

12.3 NOTATION

Revise the following notations as follows:

- A_{eff} = effective wall area (~~in.²/ft~~) (in.²/in.) (~~(12.12.3.5.2)~~) ((12.12.2.2))
 A_g = gross wall area within a length of one period (~~in.²~~) (in.²/in.) (~~(12.12.3.5.3e)~~) ((12.12.3.5))

12.3 NOTATION

Revise the following notations as follows:

- ~~B'~~ = ~~nonuniform stress distribution factor (12.12.3.5.2)~~
- b = width of section resisting M , N , and V ; usually $b=12.0$ in.; ~~element effective width (12.12.4.2.4c)~~
(12.12.3.5.3e)
- b_e = element effective width (in.) (12.12.3.10.1b)
- C_L = live load distribution coefficient (~~12.12.3.4~~) (12.12.2.2)
- C_n = calibration factor to account for nonlinear effects (12.12.3.12.1e)
- ~~e~~ = ~~distance from inside face to neutral axis of thermoplastic pipe (in.); distance from inside surface to neutral axis (in.); distance from neutral axis extreme fiber (in.) (12.12.3.6) (12.12.3.5.2) (12.12.3.5.4b)~~
- D = straight leg length of haunch (in.); pipe diameter (in.); required D -load capacity of reinforced concrete pipe (klf); diameter to centroid of pipe wall (in.) (12.9.4.1) (12.6.6.2) (12.10.4.3.1) (~~12.12.3.5.4b~~) (12.12.2.2)
- ~~D_e~~ = ~~effective diameter of thermoplastic pipe (in.) (12.12.3.6)~~
- D_f = shape factor (~~12.12.3.5.4b~~) (12.12.3.12.2b)
- D_L = deflection lag factor (12.12.2.2)
- D_o = outside diameter of pipe (~~#in.~~) (~~12.12.3.4~~) (12.12.2.2)
- E = initial modulus of elasticity (ksi) (12.12.3.6)
- E_{50} = 50-year modulus of elasticity (ksi) (~~12.12.3.5.3e~~) (12.12.3.3)
- E_{75} = 75-year modulus of elasticity (ksi) (12.12.3.3)
- ~~E_p~~ = ~~-or long-term modulus of pipe material as specified in Table 12.12.3.3-1 (ksi) (12.12.2.2)~~
- F_u = specified minimum tensile strength (ksi); material yield strength for design load duration (ksi) (12.7.2.4) (12.12.3.10.1b)

12.3 NOTATION

Revise the following notations as follows:

- H_w = depth of water table above spring line of pipe (ft) (12.12.3.7)
 ~~h_w = height of water surface above top of pipe (ft) (12.12.3.5.2)~~
 I_p = moment of inertia of pipe profile per unit length of pipe (in.4/in.) (12.12.2.2)
 IM = dynamic load allowance as specified in Table 3.6.1.1.2-1 (percent) (12.12.3.9)
 K_L = coefficient to consider design location (in.) (12.12.3.9)
 K_2 = coefficient to account for thrust variation around circumference (12.12.3.5)
 K_B = bedding coefficient (12.12.2.2)
 K_t = time factor as specified in Table 12.12.3.10.1b-1 (12.12.3.10.1b)
 K_{wz} = factor for uncertainty in level of ground water table (12.12.3.8)
 K_{yF} = installation factor (12.12.3.5)
 k = soil stiffness factor; edge support coefficient; plate buckling coefficient (12.7.2.4) (12.13.3.3)
~~(12.12.3.5.3e) (12.12.3.10.1b)~~
 $LLDF$ = factor for distribution of live load through earth fills as specified in Article 3.6.1.2.6 (12.12.3.5)
 L_0 = length of live load surface contact area parallel to pipe diameter as specified in Article 3.6.1.2.5 (in.) (12.12.3.9)
 L_w = lane width (ft); horizontal live load distribution width in the circumferential direction, at the elevation of the crown (~~#in.~~) (12.8.4.2) ~~(12.12.3.4)~~ (12.12.3.5)
 M_s = bending moment at service limit state (kip-in./ft); moment acting on a crossing-section of width, b, at service limit state taken as an absolute value in design equations (kip-in./ft); constrained soil modulus specified in Table 12.12.3.5-1 ~~12.12.3.4.1~~ (ksi); soil modulus (ksi) (12.10.4.2.4d) (C12.11.3) (12.12.3.4.2.2) (12.12.3.5.2)
 m = multiple presence factor as specified in Table 3.6.1.1.2-1 (12.12.3.9)
 P = design wheel load as specified in Article 3.6.2.2 (1b) (12.12.3.9)
 ~~P_r = factored vertical crown pressure (ksf) (12.12.3.4)~~
 P_L = factored design crown pressure (ksf); pressure due to live load (LL) and dynamic load allowance (IM) ~~(ksf psi)~~; service live load on culvert (psi) (12.7.2.2) ~~(12.12.3.4)~~ (12.12.2.2) (12.12.3.9)
 P_s = design service load (psi) (12.12.2.2)
 P_{sp} = ~~geostatic earth pressure (EV), does not include hydrostatic pressure (ksf)~~; soil prism pressure (psi) ~~(12.12.3.4) (12.12.2.2)~~
 P_{st} = stub compression capacity from T341 (lb/in) (12.12.3.10.1b)
 P_u = design factored load (psi) (12.12.3.5)
 P_w = hydrostatic water pressure ~~(psi/ksf)~~ ~~(12.12.3.4)~~ (12.12.3.5)

12.3 NOTATION

Revise the following notations as follows:

- R = rise of structure (ft); rise of box culvert or long-span structural plate structures (ft); ~~radius of centroid of culvert wall (in.); radius of pipe (in.);~~ radius to centroid of pipe wall profile (in.) (12.8.4.1) (12.9.4.1) ~~(12.12.2.2) (12.12.3.4) (12.12.3.5.2) (12.12.3.5.4b)~~
- R_h = haunch moment reduction factor; correction factor for backfill soil geometry (12.9.4.3) (12.12.3.10.1e)
- ~~R_w = water buoyancy factor (12.12.3.5.2)~~
- S = pipe, tunnel, or box diameter or span (in.) or (ft) as indicated; span of structure between springlines of long-span structural plate structures (ft); box culvert span (ft) (12.6.6.3) (12.8.4.1) (12.9.4.2) (12.12.3.6)
- S_H = hoop stiffness factor ~~(12.12.3.4)~~ (12.12.3.5)
- ~~T_u = factored thrust per unit length (lb/in.) (12.12.3.10.1c)~~
- ~~T_s = service thrust per unit length (lb/in.) (12.12.2.2)~~
- t = required thickness of cement concrete relieving slab (in.); thickness of element (in.) (19.9.4.6) ~~(12.12.3.5.3e) (12.12.3.10.1b)~~
- W_0 = width of live load ground-surface contact area parallel to flow in pipe (in.) (12.12.3.5)

12.3 NOTATION

Revise the following notations as follows:

- γ_b = unit weight of boyant soil (lb/ft³) (12.12.3.7)
- γ_{EV} = load factor for vertical pressure from dead load of earth fill (~~(12.12.3.4)~~) (12.12.3.5)
- γ_{LL} = load factor for live load (~~(12.12.3.4)~~) (12.12.3.5)
- γ_s = unit weight of backfill (kcf); soil unit weight (kcf); wet unit weight of soil (lb/ft³) (C12.9.2) (12.9.4.2) (12.12.3.7)
- γ_w = unit weight of water (~~kcf~~ lb/ft³) (~~(12.12.3.4)~~) (12.12.3.8)
- γ_{WA} = load factor for hydrostatic pressure (~~(12.12.3.4)~~) (12.12.3.5)
- Δ_f = deflection of pipe due to flexure (in.) (12.12.3.10.2b)
- Δ_t = total deflection of pipe (in.) (12.12.2.2)
- Δ_A = total allowable deflection of pipe (in.) (12.12.2.2)
- ϵ_f = factored strain due to flexure (12.12.3.10.2b)
- ϵ_{sc} = service compressive strain (in./in.) (12.12.3.10.1e)
- ϵ_{bck} = nominal strain capacity for general buckling (12.12.3.10.1e)
- ~~ϵ_{bt} = factored bending strain = $\gamma_b \epsilon_b$ (in./in.) (12.12.3.5.4a)~~
- ~~ϵ_{lt} = factored long term tension strain (in./in.) (12.12.3.5.4a)~~
- ~~ϵ_t = allowable tension strain (12.12.3.5.4a)~~
- ϵ_{uc} = factored compressive strain due to thrust (12.12.3.10.1c)
- ϵ_{yc} = factored compressive strain limit as specified in Table 12.12.3.3-1 (12.12.3.10.1b)
- ϵ_{yl} = service long-term strain limit as specified in Table 12.12.3.3-1 (12.12.3.10.2b)
- η_{EV} = load modifier, specified in Article 1.3.2, as they apply to vertical earth loads on culverts (~~(12.12.3.4)~~) (12.12.3.5)
- η_{LL} = load modifier as they apply to live loads on culverts (~~(12.12.3.4)~~) (12.12.3.5)
- λ = slenderness factor (~~(12.12.3.5.3e)~~) (12.12.3.10.1b)
- ν = Poisson's ratio of soil (12.12.3.10.1e)
- ρ = effective width factor (~~(12.12.3.5.3e)~~) (12.12.3.10.1b)
- ϕ_{bck} = resistance factor for buckling (12.12.3.10.1e)
- ϕ_s = resistance factor for soil stiffness, $\phi_s = 0.9$; resistance factor for soil pressure (~~(12.12.3.4)~~) (12.12.3.5) (12.12.3.10.1e)
- ϕ_T = resistance factor for thrust effects (12.12.3.10.1d)
- ω = spacing of corrugation (in.) (~~(12.12.3.5.3e)~~) (12.12.3.10.1b)

12.4.1.3 Envelope Backfill Soils

Add the following bullet to the end of the existing bullet list:

- For thermoplastic culverts, bedding and backfill materials: A-1, A-2-4, A-2-5, or A-3 soils. A maximum of 50 percent of the particle sizes may pass the 0.149 mm (No. 100 sieve) and a maximum of 20 percent may pass the 0.074 mm (No. 200 sieve).

