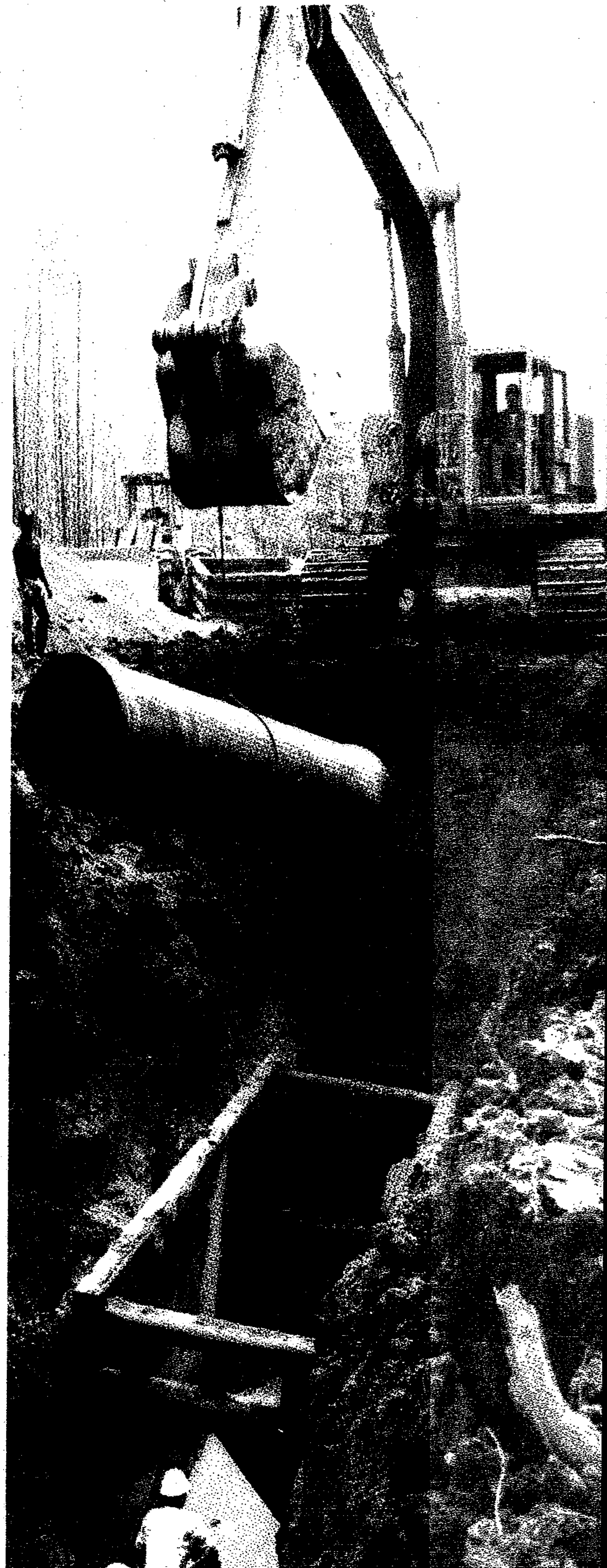


PERFORMANCE EVALUATION OF FLEXIBLE METAL PIPES FOR GRAVITY FLOW APPLICATIONS

DESIGN ISSUES

FINAL REPORT
Prepared By

Omar Chaallal, Ph.D., P.E.
Mohsen Shahawy, Ph.D., P.E.
William Nickas, P.E.

FDOT
Structures Research Center
2007 E. Paul Dirac Drive
Tallahassee, FL 32310

April 2000

EXECUTIVE SUMMARY

The main objective of this research study was to evaluate the performance limits of flexible metal pipes; with particular emphasis on structural design including deflection, and service life expectancy. Specific objectives were set as follows:

(a) Review the relevant technical documents gathered on the subject;

(b) Review AASHTO code requirements and DOT's practice regarding design of metal pipes;

(c) Analyze and evaluate the current design requirements in terms of wall area, allowable deformations and strains, buckling, seam failure, and installation; and

(d) Provide recommendations for appropriate application of flexible metal pipes as gravity flow conduits.

