SECTION 12 - SOIL-CORRUGATED METAL STRUCTURE INTERACTION SYSTEMS

12.1 GENERAL

12.1.1 Scope

The specifications of this section are intended for the structural design of corrugated metal structures. It must be recognized that a buried flexible structure is a composite structure made up of the metal ring and the soil envelope, and that both materials play a vital part in the structural design of flexible metal structures.

12.1.2 Notations

\+ A = area of pipe wall (Article 12.3.1)
\+ E_m = modulus of elasticity of metal (Articles 12.3.2
\+ and 12.3.4)
\+ FF = flexibility factor (Article 12.3.4)
\+ f_{cr} = critical buckling stress (Article 12.3.2)
\+ f_u = specified minimum tensile strength (Article
\+ 12.3.2)
\+ f_y = specified minimum yield point (Article 12.3.1)
\+ I = moment of inertia, per unit length, of cross
\+ section of the pipe wall (Article 12.3.4)
\+ k = soil stiffness factor (Article 12.3.2)
\+ P = design load (Article 12.1.4)
\+ r = radius of gyration of corrugation (Article 12.3.2)
\+ S = diameter or span (Article 12.1.4)
\+ s = pipe diameter or span (Articles 12.3.2, and 12.3.4)
\+ SS = required seam strength (Article 12.3.3)
\+ T = thrust (Article 12.1.4)
\+ T_L = thrust, load factor (Articles 12.3.1 and 12.3.3)
\+ γ = load factor
\+ β_e = effective density increase
\+ ϕ = capacity modification factor (Articles 12.3.1 and
\+ 12.3.3)

12.1.3 Loads

\+ Design load, P, shall be the pressure acting on the
\+ structure. For earth pressures see Article 6.2. For live load
\+ see Articles 3.7 and 6.5. For loading combinations see
\+ Article 3.22.

12.1.4 Design

12.1.4.1 The thrust in the wall shall be checked by three criteria. Each considers the mutual function of the metal wall and the soil envelope surrounding it. The criteria are:

(a) Wall area
(b) Buckling stress
(c) Seam strength (structures with longitudinal seams)

12.1.4.2 The thrust in the wall is:

$$T = P \times \frac{S}{2} \qquad (12\text{-}1)$$

where

P = design load, in pounds per square foot;
S = diameter or span, in feet;
T = thrust, in pounds per foot.

12.1.4.3 Handling and installation strength shall be sufficient to withstand impact forces when shipping and placing the pipe.

12.1.5 Materials

The materials shall conform to the AASHTO specifications referenced herein.

12.1.6 Soil Design

12.1.6.1 Soil Parameters

The performance of a flexible culvert is dependent on soil structure interaction and soil stiffness.

The following must be considered:

(a) Soils
(1) The type and anticipated behavior of the foundation soil must be considered; i.e., stability

for bedding and settlement under load.
(2) The type, compacted density, and strength properties of the soil envelope immediately adjacent to the pipe must be established.

Good side fill is obtained from a granular material with little or no plasticity and free of organic material, i.e., Caltrans classifications shall be followed for the 90% and 95% compaction specified in Figure 12.7.4A and Standard Plan A62-F.

(b) Dimensions of soil envelope

The general recommended criteria for lateral limits of the culvert soil envelope are as follows:

(1) *Trench installations*—2 feet minimum each side of culvert. This recommended limit should be modified as necessary to account for variables such as poor in-situ soils.
(2) *Embankment installations*—2 feet minimum on each side of culvert.
(3) The minimum upper limit of the soil envelope is 2 feet above the culvert.

12.1.6.2 Pipe Arch Design

The design of the corner backfill shall account for corner pressure which shall be considered to be approximately equal to thrust divided by the radius of the pipe arch corner. The soil envelope around the corners of pipe arches shall be capable of supporting this pressure.

12.1.6.3 Arch Design

12.1.6.3.1 Special design considerations may be applicable; a buried flexible structure may raise two important considerations. The first is that it is undesirable to make the metal arch relatively unyielding or fixed compared with the adjacent side fill. The use of massive footings or piles to prevent any settlement of the arch is generally not recommended.

Where poor materials are encountered, consideration should be given to removing some or all of this poor material and replacing it with acceptable material.

The footing should be designed to provide uniform longitudinal settlement, of acceptable magnitude from a functional aspect. Providing for the arch to settle will protect it from possible drag down forces caused by the consolidation of the adjacent side fill.

The second consideration is bearing pressure of soils under footings. Recognition must be given to the effect of depth of the base of footing and the direction of the footing reaction from the arch.

Footing reactions for the metal arch are considered to act tangential to the metal plate at its point of connection to the footing. The value of the reaction is the thrust in the metal arch plate at the footing.

12.1.6.3.2 Invert slabs and other appropriate measures shall be provided to anticipate scour.

12.1.7 Abrasive or Corrosive Conditions

Extra metal thickness, or coatings, may be required for resistance to corrosion and abrasion. For highly abrasive conditions, a special design may be required.

12.1.8 Minimum Spacing

When multiple lines of pipes or pipe arches greater than 48 inches in diameter or span are used, they shall be spaced so that the sides of the pipe shall be no closer than one-half diameter or 3 feet, whichever is less to permit adequate compaction of backfill material. For diameters up to and including 48 inches, the minimum clear spacing shall not be less than 2 feet.