C12.4.1.3

Revise the 1st paragraph as follows:

Refer to Sections 26, ~~and~~ 27, and 30 of the *AASHTO LRFD Bridge Construction Specifications*; for compaction criteria of soil backfill for flexible and rigid culverts, ~~respectively~~.

Add the following paragraph to the end of Article C12.4.1.3:

The restriction on material passing the No. 100 sieve and No. 200 sieve for thermoplastic culverts are intended to eliminate uniform fine sands for use as pipe embedment. Such materials are difficult to work with, are sensitive to moisture content, and do not provide support comparable to coarser or more-broadly-graded materials at the same percentage of maximum density. The engineer may permit exceptions to these restrictions in special cases. If so, a suitable plan should be submitted for control of moisture content and compaction procedures. These silty and clayey materials should never be used in a wet site. Increased inspection levels should be considered if such a plan is approved.

Insert the following new commentary:

C12.4.2.8

The AASHTO materials specifications also include a provisional specification, MP 20, for steel-reinforced polyethylene pipe (PE) ribbed pipe, 12.0 to 36.0 in. diameter. The steel ribs are the main load carrying members for the pipe and the thermoplastic material braces the steel ribs from distortion or buckling. The thermoplastic also distributes the load between the ribs. It is necessary to evaluate the composite system of thermoplastic liner and steel rib for adequacy. It is important to ensure that the tensile strains within the thermoplastic do not exceed the long-term strain capacity for the thermoplastic material used in the construction of the pipe. Three-dimensional finite element analysis of the profile which has been calibrated against results for full scale tests is recommended. Design specifications for this product will be considered for inclusion in these Specifications when a satisfactory number of instrumented installations are documented to validate performance.

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12.5.5 Resistance Factors

C12.5.5

Add the following paragraph to the end of Article:

The new thermoplastic design methods evaluate more load conditions than prior specifications. Separate resistance factors are provided for each mode of behavior. The resistance factor for buckling is set at 0.7 and preserves the same level of safety as prior editions of these Specifications with the inclusion of the Installation Factor of Article 12.12.3.5. Buckling is an undesirable failure mode for culverts. Buckling can result in near total collapse of the culvert and blockage of the waterway.

Revise Table 12.5.5-1 under the row “Thermoplastic Pipe” as follows:

Thermoplastic Pipe	
PE and PVC pipe:	
• <u>Thrust, ϕ_T</u>	<u>1.00</u>
• <u>Soil stiffness, ϕ_s</u>	<u>0.90</u>
• Minimum wall area and buckling	1.00
• <u>Global buckling, ϕ_{bck}</u>	<u>0.70</u>
• <u>Flexure, ϕ_f</u>	1.00

Revise the title of Article 12.5.6.3 as follows:

~~12.5.6.3 Thermoplastic Pipe~~

**12.5.6.3 Flexibility Limits and
Construction Stiffness - Thermoplastic
Pipe**

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12.6.6.1 Trench Installations

Revise the 1st Paragraph as follows:

The minimum trench width shall provide a 24-in. minimum side wall clearance ~~sufficient space~~ between the pipe and the trench wall to ensure sufficient working room to properly and safely place and compact backfill material.

C12.6.6.1

Revise as follows:

~~As a guide, the minimum trench width should not be less than the greater of the pipe diameter plus 16.0 in. or the pipe diameter times 1.5 plus 12.0 in.~~ The use of specially designed equipment may enable satisfactory installation and embedment even in narrower trenches. If the use of such equipment provides an installation meeting the requirements of this Article, narrower trench widths may be used as approved by the Engineer.

For trenches excavated in rock or high-bearing Soils, decreased trench widths may be used up to the limits required for compaction. For these conditions, the use of a flowable backfill material, as specified in Article 12.4.1.3, allows the envelope to be decreased to within 6.0 in. along each side of the pipe for pipes up to and including 42 inches in diameter or span, or 12 inches for pipes over 42 inches in diameter or span.

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C12.6.6.2

Table C12.6.6.2-1 Minimum Width of Soil Envelope

Revise as follows:

Diameter, S (in.)	Minimum Envelope Width (ft.)
<24	S/12
24-144-108	2.0
>144-108	5.0

Add new Commentary as follows:

12.6.6.3 Minimum Soil Cover

C12.6.6.3

McGrath et al. (2005) have shown that the significant thermal expansion in thermoplastic pipe can affect pavement performance under shallow fills.

In Table 12.6.6.3-1, revise as follows:

Type	Condition	Minimum Cover
Corrugated Metal Pipe	—	$S/8 \geq 12.0$ in. 24.0 in.
Spiral Rib Metal Pipe	Steel Conduit	$S/4 \geq 12.0$ in. 24.0 in.
	Aluminum Conduit where $S \leq 48.0$ in.	$S/2 \geq 12.0$ in. 24.0 in.
	Aluminum Conduit where $S > 48.0$ in.	$S/2.75 \geq 24.0$ in.
Structural Plate Pipe Structures	—	$S/8 \geq 12.0$ in. 24.0 in.
Long-Span Structural Plate Pipe Structures	—	Refer to Table 12.8.3.1.1-1
Structural Plate Box Structures	—	1.4 ft. as specified in Article 12.9.1
Reinforced Concrete Pipe	Unpaved areas and under flexible pavement	$B_c/8$ or $B'_c/8$, whichever is greater, ≥ 12.0 in. 24.0 in.
	Compacted granular fill under rigid pavement	9.0 in. 12.0 in.
Thermoplastic Pipe	<u>General</u>	$ID/8 \geq 12.0$ in. 24.0 in.
	<u>Under pavement</u>	$ID/2 \geq 24.0$ in.

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Table 12.10.2.1-1 Standard Embankment Installation Soils and Minimum compaction Requirements

Revise as follows:

Installation Type	Bedding Thickness	Haunch and Outer Bedding	Lower Side
Type 1	For soil foundation, use $B_c/2$ ft <u>in.</u> minimum, not less than 3.0 in. For rock foundation, use B_c ft <u>in.</u> 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, use $B_c/2$ ft <u>in.</u> minimum, not less than 3.0 in. For rock foundation, use B_c ft <u>in.</u> 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, use $B_c/2$ ft <u>in.</u> minimum, not less than 3.0 in. For rock foundation, use B_c ft <u>in.</u> 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 $B_c/2$ ft 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

Table 12.10.2.1-2 Standard Trench Installation Soils and Minimum compaction Requirements

Revise as follows:

Installation Type	Bedding Thickness	Haunch and Outer Bedding	Lower Side
Type 1	For soil foundation, use $B_c/2$ ft in. minimum, not less than 3.0 in. For rock foundation, use B_c ft in. minimum, not less than 6.0 in	95% SW	90% SW, 95% ML, or 100% CL, or natural soils of equal firmness
Type 2-Installations are available for horizontal elliptical, vertical elliptical, and arch pipe	For soil foundation, use $B_c/2$ ft in. minimum, not less than 3.0 in. For rock foundation, use B_c ft in. minimum, not less than 6.0 in	90% SW or 95% ML	85% SW, 90% ML, or 95% CL, or natural soils of equal firmness
Type 3-Installations are available for horizontal elliptical, vertical elliptical, and arch pipe	For soil foundation, use $B_c/4$ ft in. minimum, not less than 3.0 in. For rock foundation, use B_c ft in. minimum, not less than 6.0 in	85% SW, 90% ML, or 95% CL	85% SW, 90% ML, or 95% CL, or natural soils of equal firmness
Type 4	For soil foundation, use $B_c/2$ ft in. minimum, not less than 6.0 in. For rock foundation, no bedding required.	95% SW No compaction required, except if CL, use 85% CL	90% SW, 95% ML, or 100% CL, or natural soils of equal firmness No compaction required, except if CL, use 85% CL, or natural soils of equal firmness

Table 12.10.2.1-3 Coefficients for use with Figure 1.

Revise as follows:

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

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12.10.2.1 Standard Installations

Add an additional paragraph and three figures (after the last paragraph in AASHTO 12.10.2.1) as follows:

When non-standard installations are used, the earth load on the structure shall be the prism earth load above the pipe. The unit weight of soil shall be 140 lbs/ft³. Pressure distribution shall be determined by an appropriate soil-structure interaction analysis. Acceptable pressure distributions for non-standard installations are: the Olander/Modified Olander Radial Pressure Distribution - see Figure 2(a), or the Paris/Manual Uniform Pressure Distribution - see Figure 2(b). For bedding angles and lateral pressures used with the latter distributions see Figure 3 and Figure 4. Above information is based on the *Caltrans Bridge Design Specifications (2000)*.