The study reviewed in addition to relevant standards and code, numerous publications and reports on the subject, including the industry proposal to relax the FDOT deflection requirements.

The review and analysis of documents indicated that, although in current practice the design of flexible metal pipes is generally based on deflection limitation, it should consider other possible performance factors that might control the design and their effects on the overall behavior of flexible metal buried pipes.

The review also indicated that the AASHTO Standards provide a reasonable basis for design of flexible metal pipe, particularly in view of the excellent field performance for several decades, and the very few cases of failure due to design. However, it presents some shortcomings related to lack of information and guidelines on the following important aspects:

(i) The loads including live loads,

(ii) Shallow installation conditions,

(iii) Vertical deflection limitations,

(iv) Behavior of large diameter pipes,

(v) Durability with relation to service life expectancy,

(vi) Safety factors, and

(vii) Acceptability criteria.

Based on the evaluation of the listed documents and on a literature review, the following preliminary recommendations are offered. The bases of these preliminary recommendations are provided in Chapter 4 - Conclusions and Recommendations. Further testing and verifications are necessary before these recommendations can be implemented.

- The vertical earth load can be conservatively assumed equal to prism load, W_P .

- Live load including impact should be considered for shallow condition that is for covers smaller than 8 feet for HS20 vehicles. Impact effect can be neglected if the cover is higher than 3 feet, or the pipe diameter; whichever is greater. If construction loads are expected to be higher than HS20, then the minimum cover should be increased consequently.

- Verification of thrust resistance should be carried out according to AASHTO (Eqs. 2.2 and 2.3). Resistance to buckling of corrugated: metal pipe should be verified according to AASHTO Specifications. For non-corrugated metal pipe, Eq. (3.14) may be used.

- Seams resistance should be verified as per AASHTO using a resistance factor of 0.67 as recommended by AASHTO LRFD (Table 12.5.5-1).

- Limit on vertical deflection after installation could be increased, after further testing and verifications are made.

- Flexural deflection limits during handling and installation as per AASHTO LRFD (Table 12.5.6.1-1) should be maintained.

- The irregularities of the bedding surface (grade control) should be limited to 1 % of a single section.

- Installation geometry and materials should follow the current AASHTO and ASTM specifications, as conveniently summarized in Fig. 3.16.

- Durability of flexible :metal pipe in relation to service life expectancy should be addressed during the design process. The document prepared by the FDOT and presented in Appendix C, provide a good guidelines. Additionally, Fig. 3.8 as well as the considerations given in section 3.7 can provide some guidance on the required metal thickness for the corrosion allowance per year of service.

- Coordination between the pipe manufacturer and the contractor should be reinforced.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

1.1 Problem Statement

Flexible metal pipes are used as buried underground gravity flow conduits. For road and highway applications, the design of flexible metal pipes is currently based on the AASHTO requirements and DOT's design practice. Recently, the flexible metal pipe industry expressed the need to relax some of the performance limits practiced by DOT agencies, and particularly those related to field deflection limitations. This report presents an evaluation of the current requirements and design practice as well as the industry's proposals and recommends guidelines for appropriate application of these pipes.

1.2 Objectives of the Study

The main objective of this research study was to evaluate the performance limits of flexible metal pipes, with particular emphasis on structural design including deflection, and service life expectancy. Specific objectives were set as follows:

- Review the relevant technical documents gathered on the subject at hand.
- Review AASHTO code requirements and DOT's practice regarding design of metal pipes.
- Analyze and evaluate the current design requirements in terms of wall area, allowable deformations and strains, buckling, seam failure, and installation requirements.
- Provide guidelines for appropriate application of flexible metal pipes as gravity flow conduits.

1.3 List of Documents

Following is a list of relevant technical documents and scientific publications that have been reviewed and analyzed.

A-- LIST OF STANDARDS AND REFERENCE BOOKS

- AASHTO, 1994, LRFD Bridge Design Specification, 1st ed., American association of State Highway Transportation Officials, Washington, D.C. USA.

- AASHTO, 1999, Standard Specification for Corrugated Steel Pipe, Metallic-coated for Sewers and Drains, AASHTO M 36M-98, Interim Edition, American Association of State Highway and Transportation Officials, Washington, D.C. USA.