12.1.9 End Treatment

Protection of end slopes may require special consideration where backwater conditions may occur, or where erosion and uplift could be a problem. Culvert ends constitute a major run-off-the-road hazard if not properly designed. Safety treatment, such as structurally adequate grating that conforms to the embankment slope, extension of culvert length beyond the point of hazard, or provision for guardrail, are among the alternatives to be considered. End walls on skewed alignment require a special design.

12.1.10 *Deleted*

12.2 SERVICE LOAD DESIGN

Service Load Design method shall not be used.

12.3 LOAD FACTOR DESIGN

Load Factor Design is a method of design based on ultimate strength principles.

12.3.1 Wall Area

$$A = \frac{T_L}{\phi f_y} \qquad (12\text{-}7)$$

where

A = area of pipe wall in square inches per foot;
T_L = thrust, load factor in pounds per foot;
f_y = specified minimum yield point in pounds per square inch;
ϕ = capacity modification factor.

12.3.2 Buckling

If f_{cr} is less than f_y, A must be recalculated using f_{cr} in lieu of f_y.

$$\text{If } s < \frac{r}{k}\sqrt{\frac{24E_m}{f_u}} \text{ then } f_{cr} = f_u - \frac{f_u^{\,2}}{48E_m}\left(ks/r\right)^2 \qquad (12\text{-}8)$$

$$\text{If } s > \frac{r}{k}\sqrt{\frac{24E_m}{f_u}} \text{ then } f_{cr} = \frac{12E_m}{\left(ks/r\right)^2} \qquad (12\text{-}9)$$

where

f_u = specified minimum tensile strength in pounds per square inch;
f_{cr} = critical buckling stress in pounds per square inch;
k = soil stiffness factor = 0.22;
s = pipe diameter or span in inches;
r = radius of gyration of corrugation in inches;
E_m = modulus of elasticity of metal in pounds per square inch.

12.3.3 Seam Strength

For pipe fabricated with longitudinal seams (riveted, spot-welded, bolted), the seam strength shall be sufficient to develop the thrust in the pipe wall. The required seam strength shall be:

$$SS = \frac{T_L}{\phi} \qquad (12\text{-}10)$$

where

SS = required seam strength in pounds per foot;
T_L = thrust multiplied by applicable factor, in pounds per linear foot;
ϕ = capacity modification factor.

12.3.4 Handling and Installation Strength

Handling rigidity is measured by a flexibility factor, FF, determined by the formula

$$FF = \frac{s^2}{E_m I} \qquad (12\text{-}11)$$

where

FF = flexibility factor in inches per pound;
s = pipe diameter or maximum span in inches;
E_m = modulus of elasticity of the pipe material in pounds per square inch;
I = moment of inertia per unit length of cross section of the pipe wall in inches to the 4th power per inch.

12.4 CORRUGATED METAL PIPE

12.4.1 General

12.4.1.1 Corrugated metal pipe and pipe-arches may be of riveted, welded, or lock seam fabrication with annular or helical corrugations. The specifications are:

Aluminum	Steel
AASHTO M 190, M 196	AASHTO M 36, M 245, M 190

12.4.1.2 Service Load Design—Safety Factor, SF:

Service Load Design method shall not be used. +

12.4.1.3 Load Factor Design—Capacity Modification Factor, ϕ.

	Helical pipe with lock seam or fully welded seam	Annular pipe with spot welded, riveted or bolted seam
γ	1.3	1.3
β_E	1.5	1.5
ϕ wall area & buckling	0.9	0.9
ϕ seam strength	-	0.67

12.4.1.4 Flexibility Factor

(a) For steel conduits, FF should generally not exceed the following values:

For $^1/_4$-in. and $^1/_2$-in. depth corrugation:
FF = 4.3 × 10^{-2}
For 1-in. depth corrugation:
FF = 3.3 10^{-2}

(b) For aluminum conduits, FF should generally not exceed the following values:

For $^1/_4$-in. and $^1/_2$-in. depth corrugation with:
0.6 in. and thinner material thickness
FF = 3.1 10^{-2}
0.75 in. thickness
FF = 6.1 10^{-2}
All other material thicknesses
FF = 9.2 10^{-2}
For 1-in. depth corrugation:
FF = 6 10^{-2}

12.4.1.5 Minimum Cover

The minimum cover for design load shall be Span/5 or 2 feet minimum (flexible pavement or unpaved) and Span/5 or 1.2 feet minimum (rigid pavement).

12.4.2 Seam Strength

Minimum Longitudinal Seam Strength

2 ½ and 2-⅔ ½ Corrugated Steel Pipe — Riveted or Spot Welded

Thickness (in.)	Rivet Size (in.)	Single Rivets (kips/ft.)	Double Rivets (kips/ft.)
0.064	5/16	16.7	21.6
0.079	5/16	18.2	29.8
0.109	3/8	23.4	46.8
0.138	3/8	24.5	49.0
0.168	3/8	25.6	51.3

3 1 Corrugated Steel Pipe—Riveted or Spot Welded

Thickness (in.)	Rivet Size (in.)	Double Rivets (kips/ft.)
0.064	3/8	28.7
0.079	3/8	35.7
0.109	7/16	53.0
0.138	7/16	63.7
0.168	7/16	70.7

2 ½ and 2-⅔ ½ Corrugated Aluminum Pipe — Riveted

Thickness (in.)	Rivet Size (in.)	SingleRivets (kips/ft.)	Double Rivets (kips/ft.)
0.060	5/16	9.0	14.0
0.075	5/16	9.0	18.0
0.105	3/8	15.6	31.5
0.135	3/8	16.2	33.0
0.164	3/8	16.8	34.0