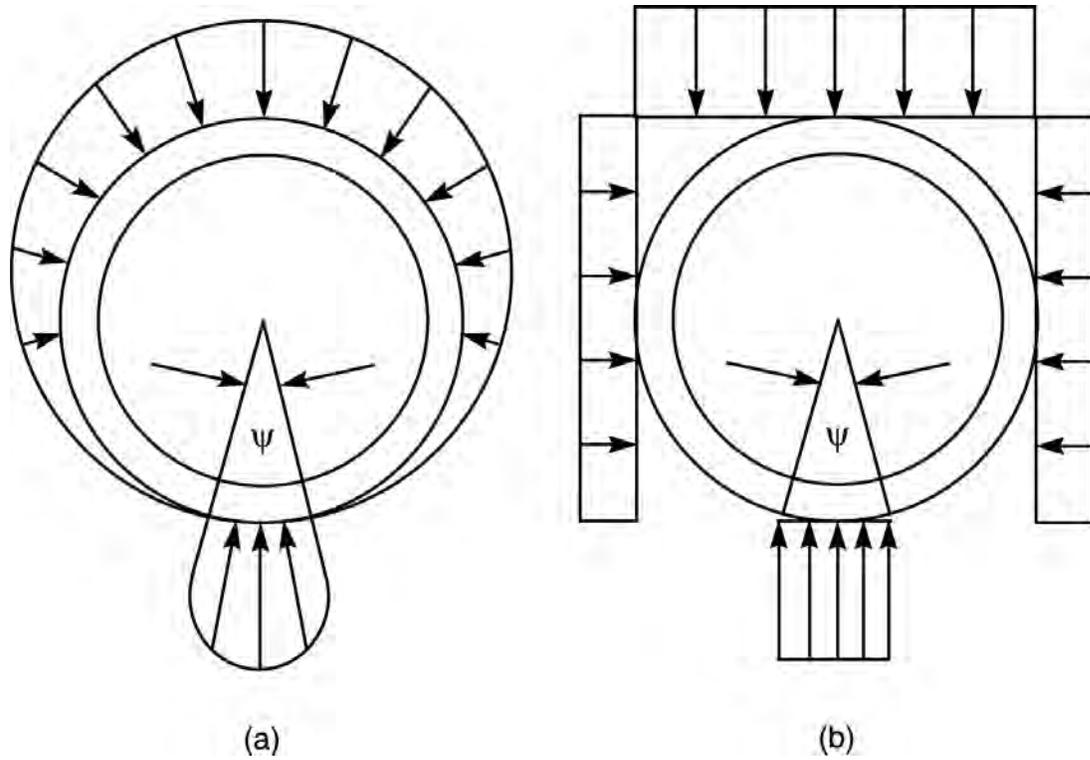
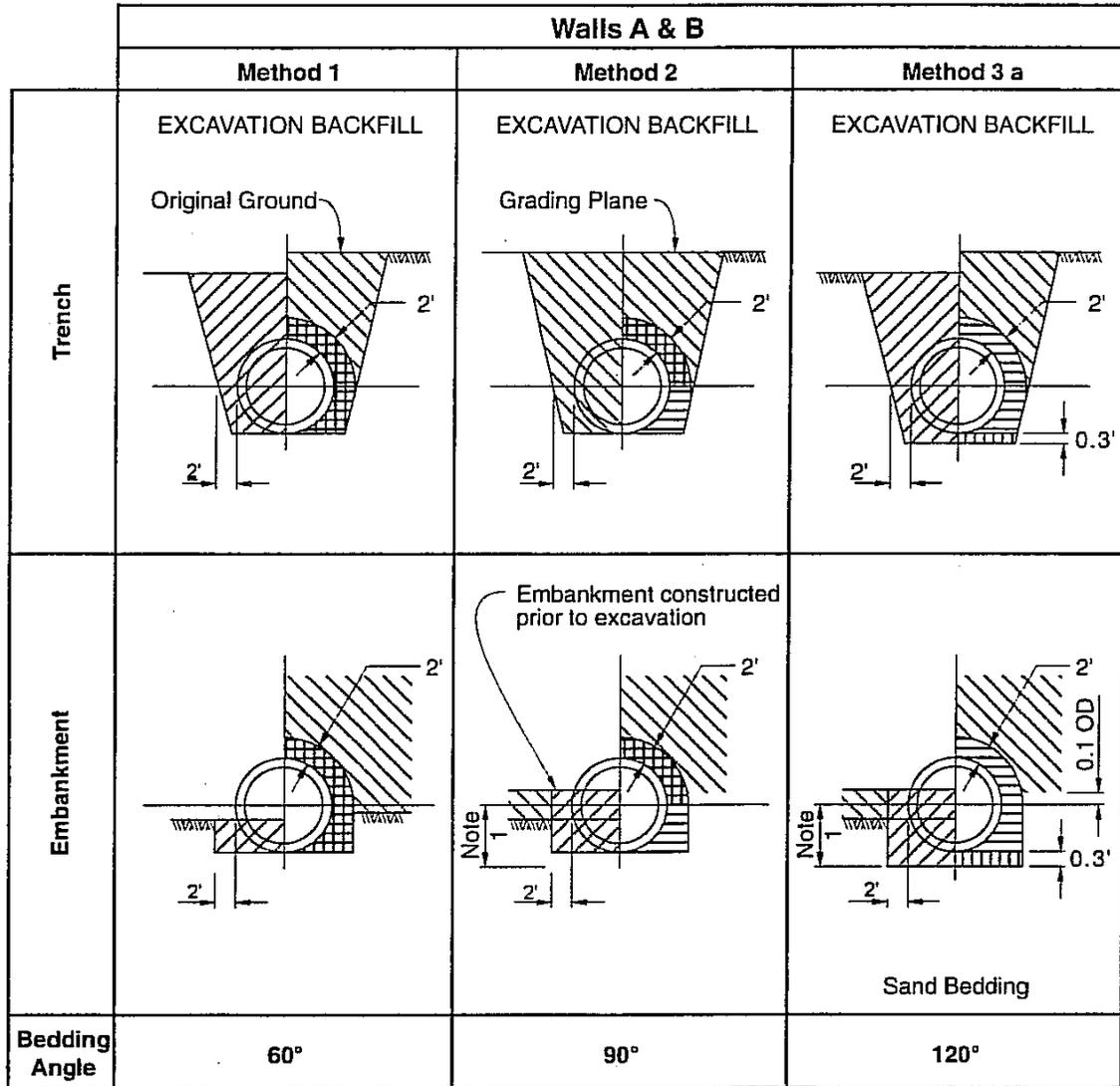


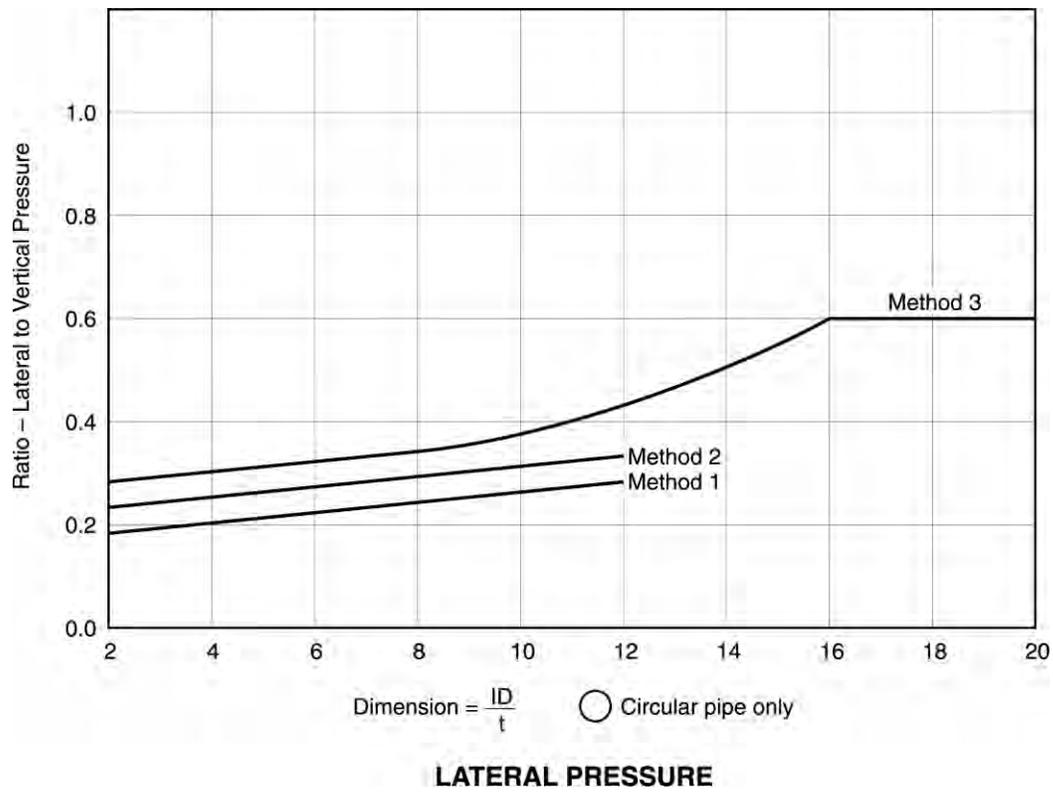
Figure 12.10.2.1-2(a) Olander/Modified Olander Radial Pressure Distribution Diagram
Figure 12.10.2.1-2(b) Paris/Manual Uniform Pressure Distribution Diagram



Legend

- | | | | |
|--|---|---|--------------------|
| | Structure Excavation (Culvert) | | Roadway Embankment |
| | Structure Backfill (Culvert)
95% relative compaction | | Original Ground |
| | Structure Backfill (Culvert)
90% relative compaction | Note 1. 30° minimum up to 45° OD, then 2/3 OD (outside diameter) but no more than 60° required. | |
| | Sand Bedding | | |

Figure 12.10.2.1-3 Trench and Embankment Backfill Bedding Angles



Legend
 ID = inside diameter of pipe, t = wall thickness of pipe

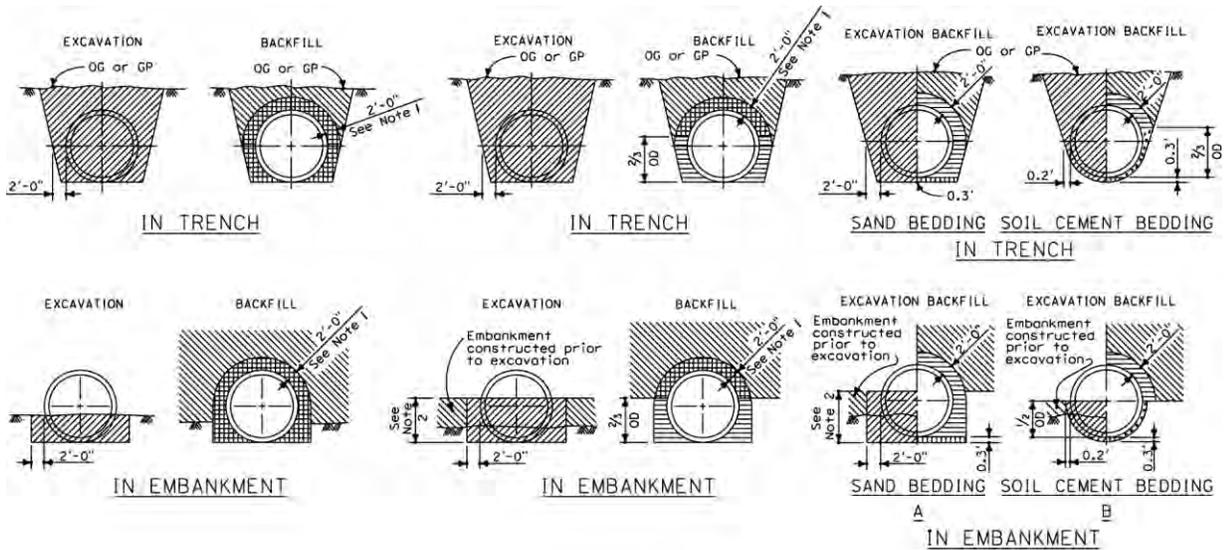
Figure 12.10.2.1-4 Non-standard Installation Lateral Pressures Distribution

