

Proposed revisions adding High Density Polyethylene pipe to Part 4 (Culverts),
 Chapter 1 (Roadway and Ballast), AREMA Manual for Railway Engineering
 (Subcommittee Assignment 01.11.01)



Part 4
Culverts¹

— 2006 —

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4.1.3 CHARACTER OF HYDRAULIC BEDLOAD (ABRASIVE, CORROSIVE, ETC.) (1995 2011)

b. Turning to internal corrosion, mine water, especially from coal mines, is particularly difficult to handle as it attacks all *most* commonly used materials except possibly *high density polyethylene pipe*.

e. Sea-Salt water is injurious to all *most* types of drainage materials. The chlorides in the salt water shorten the life of metal structures, while the alternate wetting and drying, and the frost action in cold climates accelerate the deterioration of concrete. *High density polyethylene is highly resistant to chlorides in salt water.*

f. *High density polyethylene is unaffected by stray electrical current.*

f. g. Wherever the service conditions are such as to indicate severe abrasive or corrosive action, the available drainage material that will be least affected should be used, resulting in a structure that will give the lowest cost per year of service.

4.1.6 HEIGHT AND CHARACTER OF EMBANKMENT (1987 2011)

A factor that must be considered in the selection of structures is that of transverse forces in fills that cause movement transverse to the length of the embankment. These forces are manifested by the tendency of the fill material to move downward and outward, seeking its angle of repose and tending to separate the lengths of pipe culverts and open cracks in masonry. Transverse forces are present in every fill but are likely to be particularly severe on side hill locations. *Fills over critical culverts should be designed to minimize transverse forces.*

The creation of this section will require all subsequent section to shift one (1) number place.

SECTION 4.8 SPECIFICATIONS FOR CORRUGATED HIGH DENSITY POLYETHYLENE PIPE

4.8.1 GENERAL (2011)

This specification covers corrugated high density polyethylene pipe for under track culverts and storm drain applications.

4.8.2 MATERIALS (2011)

4.8.2.1 CORRUGATED HIGH DENSITY POLYETHYLENE PIPE

12 through 60-inch (300 to 1500mm) Corrugated High Density Polyethylene Pipe shall be fabricated per AASHTO M294 or ASTM F2306 and shall be smooth lined with a corrugated exterior.

4.8.2.2 HIGH DENSITY POLYETHYLENE FITTINGS

Fittings shall conform to ASTM F 2306. Fittings in field structural performance shall meet or exceed pipe performance.

4.8.3 COUPLINGS (2011)

4.8.3.1 BELL AND SPIGOT CONNECTIONS

Bell and Spigot pipe and fittings shall be watertight according to the requirements of ASTM D3212. Gaskets shall meet the requirements of ASTM F477. The gasket shall be factory installed on the pipe and protected with a wrap during shipping and storage. If the gasket is removed and replaced in the field, care should be taken to ensure the gasket is properly placed on the pipe.

4.8.3.2 SPLIT COUPLING BANDS

Plain end pipe & fittings shall be joined with coupling bands that cover at least two full corrugations of both abutting ends of both pipes. Split coupling bands are considered soil-tight. Split coupling bands shall be wrapped with minimum 12 ounce non-woven geotextile fabric meeting AASHTO M288 Class1. Fabric wrap shall cover a length of pipe that extends 12" beyond the ends of the coupling band and overlap a minimum of 12 inches.

4.8.3.3 UNDER DRAIN CONNECTIONS

Underdrains typically do not have watertight connections. Where watertight connections are not used, connections should be designed to prevent the migration of fines.

Table 1-4-14 is located in Section 4.8.3.1

Table 1-4-14. Entrance Loss Coefficients for Corrugated Metal Pipe or Pipe Arch (Reference 22), and Corrugated High Density Polyethylene Pipe.

Inlet End of Culvert	Coefficient k_e
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls square-edge	0.5
Mitered (beveled) to conform to fill slope	0.7
End-Section conforming to fill slope (Note 1)	0.5
Headwall, rounded edge	0.2
Beveled Ring	0.25
Note 1: End Sections available from manufacturers.	

4.89.3.7 Friction Loss (Hf)

- d. Manning's design friction factor (n) for Smooth lined (type S) Corrugated High Density Polyethylene pipe is recommended to be 0.012, and for unlined (type C) Corrugated High Density Polyethylene pipe is recommended to be 0.024.
- e. Manning's design factor (n) for precast concrete pipe and precast reinforced concrete pipe (RCP) is recommended to be 0.012.