3 1 Corrugated Aluminum Pipe—Riveted

Thickness (in.)	Rivet Size (in.)	Double Rivets (kips/ft.)
0.060	3/8	16.5
0.075	3/8	20.5
0.105	1/2	28.0
0.135	1/2	42.0
0.164	1/2	54.5

12.4.3 Section Properties

12.4.3.1 Steel Conduits

1½ ¼ Corrugation			
Thickness (inch)	A_s (sq.in./ft.)	r (inch)	I 10^{-3} (in.^{4}/in.)
0.028	0.304	—	—
0.034	0.380	—	—
0.040	0.456	0.0816	0.253
0.052	0.608	0.0824	0.344
0.064	0.761	0.0832	0.439
0.079	0.950	0.0846	0.567
0.109	1.331	0.0879	0.857
0.138	1.712	0.0919	1.205
0.168	2.098	0.0967	1.635

×

2⅔ ½ Corrugation			
Thickness (inch)	A_s (sq.in./ft.)	r (inch)	I 10^{-3} (in.^{4}/in.)
0.040	0.465	0.1702	1.121
0.052	0.619	0.1707	1.500
0.064	0.775	0.1712	1.892
0.079	0.968	0.1721	2.392
0.109	1.356	0.1741	3.425
0.138	1.744	0.1766	4.533
0.168	2.133	0.1795	5.725

3 1 Corrugation			
Thickness (inch)	A_s (sq.in./ft.)	r (inch)	I 10^{-3} (in.^{4}/in.)
0.064	0.890	0.3417	8.659
0.079	1.113	0.3427	10.883
0.109	1.560	0.3448	15.459
0.138	2.008	0.3472	20.183
0.168	2.458	0.3499	25.091

5 1 Corrugation			
Thickness (inch)	A_s (sq.in./ft.)	r (inch)	I 10^{-3} (in.^{4}/in.)
0.064	0.794	0.3657	8.850
0.079	0.992	0.3663	11.092
0.109	1.390	0.3677	15.650
0.138	1.788	0.3693	20.317
0.168	2.186	0.3711	25.092

12.4.3.2 Aluminum Conduits

1½ ¼ Corrugation			
Thickness (inch)	A_s (sq.in./ft.)	r (inch)	I 10^{-3} (in.^{4}/in.)
0.048	0.608	0.0824	0.344
0.060	0.761	0.0832	0.349

2⅔ ½ Corrugation			
Thickness (inch)	A_s (sq.in./ft.)	r (inch)	I 10^{-3} (in.^{4}/in.)
0.060	0.775	0.1712	1.892
0.075	0.968	0.1721	2.392
0.105	1.356	0.1741	3.425
0.135	1.745	0.1766	4.533
0.164	2.130	0.1795	5.725

3 1 Corrugation			
Thickness (inch)	A_s (sq.in./ft.)	r (inch)	I 10^{-3} (in.^{4}/in.)
0.060	0.890	0.3417	8.659
0.075	1.118	0.3427	10.883
0.105	1.560	0.3448	15.459
0.135	2.088	0.3472	20.183
0.164	2.458	0.3499	25.091

12.4.4 Chemical and Mechanical Requirements

12.4.4.1 Aluminum-corrugated metal pipe and pipe-arch material requirements—AASHTO M 197.

Mechanical Properties for Design			
Material Grade	Minimum Tensile Strength (psi)	Minimum Yield Point (psi)	Modulus of Elasticity (psi)
3004-H34	31,000	24,000	$10 \quad 10^6$
3004-H32	27,000	20,000	$10 \quad 10^6$
Material Grade 3004-H32 is to be used with helical corrugated pipe only			

12.4.4.2 Steel-corrugated metal pipe and pipe-arch material requirements—AASHTO M 218 and M246.

Mechanical Properties for Design		
Minimum Tensile Strength (psi)	Minimum Yield Point (psi)	Modulus of Elasticity (psi)
45,000	33,000	$29 \quad 10^6$

12.4.5 Smooth Lined Pipe

Corrugated metal pipe composed of a smooth liner and corrugated shell integrally with helical seams shall not be used.

12.5 SPIRAL RIB METAL PIPE

12.5.1 General

12.5.1.1 Spiral rib metal pipe fabricated from a single thickness of smooth sheet with helical spaced ribs projecting outwardly shall be designed in accordance with Article 12.3 and the effective section properties of Article 12.5.3. The specifications are:

Aluminum	Steel
AASHTO M 190, M 196	AASHTO M 36, M 245, M 190

12.5.2 Design

12.5.2.1 Load Factor Design

γ	1.3
β_E	1.5
ϕ	0.9

Service Load Design Method shall not be used.

12.5.2.2 Flexibility Factor

(a) For steel conduits, FF should generally not exceed the following values:

$FF = 0.263\, I^{0.33}$ for $^3/_4 \quad ^3/_4 \quad 7^1/_2$ configurations

$FF = 0.163\, I^{0.33}$ for $^3/_4 \quad 1 \quad 8^1/_2$ and $^3/_4 \quad 1 \quad 11^1/_2$ configurations

(b) For aluminum conduits, FF should generally not exceed the following value:

$FF = 0.420\, I^{0.33}$ for $^3/4 \quad ^3/4 \quad 7^1/2$ configurations

$FF = 0.215\, I^{0.33}$ for $^3/4 \quad 1 \quad 11^1/2$ configurations

12.5.2.3 Minimum Cover

For steel conduit the minimum cover shall not be less than Span/4 or 2 feet minimum (flexible pavement or unpaved) and Span/4 or 1.2 feet minimum (rigid pavement).