12.10.4.3 Indirect Design Method

12.10.4.3.1 Bearing Resistance

Add a new second paragraph, a figure, and a table as follows:

Reinforced concrete pipe culvert excavation/backfill criteria for Caltrans non-standard installation Methods 1, 2, and 3 are summarized in Figure 1 below. Associated fill heights and pipe classes are indicated in the adjacent D-Load Overfill Table 1. Pipe backfill is to be placed over the full width of excavation except where dimensions are shown for specific backfill width or thickness. Dimensions shown are minimums. Above information is based on Caltrans research (*Transportation Record 878*), and *Caltrans Standard Plans (May 2006)*.



METHOD 1

METHOD 2

METHOD 3

Note:

1. Embankment compaction requirements govern over the 90% relative compaction backfill requirement within 2'-6" of finished grade.
2. Embankment height prior to excavation for installation of all classes of RCP under Method 2 and Method 3A shall be as follows:

Pipe sizes 1'-0" to 3'-6" ID = 2'-6"
 Pipe sizes 4'-0" to 7'-0" ID = 2/3 OD
 Pipe sizes larger than 7'-0" ID = 5'-0"

LEGEND

 Structure Excavation (Culvert)	 Sand Bedding
 Structure Backfill (Culvert) 95% relative compaction	 Soil Cement Bedding
 Structure Backfill (Culvert) 90% relative compaction	 Roadway Embankment
 Loose Backfill	 Original Ground

OD = Outside diameter for circular pipes and maximum vertical dimension for other shapes
 ID = Inside diameter for circular pipes and minimum vertical dimension for other shapes

Figure 12.10.4.3.1-1 Non-Standard Installation Excavation Backfill

Table 12.10.4.3.1-1 D-Load Overfill Table

MINIMUM ALLOWABLE CLASSES OF RCP FOR METHOD 1		MINIMUM ALLOWABLE CLASSES OF RCP FOR METHOD 2		MINIMUM ALLOWABLE CLASSES OF RCP FOR METHOD 3	
COVER	MINIMUM CLASS AND D-LOAD	COVER	MINIMUM CLASS AND D-LOAD	COVER	MINIMUM CLASS AND D-LOAD
5.9'	Class II 1000D	15.9'	Class II 1000D	25.9'	Class II 1000D
6.0' - 7.9'	Class III 1350D	16.0' - 19.9'	Class III 1350D	26.0' - 31.9'	Class III 1350D
8.0' - 9.9'	Class III Special 1700D	20.0' - 24.9'	Class III Special 1700D	32.0' - 37.9'	Class III Special 1700D
10.0' - 11.9'	Class IV 2000D	25.0' - 27.9'	Class IV 2000D	38.0' - 44.9'	Class IV 2000D
12.0' - 13.9'	Class IV Special 2500D	28.0' - 34.9'	Class IV Special 2500D	45.0' - 55.9'	Class IV Special 2500D
14.0' - 16.9'	Class V 3000D	35.0' - 41.9'	Class V 3000D	56.0' - 67.9'	Class V 3000D
17.0' - 20.0'	Class V Special 3600D	42.0' - 50.0'	Class V Special 3600D	68.0' - 80.0'	Class V Special 3600D

METHOD 1

METHOD 2

METHOD 3

REINFORCED CONCRETE PIPE

The maximum size for all classes of RCP placed under Method 1 is 78" ID.

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Table 12.10.4.3.2a-1 Bedding Factors for circular Pipe.

Revise as follows:

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

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Replace Article 12.12 with the following:

12.12 THERMOPLASTIC PIPES

12.12.1 General

The provisions herein shall apply to the structural design of buried thermoplastic pipe with solid, corrugated, or profile wall, manufactured of PE or PVC.

12.12.2 Service Limit States

12.12.2.1 General

The allowable maximum localized distortion of installed plastic pipe shall be limited based on the service requirements and overall stability of the installation. The extreme fiber tensile strain shall not exceed the allowable long-term strain in Table 12.12.3.3-1. The net tension strain shall be the numerical difference between the bending tensile strain and ring compression strain.

C12.12.1

These structures become part of a composite system comprised of the plastic pipe and the soil envelope.

The following specifications are applicable:

For PE:

- Solid Wall—ASTM F 714
- Corrugated—AASHTO M294
- Profile—ASTM F 894

For PVC:

- Solid Wall—AASHTO M 278
- Profile—AASHTO M 304

C12.12.2.1

The allowable long-term strains should not be reached in pipes designed and constructed in accordance with this Specification. Deflections resulting from conditions imposed during pipe installation should also be considered in design.

12.12.2.2 Deflection Requirement

Total deflection, Δ_t , shall be less than the allowable deflection, Δ_A , as follows:

$$\underline{\Delta_t \leq \Delta_A} \quad (12.12.2.2-1)$$

where:

Δ_t = total deflection of pipe expressed as a reduction of the vertical diameter taken as positive for reduction of the vertical diameter and expansion of horizontal diameter. (in.)

Δ_A = total allowable deflection of pipe, reduction of vertical diameter (in.)

Total deflection, calculated using Spangler's expression for predicting flexural deflection in combination with the expression for circumferential shortening, shall be determined as:

C12.12.2.2

Deflection is controlled through proper construction in the field, and construction contracts should place responsibility for control of deflections on the contractor. However, feasibility of a specified installation needs to be checked prior to writing the project specifications.

The construction specifications set the allowable deflection, Δ_A , for thermoplastic pipe at five percent as a generally appropriate limit. The Engineer may allow alternate deflection limits for specific projects if calculations using the design method in this section show that the pipe meets all of the strength-limit-state requirements.

$$\Delta_t = \frac{K_B(D_L P_{sp} + C_L P_L)D_o}{1000(E_p I_p / R^3 + 0.061 M_s)} + \epsilon_{sc} D$$

(12.12.2.2-2)

in which:

$$\epsilon_{sc} = \frac{T_s}{1000(A_{eff} E_p)}$$

(12.12.2.2-3)

$$T_s = P_s \left(\frac{D_o}{2} \right)$$

(12.12.2.2-4)

where:

ϵ_{sc} = service compressive strain due to thrust, as specified in Article 12.12.3.10.1c and taken as positive for compression

T_s = service thrust per unit length (lb/in.)

D_L = deflection lag factor, a value of 1.5 is typical

K_B = bedding coefficient, a value of 0.10 is typical

P_{sp} = soil prism pressure (EV), evaluated at pipe springline (psi)

Eq. 12.12.2.2-2 uses the constrained soil modulus, M_s , as the soil property. Note that the soil prism load is used as input, rather than the reduced load used to compute thrust.

This check should be completed to determine that the expected field deflection based on thrust and flexure is lower than the maximum allowable deflection for the project.

Thrust and hoop strain in the pipe wall are defined positive for compression.

There are no standard values for the deflection lag factor. Values from 1.0 to 6.0 have been recommended. The highest values are for installations with quality backfill and low initial deflections and do not generally control designs. A value of 1.5 provides some allowance for increase in deflection over time for installations with initial deflection levels of several percent.

The bedding coefficient, K_B , varies from 0.083 for full support to 0.110 for line support at the invert. Haunching is always specified to provide good support; however, it is still common to use a value of K_B equal to 0.10 to account for inconsistent haunch support.

C_L = live load distribution coefficient

P_L = design live load pressure including vehicle, dynamic load allowance, and multiple presence effect (psi)

D_o = outside diameter of pipe (in.) as shown in Figure C12.12.2.2-1

E_p = short- or long-term modulus of pipe material as specified in Table 12.12.3.3-1 (ksi)

I_p = moment of inertia of pipe profile per unit length of pipe (in.⁴/in.)

R = radius from center of pipe to centroid of pipe profile (in.) as shown in Figure C12.12.2.2-1

D = diameter to centroid of pipe profile (in.) as shown in Figure C12.12.2.2-1

M_s = secant constrained soil modulus, as specified in Article 12.12.3.5-1 (ksi)

P_s = design service load (psi)

A_{eff} = effective area of pipe wall per unit length of pipe as specified in Article 12.12.3.10.1b (in.²/in.)

12.12.3 Safety Against Structural Failure

12.12.3.1 General

Buried thermoplastic culverts shall be investigated at the strength limit states for thrust, general and local buckling, and combined strain.

12.12.3.2 Section Properties

Section properties for thermoplastic pipe, including wall area, moment of inertia, and profile geometry should be determined from cut sections of pipe or obtained from the pipe manufacturer.

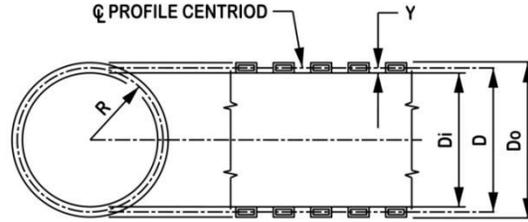


Figure C12.12.2.2-1—Schematic for Thermoplastic Pipe Terms

C12.12.3.1

Total compressive strain in a thermoplastic pipe can cause yielding or buckling, and total tensile strain can cause cracking.

