_N - xq} \qquad (12.10.4.3.2b\text{-}1)$$

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

Pipe Shape	C_A	Installation Type	C_N	Projection Ratio, p	x
Horizontal Elliptical and Arch	1.337	2	0.630	0.9 0.7	0.421 0.369
		3	0.763	0.5 0.3	0.268 0.148
Vertical Elliptical	1.021	2	0.516	0.9 0.7	0.718 0.639
		3	0.615	0.5 0.3	0.457 0.238

Horizontal Elliptical Bedding Factor

- For arch and horizontal elliptical pipe:

$$q = 0.23 \frac{p}{F_e}\left(1 + 0.35\, p \frac{B_c}{H}\right) \qquad (12.10.4.3.2b\text{-}2)$$

- $F_e = 1.4$

Bedding Factor Per AASHTO

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

$$B_{FE} = \frac{C_A}{C_N - xq} \quad (12.10.4.3.2b\text{-}1)$$

Live Load Bedding Factors

Table 12.10.4.3.2c-1

Pipe Diameter, in	Fill Height, ft	
	< 2 ft	≥ 2 ft
12	3.2	2.4
18	3.2	2.4
24	3.2	2.4
30 and larger	2.2	2.2

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/ft^3

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 lbs/ft^3)(1ft.)(5.25 ft.)
  - PL = 630 lbs/ft
  - **W = VAF x PL (AASHTO Equation 12.10.2.1-1)**
  - **Type 2**
  - W = (1.40)(630 lbs/ft)
  - **W = 882 lbs/ft**

