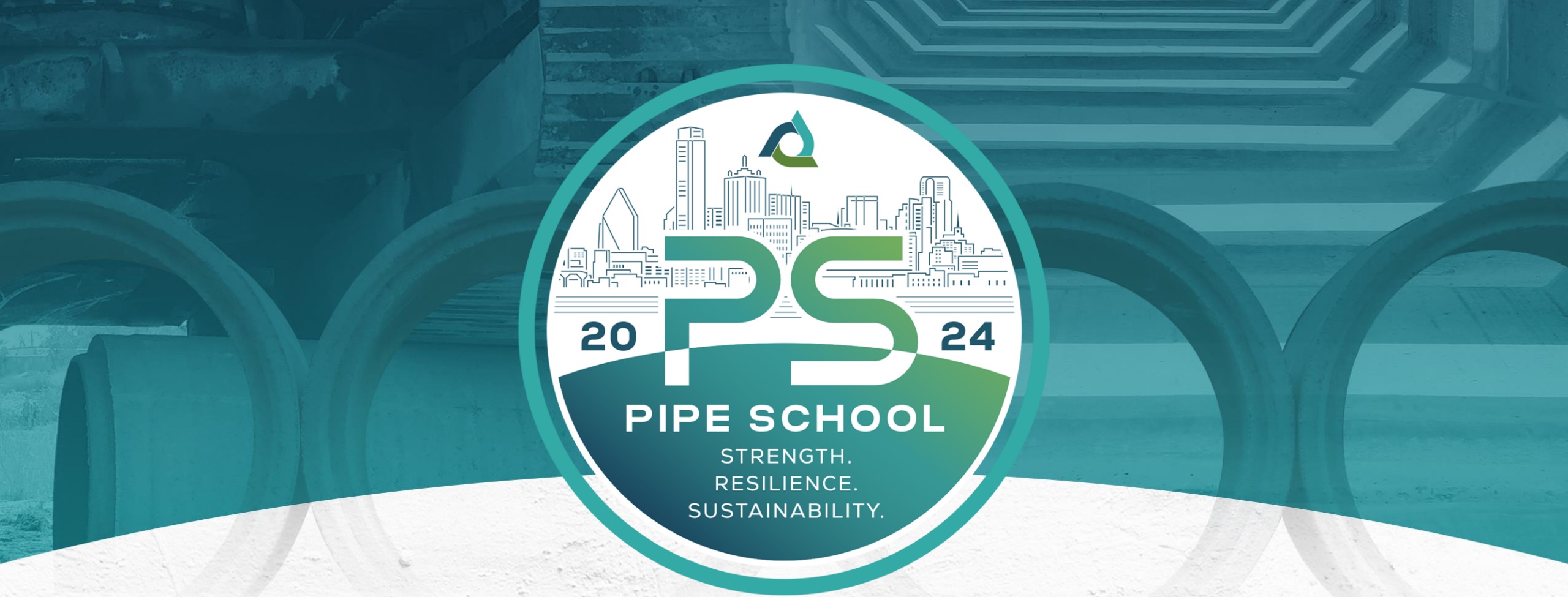
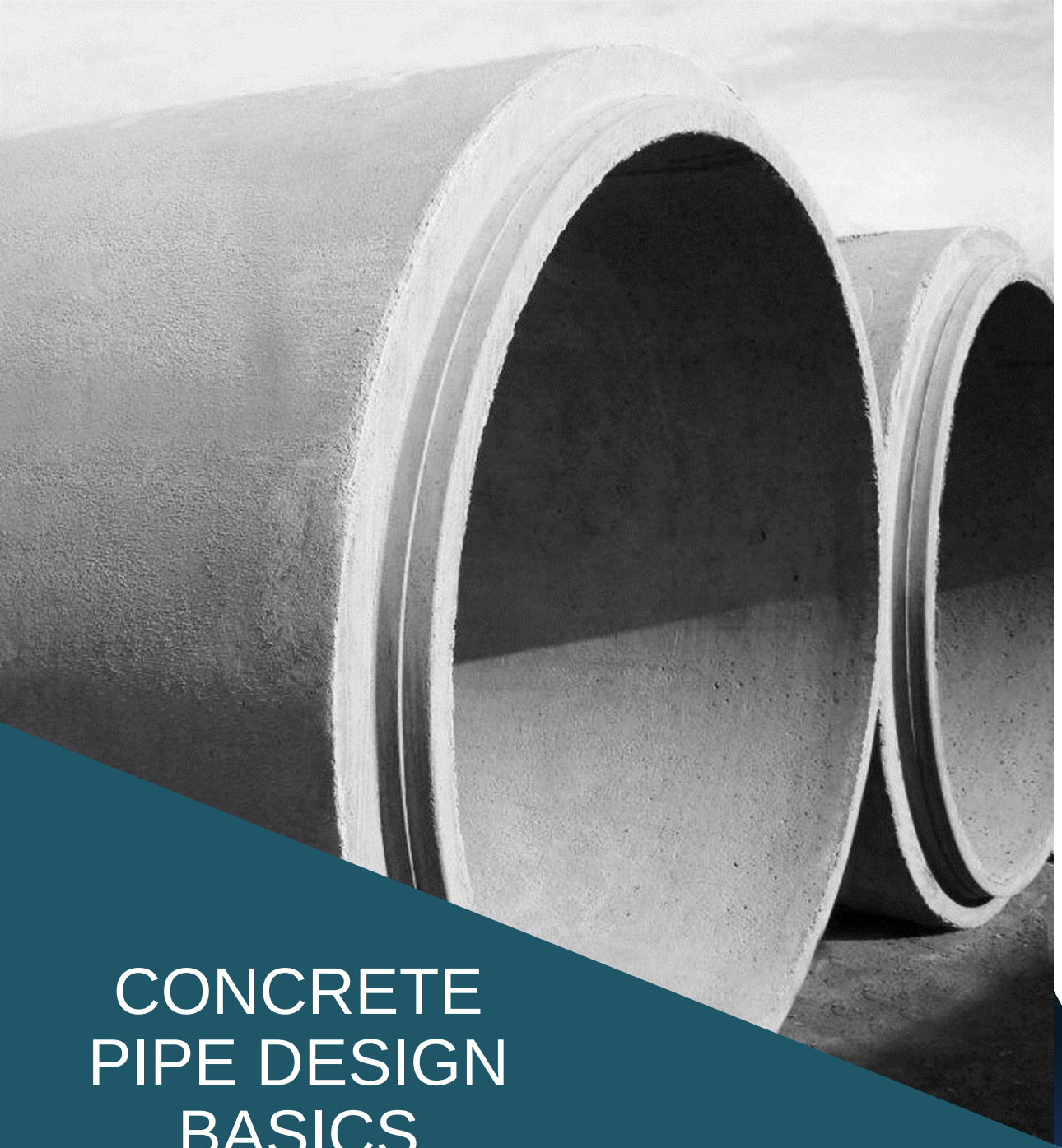


Concrete Pipe Design Basics

Melitza Avila
Rinker Materials

Jennifer Schaff, PE
County Materials



CONCRETE PIPE DESIGN BASICS

OUTLINE

- History – RCP Design
- Direct Design
- Indirect Design
  - Steps
  - 3EB
- Fill Height Tables
- Pipe Pac

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CONCRETE PIPE HISTORY

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Concrete Pipe History

- 1842 – 1st documented concrete pipe in U.S.
- 1852 – ASCE founded
- 1867 –’68 – Joseph Monier patents wire reinforcement RCP production
- 1896 – Precast RCP commercially produced
- 1905 – Precast RCP introduced in U.S.

Concrete Pipe History

1910 – Research rigid pipe installations

1913 – Formal practice of calculating loads on buried pipe

1920s – Indirect Design & Bedding Factor

1960s – Rein. Concrete beam theory adapted to concrete pipe

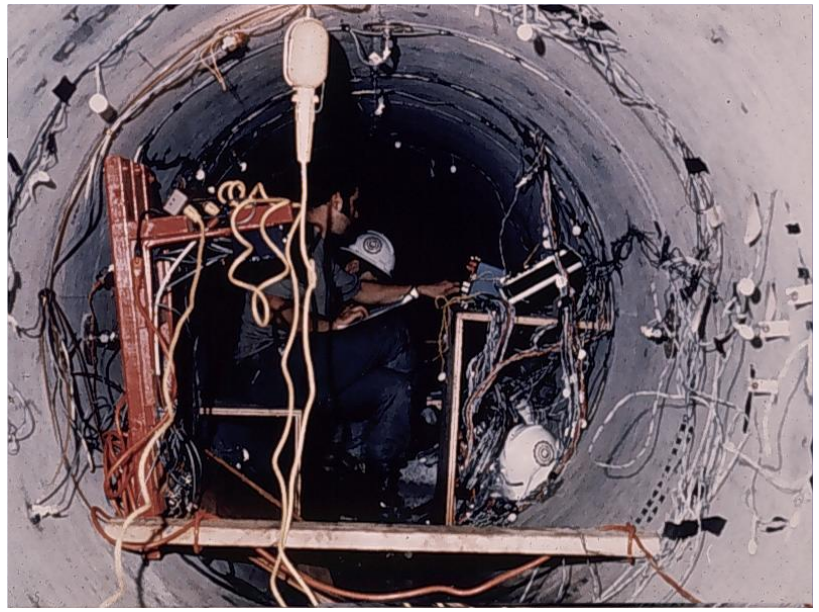
Concrete Pipe History

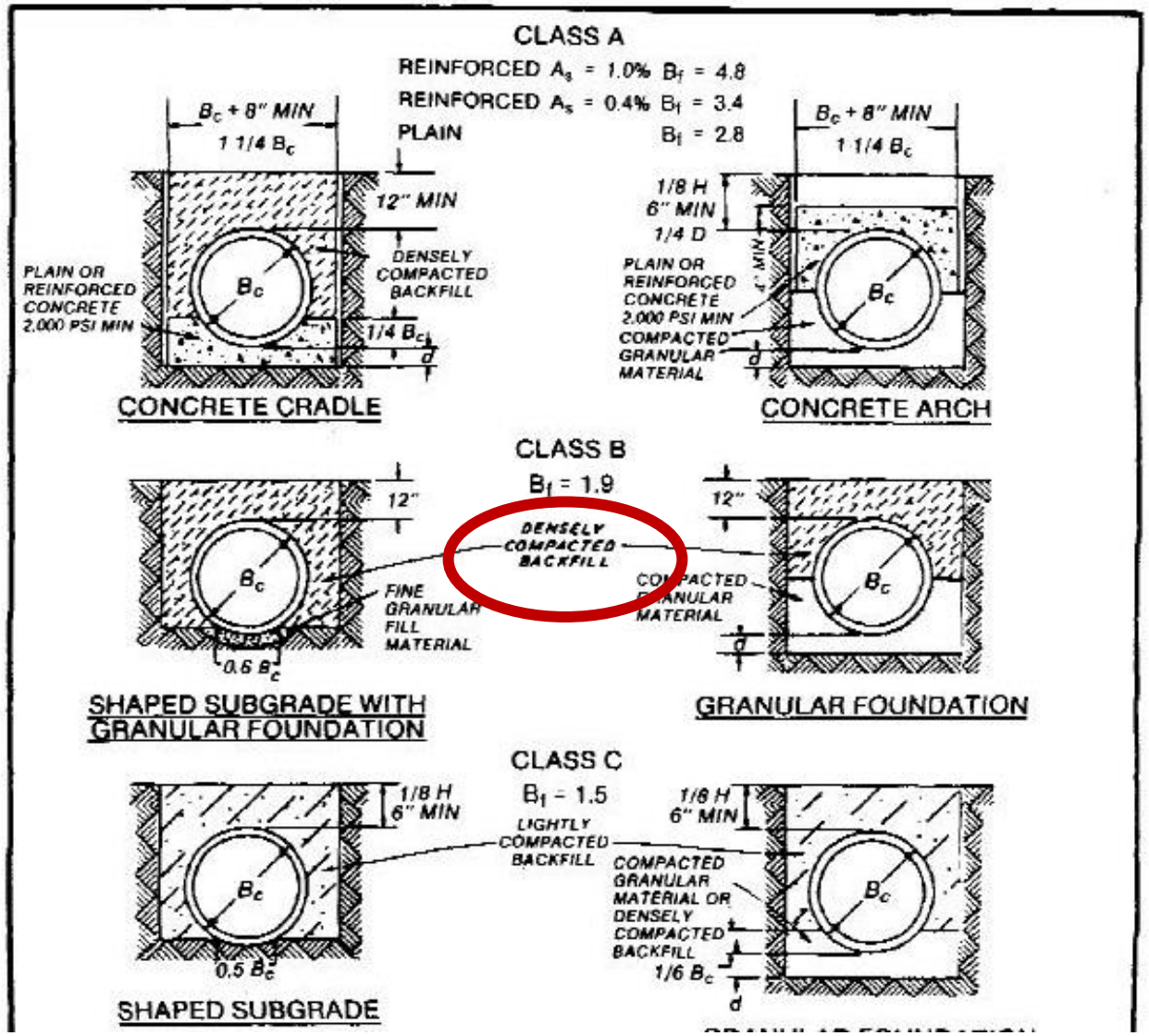
1970-80s – Research and FEA of interaction of concrete pipe and embedment, native soils