C12.12.3.2

Historically, AASHTO Bridge Specifications have contained minimum values for the moment of inertia and wall area of thermoplastic pipe; however, these values have been minimum values and are not meaningful for design. This is particularly so since provisions to evaluate local buckling were introduced in 2001. These provisions require detailed profile geometry that varies with manufacturer. Thus, there is no way to provide meaningful generic information on section properties. A convenient method for determining section properties for profile wall pipe is to make optical scans of pipe wall cross-sections and determine the properties with a computer drafting program.

12.12.3.3 Chemical and Mechanical Requirements

Mechanical properties for design shall be as specified in Table 12.12.3.3-1.

Except for buckling, the choice of either initial or long-term mechanical property requirements, as appropriate for a specific application, shall be determined by the Engineer. Investigation of general buckling shall be based on the value of modulus of elasticity that represents the design life of the project.

C12.12.3.3

Properties in Table 12.12.3.3-1 include ~~“initial”~~ and long-term values. No product standard requires determining the actual long-term properties; thus, there is some uncertainty in the actual values. However, pipe designed with the Table 12.12.3.3-1 values for 50-year modulus of elasticity have performed well, and the properties are assumed to be reasonably conservative. Estimated values for a modulus of elasticity for a 75-year design life have been estimated from relaxation tests on PVC and PE in parallel plate tests. The tests were conducted for over two years and show that the modulus of elasticity reduces approximately linearly with the logarithm of time. Further, with a log-linear extrapolation, the differences between 50-year and 75-year modulus values are very small. These values should be reasonably conservative, with the same reliability as the 50-year values. Pipe and thermoplastic resin suppliers should be asked to provide confirmation of long-term modulus values for any particular product. Values should meet or exceed those provided in Table 12.12.3.3-1. Where service life is in excess of 75 years, test data may be used for the desired life.

The service long-term tension strain limit and the factored compression strain limit in Table 12.12.3.3-1 need to be multiplied by the appropriate resistance factors to obtain the strain limits.

Table 12.12.3.3-1—Mechanical Properties of Thermoplastic Pipe

Type of Pipe	Minimum Cell Class	Service Long-Term Tension Strain Limit, ϵ_{VT} (%)	Factored Compr. Strain Limit, ϵ_{VC} (%)	Initial		50-Year		75-Year	
				E_{\min} (ksi)					
Solid Wall PE Pipe – ASTM F714	ASTM D3350, 335434C	5.0	4.1	3.0	110.0	1.44	22	1.40	21
Corrugated PE Pipe – AASHTO M294	ASTM D3350, 435400C	5.0	4.1	3.0	110.0	0.90	22	0.90	21
Profile PE Pipe – ASTM F894	ASTM D3350, 334433C	5.0	4.1	3.0	80.0	1.12	20	1.10	19
	ASTM D3350, 335434C	5.0	4.1	3.0	110.0	1.44	22	1.40	21
Solid Wall PVC Pipe – AASHTO M278, ASTM F679	ASTM D1784, 12454C	5.0	2.6	7.0	400.0	3.70	140	3.60	137
	ASTM D1784, 12364C	3.5	2.6	6.0	440.0	2.60	158	2.50	156
Profile PVC Pipe – AASHTO M304	ASTM D1784, 12454C	5.0	2.6	7.0	400.0	3.70	140	3.60	137
	ASTM D1784, 12364C	3.5	2.6	6.0	440.0	2.60	158	2.50	156

12.12.3.4 Thrust

Loads on buried thermoplastic pipe shall be based on the soil prism load, modified as necessary to consider the effects of pipe-soil interaction. Calculations shall consider the duration of a load when selecting pipe properties to be used in design. Live loads need not be considered for the long-term loading condition.

C12.12.3.4

Because of the time-dependent nature of thermoplastic pipe properties, the load will vary with time.

Time of loading is an important consideration for some types of thermoplastic pipe. Live loads and occasional flood conditions are normally considered short-term loads. Earth loads or permanent high groundwater are normally considered long-term loads.

12.12.3.5 Factored and Service Loads

The factored load, P_u , in psi shall be taken as:

$$P_u = \eta_{EV} (\gamma_{EV} K_{\gamma E} K_2 VAF P_{sp} + \gamma_{WA} P_W) + \eta_{LL} \gamma_{LL} P_L C_L \quad (12.12.3.5-1)$$

The service load, P_s , in psi shall be taken as:

$$P_s = K_2 VAF P_{sp} + P_L C_L + P_W \quad (12.12.3.5-2)$$

in which:

$$VAF = 0.76 - 0.71 \left(\frac{S_H - 1.17}{S_H + 2.92} \right) \quad (12.12.3.5-3)$$

$$S_H = \frac{\phi_s M_s R}{E_p A_g} \quad (12.12.3.5-4)$$

$$C_L = \frac{L_W}{D_o} \leq 1.0 \quad (12.12.3.5-5)$$

$$L_W = W_o + 12 \cdot LLDF (H) \quad (12.12.3.5-6)$$

where:

C12.12.3.5

For η factors, refer to Article 12.5.4 regarding assumptions about redundancy for earth loads and live loads.

The factor K_2 is introduced to consider variation in thrust around the circumference, which is necessary when combining thrust with moment or thrust due to earth and live load under shallow fill. K_2 is set at 1.0 to determine thrust at the springline and 0.6 to determine thrust at the crown. The term P_L is also modified for this reason in later sections.

Figure C3.11.3-1 shows the effect of groundwater on the earth pressure. P_{sp} does not include the hydrostatic pressure. P_{sp} is the pressure due to the weight of soil above the pipe and should be calculated based on the wet density for soil above the water table and based on the buoyant density for soil below the water table. See Table 3.5.1-1 for common unit weights.

In computing L_W , add axle spacing (and increase total live load) if depth is sufficient for axle loads to interact.

$K_{y/E}$ = installation factor typically taken as 1.5 to provide traditional safety. Use of a value less than 1.5 requires additional monitoring of the installation during construction and provisions for such monitoring shall be provided on the contract documents.

The factor $K_{y/E}$ is introduced to provide the same safety level as traditionally used for thermoplastic culverts. Designers may consider using values of $K_{y/E}$ as low as 1.0 provided that procedures are implemented to ensure compliance with construction specifications. For culvert designs completed with an installation factor less than 1.5, the designer is required to specify additional minimum performance measures such as testing, monitoring, construction controls, gradation and backfill requirements including active monitoring of the backfill gradation and compaction (see Article 30.7.4 of *AASHTO LRFD Bridge Construction Specifications*). The construction controls include deflection measurements and shall require the Contractor to submit and get approval from the Owner's Engineer for his/her construction plan to be used to achieve the more stringent performance measures which allowed for the use of a smaller installation factor in the design. Backfill placement and monitoring shall be done at levels along the side of the culvert and includes measurement of change in vertical pipe diameter when the backfill reaches the top of the pipe. As the backfill nears the top of pipe the vertical pipe diameter should be greater than the vertical diameter prior to backfilling, but not more than three percent greater than the vertical diameter prior to backfilling.

K_2 = coefficient to account for variation of thrust around the circumference
 = 1.0 for thrust at the springline
 = 0.6 for thrust at the crown

VAF = vertical arching factor

The use of the vertical arching factor is based on the behavior, demonstrated by Burns and Richard (1964), that pipe with high hoop-stiffness ratios (S_{H_e} , ratio of soil stiffness to pipe hoop stiffness) carry substantially less load than the weight of the prism of soil directly over the pipe. This behavior was demonstrated experimentally by Hashash and Selig (1990) and analytically by Moore (1995). McGrath (1999) developed the simplified form of the equation presented in this Section.

The VAF approach is only developed for the embankment load case. No guidance is currently available to predict the reduced loads on pipe in trench conditions. The only trench load theory proposed for flexible pipe was that by Spangler, which does not have good guidance on selection of input parameters. It is conservative to use the VAF approach as presented for embankments.

S_{H_e} = hoop stiffness factor

If evaluating the short-term load condition, then use the initial modulus of elasticity to compute S_{H_e} . Similarly, if evaluating the long-term loading condition, then use the long-term modulus of elasticity to compute S_{H_e} .

P_w = hydrostatic water pressure at the springline of the pipe (psi)

C_L = live load distribution coefficient

L_w = live load distribution width in the circumferential direction at the elevation of the crown (in.)

H = depth of cover (ft.)

η_{EV} = load modifier as specified in Article 1.3.2, as they apply to vertical earth loads on culverts

γ_{EV} = load factor for vertical pressure from dead load of earth fill, as specified in Article 3.4.1

P_{sp} = soil prism pressure (EV), evaluated at pipe springline (psi)

γ_{WA} = load factor for hydrostatic pressure, as specified in Article 3.4.1

η_{LL} = load modifier as specified in Article 1.3.2, as they apply to live loads on culverts

γ_{LL} = load factor for live load, as specified in Article 3.4.1

P_L = live load pressure (LL) with dynamic load allowance (psi)

ϕ_s = resistance factor for soil stiffness

M_s = secant constrained soil modulus as specified in Table 12.12.3.5-1 (ksi)

The term ϕ_s appears in Eq. 12.12.3.5-4 to account for variability in backfill compaction. A lower level of compaction increases the applied thrust force on the pipe.

For selecting values of the constrained soil modulus, M_s , prior editions of the specifications contained the commentary –Suggested practice is to design for a standard Proctor backfill density five percent less than specified by the contract documents.” This statement is not considered necessary with the addition of post-construction inspection guidelines to the *LRFD Bridge Construction Specifications*, which should provide reasonable assurance that the design condition is achieved.