4.89.4 HYDRAULIC COMPUTATIONS (1989 2011)

- m. Inlet control for Corrugated High Density Polyethylene Pipe: HW/D Scale (1) and (3) in Figure 1-4-6. Inlet Control – Headwater Depths for Corrugated Metal Pipe Culverts, may be used to evaluate inlet control for Smooth lined (type S) and Unlined (type C) Corrugated High Density Polyethylene pipe. SW/D Scale (2) may also be considered for pipes less than 24" in diameter.
- n. Outlet control for Corrugated High Density Polyethylene Pipe: Use Figure 1-4-17. Outlet Control – Head for Concrete Pipe Culverts with Submerged Outlet and Flowing Full to calculate outlet control for Smooth lined (type S) Corrugated High Density Polyethylene Pipe (Manning's friction factor $n=0.012$).
- o. When using figures 1-4-6 through 1-4-20 make sure to adjust the diameter (D) as needed to accommodate for manufacturing tolerances.

4.910.3 LOADS (2011)

- a. DL, Dead load pressure = ~~120 lb per cubic foot~~ specified compacted soil density x height of cover in feet.
- b. LL, Live load pressure, including 50% impact, for Cooper E-80 as shown in Table 1-4-24. Live load pressure may be interpolated for heights of cover not listed in Table 1-4-24. Typically railroad culverts are installed with heights of cover of 2 ft. or greater. If height of cover is less than 2 feet, the designer should determine the live load pressure. AREMA *Volume 1, Chapter 1, Part 2.11.2 Design* is a reference source for live load pressure determination through soil at low heights of cover.

Table 1-4-24. Live Load Pressure for Cooper E-80, Height of cover is measured from base of cross tie to top outside of pipe.

Height of Cover (ft.)	Live Load (PSF)
2	3800
5	2400
8	1600
10	1100
12	800
15	600
20	300
30	100

c. $P_v =$

Total load pressure = DL+LL
EQ. 4 – 7

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SECTION 4.12 STRUCTURAL DESIGN CONSIDERATIONS OF CORRUGATED HIGH DENSITY POLYETHYLENE PIPES

4.12.1 INTRODUCTION (2011)

The strength of corrugated high density polyethylene pipe is based on interaction between the pipe and the backfill surrounding it. It is important to note that the pipe backfill type and compaction requirements must be met for high density polyethylene pipe to perform satisfactorily.

4.12.2 Design Criteria (2011)

The structural design of corrugated high density polyethylene pipe follows the Load Resistance Factor Design (LRFD) Methodology from Section 12 Buried Structures and Tunnel Liners of the AASHTO LRFD Bridge Specifications. The pipe's profile dimensions, including section properties necessary for the completion of Section 12 analysis, shall be provided by manufacturer upon request.

4.12.3 Loads and Load Factors (2011)

4.12.3.1 GENERAL COMMENTS

Section 3 Loads and Load Factors of the AASHTO LRFD Bridge Specification defines most loads and load factors for corrugated high density polyethylene pipe. Additional guidelines are presented herein.

Note: Thermoplastic materials such as high density polyethylene exhibit viscoelastic material behavior under a given load. In short, this means mechanical properties, such as modulus of elasticity and design tensile strength, will decrease with time under a given stress. For analysis per LRFD Section 12 and through this design section, the terms short-term and long-term mechanical properties are used to account for this creep behavior. The term short-term shall refer to the initial mechanical properties as shown in LRFD Section 12. The term long-term shall refer to the lowest value for a given mechanical property represented in LRFD Section 12.

4.12.3.2 LOAD FACTORS AND COMBINATIONS

Typically corrugated high density polyethylene pipe will be designed using Strength I, Strength II, and Service I Limit States from Section 3 Loads and Load Factors of the AASHTO LRFD Bridge Specifications. While each of these design states are listed, Strength 1 Limit State will generate the greatest factored load of the three cases and result in the most conservative limit state regarding allowable fill heights in a given design condition.

4.12.3.3 PERMANENT LOADS

Permanent Loads consist of Dead Loads and Earth loads as contained in Section 3 Loads and Load Factors of the AASHTO LRFD Bridge Specifications. As stated in the AASHTO Section 12, code, long term mechanical properties should be used when calculating strength limit states for permanent loads.

4.12.3.4 LIVE LOADS

Cooper E-80 live loads are normally used as the basis for determining live load pressures for under track culvert design. These live load pressures are provided in Section 4.10.3 of the AREMA Manual. Additionally, it is common practice to use a live load distribution coefficient (C_L) of 1.16 for rail loading where the total factored live load (P_L) equals the Cooper E-80 live load pressure from Section 4.10.3 times C_L (1.16) times live load factor (γ_{LL} , shown in AASHTO LRFD Section 3.4.1) times load modifier (η_{LL} , shown in AASHTO LRFD Section 1.3.2)

4.12.3.5 SURCHARGE LOADS

In addition to permanent and live loads, surcharge loads should also be considered in the analysis. Surcharge loads include items such as parked railroad cars and locomotives, temporary structures, and material stock piles. For analysis of surcharge loads, the surcharge load shall be considered a permanent load with long-term mechanical properties used in the analysis. Where a static live load is generated by a parked railroad car or locomotive in the surcharge loading condition, the live load pressure from section 4.10.3 (2010) Table 1-4-24

shall be used minus impact. Static live load = Live load from table 1-4-24 divided by 1.5.