For aluminum conduits, the minimum cover shall be less than Span/2.75 or 2 feet minimum.

12.5.3 Section Properties

12.5.3.1 Steel Conduits

$^3/_4" \quad ^3/_4"$ @ $7^1/_2"$ spacing

Thickness (in.)	A_s (sq. in./ft.)	r (in.)	$I \quad 10^{-3}$ (in.^{4}/in.)
0.064	0.509	0.258	2.821
0.079	0.712	0.250	3.701
0.109	1.184	0.237	5.537

$3/4$" 1" @ $11^1/_2$" spacing

Thickness (in.)	A_s (sq. in./ft.)	r (in.)	I 10^{-3} (in.^{4}/in.)
0.064	0.374	0.383	4.580
0.079	0.524	0.373	6.080
0.109	0.883	0.355	9.260

$3/4$" 1" @ $8^1/_2$" spacing

Thickness (in.)	A_s (sq. in./ft.)	r (in.)	I 10^{-3} (in.^{4}/in.)
0.064	0.499	0.379	5.979
0.079	0.694	0.370	7.913
0.109	1.149	0.354	11.983

12.5.3.2 Aluminum Conduits

$3/4$" $3/4$" @ $7^1/_2$" spacing

Thickness (in.)	A_s (sq. in./ft.)	r (in.)	I 10^{-3} (in.^{4}/in.)
0.060	0.415	0.272	2.558
0.075	0.569	0.267	3.372
0.105	0.914	0.258	5.073

$3/4$" 1" @ $11^1/_2$" spacing

Thickness (in.)	A_s (sq. in./ft.)	r (in.)	I 10^{-3} (in.^{4}/in.)
0.060	0.312	0.396	4.080
0.075	0.427	0.391	5.450
0.105	0.697	0.380	8.390

12.5.4 Chemical and Mechanical Requirements

12.5.4.1 Steel Spiral Rib Pipe and Pipe -Arch Requirements-AASHTO M 218

Mechanical Properties for Design

Minimum Tensile Strength (psi)	Minimum Yield Point (psi)	Modulus of Elasticity (psi)
45,000	33,000	29 10^6

12.5.4.2 Aluminum Spiral Rib Pipe and Pipe - Arch Requirements-AASHTO M 197

Mechanical Properties for Design

Minimum Tensile Strength (psi)	Minimum Yield Point (psi)	Modulus of Elasticity (psi)
31,000	24,000	10 10^6

12.5.5 Construction Requirements

The deflection or elongation of the structure shall not exceed 5% at any time during construction or after.

12.6 STRUCTURAL PLATE PIPE STRUCTURES

12.6.1 General

12.6.1.1 Structural plate pipe, pipe-arches, and arches shall be bolted with annular corrugations only.

The specifications are:

Aluminum	Steel
AASHTO M 219	AASHTO M 167

12.6.1.2 Service Load Design—Safety Factor, SF

Service Load Design Method shall not be used.

12.6.1.3 Load Factor Design Capacity Modification Factor

γ	1.3
β_E	1.5
ϕ	0.9

See Figure 12.6.1.3A

LOAD FACTOR DESIGN - SSPP

Group X - Culvert =

Where ã =1.3; â$_D$ =1.0; â$_E$ =1.5; â$_L$ =1.67

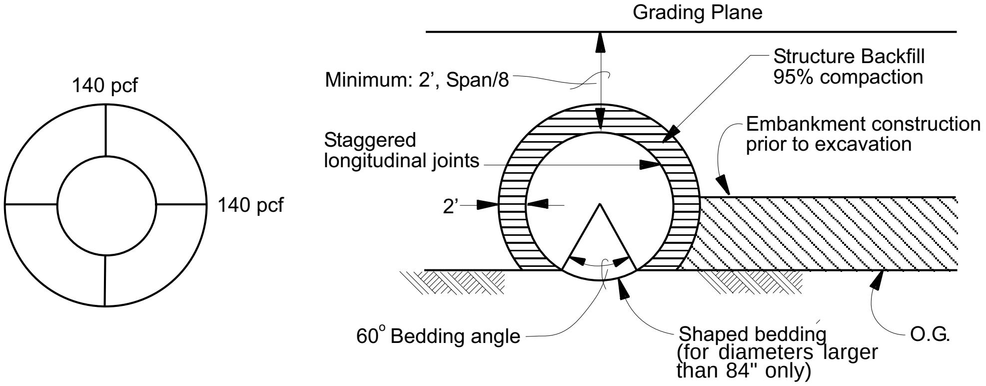


Figure 12.6.1.3A

12.6.1.4 Flexibility Factor

(a) For steel conduits, FF should generally not exceed the following values:
6 in 2 in. corrugation FF = 2.0 10^{-2} (pipe)
6 in. 2 in. corrugation FF = 3.0 10^{-2} (pipe-arch)
6 in. 2 in. corrugation FF = 3.0 10^{-2} (arch)

(b) For aluminum conduits, FF should generally not exceed the following values:
9 in. $2^1/_2$ in. corrugation FF = 2.5 10^{-2} (pipe)
9 in. $2^1/_2$ in. corrugation FF = 3.6 10^{-2} (pipe-arch)
9 in. $2^1/_2$ in. corrugation FF = 3.6 10^{-2} (arch)

12.6.1.5 Minimum Cover

The minimum cover for design loads shall be Span/8 or 2 feet minimum (flexible pavement or unpaved) and Span/8 or 1.2 feet minimum (rigid pavement).