- R = radius from center of pipe to centroid of pipe profile (in.)
- E_p = short- or long-term modulus of pipe material as specified in Table 12.12.3.3-1 (ksi)
- A_g = gross area of pipe wall per unit length of pipe (in.²/in.)
- D_o = outside diameter of pipe (in.)
- W_o = width of live load ground-surface contact area parallel to flow in pipe as specified in Article 3.6.1.2.5 (in.)
- $LLDF$ = factor for distribution of live load through earth fills in Article 3.6.1.2.6

In the absence of site-specific data, the secant constrained soil modulus, M_s , may be selected from Table 12.12.3.5-1 based on the backfill type and density and the geostatic earth pressure, P_{sp} . Linear interpolation between soil stress levels may be used for the determination of M_s .

For culverts in embankment or wide trench installations under depths of fill up to 10.0 ft., the soil type and density selected from Table 12.12.3.5-1 shall be representative of the conditions for a width of one-half diameter each side of the culvert, but never less than 18.0 in. on each side of the culvert. For culverts under depths of fill greater than 10.0 ft., the soil type and density selected shall be representative of the conditions for a width of one diameter on each side of the culvert.

The constrained modulus may also be determined experimentally using the stress-strain curve resulting from a uniaxial strain test on a sample of soil compacted to the field-specified density. The constrained modulus is the slope of the secant from the origin of the curve to a point on the curve corresponding to the soil prism pressure, P_{sp} . Figure C12.12.3.5-1.

For culverts in trench installations under depths of fill greater than 10.0 ft., evaluation of the values of M_s for in-situ soil for a width one diameter either side of the pipe is not necessary, provided the in-situ soil has adequate vertical and lateral stiffness. Stable trench walls, during the excavation process, are predictive of adequate vertical and lateral stiffness.

Installation in narrow trenches reduces the vertical load, provided vertical stiffness of the soil is adequate to carry the load that is distributed around the pipe due to arching, as represented by the vertical arching factor (VAF) in the design method and adequate space is preserved at the side of the pipe to place and compact backfill. The minimum trench widths provided in the *LRFD Bridge Construction Specifications* are set to provide adequate space. Narrow trenches yield a desirable level of conservatism, since the transfer of the load to in-situ trench wall is not considered in flexible pipe design.

If the structural backfill material is compacted crushed stone, then the secant constrained soil modulus, M_s , values for Sn-100 may be used. If the backfill is uncompacted (dumped) crushed stone, use the modulus values for Sn-90. While it is not common practice to monitor density of crushed stone backfills, experience has found that a modest compaction effort improves culvert performance and allows the use of the compacted values.

The width of structural backfill is an important consideration when the in-situ soil in the trench wall or the embankment fill at the side of the structural backfill is soft. Currently, only AWWA Manual M45, The Fiberglass Pipe Design Manual, addresses this issue.

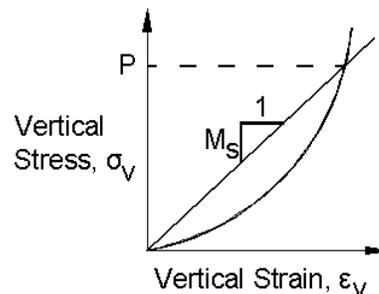


Figure C12.12.3.5-1—Schematic One-Dimensional Stress-Strain Curve of Soil Backfill

Table 12.12.3.5-1— M_s Based on Soil Type and Compaction Condition

<u>P_{sp} Stress level</u> (psi)	<u>Sn-100</u> (ksi)	<u>Sn-95</u> (ksi)	<u>Sn-90</u> (ksi)	<u>Sn-85</u> (ksi)
<u>1.0</u>	<u>2.350</u>	<u>2.000</u>	<u>1.275</u>	<u>0.470</u>
<u>5.0</u>	<u>3.450</u>	<u>2.600</u>	<u>1.500</u>	<u>0.520</u>
<u>10.0</u>	<u>4.200</u>	<u>3.000</u>	<u>1.625</u>	<u>0.570</u>
<u>20.0</u>	<u>5.500</u>	<u>3.450</u>	<u>1.800</u>	<u>0.650</u>
<u>40.0</u>	<u>7.500</u>	<u>4.250</u>	<u>2.100</u>	<u>0.825</u>
<u>60.0</u>	<u>9.300</u>	<u>5.000</u>	<u>2.500</u>	<u>1.000</u>
<u>P_{sp} Stress level</u> (psi)		<u>Si-95</u> (ksi)	<u>Si-90</u> (ksi)	<u>Si-85</u> (ksi)
<u>1.0</u>		<u>1.415</u>	<u>0.670</u>	<u>0.360</u>
<u>5.0</u>		<u>1.670</u>	<u>0.740</u>	<u>0.390</u>
<u>10.0</u>		<u>1.770</u>	<u>0.750</u>	<u>0.400</u>
<u>20.0</u>		<u>1.880</u>	<u>0.790</u>	<u>0.430</u>
<u>40.0</u>		<u>2.090</u>	<u>0.900</u>	<u>0.510</u>
<u>60.0</u>				
<u>P_{sp} Stress level</u> (psi)		<u>Cl-95</u> (ksi)	<u>Cl-90</u> (ksi)	<u>Cl-85</u> (ksi)
<u>1.0</u>		<u>0.530</u>	<u>0.255</u>	<u>0.130</u>
<u>5.0</u>		<u>0.625</u>	<u>0.320</u>	<u>0.175</u>
<u>10.0</u>		<u>0.690</u>	<u>0.355</u>	<u>0.200</u>
<u>20.0</u>		<u>0.740</u>	<u>0.395</u>	<u>0.230</u>
<u>40.0</u>		<u>0.815</u>	<u>0.460</u>	<u>0.285</u>
<u>60.0</u>		<u>0.895</u>	<u>0.525</u>	<u>0.345</u>

1. The soil types are defined by a two-letter designation that indicates general soil classification, Sn for sands and gravels, Si for silts and Cl for clays. Specific soil groups that fall into these categories, based on ASTM D2487 and AASHTO M145, are listed in Table 12.12.3.5-2.
2. The numerical suffix to the soil type indicates the compaction level of the soil as a percentage of maximum dry density determined in accordance with AASHTO T99.

Table 12.12.3.5-2—Equivalent ASTM and AASHTO Soil Classifications

<u>Basic Soil Type (1)</u>	<u>ASTM D2487</u>	<u>AASHTO M145</u>
<u>Sn</u> <u>(Gravelly sand, SW)</u>	<u>SW, SP (2)</u> <u>GW, GP</u> <u>sands and gravels with 12% or less fines</u>	<u>A1, A3 (2)</u>
<u>Si</u> <u>(Sandy silt, ML)</u>	<u>GM, SM, ML</u> <u>also GC and SC with less than 20%</u> <u>passing a No. 200 sieve</u>	<u>A-2-4, A-2-5, A4</u>
<u>Cl</u> <u>(Silty clay, CL)</u>	<u>CL, MH, GC, SC</u> <u>also GC and SC with more than 20%</u> <u>passing a No. 200 sieve</u>	<u>A-2-6, A-2-7, A5,</u> <u>A6</u>

1. The soil classification listed in parentheses is the type that was tested to develop the constrained soil modulus values in Table 12.12.3.5-1. The correlations to other soil types are approximate.
2. Uniformly graded materials with an average particle size smaller than a No. 40 sieve shall not be used as backfill for thermoplastic culverts unless specifically allowed in the contract documents and special precautions are taken to control moisture content and monitor compaction levels.

12.12.3.6 Handling and Installation Requirements

The flexibility factor, FF , in./kip shall be taken as:

$$FF = \frac{S^2}{EI} \quad (12.12.3.6-1)$$

where:

I = moment of inertia (in.⁴/in.)

E = initial modulus of elasticity (ksi)

S = diameter of pipe (in.)

The flexibility factor, FF , shall be limited as specified in Article 12.5.6.3.

12.12.3.7 Soil Prism

The soil-prism load shall be calculated as a pressure representing the weight of soil above the pipe springline. The pressure shall be calculated for three conditions:

- If the water table is above the top of the pipe and at or above the ground surface:

$$P_{sp} = \frac{\left(H + 0.11 \frac{D_o}{12} \right) \gamma_b}{144} \quad (12.12.3.7-1)$$

- If the water table is above the top of the pipe and below the ground surface:

C12.12.3.7

The soil prism load and vertical arching factor, VAF , serve as a common reference for the load on all types of pipe.

The soil prism calculation needs to consider the unit weight of the backfill over the pipe. Use the wet unit weight above the water table and the buoyant unit weight below the water table. In cases where the water table fluctuates, multiple conditions may need to be evaluated.

Figure C3.11.3-1 shows the effect of groundwater on the earth pressure. See Table 3.5.1-1 for common unit weights.

$$P_{sp} = \frac{1}{144} \left[\left(\left(H_w - \frac{D_o}{24} \right) + 0.11 \frac{D_o}{12} \right) \gamma_b + \left[H - \left(H_w - \frac{D_o}{24} \right) \right] \gamma_s \right]$$

(12.12.3.7-2)

- If the water table is below the top of the pipe:

$$P_{sp} = \frac{\left(H + 0.11 \frac{D_o}{12} \right) \gamma_s}{144} \quad (12.12.3.7-3)$$

where:

P_{sz} = soil-prism pressure (EV), evaluated at pipe springline (psi)

D_o = outside diameter of pipe (in.)

γ_b = unit weight of buoyant soil (lb/ft³)

H = depth of fill over top of pipe (ft.)

H_w = depth of water table above springline of pipe (ft.)

γ_s = wet unit weight of soil (lb/ft³)

12.12.3.8 Hydrostatic Pressure

The pressure due to ground water shall be calculated as:

$$P_W = \frac{\gamma_w K_{wa} H_w}{144} \quad (12.12.3.8-1)$$

where:

P_W = hydrostatic water pressure at the springline of the pipe (psi)

γ_w = unit weight of water (lb/ft³)

K_{wa} = factor for uncertainty in level of groundwater table

C12.12.3.8

Hydrostatic loading due to external water pressure should be calculated in all cases where water table may be above the pipe springline at any time. This load contributes to hoop thrust but does not affect deflection.