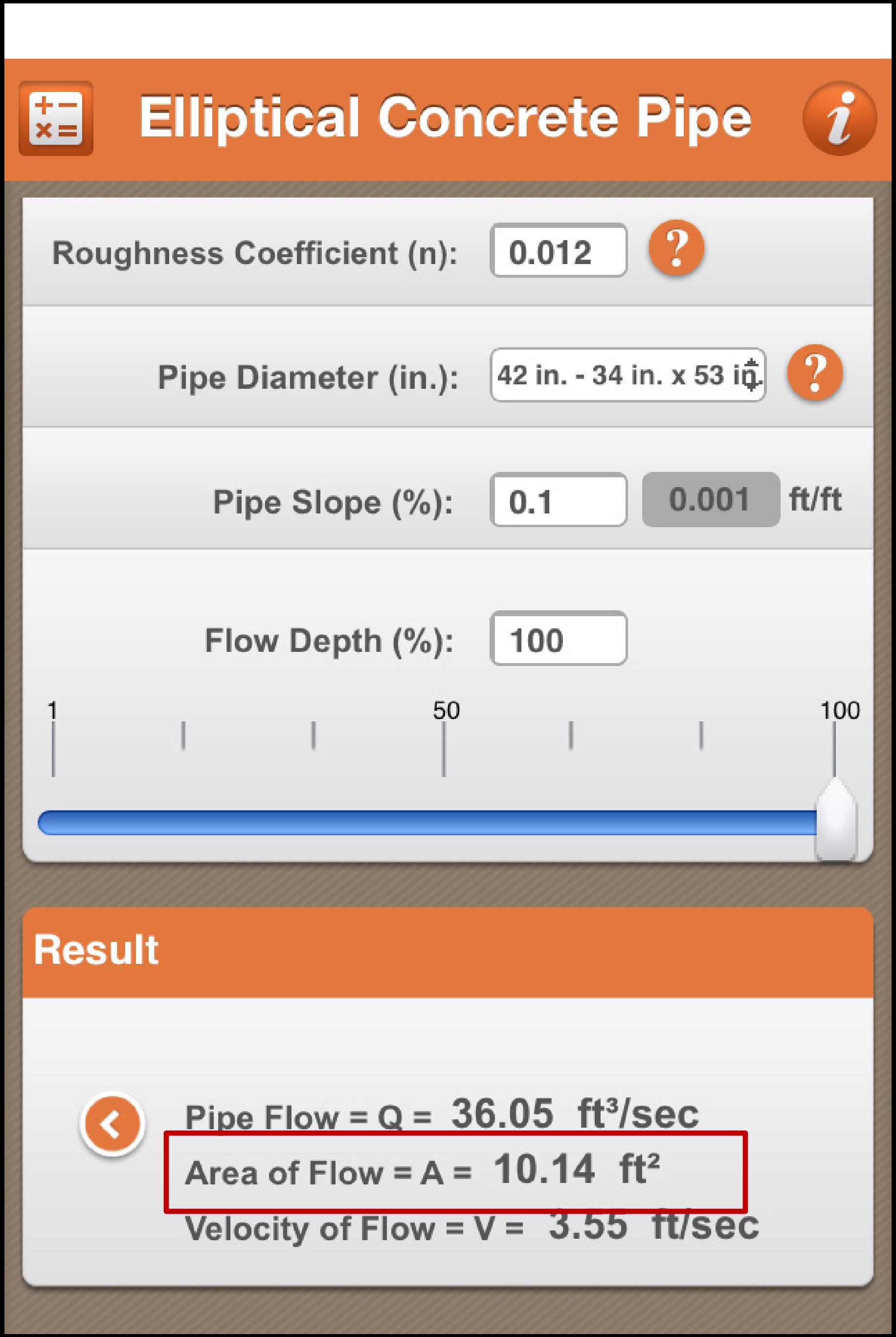
Determine Fluid Load

- $\gamma_w = 62.4$ pcf
- $A = 10.2$ ft
- $W_f = \gamma_w \times A$
- $W_f = 636$ lbs/ft

Flow Area Per ASTM C 507

Approximate Equivalent Round Size, in. K	Full Flow Water Area, ft^3	Rise, in.	Span, in.
18	1.83	14¼	22¾
24	3.28	19¼	30¼
27	4.12	21½	34
30	5.10	24	37¾
33	6.33	26¾	42
36	7.36	28¾	45½
39	8.78	31½	49½
42	10.2	34	53¼

ACPA Compare Flow App



DETERMINE LIVE LOAD

Less Than 2 Feet of Cover

E_{span} = Distribution width parallel to span in inches

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

L_T = length of contact area parallel to span (in)
LLDF = live load distribution factor
H = depth of fill

Less Than 2 Feet of Cover

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.

$$\mathbf{E = 96 + 1.44S} \qquad (4.6.2.10.2\text{-}1)$$

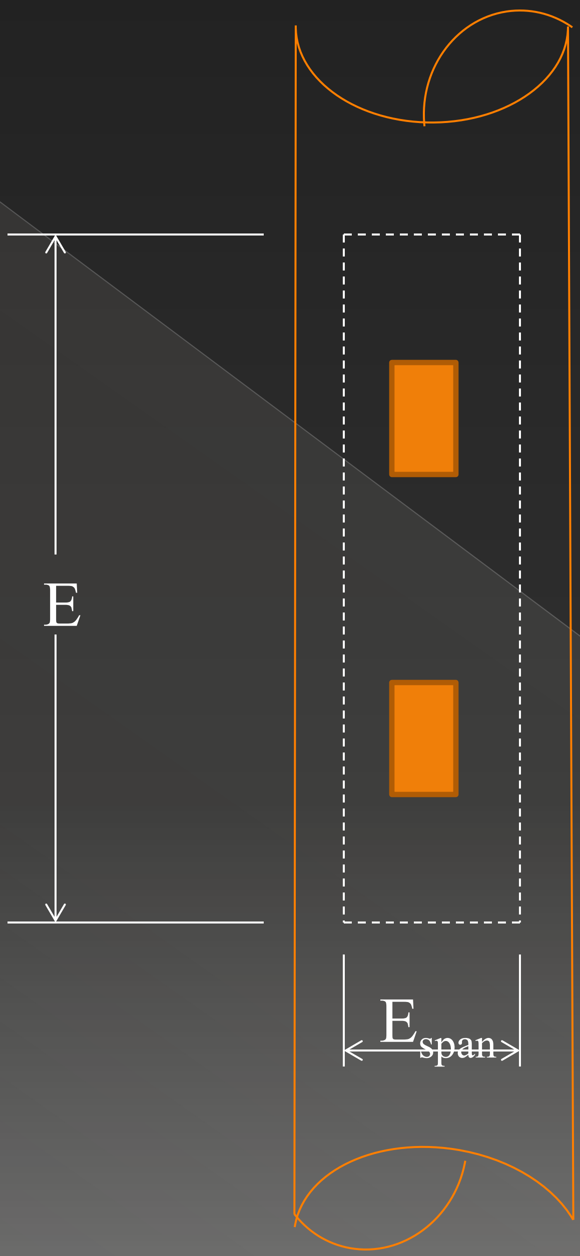
E = Distribution width perpendicular to span in inches
S = Clear Span in feet