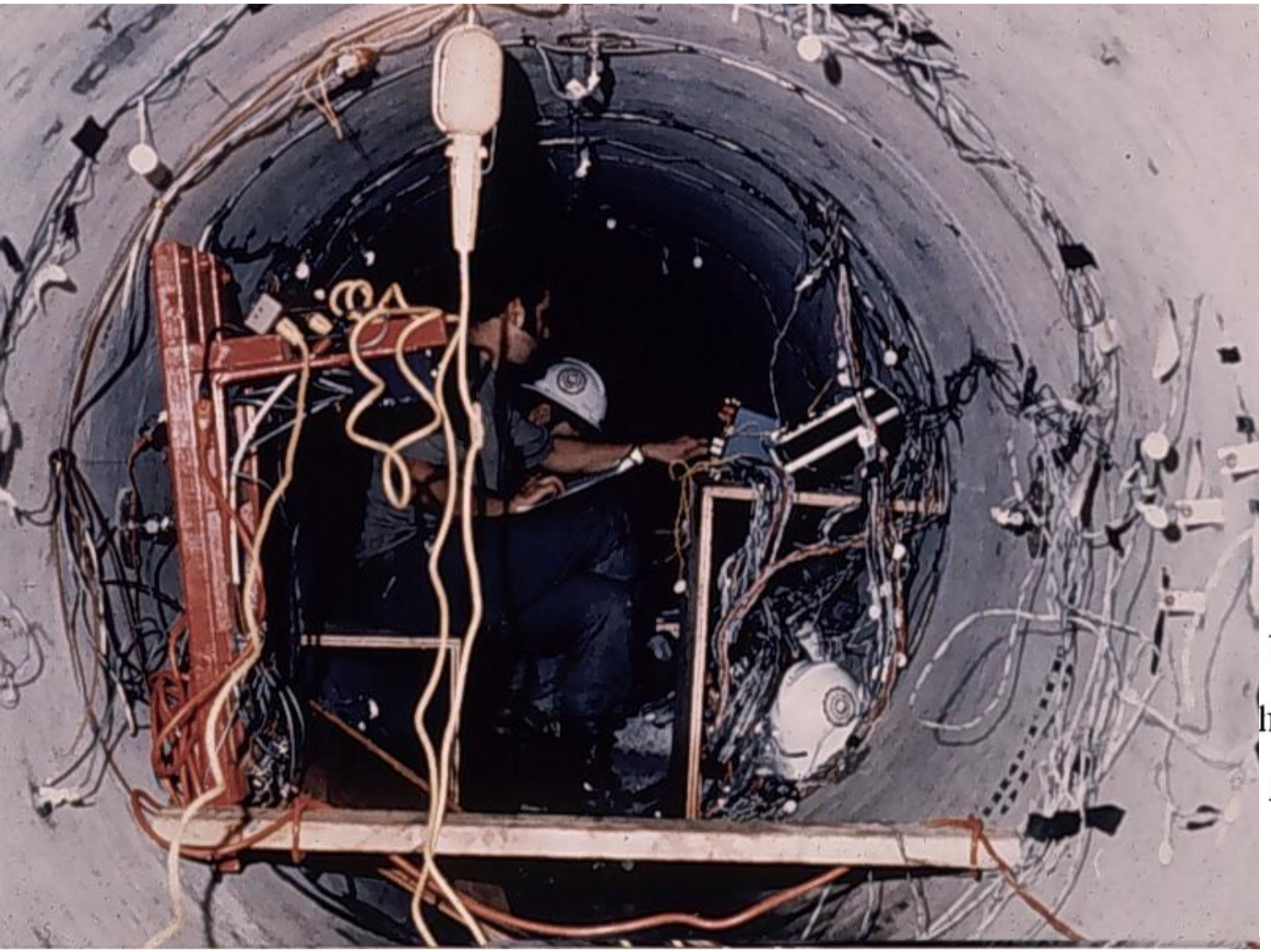
1988 – Frank Heger publishes *New Installation Designs for Buried Concrete Pipe* (ASCE)

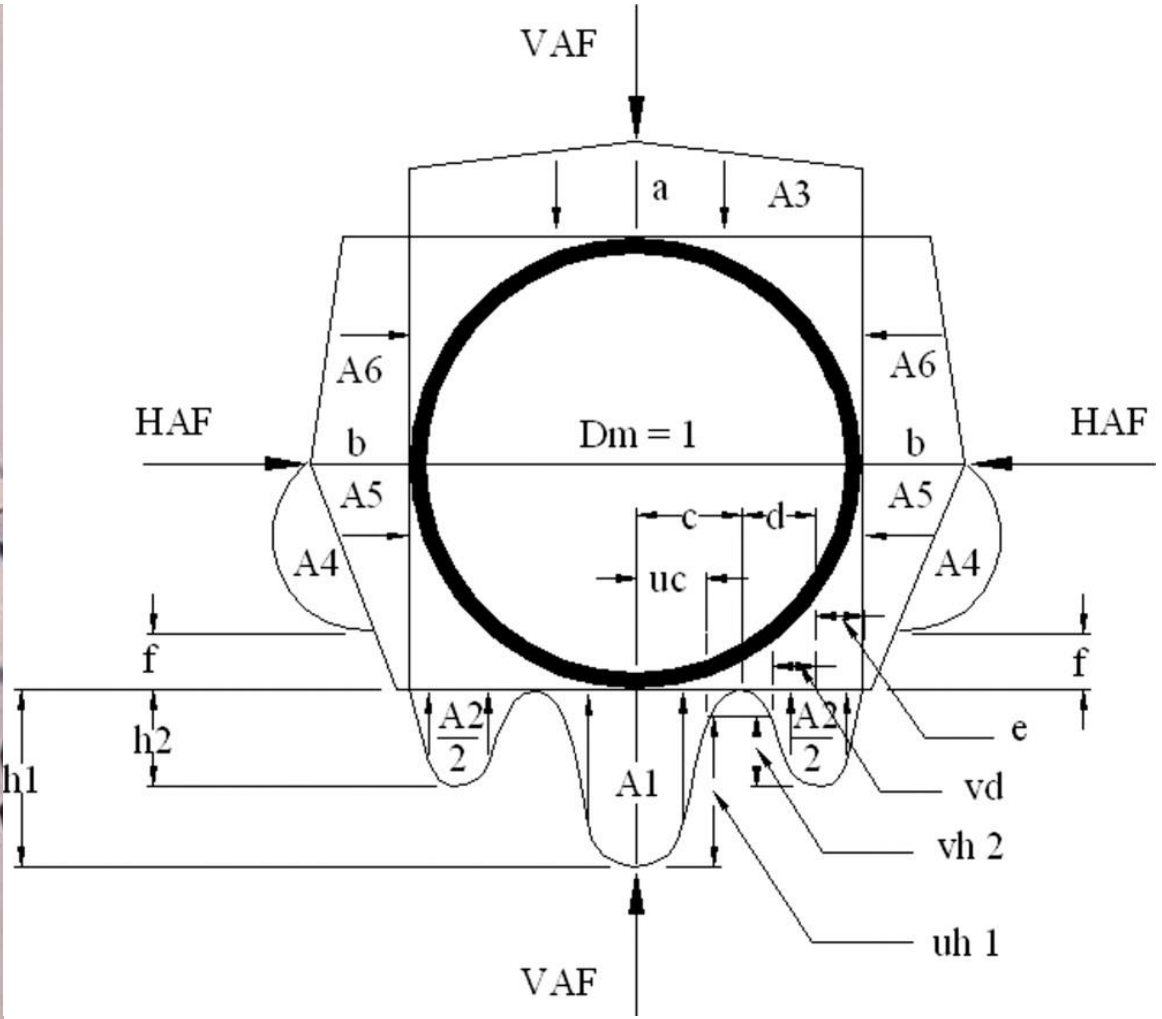
1993 – ASCE Standard 15 & Standard Installations Types 1 - 4

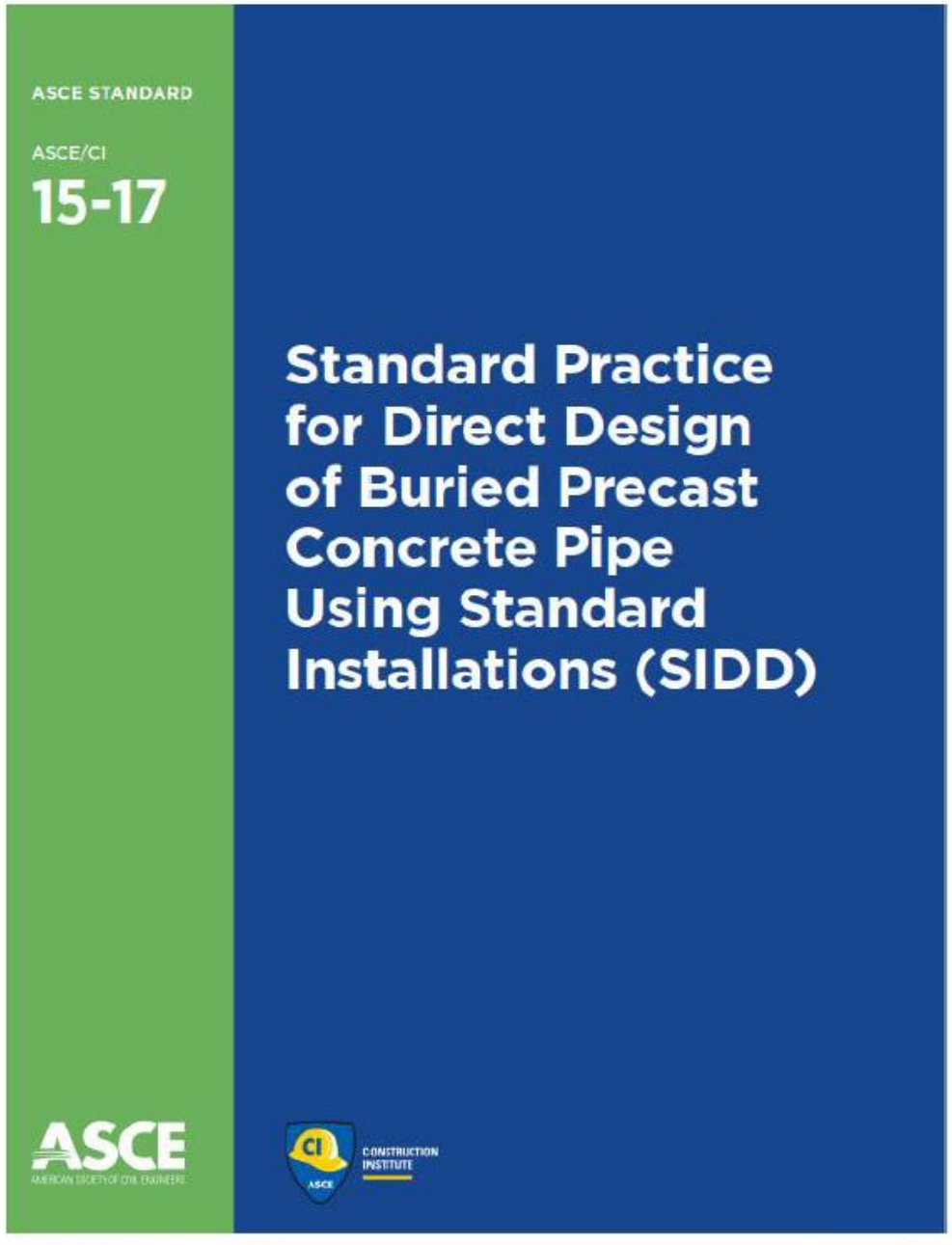
- Adopted in ASTM C1479 and AASHTO LRFD Bridge Design Standards




CLASS A
REINFORCED A_s = 1.0% B_f = 4.8
REINFORCED A_s = 0.4% B_f = 3.4
PLAIN B_f = 2.8
B_c + 8" MIN
1 1/4 B_c
12" MIN
DENSELY COMPACTED BACKFILL
PLAIN OR REINFORCED CONCRETE 2,000 PSI MIN
1/4 B_c
d
CONCRETE CRADLE
1/8 H
6" MIN
1/4 D
4" MIN
COMPACTED GRANULAR MATERIAL
CONCRETE ARCH
CLASS B
B_f = 1.9
12"
FINE GRANULAR FILL MATERIAL
0.6 B_c
SHAPED SUBGRADE WITH GRANULAR FOUNDATION
GRANULAR FOUNDATION
CLASS C
B_f = 1.5
LIGHTLY COMPACTED BACKFILL
0.5 B_c
SHAPED SUBGRADE
COMPACTED GRANULAR MATERIAL OR DENSELY COMPACTED BACKFILL
1/6 B_c




VAF
a
A3
A6
A6
HAF
b
Dm = 1
b
HAF
A5
A5
c
d
A4
A4
uc
f
f
h2
A2/2
A2/2
e
h1
A1
vd
vh 2
uh 1
VAF


ASCE STANDARD
ASCE/CI
15-17
Standard Practice for Direct Design of Buried Precast Concrete Pipe Using Standard Installations (SIDD)
ASCE
AMERICAN SOCIETY OF CIVIL ENGINEERS
CI
ASCE
CONSTRUCTION INSTITUTE

ACPA

DESIGN METHODS

ACPA

Direct Design

Design Loads
Earth
Live
Fluid
Self

Design Forces
Moment
Thrust
Shear

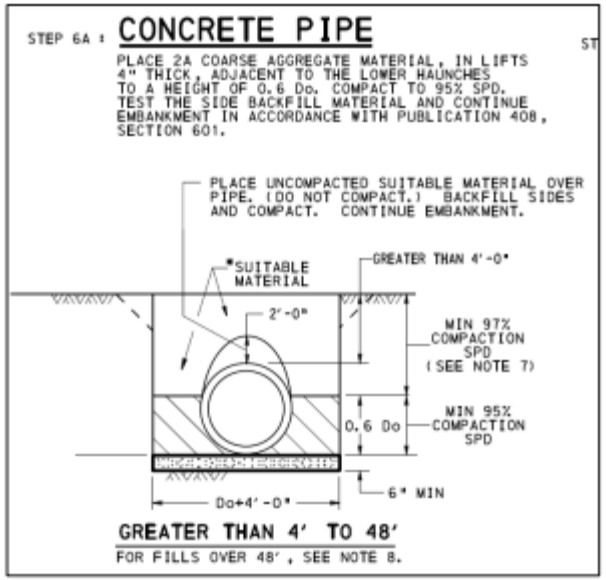
Design

$$A_s \geq \frac{g\phi d - N_u - \sqrt{g\left[g(\phi d)^2 - N_u(2\phi d - h) - 2M_u\right]}}{f_y}$$

Pipe Requirements

TYPE A STANDARD INSTALLATION - STEEL AREAS ($in.^2/ft.$)