There is often uncertainty in the level of the groundwater table and its annual variations. The designer may use the factor K_{wa} with values up to 1.3 to account for this uncertainty or may select conservative values of H_w with a lower value of K_{wa} but not less than 1.

12.12.3.9 Live Load

The live load shall be determined as a pressure applied at the pipe crown. The live load magnitude shall be based on the design vehicular live load in Article 3.6.1.2 and shall include modifiers for multiple presence/overload, dynamic load allowance, and distribution through cover soils.

The live load pressure, P_L , shall be taken as:

$$P_L = \frac{P(1 + IM/100)m}{(L_0 + (12H + K_1)LLDF)(W_0 + (12H + K_1)LLDF)}$$

(12.12.3.9-1)

where:

- P_L = service live load on culvert (psi)
- P = design wheel load as specified in Article 3.6.1.2 (lbs.)
- IM = dynamic load allowance as specified in Article 3.6.2.2 (%)
- m = multiple presence factor as specified in Table 3.6.1.1.2-1
- L_0 = length of live load surface contact area parallel to pipe diameter as specified in Article 3.6.1.2.5 (in.)
- H = depth of fill over top of pipe (ft.)
- $LLDF$ = factor for distribution of live load through earth fills as specified in Article 3.6.1.2.6
- W_0 = width of live load ground surface contact area parallel to flow in pipe as specified in Article 3.6.1.2.5 (in.)
- K_1 = coefficient to consider design location (in.)
= 0 for live load at the crown of the pipe
= $D_0/2$ for live load at the springline

C12.12.3.9

Live load calculations are included here to demonstrate the computation of live load thrust at the crown and springline. NCHRP Project 15-29 to revise this is nearing completion. This project is proposing no changes to the live load distribution.

Increase as necessary if depth is sufficient for wheels and/or axles to interact.

Add axle spacing if depth is sufficient for axles to interact.

Add wheel spacing if depth is sufficient for wheels to interact.

Setting the term K_1 to 0 is the normal assumption in distributing live loads to the pipe and accounts for the load attenuating to the top of the pipe; however, the load continues to spread longitudinally along the pipe as it attenuates from the crown to the springline. Using the term $K_1 = D_0/2$ provides a means to account for this.

12.12.3.10 Wall Resistance

12.12.3.10.1 Resistance to Axial Thrust

12.12.3.10.1a General

Elements of profile wall pipe shall be designed to resist local buckling. To determine local buckling resistance, profile-wall pipe geometry shall be idealized as specified herein and an effective area determined in accordance with the following provisions.

12.12.3.10.1b Local Buckling Effective Area

For the determination of buckling resistance, profile wall pipe shall be idealized as straight elements. Each element shall be assigned a width based on the clear distance between the adjoining elements and a thickness based on the thickness at the center of the element. The idealization of a typical corrugated profile should be based on the approximation in Figure 12.12.3.10.1b-1.

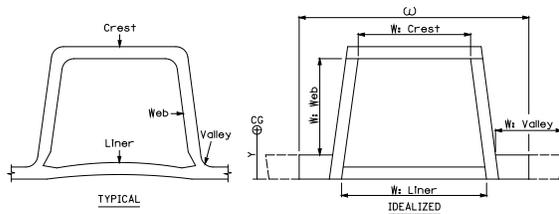


Figure 12.12.3.10.1b-1—Typical and Idealized Cross-Section of Profile Wall Pipe

To evaluate the resistance to axial thrust, the area of the profile shall be reduced to an effective area, A_{eff} , for local buckling effects. The effective area of the profile shall be determined by subtracting the ineffective area of each element from the gross section area, as:

$$A_{eff} = A_g - \frac{\sum(w - b_e)t}{\omega} \quad (12.12.3.10.1b-1)$$

in which:

$$b_e = \rho w \quad (12.12.3.10.1b-2)$$

$$\rho = \frac{(1 - 0.22 / \lambda)}{\lambda} \quad (12.12.3.10.1b-3)$$

$$\lambda = \left(\frac{w}{t}\right) \sqrt{\frac{\epsilon_{yc}}{k}} \geq 0.673 \quad (12.12.3.10.1b-4)$$

C12.12.3.10.1b

To complete the local buckling calculations, the profile is idealized into a group of rectangular elements. To complete the idealization, it should include:

- The actual total area.
- If the crest element is curved, it should be idealized at the centroid of the curvature. The idealized element need not touch the idealized webs.

See McGrath et al (2009) for guidance on other profile types.

The resistance to local buckling is based on the effective width concept used by the cold formed steel industry. This theory assumes that even though buckling is initiated in the center of a plate element, the element still has substantial post-buckling strength at the edges where the element is supported. This concept is demonstrated in Figure C12.12.3.10.1b-1.

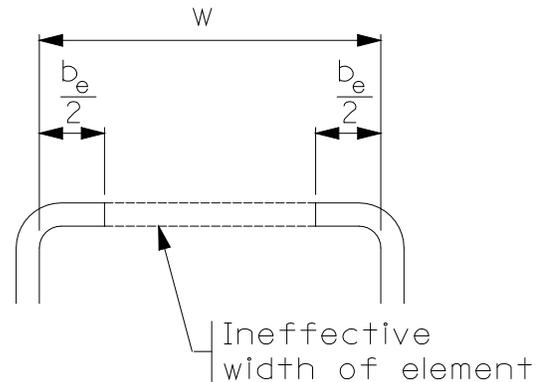


Figure C12.12.3.10.1b-1—Effective Width Concept

The local buckling evaluation reduces the capacity of pipe wall sections with high ratios of width to thickness.

The calculations in Eqs. 12.12.3.10.1b-1 to 12.12.3.10.1b-4 must be repeated for each element in the idealized profile.

where:

A_{eff} = effective area of pipe wall per unit length of pipe (in.²/in.)

b_e = element effective width (in.)

ρ = effective width factor

λ = slenderness factor

ω = spacing of corrugation (in.) as specified in Figure 12.12.3.10.1b-1

ϵ_{yc} = factored compressive strain limit as specified in Table 12.12.3.3-1

A_g = gross area of pipe wall per unit length of pipe (in.²/in.)

t = thickness of element (in.)

w = total clear width of element between supporting elements (in.)

k = plate buckling coefficient, $k = 4$ for supported elements, $k = 0.43$ for unsupported elements, such as free standing ribs

The plate buckling coefficient is analogous to the effective length factor, k , in column buckling.

As an alternate to determining the effective area by the calculation procedure presented above, the results of the stub compression test, AASHTO T341, may be used, in which case the effective area A_{eff} shall satisfy:

The stub compression test has been incorporated as a requirement into AASHTO product standards M294 and M304. The test data should be readily available from manufacturers and quality control test.

$$A_{eff} = \frac{P_{st} K_t}{F_u} \leq A_g \quad (12.12.3.10.1b-5)$$

in which:

P_{st} = stub compression capacity from T341 (kip/in.)

K_t = time factor as specified in Table 12.12.3.10.1b-1

F_u = material yield strength for design load duration ksi

Table 12.12.3.10.1b-1—Time Factor

<u>Time Period</u>	<u>PE</u>	<u>PVC</u>
<u>Initial</u>	<u>0.9</u>	<u>0.95</u>
<u>50 year</u>	<u>0.3</u>	<u>0.6</u>
<u>75 year (est.)</u>	<u>0.25</u>	<u>0.5</u>

12.12.3.10.1c Compression Strain

The factored compressive strain due to factored thrust, ε_{uc} , and the service compressive strain due to service thrust, ε_{sc} , shall be taken as:

$$\varepsilon_{uc} = \frac{T_u}{1000 (A_{eff} E_p)} \quad (12.12.3.10.1c-1)$$

$$\varepsilon_{sc} = \frac{T_s}{1000 (A_{eff} E_p)} \quad (12.12.3.10.1c-2)$$

in which:

$$T_u = P_u \left(\frac{D_o}{2} \right) \quad (12.12.3.10.1c-3)$$

where:

ε_{uc} = factored compressive strain due to thrust

ε_{sc} = service compressive strain due to thrust

T_u = factored thrust per unit length (lb./in.)

T_s = service thrust per unit length (lb./in.)

A_{eff} = effective area of pipe wall per unit length of pipe (in.²/in.)

E_p = short-term modulus for short-term loading or long-term modulus of pipe material for long-term loading as specified in Table 12.12.3.3-1 (ksi)

D_o = outside diameter of pipe (in)

P_u = factored load as specified in Eq. 12.12.3.5-1

12.12.3.10.1d Thrust Strain Limits

The factored compression strain due to thrust, ε_{uc} , shall satisfy:

$$\varepsilon_{uc} \leq \phi_T \varepsilon_{yc} \quad (12.12.3.10.1d-1)$$

where:

ε_{uc} = factored compressive strain due to thrust

ϕ_T = resistance factor for thrust effects

ε_{vc} = factored compression strain limit of the pipe wall material as specified in Table 12.12.3.3-1

12.12.3.10.1e General Buckling Strain Limits

The factored compression strain due to thrust, incorporating local buckling effects, ε_{uc} , shall satisfy:

$$\varepsilon_{uc} \leq \phi_{bck} \varepsilon_{bck} \quad (12.12.3.10.1e-1)$$

The nominal strain capacity for general buckling of the pipe shall be determined as:

$$\varepsilon_{bck} = \frac{1.2C_n(E_p I_p)^{1/3}}{A_{eff} E_p} \left(\frac{\phi_s M_s (1 - 2\nu)}{(1 - \nu)^2} \right)^{2/3} R_h$$

(12.12.3.10.1e-2)

in which:

$$R_h = \frac{11.4}{11 + \frac{D}{12H}} \quad (12.12.3.10.1e-3)$$

where:

ε_{uc} = factored compressive strain due to thrust

ϕ_{bck} = resistance factor for global buckling

ε_{bck} = nominal strain capacity for general buckling

C12.12.3.10.1e

The equations for global resistance presented here are a conservative simplification of the continuum buckling theory presented by Moore (1990). Detailed analysis using the full theory may be applied in lieu of the calculations in this section.