- AASHTO,1999, Standard Specification for Corrugated Steel Structural Plate, Zinc-coated, for Field-Bolded Pipe, Pipes-Arches, and Arches, AASHTO M 167M-98, Interim Edition, American Association of State Highway and Transportation Officials, Washington, D.C., USA.

- AASHTO, 1999, Standard Specification for Corrugated Aluminum Pipe for Sewers and Drains, AASHTO M196M-92, Interim Edition, American Association of State Highway and Transportation Officials, Washington, D.C., USA.

- AASHTO, 1999, Standard Specification for Corrugated Steel Pipe, Polymer Pre-coated, for Sewers and Drains, AASHTO M 245M-91, Interim Edition, American Association of State Highway and Transportation Officials, Washington, D.C., USA.

- A.I.S.I., 1980, Modern Sewer Design, American Iron and Steel Institute, Washington, D.C. 319 p.

- A.I.S.I., 1984, Handbook of Steel Drainage & Highway Construction Products, American Iron and Steel Institute, Washington, D.C., 413 p.

- ASCE, 1982, Gravity Sanitary Sewer Design and Construction, ASCE Manuals and Reports on Engineering Practice No. 60, WPCF Manual of Practice No. FD-5, ASME New York, NY, 275 p.

- Association Canadienne de Normalisation (Canadian Standards Association), 1982; CAN3G401-M81: Tuyaux en tole ondulee, Norme nationale du Canada, Association Canadienne de Normalisation, Rexdale, Ontario, Canada.

- Moser A.P., 1990, Buried Pipe Design, McGraw-Hill, Inc., New-York, NY, 219 p.

- Tubecon in., 1995, Canalisations et elements prefabriques en baton : Manuel technique, Association quebecoise des fabricants de tuyaux de beton, Longueuil, Quebec, Canada, 154 p;

- Watkins R:K and Anderson L.R., 1999, Structural Mechanics of Buried Pipes, CRC Press, New York, NY, 444 p.

B- LIST OF TECHNICAL PAPERS

- Brown C.B., Green, D.R., and Pawsey; S., 1968, flexible Culverts Under High Fills, Proc. ASCR, Vol. 94, No. ST4, pp. 905-917.

- Bums Q., and Richard, M:; 1964, Attenuation of Stresses for Buried Cylinders, Proc., Symposium of Soil-Structure Interaction, Univ. of Arizona Eng. Research Lab., Tucson, Arizona.

- Garber J.D. et al., 1992, Feasibility of Applying Cathodic Protection to Underground Corrugated Steel Pipe, Transportation Research Record 1371, pp. 154-161

- Hartley, D.J., and Duncan, M.J. , 1987, E' and M_s Variation with Depth, ASCE Journal of Transportation Engineering, Vol. 113, No. 5.