4.14.13.1 INTRODUCTION (1992 2011)

d. The design engineer should consider the combustibility of the pipe materials and coatings. In areas where fire may directly or indirectly cause damage to culvert pipe or pipe coatings, the design engineer should consider using non-combustible concrete or metal end treatments, riprap protection, or other similar practices to protect the integrity of the culvert.

4.1214.6 ASSEMBLY (19952011)

c. It is not the intention of this text to address the specifics of assembly for all pipe culvert products. Rather, the culvert pipe manufacturers should provide assembly instructions for their products. In addition, the reader is referred to the Reference 1, 30, 38, 47, 50, 51, and 52, and 63 at the end of this chapter for more detailed information regarding assembly of culvert pipe.

63. *Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications, ASTM D2321, American Society for Testing Materials.*

4.1214.7 BACKFILL (1995 2011)

c. Special care must be taken to provide proper bedding and haunch support for the pipe. See Figure 1-4-22. A relatively loose layer of bedding (generally several inches thick) should be placed under the pipe. However, the fill in the haunch areas is to be carefully compacted to provide support in these critical areas. This is especially important for pipe-arch shapes and *Corrugated High Density Polyethylene pipe*. Backfill type, placement, and compaction should follow ASTM D2321. To ensure proper structural performance, backfill with very low or no plasticity should be used. Backfill placement and compaction should be verified in the field. Flowable fill can alleviate compaction issues.

4.14.12 POST INSTALLATION INSPECTION (2011)

Post-installation inspection is recommended to be performed on all newly constructed culverts in accordance with inspection methods Sections 26 (Metal Pipe), 27 (Concrete pipe), and 30 (Thermoplastic pipe) of the AASHTO LRFD Bridge Construction specifications.

4.1416.5.1 Sliplining

a. If after hydraulic evaluation, the downsizing of the existing line is acceptable, then standard corrugated metal pipe, concrete pipe, or HDPE pipe may be used and provided in lengths which would facilitate insertion. Hydraulic advantages may be gained by improvements to inlet details (see Article 4.9.3.1) or by using helical corrugated steel pipe if the existing pipe is annularly corrugated.

b. Hydraulic capacity can may be improved maximized by the use of the following pipe: lined metal pipe or smooth wall High Density Polyethylene pipe. Choices of this type of pipe include:

- (1) 100% asphalt lined CMP.
- (2) 100% cement mortar lined CMP.
- (3) Double-wall CMP.
- (4) Spiral rib CMP
- (5) *Type S - Corrugated High Density Polyethylene Pipe.*

- (6) Solid Wall High Density Polyethylene pipe.
(7) Reinforced Concrete Pipe

h. When placing grout around High Density Polyethylene pipe, grout is typically gravity fed from the top and high end of the pipe. To ensure the grout will flow properly, plasticizer may be added to the grout mix. Procedures should be taken to fully grout the annular space.

4.1719.4 SAFETY (2004 2011)

a. Culvert inspection in many cases presents certain hazards to personnel performing the inspection. In order to properly evaluate the structural integrity of a culvert, it is usually necessary to perform an internal inspection of the conduit. Many smaller diameter culverts may exist under railroad properties which makes internal inspection difficult. It is recommended that culverts less than 30 inches in diameter not be entered by inspection personnel without special precautions. Internal inspection of culverts in this size range is best conducted using specially designed video cameras, deflection recording devices *such as mandrels, and laser deflectometers, or crack measuring devices such as video micrometer, feeler gauge,* or similar methods. Culverts 30 inches in diameter and larger should only be entered by inspection personnel trained in working within confined spaces and using procedures in full compliance with all applicable State, Local and Federal regulations (i.e., OSHA, Roadway Workers Protection Act, and other FRA regulations).

4.1719.5.3 Frequency of Inspection

d. It is critical to inspect culverts that have been exposed to fire. This inspection should be done after a fire, and before rail traffic resumes.

