APPENDIX 4

SERVICE LOAD DESIGN

Seven basic steps are required for the structural design of all buried corrugated metal conduits. Each considers the mutual function of the metal ring and the soil envelope surrounding it; interaction of these two materials produces a composite structure.

These steps are:

(A) Determine the design load.
(B) Calculate thrust in the pipe wall.
(C) Select the required wall configuration.
(D) Check the buckling stress.
(E) Check handling and installation strength.
(F) Check seam strength if pipe has longitudinal riveted, welded or bolted seams.
(G) Check deflection of flattening

(A) Loads

Design load is the vertical pressure acting at the crown of the structure. The live load (LL) pressure is determine from Table III-1.

TABLE III-1 HIGHWAY LIVE LOADS

Highway H 20 Loading*	
Height of Cover (Ft)	Load, psf
1	1800
2	800
3	600
4	400
5	250
6	200
7	175
8	100

*Neglect live load when less than 100 psf; use dead load only.

The dead load is determined as follows:

$DL = H \times W$

where:

H = Fill Height (ft.)
W = Unit Weight of Soil = 120 lb/CF

(B) Wall Thrust

Thrust (T) or compression in the pipe wall in pounds per lineal foot (N/m) of structure is:

$$T = (LL + DL) \times \frac{D}{2}$$

where:

LL & DL are as defined above
D is the diameter or span of the pipe in feet

(C) Required Wall

Compressive stress in the pipe wall shall not exceed 50 percent of its yield strength. Area required in pipe wall is:

$$A = \frac{T(SF)}{f_y}$$

Where A = area of pipe wall in square inches per foot (m^2/m) of pipe. See Table III-3

SF = Safety factor = 2.
f_y = Yield strength of metal in psi (MPa) See Table III-2

TABLE III-2

CHEMICAL AND MECHANICAL REQUIREMENTS

(A) ALUMINUM - Corrugated Metal Pipe and Pipe-arch
Chemical - AASHTO M 197 (ASTM B 209)

Mechanical

Thickness, in. (m)	Minimum Tensile Strength psi (MPa)	Minimum Yield Strength psi (MPa)	Minimum Elongation in 2 inches (.051m)	Mod. of Elast. psi (MPa)
0.051 to 0.113 (0.013 to 0.003)	31,000 (213.737)	24,000 (165,474)	4%	$10x10^6$ (68947)
0.114 to 0.249 (.003 to .006)	31,000 (213.737)	24,000 (165,474)	5%	$10x10^6$ (68947)

(B) ALUMINUM - Structural plate pipe and pipe-arch
Chemical - AASHTO M 219, Alloy 5052

Mechanical

Thickness, in. (m)	Minimum Tensile Strength psi (MPa)	Minimum Yield Strength psi (MPa)	Minimum Elongation in 2 inches (0.051m)	Mod. of Elast. psi (MPa)
0.090 to 0.175 (0.002 to 0.004)	35,500 (244.763)	24,000 (165,474)	6%	$10x10^6$ (68947)
0.175 to 0.250 (0.004 to 0.006)	34,000 (234.421)	24,000 (165.474)	8%	$10x10^6$ (68947)

(C) STEEL - Corrugated Metal Pipe and Pipe-arch
Chemical - AASHTO M 218 (ASTM A 444)

Mechanical

Minimum Tensile Strength, psi (MPa)	Minimum Yield Strength, psi (MPa)	Minimum Elongation in 2 inches (0.51m)	Mod. of Elast. psi (MPa)
45,000 (310.264)	33,000 (227.527)	20%	$29x10^6$ (199948)

(D) STEEL - Structural Plate Pipe and Pipe-arch
Chemical - AASHTO M 167

Mechanical

Minimum Tensile Strength, psi (MPa)	Minimum Yield Strength psi (MPa)	Minimum Elongation in 2 inches (.051m)	Mod. of Elast. psi (MPa)
42,000 (289.579)	28,000 (193.053)	30%	$29x10^6$ (199948)

TABLE III-3A

SECTIONAL PROPERTIES OF CORRUGATED STEEL SHEETS
Per Foot of Section Width for Corrugation: 2 2/3 x 1/2 in. (Annular or Helical)
Radius of Curvature: 11/16 in.