- Havens B.T. et al., 1995, Longitudinal Strength and Stiffness of Corrugated Steel-Pipe, Transportation Research Record N. 1514, pp. 1-9
- Haviland J. E., Bellair P. J., and Morrell, V. D., 1967, Durability of Corrugated Metal Culverts, Report for Dept of Trans., State of New York.
- Katona G. Michael and Akl Y. Adel, 1987, Design of Buried Culverts with Stress-Relieving Joints, Transportation Research Record 1129 pp. 39-54.
- Lester H.G. and Eric T.M., 1998, Service Life of Drainage Pipe NCHRP Synthesis 254, National Cooperative Highway Research Program, Transportation Research Board.
- Luscher U., 1966, Buckling of Soil-Surrounded Tubes, Proc. ASCE, Vol. 92, No. SM6.
- Martson A., and Anderson A.O., (1913), The Theory of Loads on Pipe in Ditches and Tests of Cement and Clay Drain Tile and Sewer Pipe, Bull. No. 31, Eng. Exper. Sta., Iowa State College.
- Martson A. , 1930, The Theory of External Loads on closed conduits in the Light of the Latest Experiments, Bull. No. 96, Eng. Exper. Sta., Iowa State College.
- Meyerhof. G.G. and L.D. Baike, 1963, Strength of Steel Culverts Sheets Bearing against Compacted Sand Backfill, Highway Research Board Proceedings, Vol. 30.
- Nielson F.D., 1967, Modulus of soil Reaction as Determined by the Triaxial Shear Test, Hwy. Res. Record No., 185, pp. 80-90.
- Nielson F.D.,1967, Soil Structure Arching Analysis of Buried Flexible Structures, Hwy. Res. Record No. 185, pp. 36-50.
- Rogers C.D.F. et al., 1995, Structural Performance of Profile-Wall Drainage Pipe Stiffness Requirements Contrasted with Results of Laboratory and Field Tests, Transportation Research Record 1656, pp. 73-79.
- Rogers C.D.F., 1987, The Influence of Surrounding Soil on Flexible Pipe Performance, Transportation Research Record 1129, pp. 1-11.
- Spangler M.G.,1958, A Practical Application of the Imperfect Ditch Method of Construction, Proc. HRB, Vol. 37, pp. 271-277.
- Spangler M.G., 1950, Theory of Loads on Negative Projecting Conduits, Proc. HRB, Vol. 30, pp. 153-161.
- Spangler M.G., 1962, Culverts and Conduits, Foundation Engineering, ed. by G.A. Leonards. McGraw-Hill, p. 997.
- Spangler M.G.,1941, The Structural Design of Flexible Pipe Culverts, Bulletin 153, Iowa Engineering Experiment Station, Ames, Iowa.

- Watkins R.K. and Spangler M.G., 1958, Some Characteristics of the Modulus of Passive Resistance of Soil. A Study in Similitude, Proc. HRB, Vol. 37, pp. 576-583.

- Watkins R.K., 1957, Characteristics of the Modulus of Passive Resistance of Soil, Ph.D. dissertation, Iowa State University.

- Watkins R.K., and A.P. Moser, 1971, Response of Corrugated Steel Pipe to External Soil Pressures, Highway Research Record 373, pp. 88-112.

- Watkins R.K. and Smith A.B., 1967, Ring Deflection of Buried Pipe, Journal AWWA, Vol. 59, No. 3.

C- LIST OF TECHNICAL REPORTS

- Ayles, J.T. and Smith C.C., 1985, Performance Characteristics of Circular Corrugated Steel Pipe Culverts, Technical Report 37, Saskatchewan Highways and Transportation, Regina, Saskatchewan; Canada.

1.4 Organization of the Report

This report contains three sections, in addition to the introduction chapter. Chapter 2 presents the current AASHTO design procedure. Chapter 3 presents the evaluation and discussion of the Standards requirements and practices of DOT agencies. Chapter 4 concludes the study and offers recommendations as well as guidelines for design and service life of buried flexible metal pipes for gravity flow applications. A review of selected papers dealing with the subject problem is provided in Appendix A.

<u>Note to reader</u>: *The symbols of the equations of this report are those used in the original sources.*

2.0 CURRENT CODE DESIGN PROCEDURE

2.1 General

Flexible metal pipes are widely used as buried underground conduits for gravity flow applications. The analysis and design of a flexible metal pipe is essentially a problem of soil-structure interaction where pipe derives its soil-load carrying capacity from its flexibility. A flexible metal pipe must support the soil overburden, the ground water, and the loads applied at the ground surface due to vehicular traffic. The current methodologies for the design of such a structure follow the following general path: 1. Determine the loads acting on the pipe; 2. Design the pipe section and installation to carry the loads. These design methods are based on the AASHTO Standards and are presented in this chapter.

2.2 AASHTO Design Procedure

2.2.1 Loading

The AASHTO code specifies that buried structures should be designed for force effects resulting from the loads applied on such structures. The loads on a buried pipe may be from two primary sources (a) dead loads due to the earth overburden, and (b) live loads due to the traffic passing over the pipe. In addition to the direct load imposed by soil overburden, the flexible metal pipe must also sustain the loads applied on the ground surface. However, the intensity of surface loads is known to decrease with increasing depth. Therefore, the consequence of traffic, or other surface loads, on deeply buried pipes is relatively minor.