Dia.	Wall Thick.	f'c (psi)	Required Fill/Cover Height H≤1.5'	1.5'≤H≤2'	2'≤H≤3'	3'≤H≤7'	7'≤H≤10'	15'	20'	25'	30'	40'	H > 40'
36"	4"	4000	0.19	0.18	0.14	0.11	0.12	0.16	0.21	0.28	0.39	**	**
			0.13	0.12	0.09	0.07	0.07	0.08	0.11	0.14	0.17	**	**
		6000	*	*	*	*	*	*	*	*	*	0.52	**
			*	*	*	*	*	*	*	*	*	0.22	**
36"	4¾"	4000	0.16	0.15	0.12	0.10	0.10	0.13	0.17	0.21	0.25	0.50	**
			0.10	0.09	0.07	0.07	0.07	0.07	0.08	0.10	0.12	0.17	**
42"	4½"	4000	0.20	0.19	0.17	0.17	0.17	0.20	0.25	0.36	0.49	**	**
			0.13	0.12	0.10	0.07	0.07	0.10	0.13	0.17	0.21	**	**
42"	5¼"	4000	0.16	0.16	0.14	0.14	0.14	0.16	0.21	0.25	0.37	**	**
			0.10	0.10	0.08	0.07	0.07	0.08	0.10	0.12	0.15	**	**
		5000	*	*	*	*	*	*	*	*	*	0.53	**
			*	*	*	*	*	*	*	*	*	0.20	**
48"	5"	4000	0.18	0.20	←	0.19	→	0.23	0.31	0.45	0.62	**	**
			0.11	0.13	←	0.12	→	0.12	0.16	0.20	0.24	**	**
48"	5¾"	4000	0.18	0.17	←	0.16	→	0.20	0.25	0.32	0.52	**	**
			0.11	0.10	←	0.10	→	0.07	0.12	0.15	0.18	**	**
		5000	*	*	*	*	*	*	*	*	*	0.71	**
			*	*	*	*	*	*	*	*	*	0.24	**
54"	5½"	4000	0.21	0.21	←	0.20	→	0.26	0.38	0.55	**	**	**
			0.14	0.13	←	0.12	→	0.14	0.18	0.23	**	**	**
		5000	*	*	*	*	*	*	*	*	0.64	**	**
			*	*	*	*	*	*	*	*	0.26	**	**
54"	6¼"	4000	0.19	0.18	←	0.18	→	0.23	0.29	0.45	0.68	**	**
			0.12	0.11	←	0.10	→	0.11	0.14	0.18	0.22	**	**



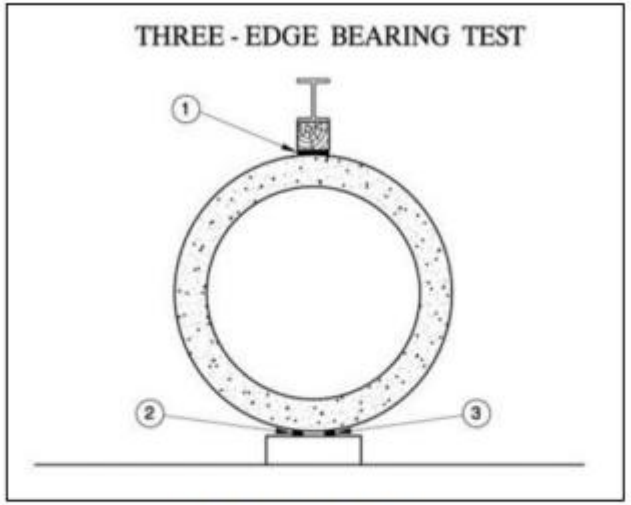
Installation Requirements

Indirect Design

Design Loads
Earth
Live
Fluid

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

Relating Installed Load to Test Load



Test setup

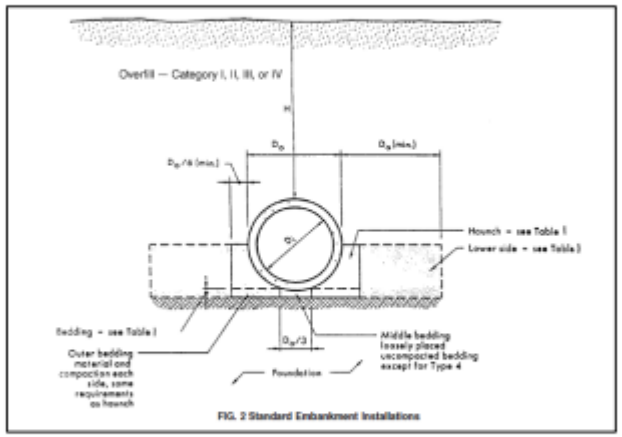


FIG. 2 Standard Embankment Installations

Installation Requirements

TABLE 2 Design Requirements for Class II 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	1000
D-load to produce the ultimate load	1500

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 Thickness, in.	Circular Reinforcement[C]		Elliptical Reinforcement[D]	Wall Thickness, in.	Circular Reinforcement[C]		Elliptical Reinforcement[D]	Wall Thickness, in.	Circular Reinforcement[C]		Elliptical Reinforcement[D]
		Inner Cage	Outer Cage			Inner Cage	Outer Cage			Inner Cage	Outer Cage	
12	1¾	0.07[B]	...	...	2	0.07[B]	...	...	2¼	0.07[B]	...	...
15	1⅞	0.07[B]	...	...	2¼	0.07[B]	...	...	3	0.07[B]	...	...
18	2	0.07[B]	...	0.07[B]	2½	0.07[B]	...	0.07[B]	3¼	0.07[B]	...	0.07[B]
21	2¼	0.12	...	0.10	2¾	0.07[B]	...	0.07[B]	3½	0.07[B]	...	0.07[B]
24	2½	0.12	...	0.11	3	0.07[B]	...	0.07[B]	3¾	0.07[B]	...	0.07[B]
27	2¾	0.15	...	0.12	3¼	0.12	...	0.11	4	0.07[B]	...	0.07[B]
30	2¾	0.15	...	0.14	3½	0.14	...	0.12	4¼	0.07[B]	...	0.07[B]

Suggested Steel Areas for the Test condition

ACPA

TABLE 3 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

Diameter, in.	Thick-nesses, In.	Reinforcement[B]		Elliptical Reinforcement[C]	Thick-nesses, In.	Reinforcement[B]		Elliptical Reinforcement[C]	Thick-nesses, In.	Reinforcement[B]		Elliptical Reinforcement[C]
		Inner Cage	Outer Cage			Inner Cage	Outer Cage			Inner Cage	Outer Cage	
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	2⅝	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	0.12	0.23	4[E]	0.17	0.10	0.19	4¾[E]	0.08	0.07	0.09
42	3½	0.24	0.15	0.27	4½	0.21	0.12	0.23	5¼	0.12	0.07	0.12
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	0.12	0.23
60	5	0.44	0.26	0.49	6	0.34	0.20	0.39	6¾	0.24	0.15	0.27
66	5½	0.50	0.30	0.55	6½	0.41	0.24	0.45	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	0.21	0.40

24 Inch RCP Class III

2 ft. I.D. @ 8 ft. long

D-load (0.01 inch)

1,350 lb/ft/ft

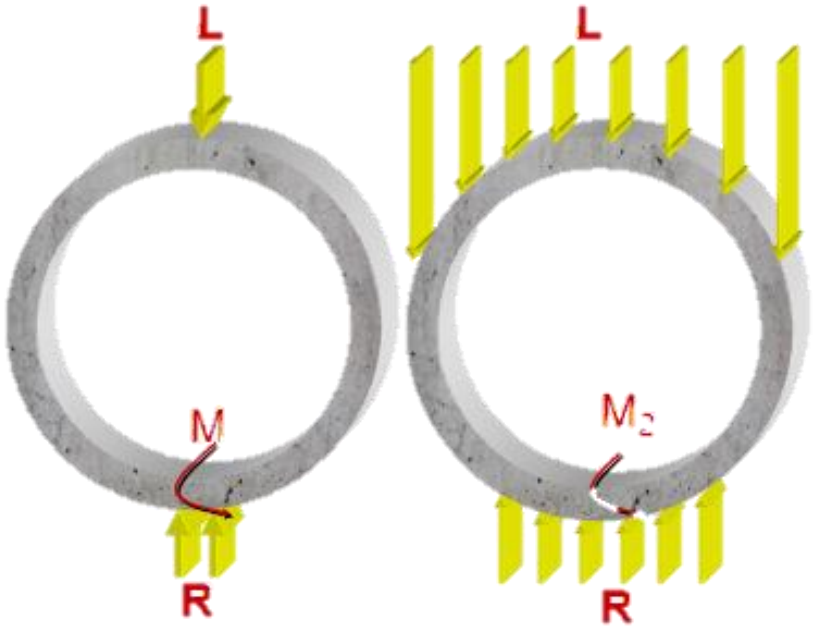
21,600 lbs
Test Load

ACPA

Indirect Design Method

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

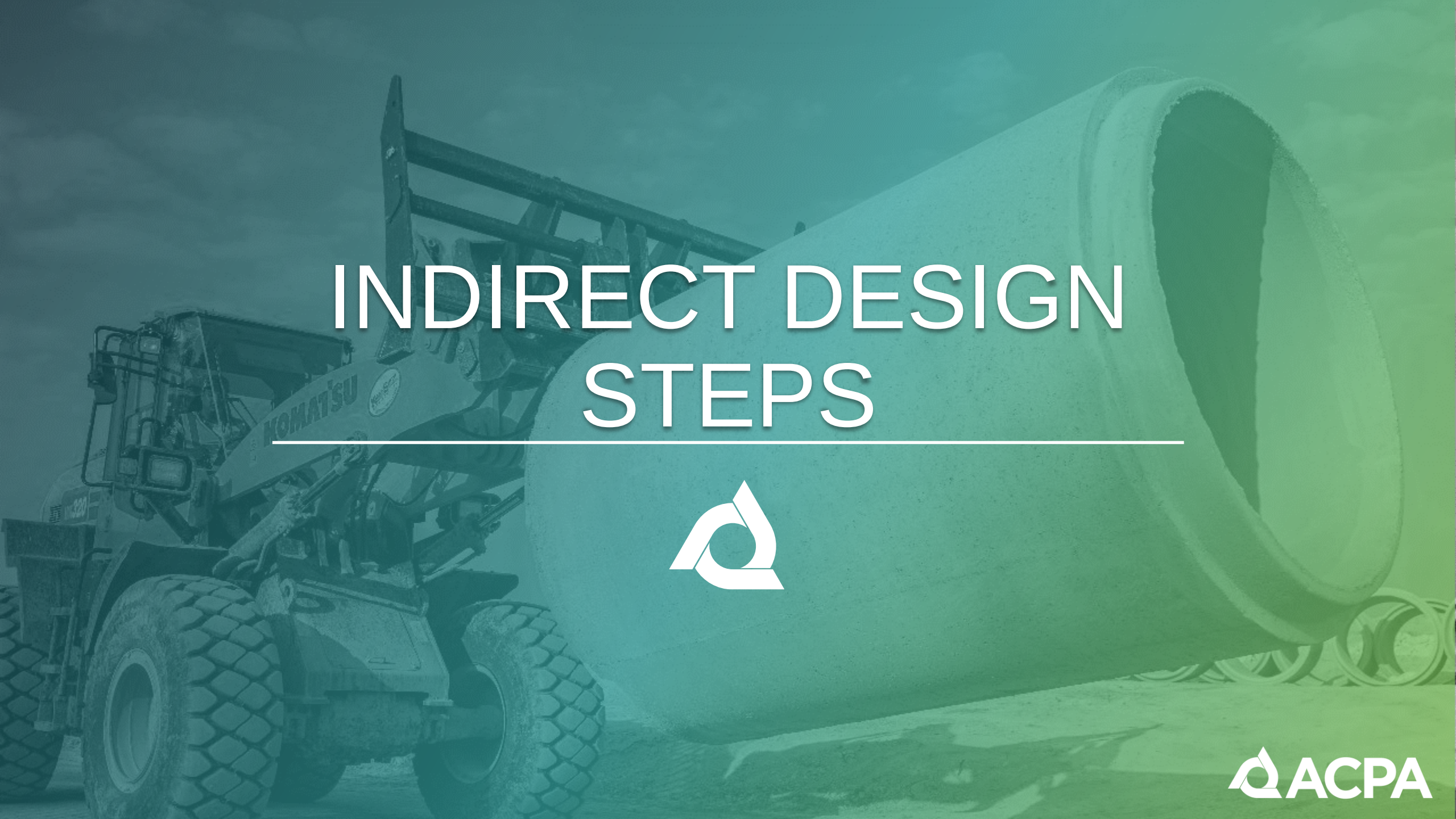
Plant Test



Field Conditions

Indirect Design Method

INDIRECT DESIGN STEPS



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SEVEN STEP INDIRECT PROCESS

1 Installation Method
2 Installation Type
3 Dead Load
4 Live Load
5 Bedding Factors
6 Apply Factor of Safety
7 Calculate Pipe Strength

