SECTION 18 - SOIL-THERMOPLASTIC PIPE INTERACTION SYSTEMS

18.1 GENERAL

18.1.1 Scope

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

18.1.2 Notations

A = area of pipe wall in square inches/foot (Article 18.3.1)
B = water buoyancy factor (Article 18.3.2)
c = distance from inside surface to neutral axis (Articles 18.3.2 and 18.4.2)
D_e = effective diameter = $ID + 2c$
E = modulus of elasticity of pipe material (Articles 18.2.2 and 18.3.2)
FF = flexibility factor (Article 18.3.3)
f_{cr} = critical buckling stress (Article 18.3.2)
f_u = specified minimum tensile strength (Articles 18.3.1 and 18.3.2)
I = average moment of inertia, per unit length, of cross section of the pipe wall (Articles 18.3.2 and 18.3.3)
ID = inside diameter (Articles 18.3.2 and 18.4.2)
M_s = soil modulus (Article 18.3.2)
OD = outside diameter (Article 18.4.2)
P = design load (Article 18.1.4)
T = thrust (Article 18.1.4)
T_L = thrust, load factor (Article 18.3.1)
ϕ = capacity modification factor (Article 18.3.1)

18.1.3 Loads

Design load, P, shall be the pressure acting on the structure. For earth pressures see Article 6.2. For live load see Articles 3.4 to 3.7, 3.11, 3.12 and 6.3. For loading combinations see Article 3.22.

18.1.4 Design

18.1.4.1 The thrust in the wall shall be checked by two criteria. Each considers the mutual function of the plastic wall and the soil envelope surrounding it. The criteria are:

(a) Wall area
(b) Buckling stress

18.1.4.2 The thrust in the wall is:

$$T = P \times \frac{D}{2} \tag{18-1}$$

where:
P = design load, in pounds per square foot;
D = diameter in feet;
T = thrust, in pounds per foot.

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

18.1.5 Materials

The materials shall conform to the AASHTO and ASTM specifications referenced herein.

18.1.6 Soil Design

18.1.6.1 Soil Parameters

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

The following must be considered:

(a) Soils:
(1) The type and anticipated behavior of the foundation soil must be considered; i.e., stability for bedding and settlement under load.

(2) The type, compacted density and strength properties of the envelope immediately adjacent to the pipe must be established.

Good side fill is obtained from a granular material with little or no plasticity and free of organic material, i.e., Caltrans structure backfill compacted to a relative compaction of not less than 95%.

(3) The density of the embankment material above the pipe must be determined. A minimum of 90% shall be specified.

(b) Dimensions of envelope

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

(1) Trench installations – 2 feet minimum each side of culvert. This recommended limit should be modified as necessary to account for variables such as poor in-situ soils.

(2) Embankment installations – the minimum width of the soil envelope shall be sufficient to ensure lateral restraint for the buried structure. The combined width of the soil envelope and embankment beyond shall be adequate to support all the loads on the pipe. As a guide, the width of the soil envelope on each side of the pipe should be 2.0 ft minimum.

(3) The minimum upper limit of the soil envelope is 2 feet above the culvert.

18.1.7 Abrasive or Corrosive Conditions

Extra thickness may be required for resistance to abrasion. For highly abrasive conditions, a special design may be required.

18.1.8 Minimum Spacing

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

18.1.9 End Treatment

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

18.1.10 *Deleted*

18.2 SERVICE LOAD DESIGN

Service Load Design method shall not be used.

18.3 LOAD FACTOR DESIGN

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

18.3.1 Wall Area

$$A = T_L/\phi f_u$$

where:

A = required area of pipe wall in square inches per foot;

T_L = thrust, load factor in pounds per foot;

f_u = specified minimum tensile strength in pounds per square inch;

ϕ = capacity modification factor.

18.3.2 Buckling

If f_{cr} is less than f_u, A must be recalculated using f_{cr} in lieu of f_u. The formula for buckling is:

$$f_{cr} = 9.24(R/A)\sqrt{BM_s EI/0.149R^3}$$

where:

B = water buoyancy factor or
= $1\text{-}0.33h_w/h$;

h_w = height of water surface above top of pipe;

h = height of ground surface above top of pipe;

E = Long term (50 year) modulus of elasticity of the plastic in pounds per square inch;

M_s = soil modulus in pounds per square inch;
= 1,700 for side fills meeting Article 18.1.6;

f_{cr} = critical buckling stress in pounds per square inch;

R = effective radius in inches;
= $c + ID/2$;

A = actual area of pipe wall in square inches/foot.