2.2.2 Soil Envelope

The performance of a flexible metal pipe is dependent on soil-structure interaction and soil stiffness. The pipe is generally installed in a relatively narrow trench excavated in undisturbed soil. The trench is then filled with well-compacted backfill, referred to as the soil envelope. The AASHTO code gives general recommendations for soil envelope in terms of trench width, embankment installations and soil cover, as described below.

(a) Trench width

The trench width must provide enough space between the pipe and the trench wall to allow for safe and proper compaction of backfill material. As a guide. AASHTO recommends a minimum trench width not less than the greater of the pipe diameter (S) plus 16.0 inches or 1.5 times the pipe diameter plus 12.0 inches. That is:

Trench width / max { (S + 16.0 in) ; (1.5S + 12.0 in))

(b) Embankment installations

The width of the soil envelope must ensure adequate lateral restraint for the pipe. As a guide, AASHTO code recommends that the minimum width of the soil envelope on each side of the buried pipe not be less than the width specified in Table 2.1.

Table 2.1 – Recommended minimum width values of soil envelope (AASHTO)

Pipe Diameter, S (in)	Minimum Envelope Width (ft)
< 24	S/12
24 – 144	2.0
> 144	5.0

(a) Minimum soil cover

The AASHTO code gives also the minimum recommended cover of a well-compacted granular sub-base, taken from the top of rigid pavement or: from the bottom of flexible pavement. AASHTO code recommends that the minimum soil cover for steel and aluminum conduits shall not be less than the one specified in Table 2.2, where S is the diameter of pipe in inches.

Table 2.2 – Minimum soil cover (AASHTO)

TYPE	CONDITION	MINIMUM COVER
Corrugated metal pipe	--	S/8 / 12.0 in.
Spiral rib metal pipe	Steel conduit	S/4 / 12.0 in.
	Aluminum conduit	S/2 / 12.0 in.
	Aluminum conduit where S > 48.0 in.	S/2.75 / 24.0 in.

2.2.3 Design procedure

Design methods are based on performance criteria where performance limits are related to stress, strain, deflection and buckling. Flexible metal pipes, as most structures, are designed so that they will have enough strength and stiffness to adequately resist the applied loads. The AASHTO code requires that flexible metal pipes be investigated at the strength limit state for : (a) wall area of pipe, (b) buckling strength and (c) seam resistance for pipes with longitudinal seams. Consequently, the structural capacity of flexible metal pipes is evaluated on the basis of wall resistance to thrust and wall resistance to buckling. A non-structural requirement is also provided in the form of a limit on maximum pipe flexibility to ensure that the pipe is not damaged by excessive deformation during shipping, handling, or installation.

(a) Wall resistance to thrust

The factored axial resistance, R_n, must be greater or equal to the factored thrust, T_L:

$$R_n / T_L \qquad (2.1)$$

The factored thrust, T_L , per unit length of wall, is taken as:

$$T_L = P_L\left(\frac{S}{24}\right) \qquad (2.2)$$

and the factored axial resistance, R_n, per unit length of wall, without consideration of buckling, is taken as:

$$R_n = \varphi F_y A \tag{2.3}$$

where:

T_L	=	factored thrust per unit length (kip/ft)
S	=	pipe span (in)
P_L	=	factored crown pressure (ksf)
A	=	wall area (in '/ft)
F_y	=	yield strength of metal (ksi)
θ	=	resistance factor

(b) Resistance to buckling

The resistance to buckling is verified using the wall area (A) calculated from the criteria of resistance to thrust by comparing the critical buckling stress (f_{cr}) to the yield strength of metal.