12.6.2 Seam Strength

Minimum Longitudinal Seam Strengths

6" 2" Steel Structural Plate Pipe				
Thickness (in.)	Bolt Size (in.)	4 Bolts/ft. (kips/ft.)	6 Bolts/ft. (kips/ft.)	8 Bolts/ft. (kips/ft.)
0.109	3/4	42.0	—	—
0.138	3/4	62.0	—	—
0.168	3/4	81.0	—	—
0.188	3/4	93.0	—	—
0.218	3/4	112.0	—	—
0.249	3/4	132.0	—	—
0.280	3/4	144.0	180	194
0.318	7/8	—	—	235.0
0.380	7/8	—	—	285.0

9" × $2^1/_2$" Aluminum Structural Plate Pipe			
Thickness (in.)	Bolt Size (in.)	Steel Bolts $5^1/_2$ Bolts Per ft. (kips/ft.)	Aluminum Bolts $5^1/_2$ Bolts Per ft. (kips/ft.)
0.100	$^3/_4$	28.0	26.4
0.125	$^3/_4$	41.0	34.8
0.150	$^3/_4$	54.1	44.4
0.175	$^3/_4$	63.7	52.8
0.200	$^3/_4$	73.4	52.8
0.225	$^3/_4$	83.2	52.8
0.250	$^3/_4$	93.1	52.8

12.6.3 Section Properties

12.6.3.1 Steel Conduits

6" 2" Corrugations			
Thickness (in.)	A_s (sq.in./ft.)	r (in.)	I 10^{-3} (in.^{4}/in.)
0.109	1.556	0.682	60.411
0.138	2.003	0.684	78.175
0.168	2.449	0.686	96.163
0.188	2.739	0.688	108.000
0.218	3.199	0.690	126.922
0.249	3.650	0.692	146.172
0.280	4.119	0.695	165.836
0.318	4.671	0.698	190.0
0.380	5.613	0.704	232.0

12.6.3.2 Aluminum Conduits

9" $2^1/_2$" Corrugations			
Thickness (in.)	A_s (sq.in./ft.)	r (in.)	I 10^{-3} (in.^{4}/in.)
0.100	1.404	0.8438	83.065
0.125	1.750	0.8444	103.991
0.150	2.100	0.8449	124.883
0.175	2.449	0.8454	145.895
0.200	2.799	0.8460	166.959
0.225	3.149	0.8468	188.179
0.250	3.501	0.8473	209.434

12.6.4 Chemical and Mechanical Properties

12.6.4.1 Steel Structural Plate Pipe, Pipe-Arch, and Arch Material Requirements—AASHTO M 167

MECHANICAL PROPERTIES FOR DESIGN		
Minimum Tensile Strength (psi)	Minimum Yield Point (psi)	Modulus of Elasticity (psi)
45,000	33,000	29 10^6

12.6.4.2 Aluminum Structural Plate Pipe, Pipe-Arch, and Arch Material Requirements—AASHTO M 219, Alloy 5052.

MECHANICAL PROPERTIES FOR DESIGN			
Thickness (in.)	Minimum Tensile Strength (psi)	Minimum Yield Point (psi)	Modulus of Elasticity (psi)
0.100 to 0.150	35,000	24,000	10 10^6
0.175 to 0.250	34,000	24,000	10 10^6

12.6.5 Structural Plate Arches

The design of structural plate arches should be based on ratios of a rise to span of 0.30 minimum.

12.7 LONG SPAN STRUCTURAL PLATE STRUCTURES

12.7.1 General

Long span structural plate structures are short span bridges defined as follows.

12.7.1.1 Structural plate structures (pipe, pipe-arch, and arch) that exceed 20 feet diameter or span, or the maximum sizes imposed by Article 12.6.

12.7.1.2 Special shapes of any size that involve a relatively large radius of curvature in crown or side plates. Vertical ellipses, horizontal ellipses, underpasses, low profile arches, high profile arches, and inverted pear shapes are the terms describing these special shapes.

12.7.1.3 Wall strength and chemical and mechanical properties shall be in accordance with Article 12.6.

12.7.2 Structure Design

12.7.2.1 General

Long span structures shall be designed in accordance with Articles 12.1, 12.3 and 12.6 except that the requirements for buckling and flexibility factor shall not apply. The span in the formulae for thrust shall be replaced by twice the top arc radius. Long span structures shall include acceptable special features. Minimum requirements are detailed in Table 12.7.1A.

These structures may be designed in accordance with Article 12.5 and may omit the special features if all requirements of that article are adhered to.

TABLE 12.7.1A Minimum Requirements for Long Span Structures with Acceptable Special Features

I. STRUCTURAL PLATE MINIMUM THICKNESS

	Top Radius (feet)				
	≤ 15	15 – 17	17 – 20	20 – 23	23 – 25
6" 2" Corrugated Steel Plates	0.109"	0.138"	0.168"	0.218"	0.249"

II. MINIMUM COVER IN FEET

Minimum cover shall be Span/8 or 3 feet mimimum. Coverage which is less than this shall have a 2 foot thick layer of Class C concrete placed over the crown. This concrete shall extend between the longitudinal stiffeners (if longitudinally stiffened) or between the points of radii change.