18.3.3 Handling and Installation Strength

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

$$FF = D_e^2 / EI$$

where:
FF = flexibility factor in inches per pound;
D_e = effective diameter in inches;
E = initial modulus of elasticity of the pipe material in pounds per square inch;
I = average moment of inertia per unit length of cross section of the pipe wall in inches to the 4th power per inch.

18.4 PLASTIC PIPE

18.4.1 General

18.4.1.1 Plastic pipe may be smooth wall, corrugated or externally ribbed and may be manufactured of polyethylene (PE) or poly (vinyl chloride) (PVC). The material specifications are:

Polyethylene (PE)

Corrugated	AASHTO M 294 Corrugated Polyethylene Pipe, 12 to 36 in. Diameter
Ribbed	ASTM 894 Polyethylene (PE) Large Diameter Profile Wall Sewer and Drain Pipe

Poly (Vinyl Chloride) (PVC)

Profile Wall (Ribbed)	AASHTO M 304 Poly (Vinyl Chloride) (PVC) Ribbed Drain Pipe and Fittings and Based on Controlled Inside Diameter

18.4.1.2 *Deleted*

18.4.1.3 Load Factor Design – Capacity modification Factor, ϕ:

PE, $\phi = 0.9$
PVC, $\phi = 0.9$

18.4.1.4 Flexibility Factor:

PE, $FF = 9.5 \times 10^{-2}$
PVC, $FF = 9.5 \times 10^{-2}$

Note: PE and PVC are thermoplastics and, therefore, subject to reduction in stiffness as temperature is increased.

18.4.1.5 Minimum Cover

The minimum cover for design loads shall be 2 feet.

18.4.1.6 Maximum Strain

The allowable deflection of installed plastic pipe may be limited by the extreme fiber tensile strain of the pipe wall. Calculation of the tension strain in a pipe significantly deflected after installment can be checked against the allowable long-term strain for the material in Article 18.4.3. Compression thrust is deducted from deflection bending stress to obtain net tension action. The allowable long-term strains shown in Article 18.4.3 should not be reached in pipes designed and constructed in accordance with this specification.

18.4.1.7 Local Buckling

The manufacturers of corrugated and ribbed pipe should demonstrate the adequacy of their pipes against local buckling when designed and constructed in accordance with this specification.

18.4.2 Section Properties

The values given in the following tables are limiting values and do not describe actual PE or PVC pipe products. Section properties for specific PE or PVC pipe products are available from individual pipe manufacturers and can be compared against the following values for compliance.

18.4.2.1 PE Corrugated Pipes (AASHTO M 294)

Nominal Size (in.)	Min. I.D. (in.)	Max. O.D. (in.)	Min. A (in.^{2}/ft.)	Min. C (in.)	Min. I (in.^{4}/in.)
12	11.8	14.7	1.50	0.35	0.024
15	14.8	18.0	1.91	0.45	0.053
18	17.7	21.5	2.34	0.50	0.062
24	23.6	28.7	3.14	0.65	0.116
30	29.5	36.4	3.92	0.75	0.163
36	35.5	42.5	4.50	0.90	0.222

18.4.2.2 PE Ribbed Pipes (ASTM F 894)

					Min. I (in.^{4}/in.)	
Nominal Size (in.)	Min. I.D. (in.)	Max. O.D. (in.)	Min. A (in.^{2}/ft)	Min. C (in.)	Cell Class 334433C	Cell Class 335434C
18	17.8	21.0	2.96	0.344	0.052	0.038
21	20.8	24.2	4.15	0.409	0.070	0.051
24	23.8	27.2	4.66	0.429	0.081	0.059
27	26.75	30.3	5.91	0.520	0.125	0.091
30	29.75	33.5	5.91	0.520	0.125	0.091
33	32.75	37.2	6.99	0.594	0.161	0.132
36	35.75	40.3	8.08	0.640	0.202	0.165
42	41.75	47.1	7.81	0.714	0.277	0.227
48	41.75	53.1	8.82	0.786	0.338	0.227