Specified Thickness In.	Uncoated Thickness T In.	Area of Section A Sq.In./Ft.	Tangent Length TL In.	Tangent Angle Degrees	Moment of Inertia I* $In.^4/Ft.$	Section Modulus S $In.^3/Ft.$	Radius of Gyration r In.
0.040	0.0359	0.465	0.785	26.56	0.0135	0.0503	0.1702
0.052	0.0478	0.619	0.778	26.65	0.0180	0.0659	0.1707
0.064	0.0598	0.775	0.770	26.74	0.0227	0.0812	0.1712
0.079	0.0747	0.968	0.760	26.86	0.0287	0.0998	0.1721
0.109	0.1046	1.356	0.740	27.11	0.0411	0.1360	0.1741
0.138	0.1345	1.744	0.720	27.37	0.0544	0.1714	0.1766
0.168	0.1644	2.133	0.699	27.65	0.0687	0.2069	0.1795

TABLE III - 3B

SECTIONAL PROPERTIES OF CORRUGATED STEEL SHEETS
Per Foot of Section Width for Corrugation: 3 x 1 in. (Annular or Helical)
Radius of Curvature: 9/16 in.

Specified Thickness In.	Uncoated Thickness T In.	Area of Section A Sq.In./Ft	Tangent Length TL In.	Tangent Angle Degrees	Moment of Inertia I* $In.^4/Ft.$	Section Modulus S $In.^3/Ft.$	Radius of Gyration r In.
0.040	0.0359	0.534	0.963	44.19	0.0618	0.1194	0.3403
0.052	0.0478	0.711	0.951	44.39	0.0827	0.1578	0.3410
0.064	0.0598	0.890	0.938	44.60	0.1039	0.1961	0.3417
0.079	0.0747	1.113	0.922	44.87	0.1306	0.2431	0.3427
0.109	0.1046	1.560	0.889	45.42	0.1855	0.3358	0.3448
0.138	0.1345	2.008	0.855	46.02	0.2421	0.4269	0.3472
0.168	0.1644	2.458	0.819	46.65	0.3010	0.5170	0.3499

* For use in formulas divide by 12 to convert units to In^4/In

TABLE III - 3C

SECTIONAL PROPERTIES OF CORRUGATED STEEL PLATES
Per Foot of Section Width for Corrugation: 6 x 2 in.
Radius of Curvature: 1 1/8 in.

Specified Thickness In.	Uncoated Thickness T In.	Area of Section A Sq.In./Ft	Tangent Length TL In.	Tangent Angle Degrees	Moment of Inertia I* $In.^4/Ft.$	Section Modulus S $In.^3/Ft.$	Radius of Gyration r In.
0.109	0.1046	1.556	1.893	44.47	0.725	0.689	0.682
0.138	0.1345	2.003	1.861	44.73	0.938	0.879	0.684
0.168	0.1644	2.449	1.828	45.00	1.154	1.066	0.686
0.188	0.1838	2.739	1.807	45.18	1.296	1.187	0.688
0.218	0.2145	3.199	1.773	45.47	1.523	1.376	0.690
0.249	0.2451	3.658	1.738	45.77	1.754	1.562	0.692
0.280	0.2758	4.119	1.702	46.09	1.990	1.749	0.695

(D) Buckling

Corrugations with required area, A, shall be checked for possible buckling. If buckling stress, f_c, is less than yield stress, f_y, required area must be recalculated using f_c in lieu of f_y. Formulae for buckling are:

$$\text{If } D < \frac{r}{k}\,\frac{24E}{f_u}, \text{ then } f_c = f_u - \frac{f_u^2}{48E}\left(\frac{kD}{r}\right)^2$$

$$\text{If } D < \frac{r}{k}\,\frac{24E}{f_u}, \text{ then } f_c = 12E \Big/ \left(\frac{kD}{r}\right)^2$$

where

f_u = minimum tensile strength, psi (MPa)
f_c = critical stress, psi (MPa)
k = soil stiffness factor
D = pipe diameter or span, in. (m)
r = radius of gyration (corrugation) in.
E = modulus of elasicity, psi (MPa)

k = 0.22, soil stiffness coefficient for good side fill material compacted to 90 percent of standard density based on AASHTO T 99.