If $S < \left(\frac{r}{k}\right)\sqrt{\frac{24E_m}{F_u}}$, then;

$$f_{cr} = F_u - \frac{\left(\frac{F_u kS}{r}\right)^2}{48E_m} \tag{2.4}$$

if $S > \left(\frac{r}{k}\right)\sqrt{\frac{24E_m}{F_u}}$, then;

$$f_{cr} = \frac{12E_m}{\left(\frac{kS}{r}\right)^2} \tag{2.5}$$

where

S = diameter of pipe or span of plate structure (in)

E_m = modulus of elasticity of metal (ksi)

F_u = tensile strength of metal (ksi)

r = radius of gyration of corrugation (in)

k = soil stiffness factor taken as 0.22

If f_{cr} is found to be less than F_y, the wall area (A) must be recalculated using f_{cr} in lieu of F_y, in the equation R_n / T_L (Eq. 2.1)

(c) Seam Resistance

For pipes fabricated with longitudinal seams, the nominal resistance of the seam shall be sufficient to develop the factored thrust in the pipe wall, T_L.

(d) Handling and installation

Pipes must have sufficient stiffness to withstand temporary loads occurring during transportation, handling and installation. Handling flexibility is defined by a flexibility factor, FF given by:

$$FF = \frac{S^2}{E_m I} \quad (2.6)$$

where

S = the diameter of pipe (in)

I = the moment of inertia of wall (in/in)

E = the modulus of elasticity of metal (ksi)

The AASHTO code limits the values of flexibility factor to those specified in Table 2.3.

Table 2.3 – Flexibility Factor Limit for Corrugated Metal Pipe and Structural Plate Structures (AASHTO)

TYPE OF CONSTRUCTION MATERIAL	CORRUGATION SIZE (in)	FLEXIBILITY FACTOR (in/kip)
Steel pipe	0.25	43
	0.5	43
	1.0	33
Aluminum pipe	0.25 and 0.50	
	0.060 Material thickness	31
	0.075 Material thickness	61
	All Others	92
	1.0	60
Steel plate	6.0 x 2.0	
	Pipe	20
	Pipe-Arch	30
	Arch	36
Aluminum plate	9.0 x 2.5	
	Pipe	25
	Pipe-Arch	36
	Arch	36

3.0 EVALUATION AND DISCUSSION

This chapter analyses and discusses the current AASHTO requirements and practice. The following performance limits specified by AASHTO and ASTM and related to the design and use of flexible metal pipes for gravity flow applications were addressed with regards to the-state-of-the-art on the subject. Summaries of relevant reviewed research studies are presented in Appendix A.

3.1 External loads

3.1.1 General Considerations

External loads are exerted on buried pipes by the soil that surrounds them (vertical earth load) as well by the traffic passing over them (surface live load). The vertical earth loads depend upon the stiffness properties of both the pipe structure and the surrounding soil (soil envelope). The effect of surface live loads at he top of buried pipe is function of the height of soil cover and therefore diminishes rapidly for deeply buried pipes. As far as design is concerned, the AASHTO code does not provide clear guidelines on how to evaluate the vertical earth load.

In current practice the determination of the loads on a buried pipe mainly depends on : (a) pipe classification (flexible or rigid), and (b) installation conditions.

(a) Pipe classification

One way of classifying pipes is by using the flexural stiffness of the pipe wall as determined from result of parallel plate testing (ASTM D 2412). That is:

$$PS = \frac{F}{\Delta_y} = \frac{EI}{0.149R^3} \tag{3.1}$$

where

PS = pipe stiffness, kN/m/m (lb/in./in.), often determined at a deflection of 5% of the nominal inside diameter of the pipe

F = parallel plate load, Mm (lb/in.)

Δ_y = change in vertical diameter, m (in.)

E	=	pipe material modulus of elasticity, kPa (psi)
I	=	pipe wall moment of inertia, mm/mm (in./in)
R	=	radius to the centroid of the pipe wall, mm (in.)

It has been suggested that if a pipe deflects at least 2% without structural distress, then it qualifies for a flexible pipe (Moser, 1990). Other researchers (Burns and Richard, 1964; McGrath, 1999) suggested that classification of pipe be based on the relative stiffness of the pipe and the soil envelope in which it is embedded, SB