The term ϕ_s appears in this expression for ε_{bck} to account for backfills compacted to levels below that specified in the design. Lower levels of compaction increases the thrust force in the pipe.

For designs meeting all other requirements of these specifications and the AASHTO LRFD Bridge Construction Specifications, the correction for backfill soil geometry, R_h , is equal to value at left.

R_h = correction factor for backfill soil geometry

The complete theory proposed by Moore (1990) provides variations in R_h that consider nonuniform backfill support. In the extreme case where the width of structural backfill at the side of the culvert is 0.1 times the span and the modulus of the soil outside of the structural backfill is 0.1 times the modulus of the backfill, then:

$$R_h = \frac{20}{56 + \frac{D}{12H}}$$

(C12.12.3.10.1e-1)

C_n = calibration factor to account for nonlinear effects = 0.55

E_p = short- or long-term modulus of pipe material as specified in Table 12.12.3.3-1 (ksi)

I_p = moment of inertia of pipe profile per unit length of pipe (in.⁴/in.)

A_{eff} = effective area of pipe profile per unit length of pipe (in.²/in.)

ϕ_s = resistance factor for soil pressure

M_s = secant constrained soil modulus as specified in Table 12.12.3.5-1 (ksi)

ν = Poisson's ratio of soil

Poisson's ratio is used to convert the constrained modulus of elasticity to the plane strain modulus. Values for Poisson's ratio of soils are provided in many geotechnical references. One reference is Selig 1990.

D = diameter to centroid of pipe profile (in.)

H = depth of fill over top of pipe (ft.)

12.12.3.10.2 Bending and Thrust Strain Limits

12.12.3.10.2a General

To ensure adequate flexural capacity the combined strain at the extreme fibers of the pipe profile must be evaluated at the allowable deflection limits against the limiting strain values.

12.12.3.10.2b Combined Strain

If summation of axial strain, ε_{uc} , and bending strain, ε_f , produces tensile strain in the pipe wall, the combined strain at the extreme fiber where flexure causes tension shall satisfy:

$$\varepsilon_f - \varepsilon_{uc} < \phi_f \varepsilon_{yt} \quad (12.12.3.10.2b-1)$$

The combined strain at the extreme fiber where flexure causes compression shall satisfy:

$$\varepsilon_f + \varepsilon_{uc} < \phi_T (1.5\varepsilon_{yc}) \quad (12.12.3.10.2b-2)$$

where:

ε_f = factored strain due to flexure

ε_{uc} = factored compressive strain due to thrust

ε_{yt} = service long-term tension strain limit of the pipe wall material as specified in Table 12.12.3.3-1

ϕ_f = resistance factor for flexure

ϕ_T = resistance factor for thrust

ε_{yc} = factored compression strain limit of the pipe wall material as specified in Table 12.12.3.3-1

In the absence of a more-detailed analysis, the flexural strain may be determined based on the empirical relationship between strain and deflection

as:

$$\varepsilon_f = \gamma_{EV} D_f \left(\frac{c}{R} \right) \left(\frac{\Delta_f}{D} \right) \quad (12.12.3.10.2b-3)$$

in which:

$$\Delta_f = \Delta_A - \varepsilon_{sc} D \quad (12.12.3.10.2b-4)$$

where:

ε_f = factored strain due to flexure

ε_{sc} = service compression strain due to thrust

C12.12.3.10.2b

The criteria for combined compressive strain is based on limiting local buckling. A higher strain limit is allowed for combined strains because under bending, the web elements have a low stress near the centroid of the element and are thus unlikely to buckle. Thus the unbuckled web elements increase the stability of the crest and valley elements.

The strain limit for combined compression strain is 50 percent higher than that for hoop compression alone because the web elements, which experience low strains due to bending, are not likely to buckle, thus increasing the stability of elements near the crest and valley. While this behavior would be more accurately modeled as an increase in the k factor of Eq. 12.12.3.10.1b-4, the increase in the limiting strain is considered adequate for this simplified design method.

For thrust capacity, the section is limited by consideration of hoop compression capacity alone. The check of combined compression strain, hoop plus bending, is used to limit the allowable pipe deflection.

Elements subjected primarily to bending (such as a web element in Figure 12.12.3.10.1b-1 when the pipe is deflected) are not highly stressed near the centroid, where buckling initiates, and theoretical k factors for plates in bending are greater than 20. To simplify the analysis for combined bending and thrust, elements, such as the web whose centroid is within $c/3$ of the centroid of the entire profile wall, may be analyzed only for the effect of hoop compression strains. That is, increases in strain due to bending may be ignored.

Past practice has used tensile strain limits specified in Table 12.12.3.3-1, with no guidance on ultimate strain limits. For purposes of design calculations, assume that ultimate tensile strain capacity is 50 percent greater than the service capacities provided in Table 12.12.3.3-1.

A higher strain limit is allowed under combined bending and compression. This increase is permitted because the web element under flexure has a low stress at the center of the element, reducing the likelihood of buckling, and allowing it to provide more stability to the crest and valley elements.

Flexural strains are always taken as positive.

Peak flexural stress occurs near the crown for live load conditions and near the haunch/invert region for deep burial cases. The factors K_1 and K_2 should be used in the thrust computations to determine the thrust strains used in Eqs. 12.12.3.10.2b-1 and 12.12.3.10.2b-2.

The service compressive strain is used for determination of the factored strain due to flexure instead of the factored compressive strain. The use of the factored compressive strain would result in an unconservative flexural strain demand.

Δ_f = reduction of vertical diameter due to flexure (in.)

γ_{EV} = load factor for vertical pressure from dead load of earth fill, as specified in Article 3.4.1

D_f = shape factor as specified in Table 12.12.3.10.2b-1. The shape factors for corrugated PE pipe can be reduced by 1.0 from the table values to account for the effect of the low hoop stiffness ratio.

c = the larger of the distance from neutral axis of profile to the extreme innermost or outermost fiber (in.)

R = radius from center of pipe to centroid of pipe profile (in.)

D = diameter to centroid of pipe profile (in.)

Δ_A = total allowable deflection of pipe, reduction of vertical diameter (in.)

The empirical shape factor is used in the design of fiberglass pipe and is presented in AWWA Manual of Practice M45 Fiberglass Pipe Design (1996). It demonstrates that bending strains are highest in low stiffness pipe backfilled in soils that require substantial compactive effort (silts and clays), and is lowest in high stiffness pipe backfilled in soils that require little compactive effort (sands and gravels).

Table 12.12.3.10.2b-1 does not cover all possible backfills and density levels. Designers should interpolate or extrapolate the Table as necessary for specific projects.

More detailed analyses must consider the likelihood of inconsistent soil support to the pipe in the haunch zone, and of local deformations during placement and compaction of backfill.

Bending strains typically cannot be accurately predicted during design due to variations in backfill materials and compactive effort used during installation. Installation deflection limits are specified in the construction specifications to assure that design parameters are not exceeded.

The deflection design limit is five percent reduction of the vertical diameter as specified in the construction specification. The pipe must be designed to permit this deflection, unless extraordinary measures are specified in contract documents to minimize compactive effort and to control deflections.

The AASHTO Bridge Construction Specifications currently restrict the allowable total vertical deflection to five percent.

Table 12.12.3.10.2b-1—Shape Factors, D_f , based on Pipe Stiffness, Backfill and Compaction Level

Pipe Stiffness $(F/\Delta_{1/2}, \text{ksi})$ $= EI / 0.149 R^3$	Pipe Zone Embedment Material and Compaction Level			
	Gravel (1)		Sand (2)	
	Dumped to Slight (3)	Moderate to High (4)	Dumped to Slight (3)	Moderate to High (4)
<u>0.009</u>	<u>5.5</u>	<u>7.0</u>	<u>6.0</u>	<u>8.0</u>
<u>0.018</u>	<u>4.5</u>	<u>5.5</u>	<u>5.0</u>	<u>6.5</u>
<u>0.036</u>	<u>3.8</u>	<u>4.5</u>	<u>4.0</u>	<u>5.5</u>
<u>0.072</u>	<u>3.3</u>	<u>3.8</u>	<u>3.5</u>	<u>4.5</u>

1. GW, GP, GW-GC, GW-GM, GP-GC and GP-GM per ASTM D2487 (includes crushed rock)
2. SW, SP, SM, SC, GM and GC or mixtures per ASTM D 2487
3. <85% of maximum dry density per AASHTO T 99, < 40% relative density (ASTM D4253 and D4254)
4. ≥85% of maximum dry density per AASHTO T 99, ≥ 40% relative density (ASTM D4253 and D4254)

12.12.4 Construction and Installation

The contract documents shall require that the construction and installation conform to Section 30, "Thermoplastic Culverts," AASHTO LRFD Bridge Construction Specifications.

REFERENCES

Add References:

AASHTO. 2009. *Standard Specifications for Transportation Material and Methods of Sampling and Testing*, 30th Edition, HM-30, American Association of State Highway and Transportation Officials, Washington, DC. Included AASHTO M, R, and T standards, which are also available individually in downloadable form.

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McGrath, T.J. and Beaver, J.L., 2005. *Performance of Thermoplastic Pipe Under Highway Vehicle Loading*, Simpson Gumpertz & Heger Inc, Oakdale, MN. Research Report to Minnesota DOT.

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Moore, I.D., 1990. –Three-Dimensional Response of Elastic Tubes,” *International Journal of Solids and Structures*, Vol.26, No.4.

Selig, E.T. 1990. –Soil Properties for Plastic Pipe Installation,” *Buried Plastic Pipe Technology*, ASTM STP 1093, George S. Buczala and Michael J. Cassidy, eds. American Society for Testing and Materials, Philadelphia, PA.

State of California, Department of Transportation, Bridge Design Specifications, LFD Version, April 2000 Section 17 - Soil Reinforced Concrete Structure Interaction Systems.

State of California, Department of Transportation, Standard Plans (May 2006), A62D Excavation and Backfill Concrete Pipe Culverts.

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