(E) Handling and Installation Strength

Handling and installation strength must be sufficient to withstand impact forces associated with shipping and placing of pipe. Both shop and field assembled pipe must have strength adequate to withstand compaction of the backfill without interior bracing to maintain pipe shape.

Handling rigidity is measured by a Flexibility Factor determined by the formula:

$$FF = D^2/EI$$

where

D = pipe diameter or maximum span, inches (m)
E = modulus of elasticity of the pipe material, psi (MPa)
I = moment of inertia per unit length of cross section of the pipe wall, inches to the 4th power per inch (m^4/m)

Limiting values of FF are listed in Table III-4.

TABLE III - 4

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

2" x 1/2"	(50.8 x 12.7)	corrugation FF = 4.3×10^{-2}
2 2/3" x 1/2"	(67.8 x 12.7)	corrugation FF = 4.3×10^{-2}
3" x 1"	(76.2 x 25.4)	corrugation FF = 3.3×10^{-2}
6" x 2"	(152.4 x 50.8)	corrugation FF = 2.0×10^{-2}
6" x 2"	(152.4 x 50.8)	corrugation pipe arch FF = 3.0×10^{-2}

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

2" x 1/2"	(50.8 x 12.7)	corrugation FF = 9.5×10^{-2}
2 2/3" x 1/2"	(67.8 x 12.7)	corrugation FF = 9.5×10^{-2}
9" x 2 1/2"	(228.6 x 63.5)	corrugation FF = 2.5×10^{-2}
3" x 1"	(76.2 x 25.4)	corrugation FF = 6×10^{-2}
9" x 2 1/2"	(288.6 x 63.5)	corrugation pipe arch FF = 3.6×10^{-2}
6" x 1"	(152.4 x 25.4)	corrugation FF = 6×10^{-2}

(F) Longitudinal Seam Strength

For pipe fabricated with longitudinal seams, the seam strength shall be sufficient to develop the thrust in the pipe wall. The required seam strength shall be:

$$SS = T(SF)$$

Where SS = required seam strength in pounds per foot (N/m) of pipe.
T = thrust in pipe wall (see paragraph B)
SF = safety factor = 3

(G) Deflection or Flattening

The Iowa Deflection Formula provides one approach to prediction of ring deflection. It relates ring deflection to the passive side pressure resisting horizontal movement of the pipe wall and to the inherent strength of the pipe. Pipe arches need not be checked for deflection.

The Iowa Deflection Formula is:

$$X = D_1 \frac{KW_cR^3}{EI + 0.061\ E'R^3}$$

where

X = horizontal deflection of the pipe, in. (m) not to exceed 5% D
D_1 = deflection lag factor 1.25 for E' = 1400 p.s.i.
K = a bedding constant (depends on bedding angle) 0.1
W_c = vertical load per unit length of pipe, lb/lin in. (N/lin. m)
R = mean radius of pipe, in. (m)
E = modulus of elasticity of pipe, psi (Pa) see Table III-2
I = moment of inertia per unit length of cross section of pipe wall, inches to the fourth power per inch (m^4/m) See Table III-3
E' = horizontal soil modulus, psi/in. (Pa/m) (side fill) resistance: 1400 psi or (9.653 MPa)

TABLE III - 5

Minimum Longitudinal Seam Strengths (Ultimate strength in kips per foot) (k N/m)
Pipe sizes are in inches except where otherwise noted