Less Than 2 Feet of Cover

E_{span} = Distribution width parallel to span in inches

$E_{span} = L_T + LLDF(H)$

L_T = length of contact area parallel to span (in)
LLDF = live load distribution factor
H = depth of fill



Live Load Spread for Less Than 2 feet of Cover (single a

(Perpendicular)

Live Load Width

- E = 96 + 1.44 (53"/12)
- E = 102.36 inches = 8.53 ft.

Live Load Length

- LLDF = 1.39
- E = 10"/12 + 1 ft x 1.39
- E = 2.22 ft.

Area of Pressure on Top of Pipe

- $A_{LL} = E * E_{span}$
- $A_{LL} = 8.53 \text{ ft} \times 2.22 \text{ ft}$
- $A_{LL} = 18.94 \text{ ft}^2$
- P = 32,000 lbs
- M = 1.2

Pressure at top of Pipe

$$P_L = \frac{P\left(1 + \frac{IM}{100}\right)(m)}{A_{LL}} \qquad (3.6.1.2.6b\text{-}7)$$

IM = 33*[1 – 0.125 (H)]

IM = 33*[1 – 0.125 (1)]

IM = 28.88

Pressure at top of Pipe

$$P_L = \frac{P\left(1 + \frac{IM}{100}\right)(m)}{A_{LL}} \qquad (3.6.1.2.6b\text{-}7)$$

$$P_L = \frac{32000\text{ lbs}\left(1 + \frac{28.88}{100}\right)(1.2)}{18.94\text{ ft}^2}$$

$P_L = 2{,}613$ psf

Live Load

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

- $W_{LL} = 2.22$ ft x 2613 psf
- $W_{LL} = 5{,}801$ lbs/ft

Recap of Loads

- Type 2
  - W_E = 882 lbs/ft
  - W_F = 636 lbs/ft
  - W_L = 5801 lbs/ft

Determination of Bedding Factors

Bedding Factor Per AASHTO

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

$$B_{FE} = \frac{C_A}{C_N - xq} \qquad (12.10.4.3.2b\text{-}1)$$

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

Pipe Shape	C_A	Installation Type	C_N	Projection Ratio, p	x
Horizontal Elliptical and Arch	1.337	2	0.630	0.9 0.7	0.421 0.369
		3	0.763	0.5 0.3	0.268 0.148
Vertical Elliptical	1.021	2	0.516	0.9 0.7	0.718 0.639
		3	0.615	0.5 0.3	0.457 0.238

Horizontal Elliptical Bedding Factor

- For arch and horizontal elliptical pipe:

$$q = 0.23\frac{p}{F_e}\left(1 + 0.35p\frac{B_c}{H}\right) \qquad (12.10.4.3.2b\text{-}2)$$

- $F_e = 1.4$
- $p = 0.7$
- $B_c = 5.25$ ft.
- $H = 1$ ft.
- $q = 0.263$

Earth Load Bedding Factor

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

$C_A = 1.337$
$C_N = 0.630$
$x = 0.369$
$q = 0.263$

$$B_{FE} = \frac{1.337}{0.630 - 0.369 * 0.263}$$

$B_{FE} = 2.5$

Live Load Bedding Factor

Table 12.10.4.3.2c-1

Pipe Diameter, in	Fill Height, ft	
	< 2 ft	≥ 2 ft
12	3.2	2.4
18	3.2	2.4
24	3.2	2.4
30 and larger	2.2	2.2

$B_{FLL} = 2.2$

Find D-load

$$D = \left(\frac{12}{S_i}\right)\left(\frac{W_E + W_F}{B_{FE}} + \frac{W_L}{B_{FLL}}\right) \qquad (12.10.4.3.1\text{-}1)$$