1 - Installation Method

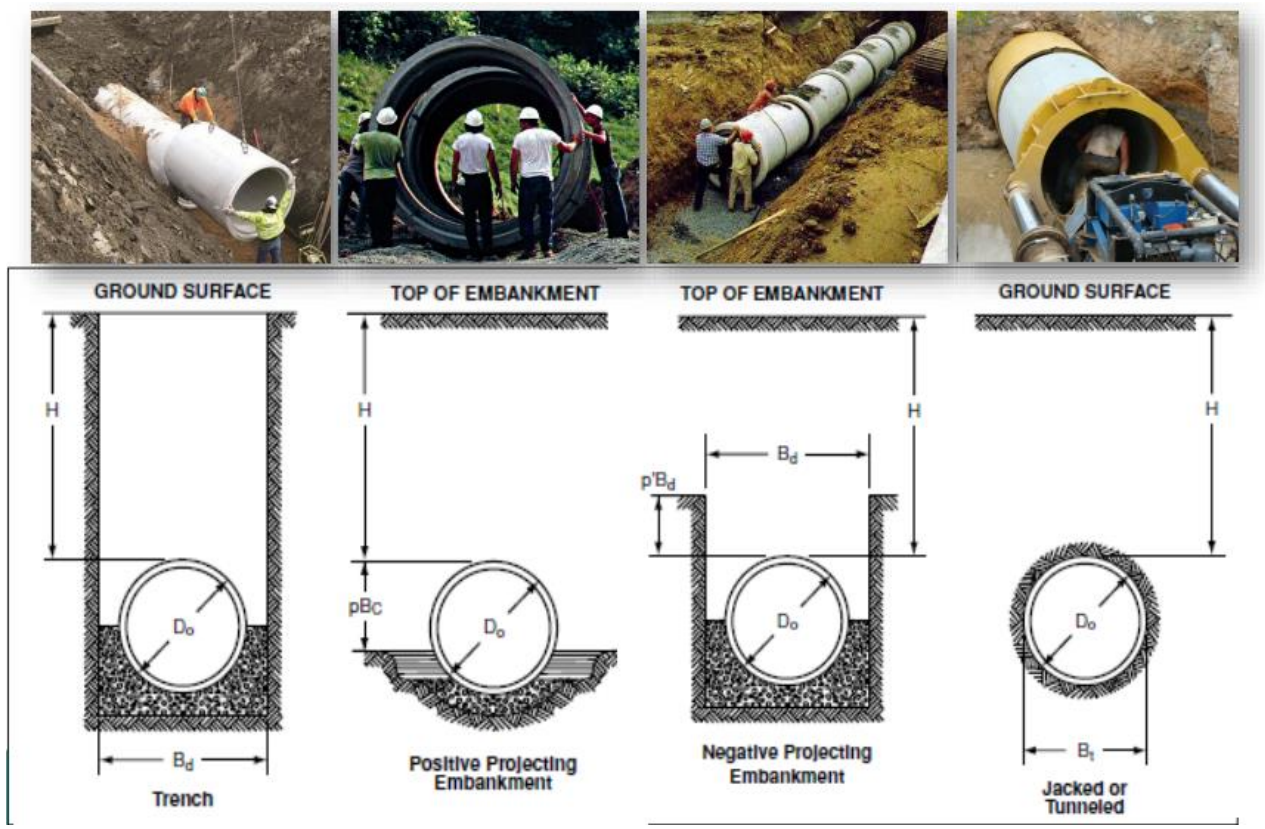
Illustration 4.5 Standard Embankment Installations Soil and Minimum Compaction Requirements

Installation Type	Bedding Thickness	Haunch and Outer Bedding	Lower Side
Type 1	D_o/24 minimum, not less than 75 mm (3"). If rock foundation, use D_o/12 minimum, not less than 150 mm (6").	95% Category I	90% Category I, 95% Category II, or 100% Category III
Type 2	D_o/24 minimum, not less than 75 mm (3"). If rock foundation, use D_o/12 minimum, not less than 150 mm (6").	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 75 mm (3"). If rock foundation, use D_o/12 minimum, not less than 150 mm (6") .	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 150 mm (6").	No compaction required, except if Category III, use 85% Category III	No compaction required, except if Category III, use 85% Category III

1 - Installation Method

Illustration 4.5 Standard Embankment Installations Soil and Minimum Compaction Requirements

Installation Type	Bedding Thickness	Haunch and Outer Bedding	Lower Side
Type 1	D_O/24 minimum, not less than 75 mm (3"). If rock foundation, use D_O/12 minimum, not less than 150 mm (6").	95% Category I	90% Category I, 95% Category II, or 100% Category III
Type 2	D_O/24 minimum, not less than 75 mm (3"). If rock foundation, use D_O/12 minimum, not less than 150 mm (6").	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 75 mm (3"). If rock foundation, use D_O/12 minimum, not less than 150 mm (6") .	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 150 mm (6").	No compaction required, except if Category III, use 85% Category III	No compaction required, except if Category III, use 85% Category III



1 - Installation Method

Stronger Pipe
Low Quality Installation

Lower Strength Pipe
High Quality Installation

ACPA

2 - Installation Type

Illustration 4.5 Standard Embankment Installations Soil and Minimum Compaction Requirements

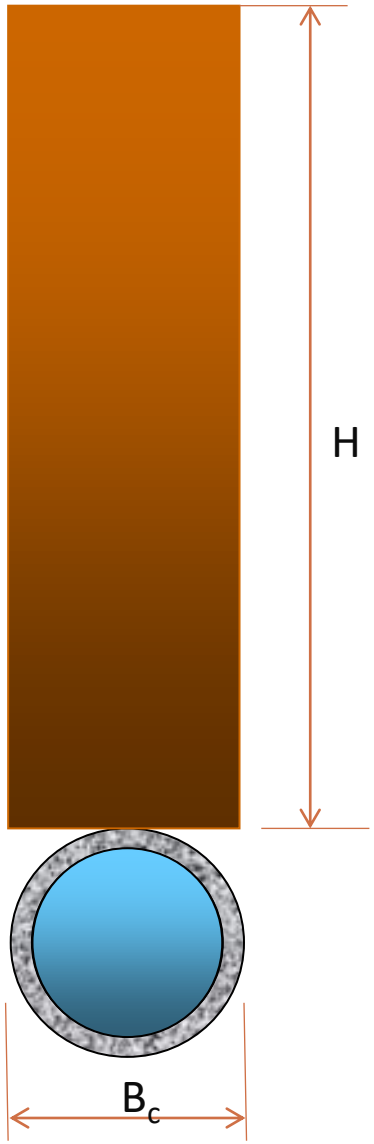
Installation Type	Bedding Thickness	Haunch and Outer Bedding	Lower Side
Type 1	D_o/24 minimum, not less than 75 mm (3"). If rock foundation, use D_o/12 minimum, not less than 150 mm (6").	95% Category I	90% Category I, 95% Category II, or 100% Category III
Type 2	D_o/24 minimum, not less than 75 mm (3"). If rock foundation, use D_o/12 minimum, not less than 150 mm (6").	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 75 mm (3"). If rock foundation, use D_o/12 minimum, not less than 150 mm (6") .	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 150 mm (6").	No compaction required, except if Category III, use 85% Category III	No compaction required, except if Category III, use 85% Category III

Step 3 - Dead Load - Calculate Soil Load

$W_E = F_e \gamma_s B_c H$

- γs = unit weight of soil (pcf)
- B_c = outside diameter of pipe (ft)
- H = fill height (ft)
- F_e = soil-structure interaction factor or Vertical Arching Factor (VAF)

Pipe – Section 12.10.2.1-1



Step 3 – Dead Load - Soil Load

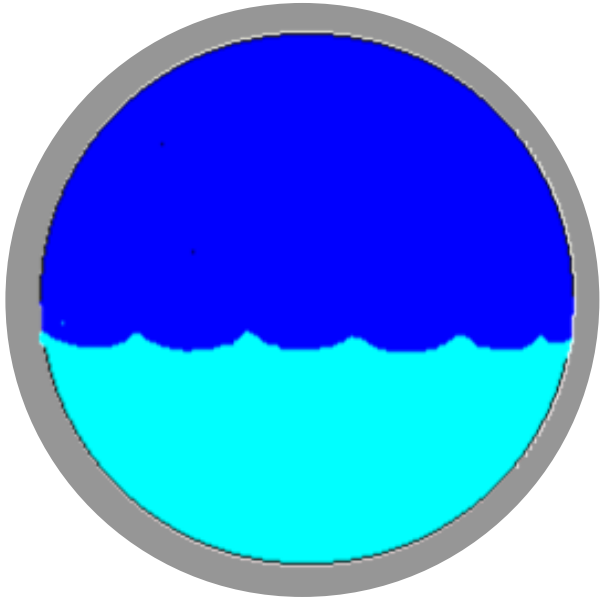
Table 12.10.2.1-3—Coefficients for Use with Figure 12.10.2.1-1

	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	—

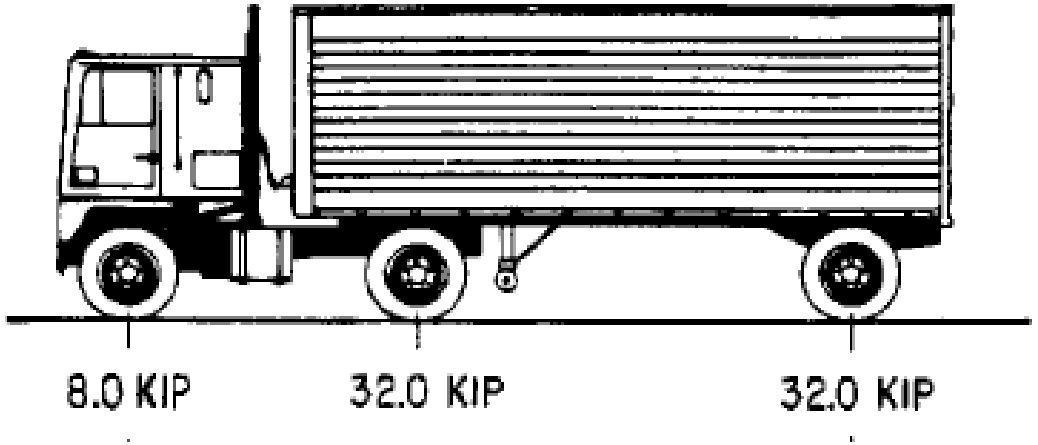
Step 3 – Dead Load - Weight of Fluid

Pipe Area = π x $(ID/24)^2$

W_f = Pipe Area x γ_w



4 – Live Load

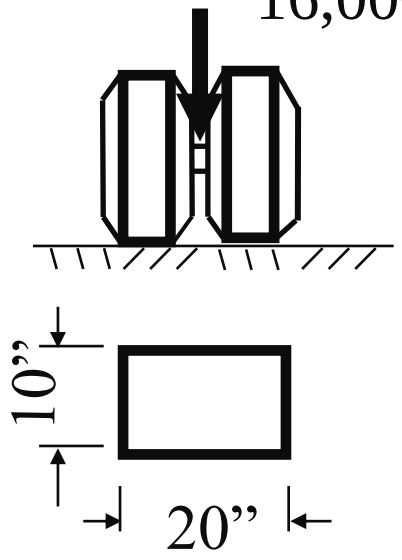


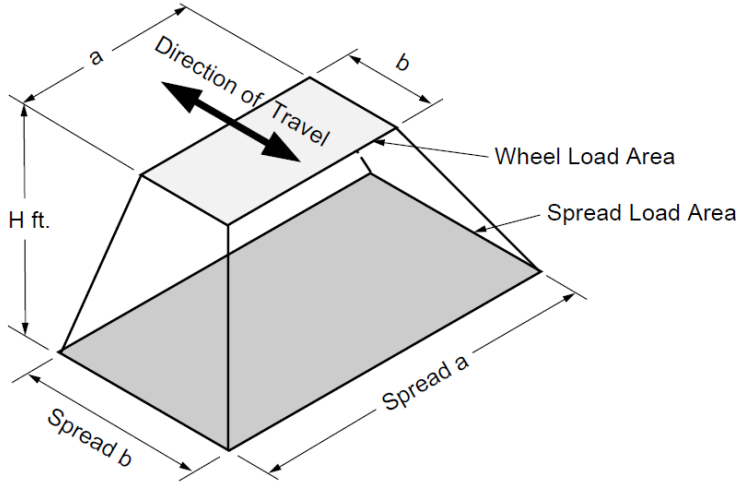
4 – Live Load

12.10.2.3—Live Loads

Live loads shall be as specified in Article 3.6 and shall be distributed through the earth cover as specified in Article 3.6.1.2.6. For standard installations, the live load on the pipe shall be assumed to have a uniform vertical distribution across the top of the pipe and the same distribution across the bottom of the pipe as given in Figure 12.10.2.1-1.

12,500 lb. or
16,000 lb.



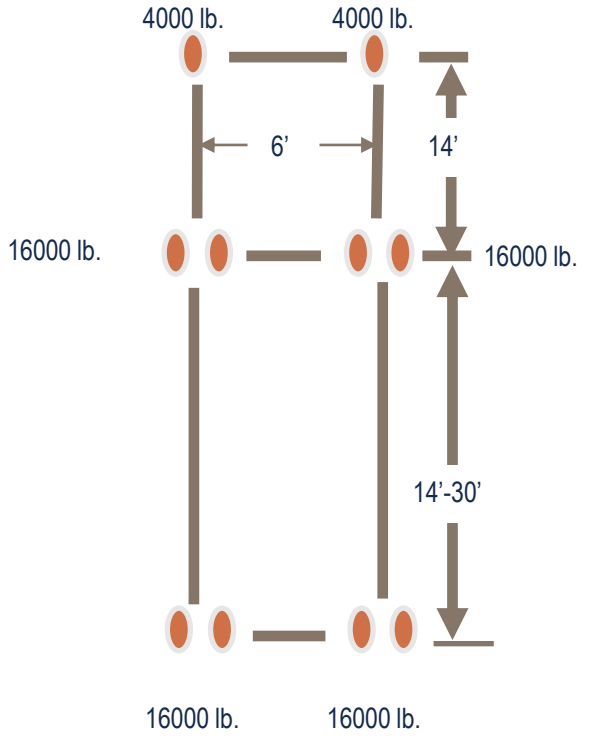


Step 4 – Live Load - Design Truck & Tandem Spacing

3.6.1.2.2—Design Truck

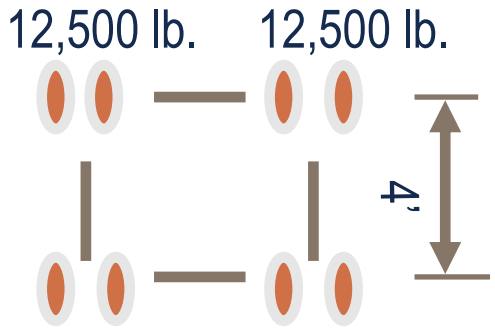
The weights and spacings of axles and wheels for the design truck shall be as specified in Figure 3.6.1.2.2-1. A dynamic load allowance shall be considered as specified in Article 3.6.2.

Except as specified in Articles 3.6.1.3.1 and 3.6.1.4.1, the spacing between the two 32.0-kip axles shall be varied between 14.0 ft and 30.0 ft to produce extreme force effects.