4.1820.5 HYDRAULIC DESIGN (2006 2011)

(2) Pipe underdrains should be placed at grades steeper than 0.5% if possible. Minimum grades of 0.2% are acceptable *upon engineering review. Underdrains should not be longer than 200' without providing a lateral drain to daylight or a catch basin.*

(5) Due to concerns for clogging, a minimum of 12-inch diameter should be considered for all newly installed underdrains. *Underdrains that are designed to be maintained should be large enough to allow passage of cleaning equipment.*

4.1820.7.4 LAYING PIPE

c. *Where pipe perforations cover only one half of the pipe, Perforated pipe shall be so laid that the perforations are in the bottom half of the pipe (the invert). Where perforated pipe installations outlet into open ditches, a minimum of 8 feet of pipe from the outlet shall be non-perforated. Pipe discharge outlets shall be constructed concurrently with the underdrains. Design and construction details must consider proper protection of the exposed ends of the pipe.*

SECTION 4.21 COMMENTARY

4.21.1 AASHTO Load Resistance Factor Design (LRFD), High Density Polyethylene (HDPE) Pipe Design Example (2011)

4.21.1.1 INTRODUCTION

Because an acceptable allowable stress design methodology doesn't exist for corrugated HDPE pipe, this design example was created to assist new users of AASHTO's Load Resistance Factor Design (LRFD) Bridge Design Specifications, to evaluate corrugated HDPE pipe in railroad applications. All "AASHTO LRFD" references in this design example refer to the AASHTO LRFD Bridge Design Specifications, Fifth Edition – 2010 revision. This example contains all necessary equations for evaluating corrugated HDPE pipe under railroads, but does not contain all tables and commentary available in the AASHTO LRFD code.

In the design example Strength Limit State 1 and Service Limit State 1 are reviewed. Strength Limit State 1 will generate the greatest factored load for HDPE pipe, and Service Limit State 1 verifies that service limits are met per the AASHTO LRFD Bridge Design Guidelines. The deflection requirement within the code is the only parameter investigated using Service Limit State 1. *In this design example, the springline limit states control over the crown limit states, therefore only the springline limit states are shown.*

4.21.1.2 APPLICATION SPECIFIC DESIGN INPUTS

- 24" corrugated HDPE pipe AASHTO M294 type S (see asterisk below).
- 5' burial depth with groundwater 2.5' above springline.
- 5% induced deflection, assumed SN backfill material @ 90% spd.
- Cooper E-80 live load.
- 75-year design material properties.

Pipe Section Properties* (Manufactured Product Specific)

Nominal ID in (mm)	Inside Diameter, S in (mm)	Outside Diameter, D _o in (mm)	Pitch in (mm)	Pipe Stiffness pii (kpa)	Section Area, A _s in ² /in (mm ² /mm)	Distance from S to Neutral Axis, c in (mm)	Moment of Inertia, I in ⁴ /in (mm ⁴ /mm)
24 (600)	24.08 (612)	27.7 (704)	3.3 (85.0)	34 (234)	0.330 (8.37)	0.717 (18.21)	0.1331 (2181)

* Pipe section properties are unique to each manufactured product and must be obtained from the manufacturer.

4.21.1.3 DEAD LOADS (DL)

a. Soil Prism Pressure (Earth Load)

$$P_{sp} = \frac{\left(\left(H_w - \frac{D_o}{24} \right) + 0.11 \frac{D_o}{12} \right) \gamma_b}{144} + \frac{\left(H - \left(H_w - \frac{D_o}{24} \right) \right) \gamma_s}{144} \quad (12.12.3.7-2)$$

Where:

P_{sp} = soil-prism pressure, evaluated at pipe springline (psi), AASHTO LRFD Eq. 12.12.3.7-2

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

D_o = outside diameter of pipe (in)

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

H = depth of cover (ft)

γ_s = unit weight of soil (lb/ft³)

$$P_{sp} = \frac{\left(\left(2.5' - \frac{27.7''}{24} \right) + 0.11 \frac{27.7''}{12} \right) 80 \text{ lb/ft}^3}{144} + \frac{\left(5' - \left(2.5' - \frac{27.7''}{24} \right) \right) 120 \text{ lb/ft}^3}{144} = 3.93 \text{ psi}$$

Note: AASHTO LRFD Section 12.12.3.7 allows for the use of three different equations to determine the soil prism earth load. For this example, AASHTO LRFD Equation (12.12.3.7-2) was used because ground water is above the crown of pipe, but below the ground surface.

If the water table would have been above the top of the pipe and at or above the ground surface, we would have used AASHTO LRFD Eq. 12.12.3.7-1.

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

If the water table would have been below the top of the pipe we would have use AASHTO LRFD Eq.12.12.3.7-3.

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

b. Vertical Arching Factor

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

$$S_H = \frac{\phi_s M_s R}{E_p A_g} = \frac{\phi_s M_s R}{E_s A_g} = \frac{(0.9)(1431 \text{ psi})(12.76'')}{(21000 \text{ psi})(0.33 \text{ in}^2 / \text{in})} = 2.4 \quad (12.12.3.5-4)$$

$$VAF = 0.76 - 0.71 \left(\frac{2.4 - 1.17}{2.4 + 2.92} \right) = 0.6$$

Where:

VAF = vertical arching factor, AASHTO LRFD Eq. 12.12.3.5-3

S_H = hoop stiffness factor, AASHTO LRFD Eq. 12.12.3.5-4

ϕ_s = resistance factor for soil stiffness. Suggested standard practice is to design for a standard proctor backfill density five percent less than specified by the contract documents, unless compaction levels are field verified.