III. GEOMETRIC LIMITS

A. Maximum Plate Radius—25 ft.
B. Maximum Central Angle of Top Arc = 80°
C. Minimum Ratio, Top Arc Radius to Side Arc Radius = 2
D. Maximum Ratio, Top Arc Radius to Side Arc Radius = 5*

*Note: Sharp radii generate high soil bearing pressures. Avoid high ratios when significant heights of fill are involved.

12.7.2.2 Acceptable Special Features

12.7.2.2.1 Longitudinally Reinforced Long Span Structural Plate Structures

Longitudinally reinforced long span structures shall have continuous longitudinal structural stiffeners connected to the corrugated plates at each side of the top arc. Stiffeners shall be reinforced concrete.

12.7.2.2.2 Transversely Reinforced Long Span Structural Plate Structures

Transversely reinforced long span structures shall have reinforcing ribs formed from structural shapes curved to conform to the curvature of the plates, fastened to the structure as required to ensure integral action with the corrugated plates, and spaced at such intervals as necessary to increase the moment of inertia of the section to that required by the design. They shall be considered a special design.

12.7.3 Foundation Design

12.7.3.1 Settlement Limits

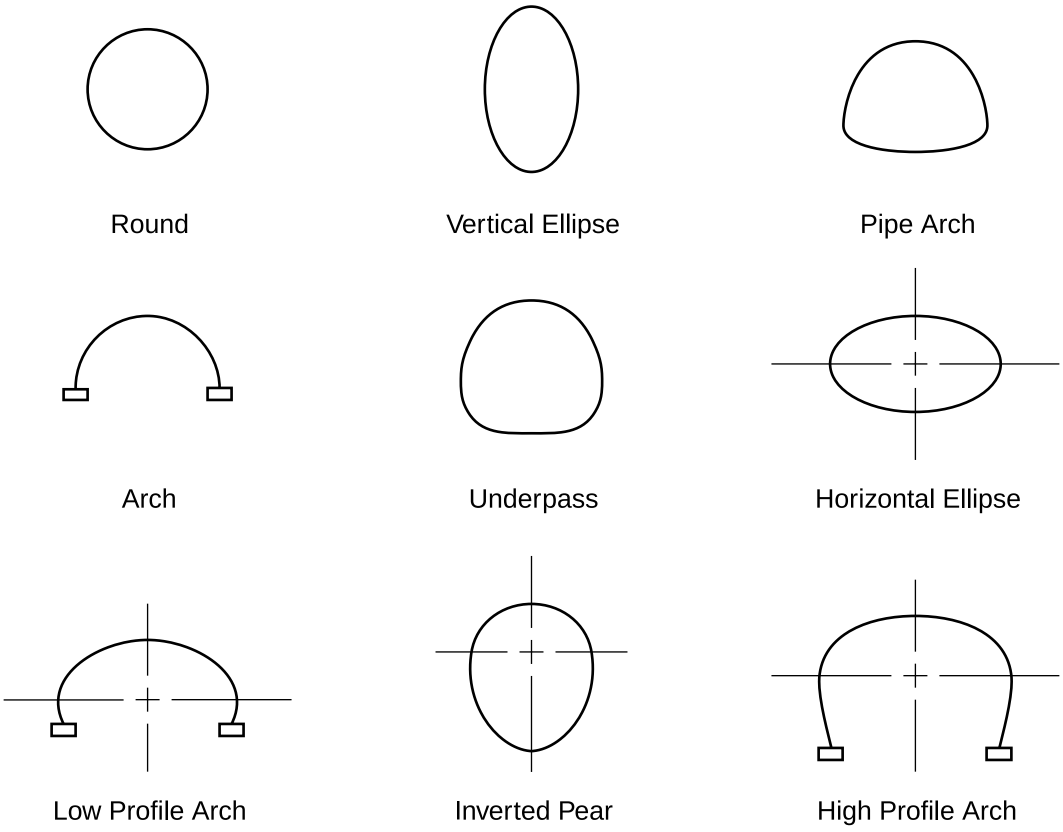
Foundation design requires a geotechnical survey of the site to ensure that both the structure and the critical backfill zone on each side of the structure will be properly supported, within the following limits and considerations.

12.7.3.1.1 Once the structure has been backfilled over the crown, settlements of the supporting backfill relative to the structure must be limited to control dragdown forces. If the sidefill will settle more than the structure, a detailed analysis may be required.

12.7.3.1.2 Settlements along the longitudinal centerline of arch structures must be limited to maintain slope and preclude footing cracks (arches). Where the structure will settle uniformly with the adjacent soils, long spans with full inverts can be built on a camber to achieve a proper final grade.

12.7.3.1.3 Differential settlements across the structure (from springline to springline) shall not exceed $0.01 (\text{Span})^2/$ rise in order to limit excessive rotation of the structure. More restrictive settlement limits may be required to protect pavements, or to limit longitudinal differential deflections.

Standard Terminology of Structural Plate Shapes including Long Span Structures



$$\left[\frac{2H_1}{L_w}+2\right] \leq$$

Figure 12.7.3

12.7.3.2 Footing Reactions (Arch Structures)

Footing reactions are calculated by simple statics to support the vertical loads. Soil load footing reactions (V_{DL}) are taken as the weight of the fill and pavement above the springline of the structure.

Live loads, which provide relatively limited pressure zones acting on the crown of the structure are distributed to the footings.