2 x 1/2 (50.8 x 12.7) and 2-2/3 x 1/2 (67.8 x 12.7mm) Corrugated Steel Pipe						3 x 1 (76.2 x 25.4 mm) Corrugated Steel Pipe			
Thickness		Single Rivets		Double Rivets*		Thickness		Double Rivets*	
In.	(mm)	k/ft.	k N/m	k/ft.	k N/m	In.	(mm)	k/ft	k N/m
0.064	(1.63)	16.7	(244)	21.6	(315)	0.064	(1.63)	28.7	(419)
0.079	(2.01)	18.2	(266)	29.8	(435)	0.079	(2.01)	35.7	(521)
0.109	(2.77)	23.4	(342)	46.8	(685)	0.109	(2.77)	53.0	(773)
0.138	(3.51)	24.5	(358)	49.0	(715)	0.138	(3.51)	63.7	(930)
0.168	(4.27)	25.6	(374)	51.3	(748)	0.168	(4.27)	70.7	(1033)

6 x 2 (152.4 x 50.8 mm) Structural Plate Steel Pipe							
Thickness		4 Bolts/		6 Bolts	(19-3/4	8 Bolts	(26-1/4
in.	(mm)	ft.	(13 bolts/m)	/ft.	bolts/m)	/ft.	bolts m)
0.109	(2.77)	42.0	(613)				
0.138	(3.51)	62.0	(905)				
0.168	(4.27)	81.0	(1182)				
0.188	(4.78)	93.0	(1360)				
0.218	(5.54)	112.0	(1635)				
0.249	(6.32)	132.0	(1930)				
0.280	(7.11)	144.0	(2102)	180	(2628)	194	(2832)

2 1/2 and 2-2/3 x 1/2 (50.8 x 12.7 and 67.8 x 12.7 mm) Corrugated Aluminum Pipe					
Thickness		Single Rivets		Double Rivets*	
in.	(mm)	k/ft.	k N/m	k/ft.	k N/m
0.060	(1.5)	9.0	(131)	14.0	(204)
0.075	(1.9)	9.0	(131)	18.0	(263)
0.105	(2.7)	15.6	(228)	31.5	(460)
0.135	(3.4)	16.2	(236)	33.0	(482)
0.164	(4.2)	16.8	(245)	34.0	(496)

9 x 2-1/2 (228.6 x 63.5mm) Structural Plate Aluminum Pipe					
		Aluminum Bolts		Steel Bolts	
Thickness		5-1/3		5-1/3	
in.	(mm)	Bolts per ft	(17-1/2 Bolts/m)	Bolts per ft	(17/1/2 Bolts/m)
0.09	(2.29)	22.2	(324)		
0.10	(2.54)	26.4	(385)		
0.125	(3.18)	34.8	(507)		
0.15	(3.81)	44.4	(647)		
0.175	(4.45)	52.8	(770)		
0.20	(5.08)			60.0	(875)
0.225	(5.72)			66.0	(962)
0.250	(6.35)			72.0	(1050)

3 x 1 (76.2 x 25.4 mm) Corrugated Aluminum Pipe			
Thickness		Double Rivets*	
In.	(mm)	k/ft.	k N/m
0.060	(1.5)	16.5	(239)
0.075	(1.9)	20.5	(297)
0.105	(2.7)	28.0	(406)
0.135	(3.4)	42.0	(608)
0.164	(4.2)	54.5	(790)

6" x 1"** (152.4 x 25.4 mm) Corrugated Aluminum Pipe			
Thickness		Double Rivets*	
in.	(mm)	k/ft.	(k N/m)
0.060	(1.5)	16.0	(232)
0.075	(1.9)	19.9	(288)
0.105	(2.7)	27.9	(405)
0.135	(3.4)	35.9	(520)
0.164	(4.3)	43.5	(631)

* Pipes of 42" (1.067m) or larger diameter require double rivets.

** 6" x 1" (152.4 x 25.4mm) Aluminum Pipe shall be limited to riveted fabrication only. Helical corrugated pipe shall not be designed using this corrugation.