M_s = secant constrained soil modulus as specified in AASHTO LRFD Table 12.12.3.5-1 (psi)

R = radius from center of pipe to centroid of pipe profile (ID/2+c), obtain from pipe manufacturer.

E_p = short or long term modulus of pipe material as specified in AASHTO LRFD Table 12.12.3.3-1

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

E_s = 110,000 psi for short term conditions (used later on in calculation)

E_l = 22,000 psi for (50 year) long term conditions
 = 21,000 psi for (75 year) long term conditions

Note: VAF is only used in calculating prism loads for long term loading conditions; therefore, use only the long term material modulus to calculate the VAF.

d. Hydrostatic Load (P_w), Refer to AASHTO LRFD Eq. 12.12.3.8-1.

$$P_w = \frac{\gamma_w K_{wa} H_w}{144} = \frac{62.4 \text{ lb/ft}^3 (1)(2.5')}{144} = 1.08 \text{ psi} \quad (12.12.3.8-1)$$

Where:

P_w = hydrostatic pressure at springline of pipe, psi
 γ_w = unit weight of water (lb/ft³)
 = 62.4 (lb/ft³)
 K_{wa} = factor for uncertainty in level of groundwater table
 = Value ranges from 1.0 to 1.3
 H_w = height of groundwater above springline of pipe, ft

4.21.1.4 RESISTANCE TO AXIAL THRUST

a. Effective Area (A_{eff})

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

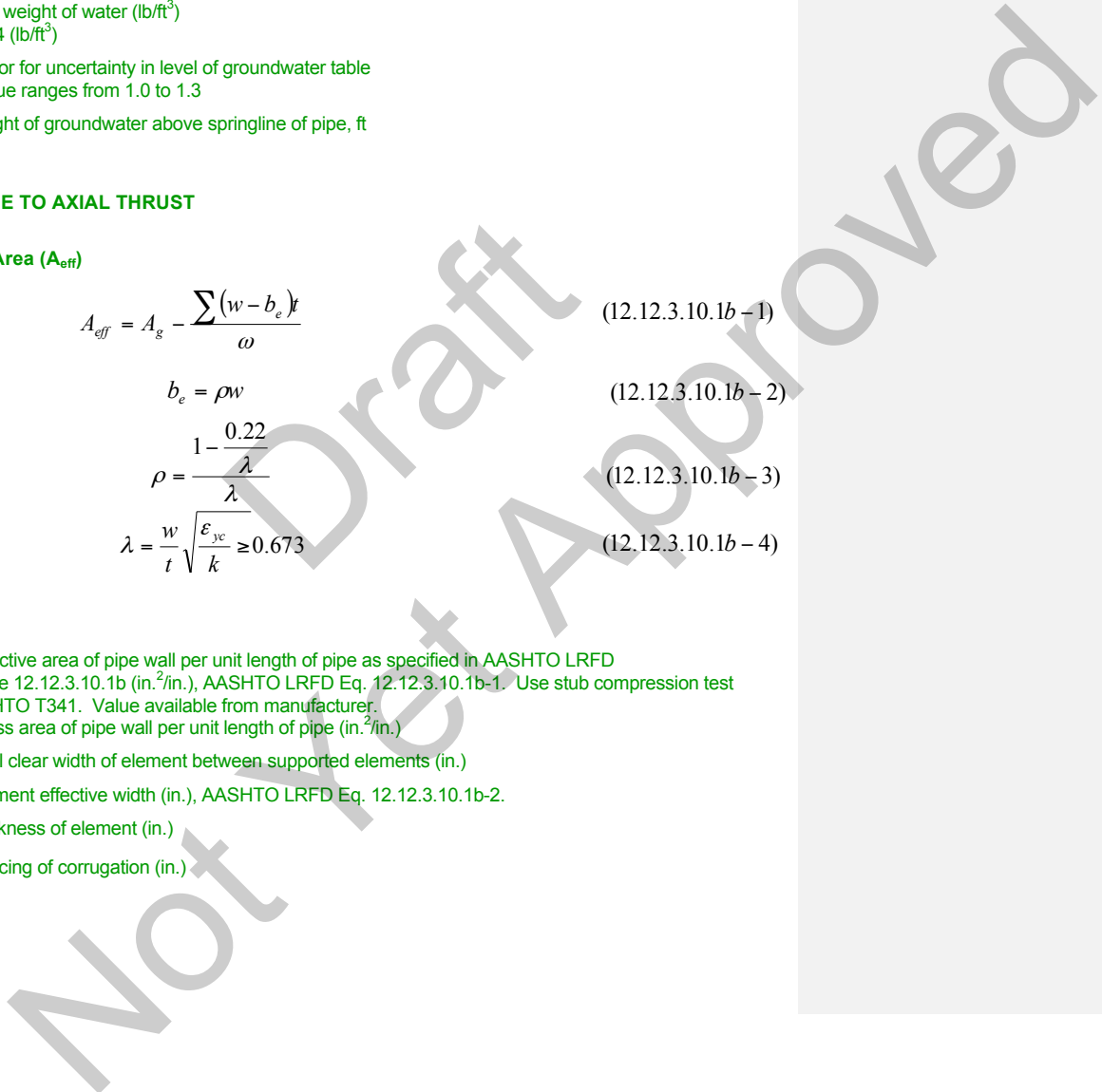
$$b_e = \rho w \quad (12.12.3.10.1b-2)$$