Footing reactions may be taken as

$$R_V = (V_{DL} + V_{LL}) \text{ Cos } \Delta \qquad (12.7.3.2\text{-}1)$$

$$R_H = (V_{DL} + V_{LL}) \text{ Sin } \Delta \qquad (12.7.3.2\text{-}2)$$

Where

R_V = Vertical footing reaction component (K/ft)

R_H = Horizontal reaction component (K/ft)

V_{DL} = $[H_2(S) – A_T]\ \alpha/2$

V_{LL} = $n(AL)/(L_W + 2H_1)$

Δ = Return angle of the structure (degrees)

AL = Axle load (K) = 50% of all axles that can be placed on the structure in cross-sectional view at one time.

32K for H20/HS20
40K for H25/HS25
50K for Tandem Axle
160K for E80 Railroad Loading

A_T = the area of the top portion of the structure above the springline (ft.^{2})

H_1 = Height of cover above the footing to traffic surface (ft.)

H_2 = Height of cover from the structure's springline to traffic surface (ft.)

L_W = Lane width (ft.)

n = interger number of traffic lanes

α = Unit weight of soil (k/ft^3)

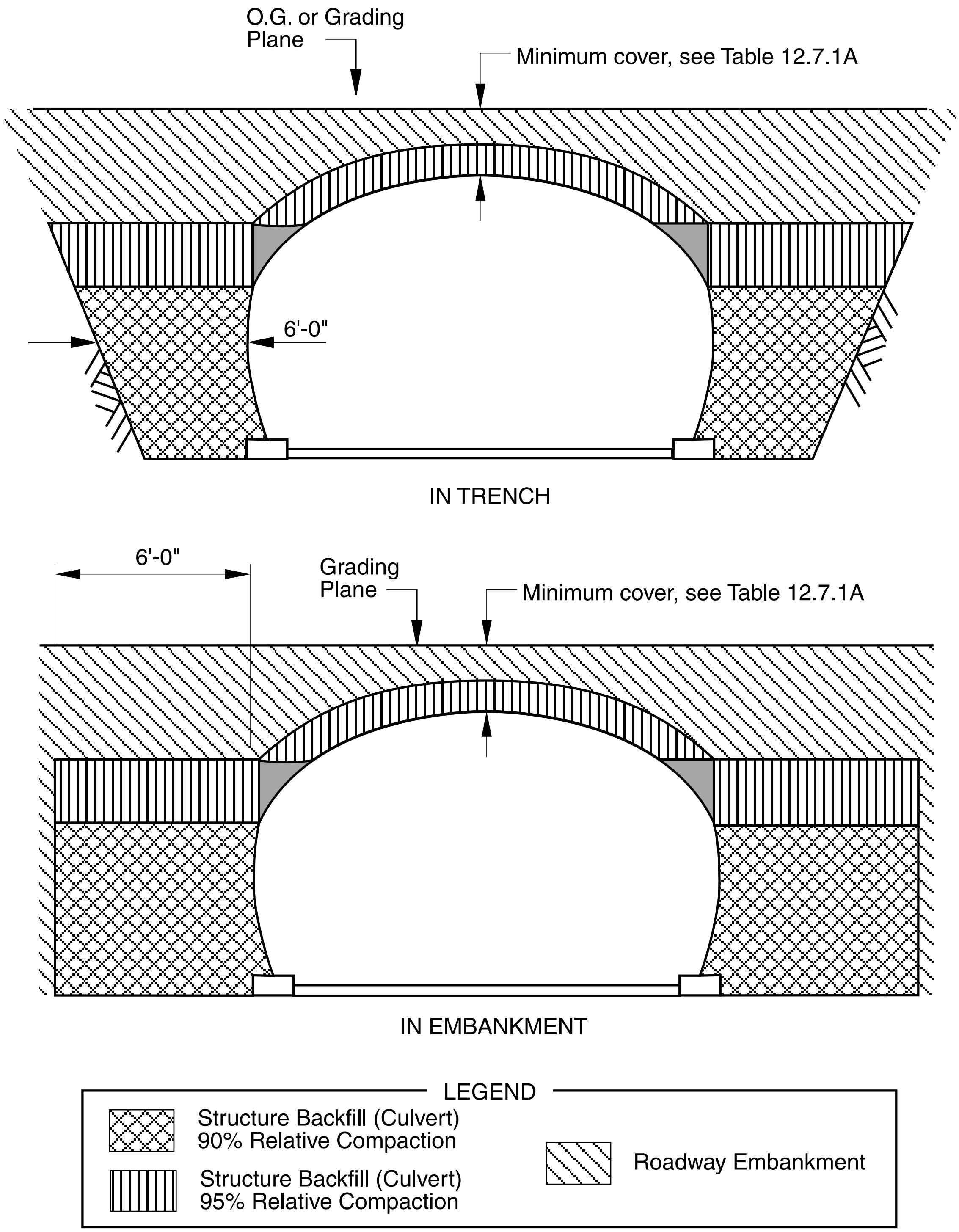


Figure 12.7.4A

12.7.3.3 Footing Design

Reinforced concrete footings shall be designed in accordance with Article 4.4 to limit settlements to the requirements of 12.7.3.1

Footings should be sized to provide bearing pressures equal to or greater than those exerted by the structural backfill on the foundation. This helps to ensure that if settlements do occur the footings and backfill will settle in approximately equal amounts avoiding excessive dragdown loads on the structure.

12.7.4 Soil Envelope Design

12.7.4.1 Caltrans specifications shall be followed for the 90% and 95% compactions specified in Figure 12.7.4A except that the percentage of fines passing the No. 200 sieve shall not exceed 25.