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

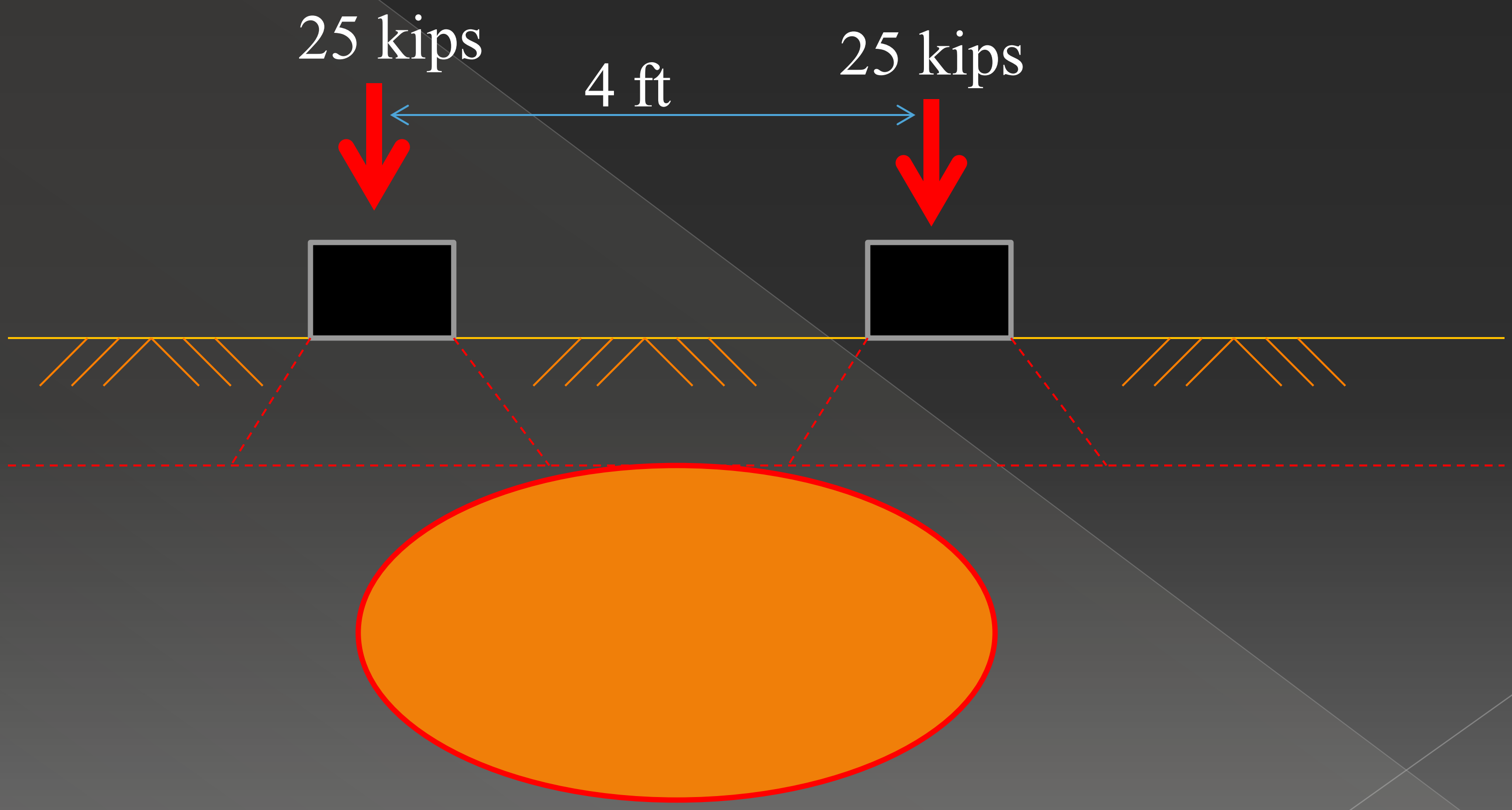
$$D_{0.01} = \left[\frac{882 \text{ lbs/ft} + 636 \text{ lbs/ft}}{2.5} + \frac{5801 \text{ lbs/ft}}{2.2} \right] \times \frac{12}{53 \text{ in.}}$$

$D_{0.01}$ = 735 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



The End