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

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

Where:

A_{eff} = effective area of pipe wall per unit length of pipe as specified in AASHTO LRFD Article 12.12.3.10.1b (in.²/in.), AASHTO LRFD Eq. 12.12.3.10.1b-1. Use stub compression test AASHTO T341. Value available from manufacturer.
 A_g = gross area of pipe wall per unit length of pipe (in.²/in.)
 w = total clear width of element between supported elements (in.)
 b_e = element effective width (in.), AASHTO LRFD Eq. 12.12.3.10.1b-2.
 t = thickness of element (in.)
 ω = spacing of corrugation (in.)



- ρ = effective width factor, AASHTO LRFD Eq. 12.12.3.10.1b-3.
 λ = slenderness factor, AASHTO LRFD Eq. 12.12.3.10.1b-4.
 ϵ_{yc} = factored compression strain limit of the pipe wall material as specified in AASHTO LRFD Table 12.12.3.3-1
 k = plate buckling coefficient. Use edge support coefficient, 4.0 for elements with both edges supported.
 w_i = see Figure 12.12.3.10.1b-1 for use of w_i

Idealized Pipe Profile Section Properties (Manufactured Product Specific)

	t	w	w_i	λ	ρ	b_e
Crest	0.124	1.556	1.556	1.270	0.65	1.013
Web	0.172	1.786	1.621	0.954	0.81	1.307
Valley	0.165	0.207	0.414	0.673	1.00	0.414
Liner	0.099	2.285	2.285	2.337	0.39	0.886
Shell	0.000	0.000	0.000	0.673	1.00	0.000

$A_g =$

$A_{eff} =$

4.21.1.5 THRUST STRAIN LIMITS

Factored Compressive Strain (ϵ_{uc}), refer to AASHTO LRFD Eq. 12.12.3.10.1c-1

$If (\epsilon_{uc} \leq \phi_T \epsilon_{yc}) = O.K.$ (12.12.3.10.1d-1)

$$\epsilon_{uc} = \frac{T_u}{A_{eff} E_p} = \left[\frac{\eta_{EV} (\gamma_{EV} K_{\gamma E} K_2 VAF(P_{sp}) + \gamma_{WA} P_W)}{A_{eff} E_l} + \frac{\eta_{LL} \gamma_{LL} P_L C_L}{A_{eff} E_s} \right] \left(\frac{D_o}{2} \right)$$
 (12.12.3.10.1c-1)

$$\epsilon_{uc} = \left[\frac{1.05(1.3)(1.5)(1.0)(0.6)(3.93 \text{ psi}) + (1.3)(1.08 \text{ psi})}{(0.236 \text{ in}^2 / \text{in})(21000 \text{ psi})} + \frac{(1.0)(1.75)(16.67 \text{ psi})(1.16)}{(0.236 \text{ in}^2 / \text{in})(110000 \text{ psi})} \right] \left(\frac{27.7}{2} \right) = 0.0357 \text{ in} / \text{in}$$

$\phi_T \epsilon_{yc} = (1.0)(4.1\%) = 0.041 \text{ in} / \text{in}$

$If (\epsilon_{uc} \leq \phi_T \epsilon_{yc}) = O.K.$

$0.0357 \text{ in} / \text{in} \leq 0.041 \text{ in} / \text{in} = O.K.$

Where:

ϵ_{uc} = factored compressive strain due to thrust

T_u = factored thrust per unit length (lb/in.) AASHTO LRFD Eq. 12.12.3.10.1c-3.

P_u = factored load as specified in AASHTO LRFD Eq. 12.12.3.5-1 (use in T_u calculation)

- η_{EV} = load modifier as specified in AASHTO LRFD 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 AASHTO LRFD Article 3.4.1
- K_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 document.
- 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
- γ_{WA} = load factor for hydrostatic pressure, as specified in AASHTO LRFD Article 3.4.1
- P_W = hydrostatic water pressure (psi)
- η_{LL} = load modifier as specified in AASHTO LRFD Article 1.3.2, as they apply to live loads
- γ_{LL} = load factor for live load, as specified in AASHTO LRFD Article 3.4.1
- P_L = live load pressure (LL) with dynamic load allowance (psi)
- C_L = live load distribution coefficient
 = the lesser of $\frac{L_w}{OD}$ or 1.0 For Highway Loads. 1.16 for E-80 Loads
- ϕ_T = resistance factor for thrust effects, value is 1.0 per AASHTO LRFD, Section 12

Note: P_L = live load pressure (LL), was converted from values found in AREMA Table 1-4-24, Live Load Pressure for Cooper E-80.