12.7.4.2 The extent of the select structural backfill about the barrel is dependent on the quality of the adjacent embankment. For ordinary installations, with good quality, well compacted embankment or in-situ soil adjacent to the structure backfill, a width of structural backfill 6 feet beyond the structure is sufficient. The structure backfill shall also extend to an elevation 2 to 4 feet over the structure. Where dissimilar materials not meeting geotechnical filter criteria are used adjacent to each other, a suitable geotextile must be used to avoid migration.

12.7.4.3 It shall not be necessary to excavate native soil at the sides if the quality of the native soil is as good as the proposed compacted side fill except to create the minimum width that can be compacted. The soil over the top shall also be select and shall be carefully and densely compacted.

12.7.4.4 A geotechnical investigation shall be required to ascertain that the backfill specified is adequate.

12.7.4.5 Concrete backfill or soil cement backfill shall not be used with any aluminum long span structure.

12.7.4.6 Where the structure has a small radius corner arc care must be taken to insure that the soil envelope will be capable of supporting the pressure.

Forces acting radially off the small radius corner arc of the structure at a distance d_1 from the structure can be calculated as

$$P_1 = \frac{T}{R_c + d_1} \qquad (12.7.4.6\text{-}1)$$

Where

P_1 = The horizontal pressure from the structure at a distance d_1 from it (psf)

d_1 = Distance from the structure (ft)

T = Total dead load and live load thrust in the structure (Article 12.7.2.1-psf)

R_c = Corner radius of the structure (ft)

The required envelope width beside the pipe, d, can be calculated for a known, allowable bearing pressure as

$$d = \frac{T}{P_{Brg}} - R_C \qquad (12.7.4.6\text{-}2)$$

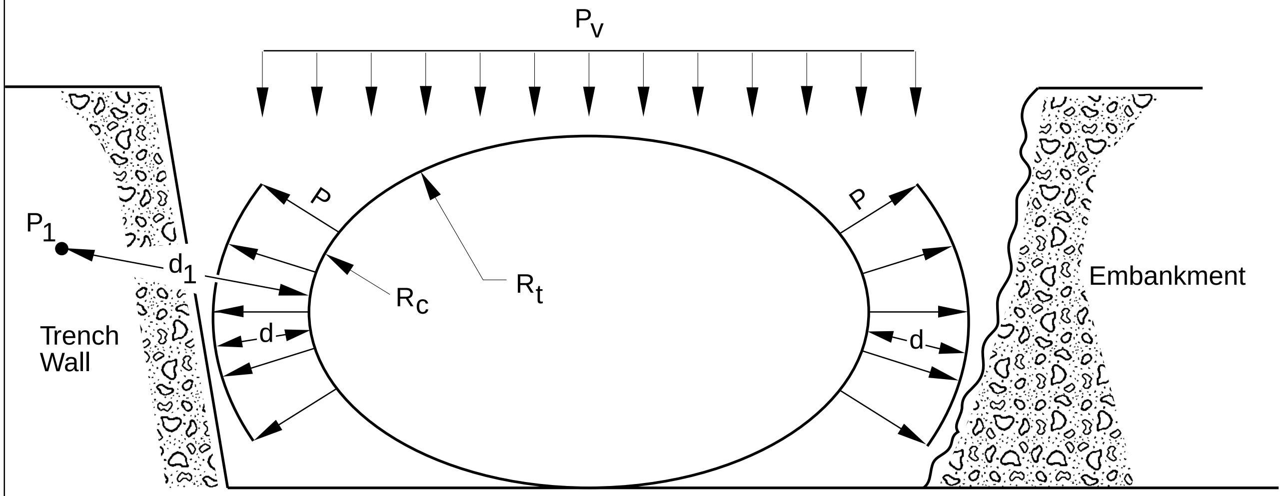
Where

d = required envelope width beside the structure (ft)

P_{Brg} = Allowable bearing pressure to limit compression (strain) in the trench wall or embankment (psf)

See Figure 12.7.4B

Assumed Pressure Distribution



Rt = Top radius of the structure
Rc = Corner radius of the structure
d = Minimum structural backfill width
P = The horizontal pressure from the structure at a distance d from it (psf)
Pv = Dead and live load pressure (psf) on the crown

Figure 12.7.4B

12.7.5 End Treatment

When headwalls are not used, special attention may be necessary at the ends of the structure. For hydraulic structures, additional reinforcement of the end is recommended to secure the metal edges at inlet and outlet against hydraulic forces. Reinforced concrete or structural steel collars, tension tiebacks or anchors in soil, partial headwalls and cut-off walls below invert elevations are some of the methods which can be used. Square ends may have side plates beveled up to a maximum 2:1 slope. Skew cut ends must be fully connected to and supported by a reinforced concrete headwall. The district Project Engineer shall approve the end treatment for hydraulic and aesthetic purposes.

12.7.6 Multiple Structures

Care must be exercised on the design of multiple closely spaced structures to control unbalanced loading. Fills should be kept level over the series of structures when possible. Significant roadway grades across a series of structures require checking of the stability of the flexible structures under the resultant unbalanced loading.

The clearance may be reduced below that specified in Section 12.1.8 to a minimum of 2 feet where Class C concrete is placed between structures.

12.8 STRUCTURAL PLATE BOX CULVERT

Structural plate box culverts specifications shall not be used, pending research and development of design standards.