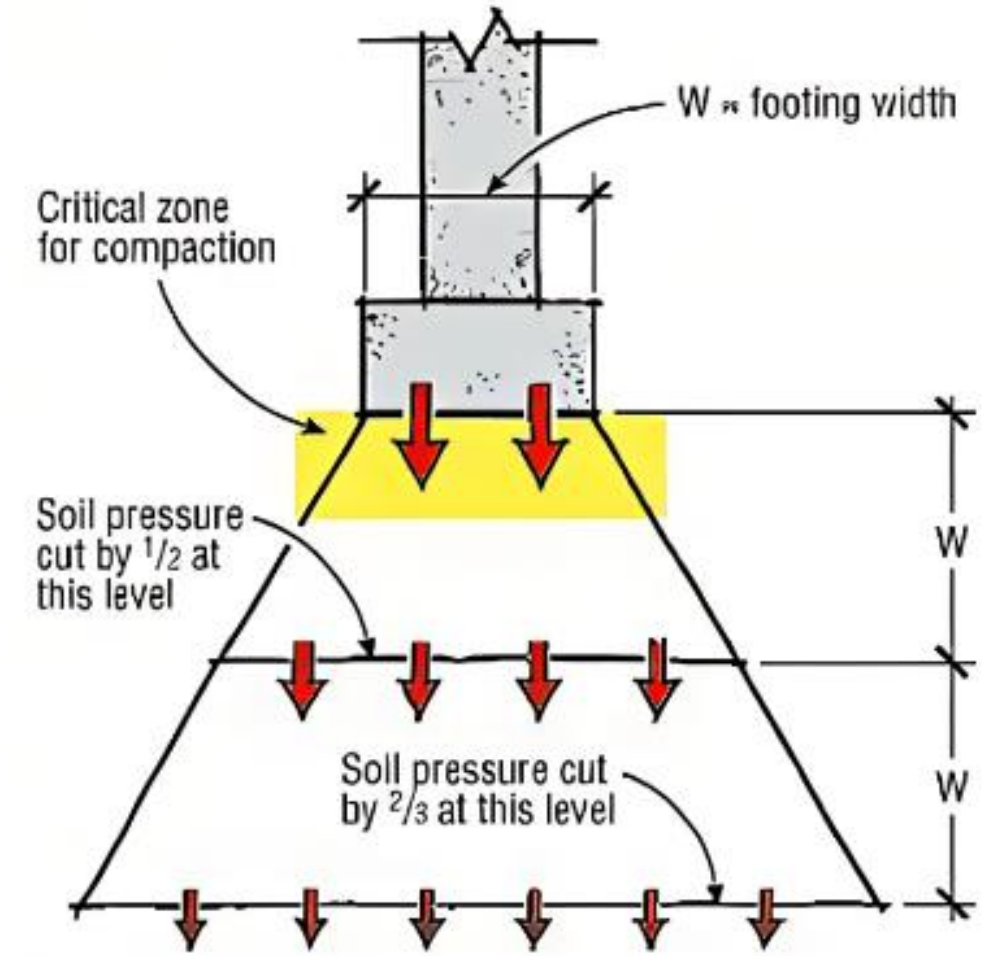


3.6.1.2.3—Design Tandem

The design tandem shall consist of a pair of 25.0-kip axles spaced 4.0 ft apart. The transverse spacing of wheels shall be taken as 6.0 ft. A dynamic load allowance shall be considered as specified in Article 3.6.2.



4 – Live Load


W = footing width
Critical zone
for compaction
Soil pressure
cut by 1/2 at
this level
Soil pressure cut
by 2/3 at this level
W
W

Step 4 - Live Load

Table 42

HIGHWAY LOADS ON CIRCULAR PIPE

POUNDS PER LINEAR FOOT

PIPE SIZE D IN INCHES	B_c (ft.)	HEIGHT OF FILL H ABOVE TOP OF PIPE IN FEET													PIPE SIZE D IN INCHES
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0	
12	1.33	3780	2080	1470	1080	760	550	450	380	290	230	190	160	130	12
15	1.63	4240	2360	1740	1280	900	660	540	450	350	280	230	190	160	15
18	1.92	4110	2610	1970	1460	1030	750	620	520	400	320	260	220	190	18
21	2.21	3920	2820	2190	1620	1150	840	690	580	450	360	300	250	210	21
24	2.50	4100	3010	2400	1780	1270	930	760	640	500	400	330	280	240	24
27	2.79	3880	2940	2590	1930	1380	1010	830	700	560	440	360	300	260	27
30	3.08	3620	2830	2770	2070	1480	1080	890	750	590	480	390	330	280	30
33	3.38	3390	2930	2950	2200	1580	1160	960	810	630	510	420	360	300	33
36	3.67	3190	2810	2930	2330	1670	1230	1020	860	670	550	450	380	330	36
39	3.96	3010	2670	2850	2440	1760	1290	1070	910	710	580	480	410	350	39
42	4.25	2860	2550	2770	2560	1840	1360	1130	950	750	610	510	430	370	42
48	4.83	2590	2330	2620	2480	1990	1470	1230	1040	820	670	560	470	410	48
54	5.42	2360	2150	2490	2360	2050	1580	1320	1120	890	730	610	520	440	54
60	6.00	2170	1990	2450	2250	1960	1680	1400	1190	950	780	650	560	480	60
66	6.58	2010	1850	2520	2160	1880	1640	1480	1260	1010	830	700	590	510	66
72	7.17	1870	1730	2580	2190	1810	1570	1510	1330	1060	880	740	630	540	72
78	7.75	1750	1630	2630	2240	1770	1520	1460	1390	1110	920	780	660	570	78
84	8.33	1650	1540	2730	2290	1810	1460	1410	1360	1160	960	810	690	600	84
90	8.92	1550	1460	2530	2330	1850	1470	1360	1310	1210	1000	850	720	630	90
96	9.50	1470	1380	2410	2290	1880	1500	1330	1270	1250	1040	880	750	650	96
102	10.08	1390	1320	2300	2190	1910	1530	1350	1240	1290	1070	910	780	680	102
108	10.67	1320	1260	2200	2090	1830	1560	1380	1230	1330	1110	940	810	700	108
114	11.25	1260	1200	2110	2010	1760	1540	1410	1260	1362	1140	970	830	730	114
120	11.83	1210	1150	2020	1930	1700	1480	1420	1280	1400	1170	990	860	750	120
126	12.42	1160	1100	1940	1860	1640	1430	1380	1300	1430	1200	1020	880	770	126
132	13.00	1110	1060	1870	1800	1580	1380	1330	1290	1460	1220	1040	900	790	132
138	13.58	1070	1020	1800	1730	1530	1340	1290	1250	1490	1250	1070	920	810	138
144	14.17	1020	980	1740	1670	1480	1300	1250	1210	1470	1280	1090	940	830	144

DATA:
1. Unsurfaced roadway.
2. Loads—AASHTO HS 20, two 16,000 lb. dual-tired wheels, 4 ft. on centers, or alternate loading, four 12,000 lb. dual-tired wheels, 4 ft. on centers with impact included.

NOTES:
1. Interpolate for intermediate pipe sizes and/or fill heights.
2. Critical loads:
   a. For H = 0.5 and 1.0 ft., a single 16,000 lb. dual-tired wheel.
   b. For H = 1.5 through 4.0 ft., two 16,000 lb. dual-tired wheels, 4 ft. on centers.
   c. For H > 4.0 ft. alternate loading.
3. Truck live loads for H = 10.0 ft. or more are insignificant.

Step 4 – Live Load

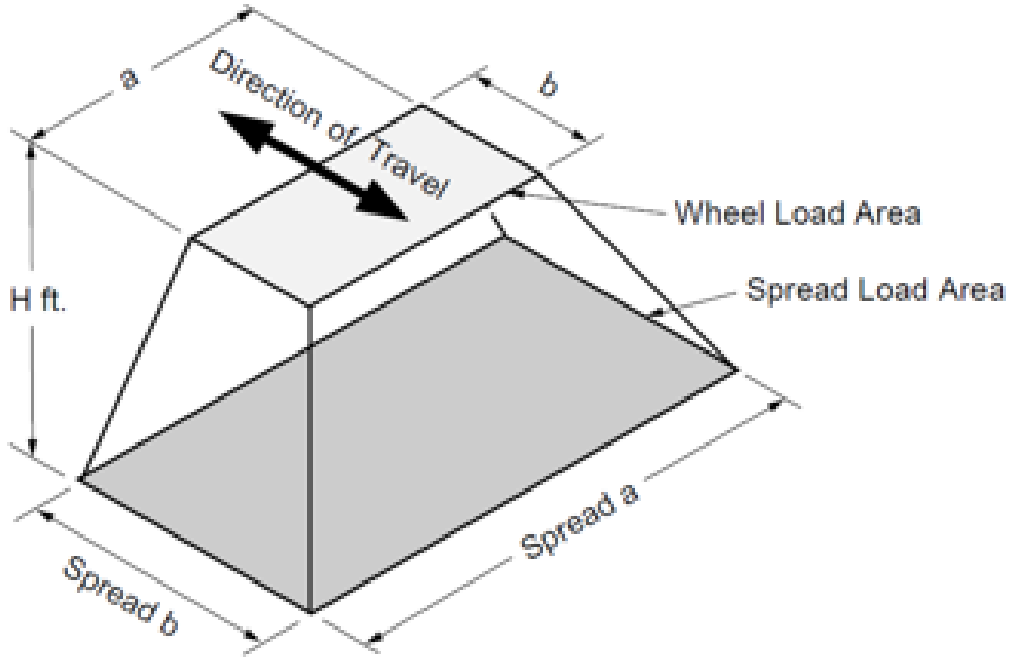
HIGHWAY LOADS ON CIRCULAR PIPE

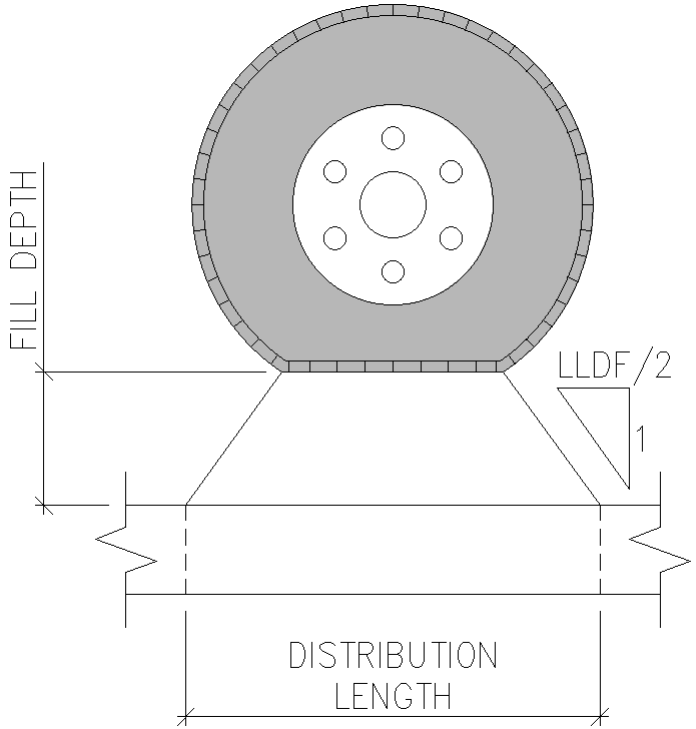
POUNDS PER LINEAR FOOT

	B_c (ft.)	HEIGHT OF FILL H ABOVE TOP OF PIPE IN FEET													
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0	
12	1.33	3780	2080	1470	1080	760	550	450	380	290	230	190	160	130	12
15	1.63	4240	2360	1740	1280	900	660	540	450	350	280	230	190	160	15
18	1.92	4110	2610	1970	1460	1030	750	620	520	400	320	260	220	190	18
21	2.21	3920	2820	2190	1620	1150	840	690	580	450	360	300	250	210	21
24	2.50	4100	3010	2400	1780	1270	930	760	640	500	400	330	280	240	24
27	2.79	3880	2940	2590	1930	1380	1010	830	700	560	440	360	300	260	27
30	3.08	3620	2830	2770	2070	1480	1080	890	750	590	480	390	330	280	30

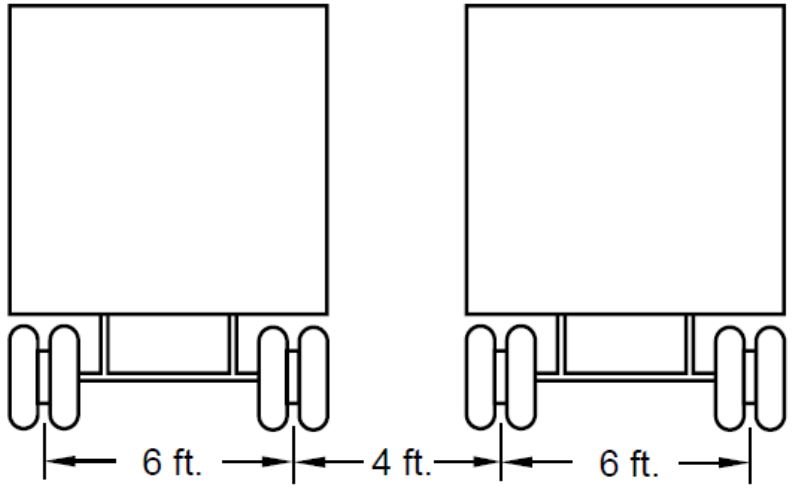
Step 4 – Live Load

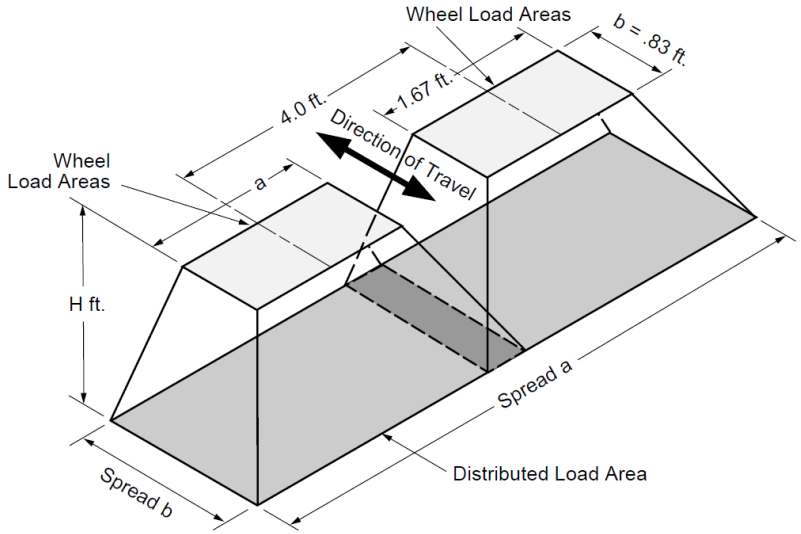
- **Live Loads (Moving Loads)**
  - **Distribution through earth fills**
  - **LLDF (Live Load Distribution Factor or Slope**