4.21.1.6 GENERAL BUCKLING STRAIN LIMITS

Critical Buckling Strain Evaluation

$$\text{If } (\varepsilon_{uc} \leq \phi_{bck} \varepsilon_{bck}) = O.K. \quad (12.12.3.10.1e-1)$$

$$R_h = \frac{11.4}{11 + \frac{D}{12H}} = \frac{11.4}{11 + \frac{25.51''}{12(5')}} = 1.0 \quad (12.12.3.10.1e-2)$$

$$\varepsilon_{bck} = \frac{1.2 C_n (E_p I_p)^{\frac{1}{3}}}{A_{eff} E_p} \left(\frac{\phi_s M_s (1 - 2\nu)}{(1 - \nu)^2} \right)^{\frac{2}{3}} R_h \quad (12.12.3.10.1e-3)$$

$$\varepsilon_{bck} = \frac{1.2(0.55) \left[(21000)(0.1331) \right]^{\frac{1}{3}}}{(0.236)(21000)} \left(\frac{(0.9)(1431)(1 - 2(0.4))}{(1 - (0.4))^2} \right)^{\frac{2}{3}} (1.0) = 0.150 \text{ in / in}$$

$$\text{If } (\varepsilon_{uc} \leq \phi_{bck} \varepsilon_{bck}) = 0.0357 \leq (0.7)(0.150) = O.K.$$

Where:

- ϕ_{bck} = resistance factor for global buckling, value is 0.7 per AASHTO LRFD, Section 12
- ϵ_{bck} = nominal strain capacity for general buckling
- C_n = calibration factor to account for nonlinear effects
= 0.55 from AASHTO LRFD, Section 12
- I_p = moment of inertia of pipe profile per unit length of pipe (in.⁴/in.) (Since the unit length of pipe is 1.0 then I_p and I are the same (see 4.21.1.2 for I).
- ν = Poisson's ratio of soil is available in many geotechnical references such as Selig (1990).
- R_n = correction factor for backfill soil geometry

Note: Material properties for buckling should be long term only, see AASHTO LRFD, section 12.12.3.3.

4.21.1.7 BENDING AND THRUST STRAIN

Flexural Strain

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

$$\epsilon_{sc} = \frac{T_s}{A_{eff}E_p} = \left[\frac{(K_2 VAF(P_{sp}) + P_W)}{E_I A_{eff}} + \frac{C_L P_L}{E_s A_{eff}} \right] \left(\frac{D_o}{2} \right) \quad (12.12.3.10.1c-2)$$

$$\epsilon_{sc} = \left[\frac{((1.0)(0.6)(3.93) + 1.08)}{(21000)(0.236)} + \frac{(1.16)(16.67)}{(110000)(0.236)} \right] \frac{27.7}{2} = 0.02$$

$$\Delta_f = 0.05(24") - (0.02)(25.51") = 0.7in$$

Assumes Deflection Limit of 5%, Nominal Pipe Diameter Used.

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

$$\epsilon_f = (1.3)(5.6) \left(\frac{1.073"}{12.76"} \right) \left(\frac{0.7"}{25.51"} \right) = 0.017in/in$$

Where:

- D = diameter to centroid of pipe profile (in.)
- Δ_f = reduction of vertical diameter due to flexure (in.)

- Δ_A = total allowable deflection of pipe, reduction of vertical diameter (in.)
- ϵ_{sc} = service compressive strain due to thrust, as specified in AASHTO LRFD Article 12.12.3.10.1c and taken as positive for compression
- T_s = service thrust per unit length (lb/in.) AASHTO LRFD Eq. 12.12.2.2-4
- P_s = design service load (psi) AASHTO LRFD Eq. 12.12.3.5-2 (used in T_s calculation)
- ϵ_f = factored strain due to flexure
- c = the larger of the distance from neutral axis of profile to the extreme inner most or outer most fiber (in.)
- D_f = shape factor as specified in AASHTO LRFD 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.