18.4.2.3 Profile Wall (Ribbed) PVC Pipes (AASHTO M 304)

					Min. I (in.^{4}/in.)	
Nominal Size (in.)	Min. I.D. (in.)	Max. O.D. (in.)	Min. A (in.^{2}/ft)	Min. C (in.)	Cell Class 12454C	Cell Class 12364C
12	11.7	13.6	1.20	0.15	0.004	0.003
15	14.3	16.5	1.30	0.17	0.006	0.005
18	17.5	20.0	1.60	0.18	0.009	0.008
21	20.6	23.0	1.80	0.21	0.012	0.011
24	23.4	26.0	1.95	0.23	0.016	0.015
30	29.4	32.8	2.30	0.27	0.024	0.020
36	35.3	39.5	2.60	0.31	0.035	0.031
42	41.3	46.0	2.90	0.34	0.047	0.043
48	47.3	52.0	3.16	0.37	0.061	0.056

18.4.3 Chemical and Mechanical Requirements

The polyethylene (PE) and poly (vinyl chloride) (PVC) materials described herein have stress/strain relationships that are nonlinear and time dependent. Minimum 50-year tensile strengths are derived from hydrostatic design bases and indicate a minimum 50-year life expectancy under continuous application of that tensile stress. Minimum 50-year moduli do not indicate a softening of the pipe material but is an expression of the time dependent relation between stress and strain. For each short-term increment of deflection, whenever it occurs, the response will reflect the initial modulus. Both short-term and long-term properties are shown. Except for buckling for which long-term properties are required, the judgement of the Engineer shall determine which is appropriate for the application. Initial and long-term relate to conditions of loading, not age of the installation. Response to live loads will reflect the initial modulus, regardless of the age of the installation.

18.4.3.1 Polyethylene

18.4.3.1.1 Deleted

18.4.3.1.2 Corrugated PE pipe requirements – AASHTO M 294:

Mechanical Properties for Design

Initial		50-Year	
Minimum Tensile Strength (psi)	Minimum Mod. of Elast. (psi)	Minimum Tensile Strength (psi)	Minimum Mod. of Elast. (psi)
3,000	110,000	900	22,000

Minimum cell class, ASTM D 3350, 335420C

Allowable long-term strain = 5%

18.4.3.1.3 Ribbed PE pipe requirements – ASTM F 894:

Mechanical Properties for Design

Initial		50-Year	
Minimum Tensile Strength (psi)	Minimum Mod. of Elast. (psi)	Minimum Tensile Strength (psi)	Minimum Mod. of Elast. (psi)
3,000	80,000	1,125	20,000

Minimum cell class, ASTM D 3350, 334433C
Allowable long-term strain = 5%

OR:

Initial		50-Year	
Minimum Tensile Strength (psi)	Minimum Mod. of Elast. (psi)	Minimum Tensile Strength (psi)	Minimum Mod. of Elast. (psi)
3,000	110,000	1,440	22,000

Minimum cell class, ASTM D 3350, 335434C
Allowable long-term strain = 5%

18.4.3.2 Poly (Vinyl Chloride) (PVC)

18.4.3.2.1 Deleted

18.4.3.2.2 Profile Wall (Ribbed) PVC pipe requirements – AASHTO M 304

Mechanical Properties for Design

Initial		50-Year	
Minimum Tensile Strength (psi)	Minimum Mod. of Elast. (psi)	Minimum Tensile Strength (psi)	Minimum Mod. of Elast. (psi)
7,000	400,000	3,700	140,000

Minimum cell class, ASTM D 1784, 12454C
Allowable long-term strain = 5%

OR:

Initial		50-Year	
Minimum Tensile Strength (psi)	Minimum Mod. of Elast. (psi)	Minimum Tensile Strength (psi)	Minimum Mod. of Elast. (psi)
6,000	440,000	2,600	158,400

Minimum cell class, ASTM D 1784, 12364C
Allowable long-term strain = 3.5%