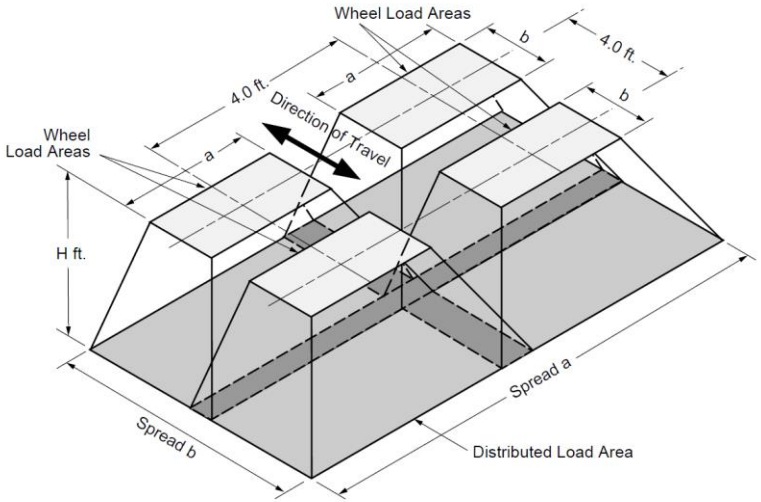




Step 4 - Live Load Spacing – HL-93



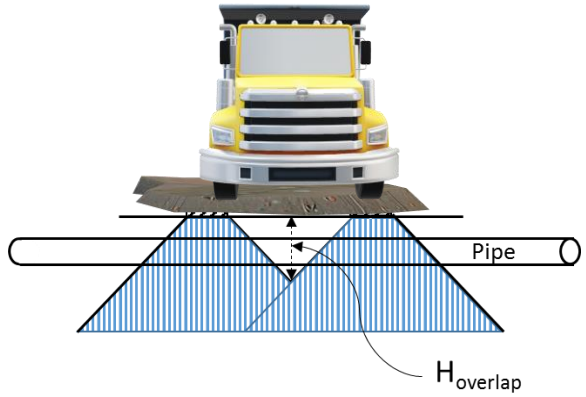


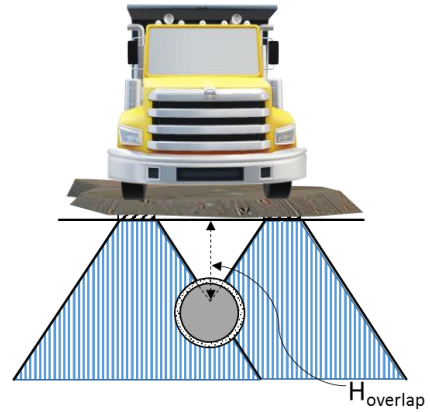


Step 4 - Live Load Analysis

- Traffic Travelling Parallel to the span
  - Single Axle Load – one lane
  - Tandem Load – one lane

- Traffic traveling perpendicular to the span
  - Single Axle Load – one lane
  - Single Axle Load – two lanes
  - Tandem Load – one lane
  - Tandem Load – two lanes





Step 4 - Live Load Analysis

- **Live Loads (Moving Loads)**
  - **Distribution through earth fills**
  - **For >= 2’ of fill**
    - **Distribution equations are basically the same regardless of traffic direction**

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

3.6.1.2.6b—Traffic Parallel to the Culvert Span

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

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

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

3.6.1.2.6c—Traffic Perpendicular to the Culvert Span

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

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

$$l_w = \frac{l_t}{12} + s_a + LLDF(H) \qquad (3.6.1.2.6b\text{-}6)$$

Live Load

- Live load area = $A_{LL} = l_w * w_w$

- Impact Factor $= IM = 33 * (1.0 - 0.125 * D_E) \geq 0\%$

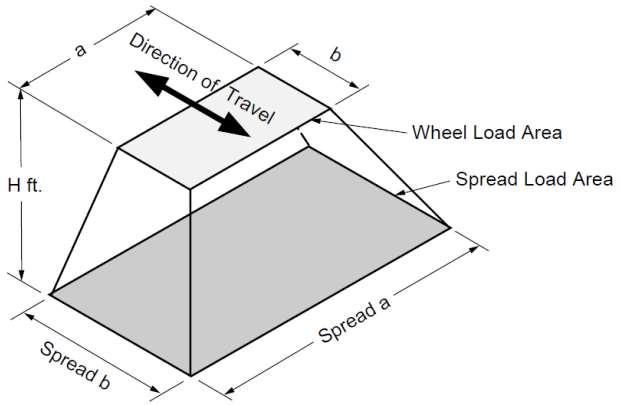
  D_E minimum depth of earth above the structure (ft)

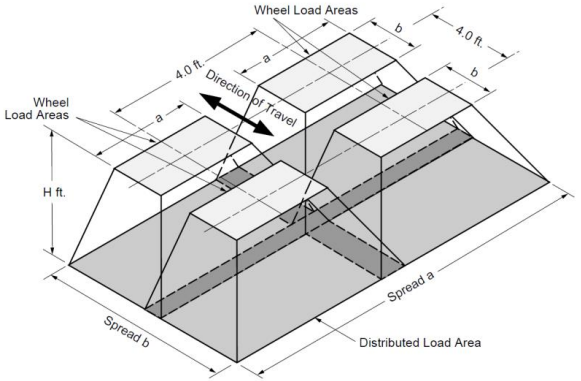
- Applied pressure at the top of the pipe:

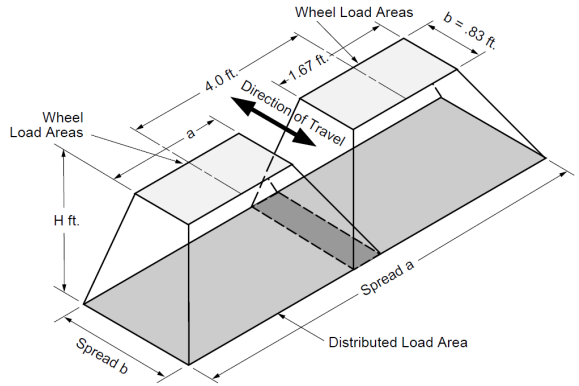
$$P_L = \frac{P * \left(1 + \frac{IM}{100}\right) * mpf}{A_{LL}}$$

  mpf = multiple presence factor

  P is the load applied from either the wheel or axle, depending on if there is overlap







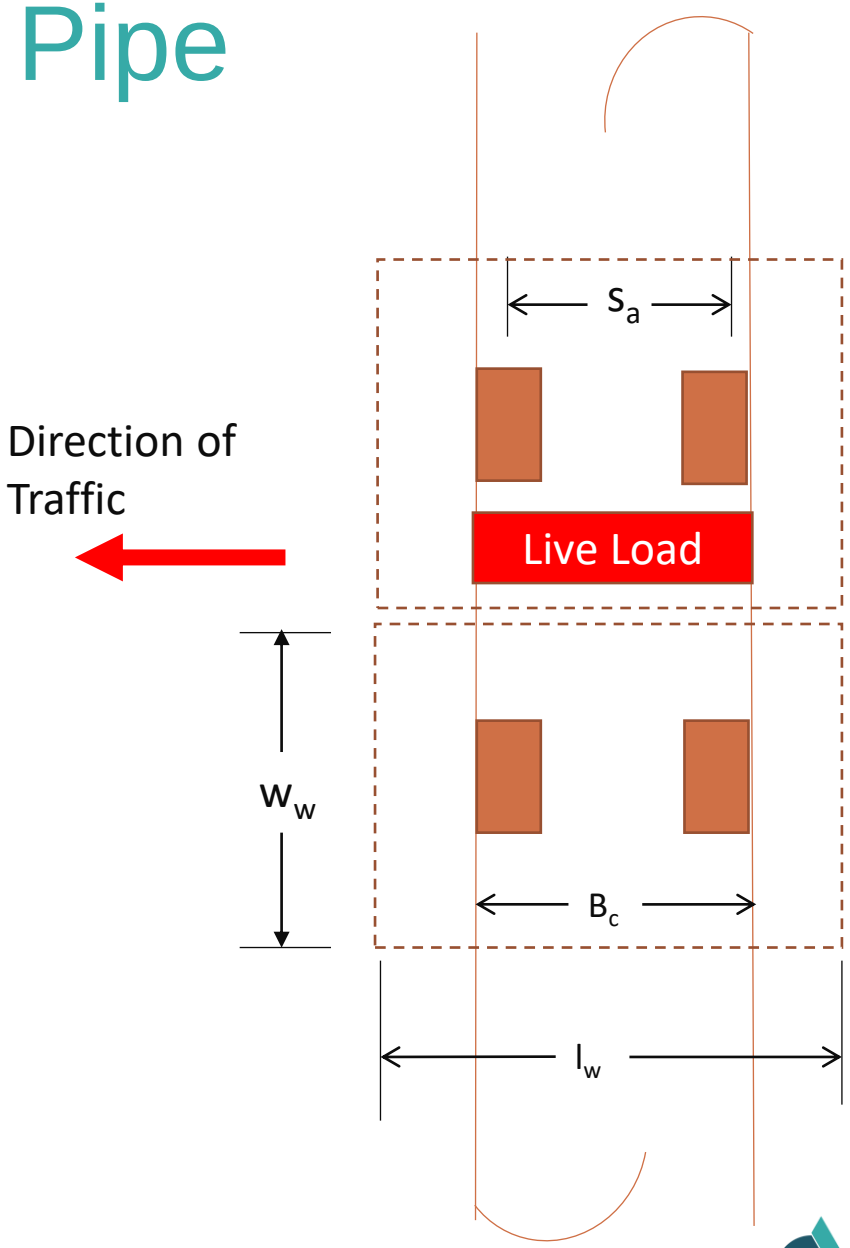
Step 4 - Live Load on the Pipe

P_L live load pressure top of the pipe

Dim = smaller of B_c or l_w

$W_{LL} = Dim \times P_L$ (lbs/ft)

W_{LL} load per linear ft is used in the 3EB equation



Step 5 – Bedding Factors

D-Load Equation

Known

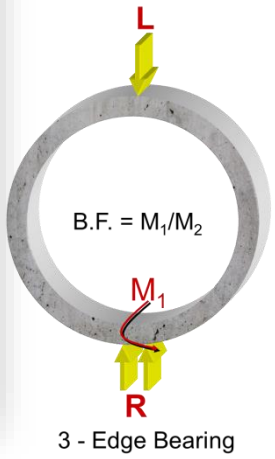
$$D = \left(\frac{12}{S_i}\right)\left(\frac{W_E + W_F}{B_{FE}} + \frac{W_{LL}}{B_{FLL}}\right) \quad (12.10.4.3.1\text{-}1)$$

B_{FE} = Earth Load Bedding Factor
B_{FLL} = Live Load Bedding Factor

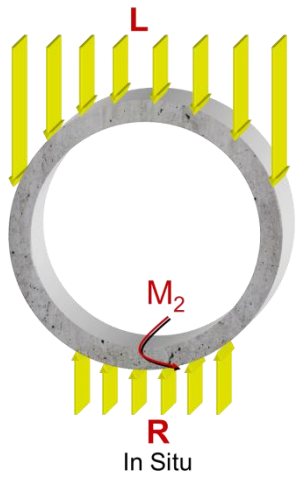
Unknown

Step 5 - Bedding Factors

$$B_f = \frac{M_{TEST}}{M_{FIELD}}$$



3 - Edge Bearing



In Situ

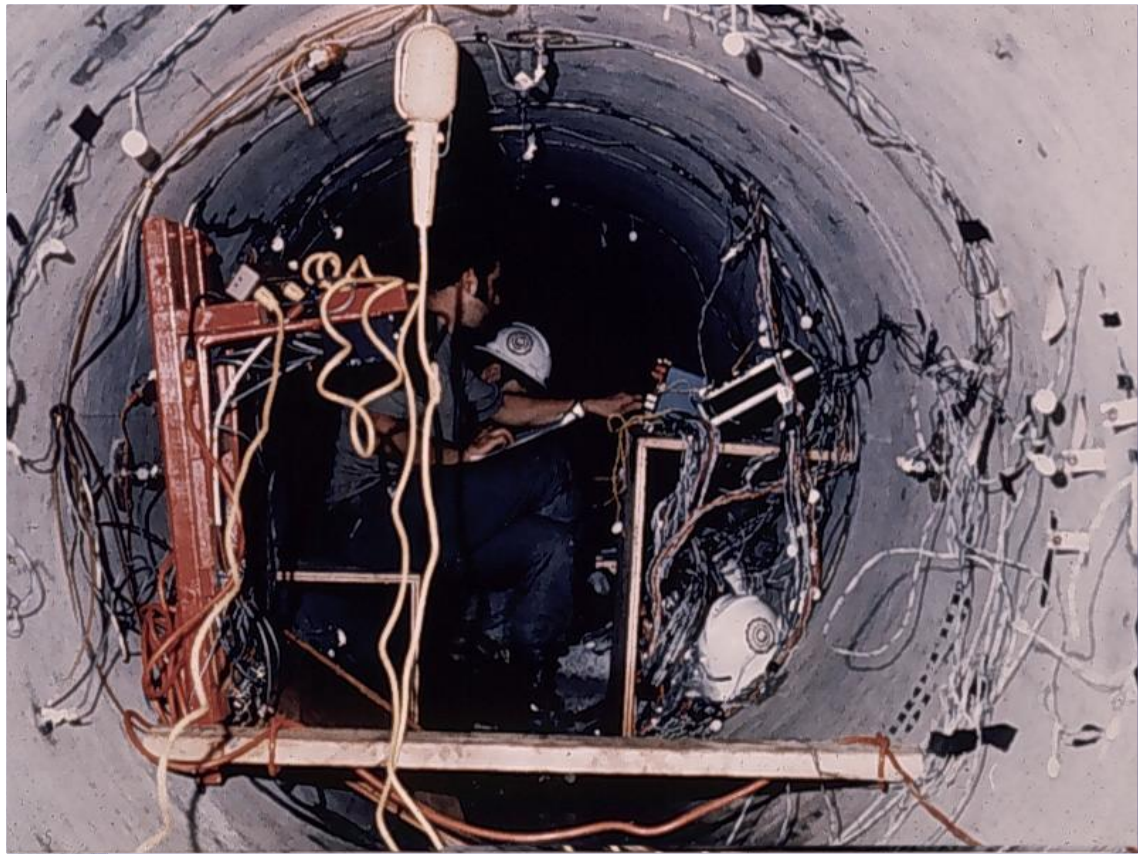
Where:

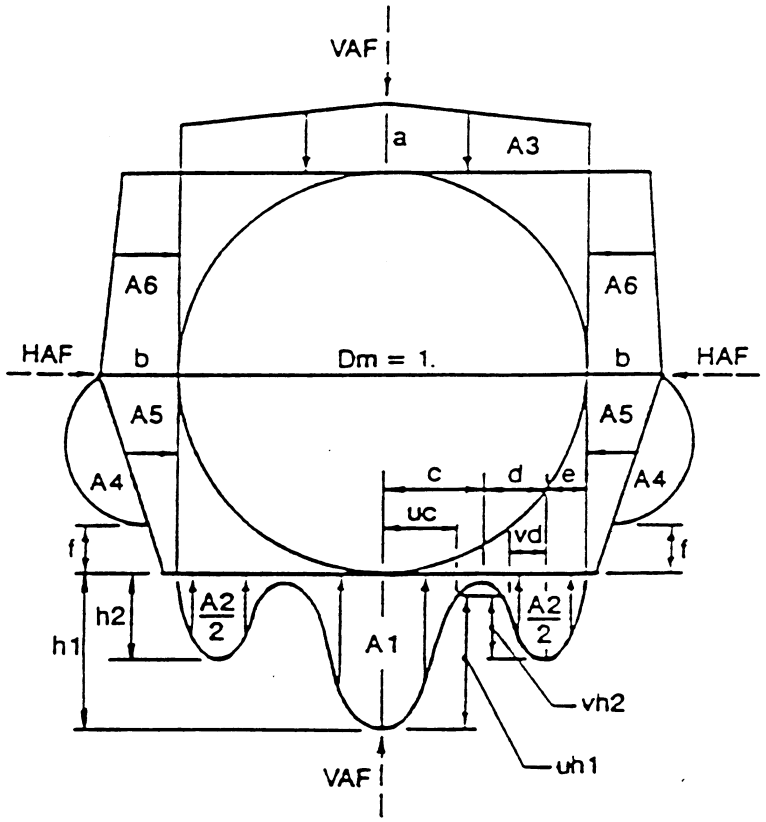
Bf = Bedding factors

M_{FIELD} = Maximum moment in pipe under field loads before failure, (inch-pounds)

M_{TEST} = Maximum moment in pipe under three-edge bearing test before failure, (inch-pounds)

Step 5 - Bedding Factors





Step 5 - 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

$$B_f = \frac{M_{TEST}}{M_{FIELD}}$$

Step 6 – Factor of Safety

Design is based on a service load 0.01-inch crack criteria, so use a value of 1.0 for the factor of safety.

Step 7 - D-Load and class of the pipe

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

POP QUIZ

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DESIGN RESOURCES

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ACPA Fill Height Table

Fill Height Tables are based on:

1. γs = 120 pcf
2. AASHTO HL-93 live load
3. Positive Projecting Embankment Condition - this gives conservative results in comparison to trench conditions
4. A Type 1 installation requires greater soil stiffness from the surrounding soils than the Type 2, 3, and 4 installations, and is thus harder to achieve. Therefore, field verification of soil properties and compaction levels should be performed.

D-Load (lb/ft/ft) for Type 1 Bedding

Class I
Class II
Class III
Class IV
Class V
Special Design

Fill Height in Feet														
Pipe Size (in)	15	16	17	18	19	20	21	22	23	24	25	26	27	28
12	898	957	1016	1075	1134	1194	1253	1312	1371	1430				
15	876	933	990	1048	1105	1163	1220	1277	1335	1392				
18	865	921	978	1034	1091	1147	1203	1260	1316	1373				
21	861	917	973	1029	1084	1140	1196	1252	1308	1364				
24	861	917	972	1028	1084	1139	1195	1251	1306	1362				
27	864	920	975	1031	1087	1142	1198	1254	1309	1365				
30	870	925	981	1037	1093	1148	1204	1260	1316	1372				
33	877	933	989	1045	1101	1157	1213	1269	1325	1381				
36	885	941	998	1054	1110	1167	1223	1279	1335	1392				
42	890	946	1002	1058	1115	1171	1227	1283	1339	1395	1451	1508	1564	1620
48	897	953	1010	1066	1122	1178	1234	1290	1346	1403	1459	1515	1571	1627

Table 3: Reinforced Pipe Classes for 0.01 Inch Crack Per ASTM C 76 (lbs/ft/ft)

Class I	≤ 800
Class II	≤ 1000
Class III	≤ 1350
Class IV	≤ 2000
Class V	≤ 3000
Special Design	> 3000

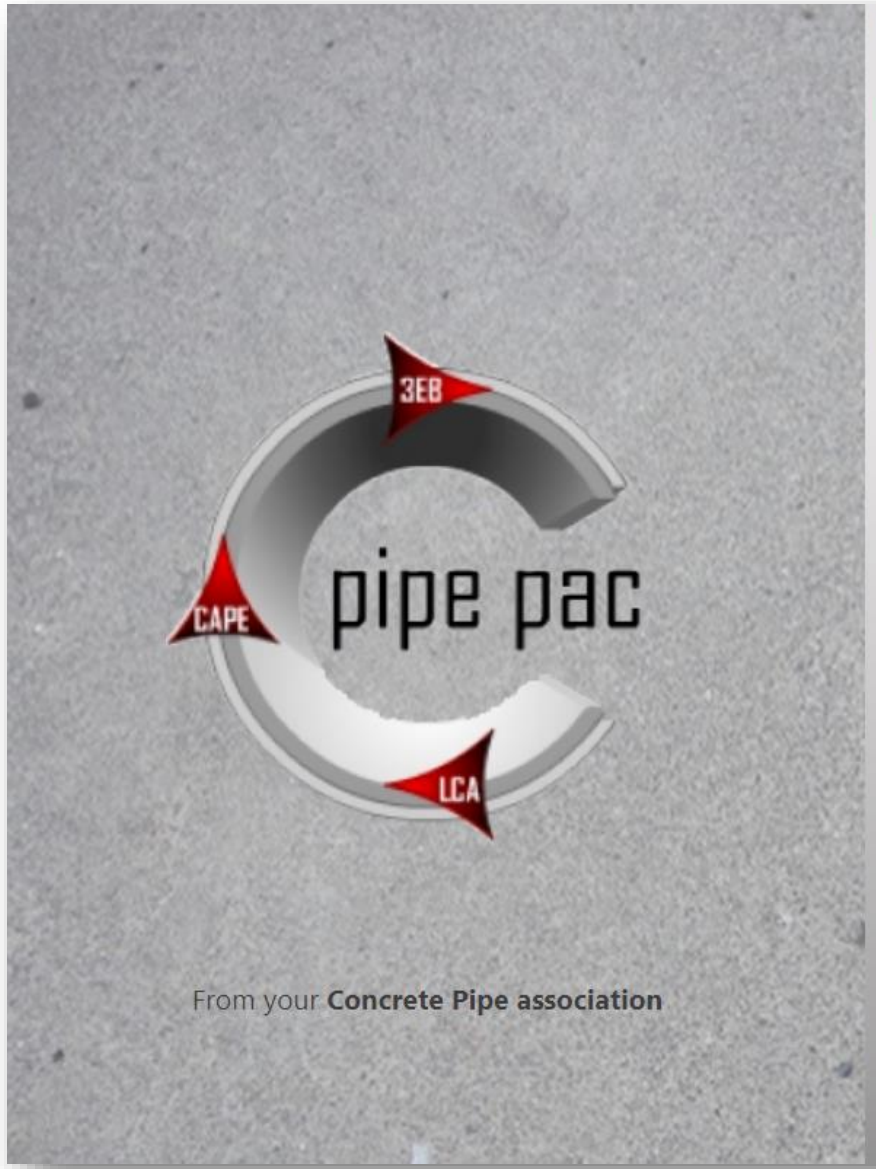
ACPA Fill Height Table

Fill Height Tables are based on:
1. γs = 120 pcf
2. AASHTO HL-93 live load
3. Positive Projecting Embankment Condition - this gives conservative results in comparison to trench conditions

D-Load (lb/ft/ft) for Type 3 Bedding

Class I
Class II
Class III
Class IV
Class V
Special Design

Fill Height in Feet														
Pipe Size (in)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
12	1518	1369	947	817	805	838	896	964	902	1000	1098	1196	1294	1392
15	1459	1318	916	794	783	815	872	939	880	975	1070	1165	1260	1355
18	1384	1285	897	781	772	804	860	926	870	963	1057	1150	1243	1337
21	1247	1263	886	775	767	799	855	921	867	959	1051	1144	1236	1329
24	1229	1248	879	772	765	798	854	920	868	960	1051	1143	1235	1327
27	1372	1251	881	778	770	804	860	925	872	963	1055	1147	1238	1330
30	1500	1260	887	786	777	812	868	933	878	970	1061	1153	1245	1337
33	1378	1218	871	780	775	813	871	936	886	978	1070	1162	1254	1345
36	1276	1189	857	776	774	815	875	941	895	987	1079	1172	1264	1356
42	1119	1113	829	765	770	815	875	942	903	995	1087	1179	1271	1363
48	1004	992	808	758	770	817	879	946	913	1005	1097	1189	1281	1373



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PipePac helps you select the right material for pipelines and culverts and determine the cost of materials over the design life of a project.

Benefits are reliable design information and ease of use based on 20 years of service to designers, specifiers, contractors, purchasers and planners throughout North America and abroad.

The optimal times to apply PipePac are at the planning stage, or when specifications are being drafted to confirm long-term costs of recommended pipe materials, and durability.

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CCPPA Canadian Concrete Pipe & Precast Association *Build on our strength*

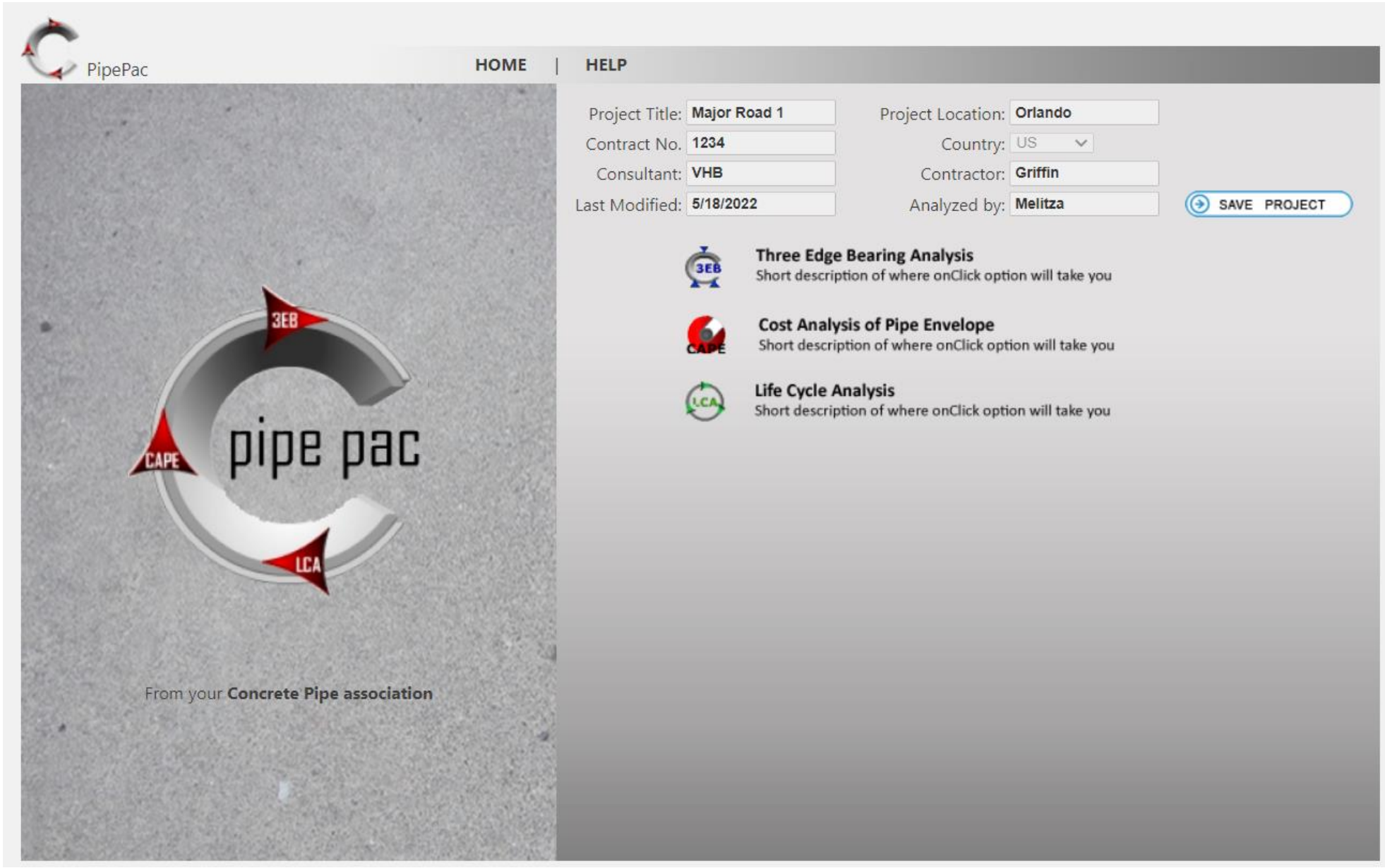
OCPA Ontario Concrete Pipe Association *The choice of a lifetime*

American Concrete Pipe Association

ACM SOFT Agility Communication Momentum

TUBÉCON L'association québécoise des fabricants de tuyaux de béton

ACPA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Project Location: Orlando
Contract No. 1234
Country: US
Consultant: VHB
Contractor: Griffin
Last Modified: 5/18/2022
Analyzed by: Melitza
SAVE PROJECT
3EB
CAPE
LCA
pipe pac
From your Concrete Pipe association
Three Edge Bearing Analysis
Short description of where onClick option will take you
Cost Analysis of Pipe Envelope
Short description of where onClick option will take you
Life Cycle Analysis
Short description of where onClick option will take you