4.21.1.8 COMBINED STRAIN

a. Factored Combined

Compressive Strain

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

$$\epsilon_f + \epsilon_{uc} = 0.017 + 0.0357 = 0.052 \text{ in/in}$$

b. Limiting Combined Compressive Strain

$$\phi_T (1.5 \epsilon_{yc}) = (1.0)(1.5)(0.041) = 0.062 \text{ in/in}$$

$$0.052 \text{ in/in} < 0.062 \text{ in/in} = O.K.$$

c. Factored Combined Tension Strain

$$\epsilon_f - \epsilon_{uc} < \phi_f \epsilon_{yt} \quad (12.12.3.10.2b-1)$$

$$\epsilon_f - \epsilon_{uc} = 0.017 - 0.0357 = -0.019 \text{ in/in}$$

Where:

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

d. Limiting Combined Tension Strain

$$\phi_f \epsilon_{yt} = (1.0)(0.05) = \pm 0.028 \text{ in/in}$$

$$-0.019 \text{ in/in} < -0.028 \text{ in/in} = O.K.$$

4.21.1.9 FLEXIBILITY FACTOR

$$FF = \frac{S^2}{EI} = \frac{24^2}{(110000 \text{ psi})(0.133 \text{ in}^4 / \text{in})} = 0.040 \text{ in} / \text{lb.} \quad (12.12.3.6 - 1)$$

$$0.040 \text{ in} / \text{lb.} < 0.095 \text{ in} / \text{lb.} = O.K.$$

Where:

FF = flexibility factor (in./lb.)

S = diameter of pipe (in.)

E = initial modulus of elasticity (psi)

I = moment of inertial (in.⁴/in.) (see 4.21.1.2 for I)

4.21.1.10 CALCULATED DEFLECTION

$$\Delta_t = \left[\frac{K_B(D_L P_{sp} + C_L P_L)D_o}{\frac{E_p I_p}{R^3} + 0.061 M_s} \right] + \epsilon_{sc} D = \left[\frac{D_L K_B P_{sp}(D_o)}{\frac{E_p I_p}{R^3} + 0.061 M_s} \right] + \left[\frac{C_L P_L K_B(D_o)}{\frac{E_s I_p}{R^3} + 0.061 M_s} \right] + \epsilon_{sc} D \quad (12.12.2.2 - 2)$$

$$\Delta_t = \left[\frac{(1.5)(0.1)(3.93)(27.7)}{\frac{(21000)(0.1331)}{12.76^3} + 0.061(1431)} \right] + \left[\frac{(1.16)(16.67)(0.1)(27.7)}{\frac{(110000)(0.1331)}{12.76^3} + 0.061(1431)} \right] + (0.02)(25.51)$$

$$\Delta_t = 1.26 \text{ in} = 4.94\%$$

Where:

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

K_B = bedding coefficient, a value of 0.1 is typical, AASHTO LRFD, section 12, page 104

D_L = deflection lag factor, a value of 1.5 is typical, AASHTO LRFD, section 12, page 104

4.21.1.11 RESULTS REVIEW

- 4.21.1.1 INTRODUCTION – Brief explanation of why we are using AASHTO's LRFD Design Methodology.
- 4.21.1.2 APPLICATION SPECIFIC DESIGN INPUT – Site and Manufacturer specific product data determined.

3. 4.21.1.3 DEAD LOADS (DL) – Long-term loading conditions calculated.
4. 4.21.1.4 RESISTANCE TO AXIAL THRUST – Pipe properties specific to profile and resistance factors determined. Live loads incorporated into design.
5. 4.21.1.5 THRUST STRAIN LIMITS: To ensure the pipe wall section doesn't fail in thrust, the factored compressive strain must be less than or equal to the pipe's thrust strain limit. The design example shows that the factored compressive strain is less than the thrust strain limit, which means that the pipe wall will not crush under the designated loading conditions.
6. 4.21.1.6 BENDING AND THRUST STRAIN – To ensure the pipe wall will not buckle, the critical buckling strain must be less than or equal to the general buckling strain limit. The design example shows that the critical buckling strain was less than the general buckling strain limit, which means the pipe wall will not buckle.
7. 4.21.1.7 COMBINED STRAIN – To ensure the pipe wall doesn't excessively bend as a result of compression or does not yield in tension, the combined compressive strain and combined tension strain are reviewed. To account for variability in site conditions factors are applied to these values. The factored combined compressive strain must be less than the limiting combined compressive strain and the factored combined tension strain must be less than the limiting combined tension strain. The design example shows that both the factored combined compressive strain and factored combined tension strain are less than the limiting strain values.
8. 4.21.1.8 FLEXIBILITY FACTOR – To ensure the pipe will adequately perform during installation. The Flexibility Factor is checked. In this example the calculated flexibility factor less than the designated value.
9. 4.21.1.9 CALCULATED DEFLECTION – To verify the pipe doesn't excessively deflect, and maintains a shape that allows the LRFD design equations to function properly, deflection calculated and checked. Provided the pipe deflects less than 5%, it will meet all LRFD requirements. In some cases, deflection may extend up to 7.5% before pipe repair or removal is recommended. However, when pipes are between 5.0% and 7.5% additional evaluation should be done on the system to ensure all design criteria are met. The design example shows that the calculated deflection is less than 5.0%.

Not Yet Approved