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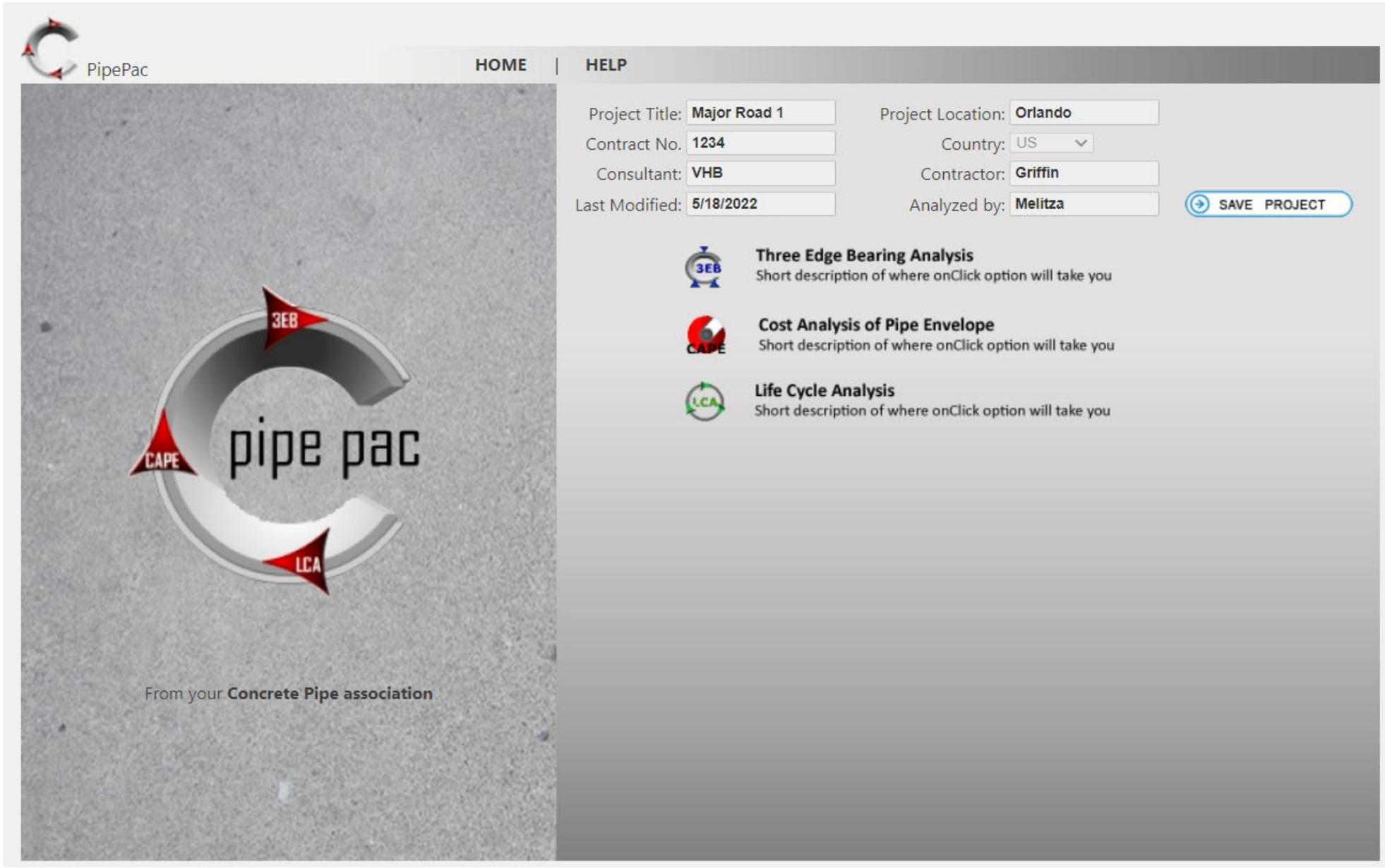
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Short description of where onClick option will take you
Life Cycle Analysis
Short description of where onClick option will take you

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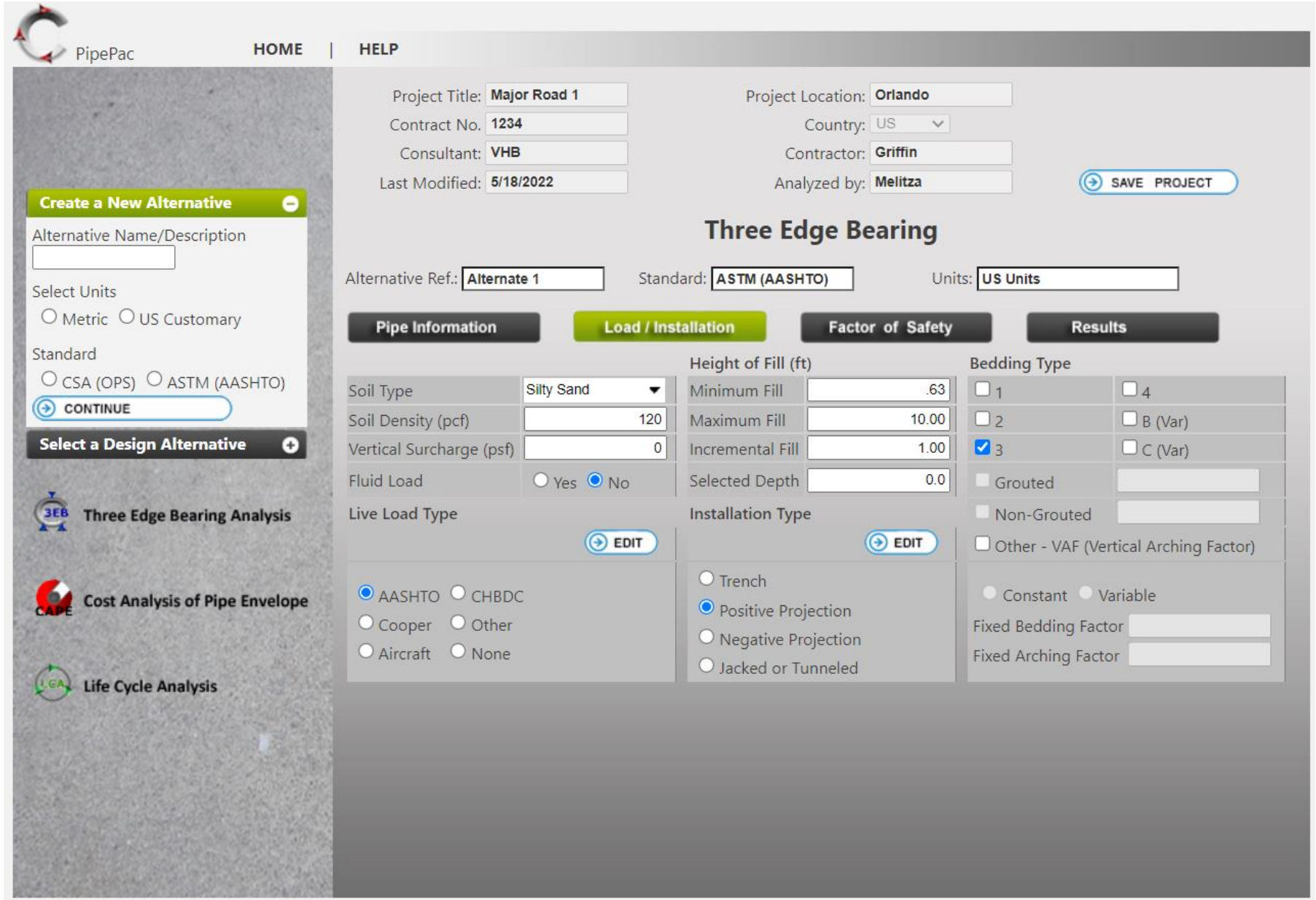
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Project Title: Major Road 1
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Contract No. 1234
Country: US
Consultant: VHB
Contractor: Griffin
Last Modified: 5/18/2022
Analyzed by: Melitza
SAVE PROJECT
Create a New Alternative
Alternative Name/Description
Select Units
Metric US Customary
Standard
CSA (OPS) ASTM (AASHTO)
CONTINUE
Select a Design Alternative
Three Edge Bearing Analysis
Cost Analysis of Pipe Envelope
Life Cycle Analysis
Three Edge Bearing
Alternative Ref.: Alternate 1
Standard: ASTM (AASHTO)
Units: US Units
Pipe Information
Load / Installation
Factor of Safety
Results
Soil Type: Silty Sand
Soil Density (pcf): 120
Vertical Surcharge (psf): 0
Fluid Load: Yes No
Height of Fill (ft)
Minimum Fill: .63
Maximum Fill: 10.00
Incremental Fill: 1.00
Selected Depth: 0.0
Bedding Type
1 4
2 B (Var)
3 C (Var)
Grouted
Non-Grouted
Other - VAF (Vertical Arching Factor)
Live Load Type
EDIT
AASHTO CHBDC
Cooper Other
Aircraft None
Installation Type
EDIT
Trench
Positive Projection
Negative Projection
Jacked or Tunneled
Constant Variable
Fixed Bedding Factor
Fixed Arching Factor

D-LOAD REQUIREMENTS FOR A 42 (in) DIAMETER CIRCULAR PIPE
Comparison of required D-Load Values for Selected Bedding Types

Pipe Depth (ft)	Type 1	Type 2	Type 3	Type 4	Type B	Type C
0.63			**826 (CL-II)**			
1.63			629 (CL-I)			
2.63			631 (CL-I)			
3.63			635 (CL-I)			
4.63			652 (CL-I)			
5.63			695 (CL-I)			
6.63			757 (CL-I)			
7.63			825 (CL-II)			
8.63			900 (CL-II)			
9.63			979 (CL-II)			
10.00			1008 (CL-III)			

Selected Depth: 0 ft. (closest pipe depth: 0.63 ft)
Reinforced Pipe Classes for 0.01 in. crack per ASTM C76 (lb/ft/ft):
CL I <= 800; CL II <= 1000; CL III <= 1350; CL IV <= 2000; Class V <= 3000

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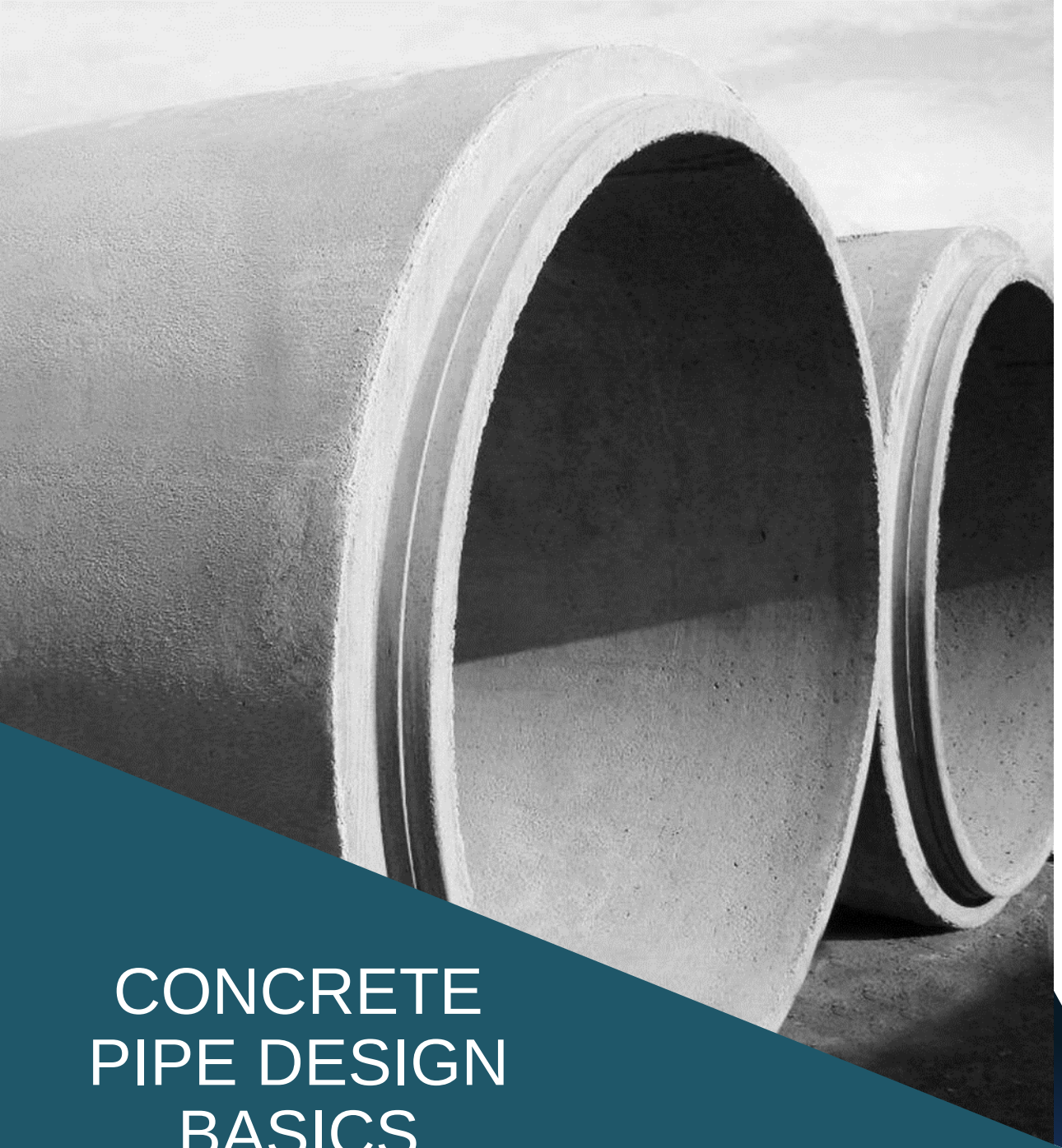

CONCRETE PIPE DESIGN BASICS

SUMMARY

- History – RCP Design
- Direct Design
- Indirect Design
  - 3EB
  - Steps
- Fill Height Tables
- Pipe Pac

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Thank You

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American Concrete Pipe Association