$$S_B = \frac{M_s R^3}{EI} \quad (3.2)$$

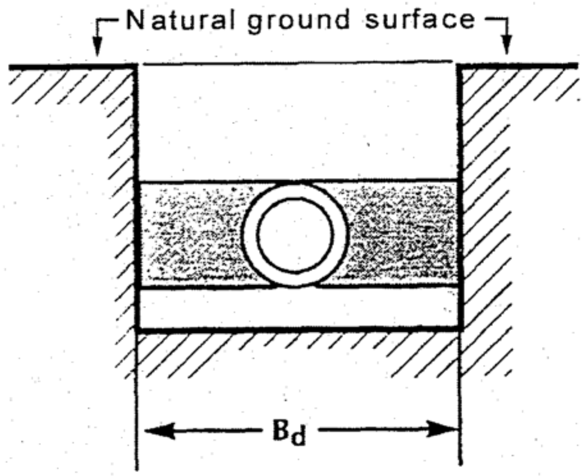
The latter is used to calculate the vertical arching factor (VAF) using continuum theories such as finite element analysis or the Burns and Richard (1964) elasticity solution (see Appendix B). If VAF < 1.0, then the pipe is considered flexible, otherwise it is considered rigid.

(b) **Installation condition**

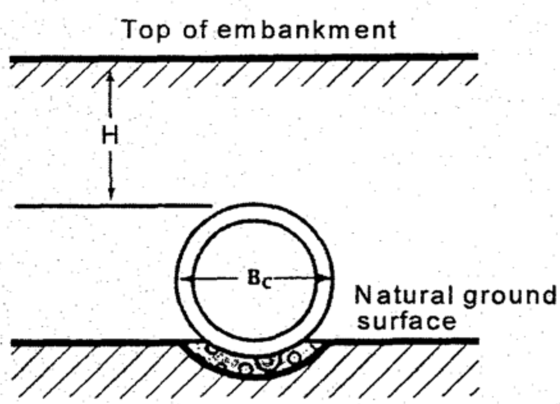
The intensity of the loads on a buried pipe depends also on installation conditions. Trench condition and embankment condition are the two major installation parameters (ASCE, 1982).

(a) Trench condition is one where the pipe is installed in a relatively narrow trench excavated in undisturbed soil and then back-filled (Fig. 3.1 a).

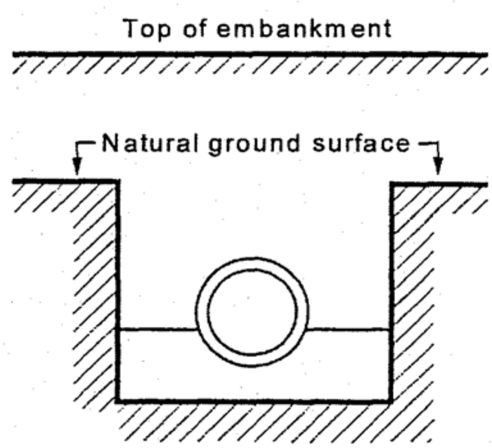
(b) Embankment condition is subdivided into positive projecting installation (Fig. 3.1 b) and :negative projecting installation (Fig. 3.1c). A positive projecting installation is one where the pipe is installed directly on top of the natural ground and then covered with embankment material. A negative projecting installation is one where the pipe is installed in a relatively narrow and shallow trench with its top below the natural ground, and then covered with the embankment material.



(a) Trench condition



(b) Embankment condition:
Positive projecting installation



(c) Embankment condition:
Negative projecting installation

Figure 3.1 : Installation Conditions (Source : Tubécon, 1995)

3.1.2 Vertical earth load

The load theory developed by Martson is widely used to calculate the vertical earth load acting on top of buried pipes of most commonly encountered construction conditions. In general, Martson theory states that the load on a buried pipe is equal to the weight of the prism of soil located directly above the pipe to the level of the ground, referred to as the prism load, plus the effects of shear forces along the edges of the prism. The prism load, W_p, is defined by:

$$W_p = \gamma H B_c \tag{3.3}$$

where:

γ = unit weight of the soil

H = depth of fill over the top of the pipe

B_c = outside diameter of the pipe

3.1.2.1 Load determination by Martson Theory

The general form of Martson's equation used to calculate the load, W, acting on a buried pipe can be expressed as:

$$W = C\omega B^2 \tag{3.4}$$

where:

ω = unit weight of the soil

B = trench or pipe width, depending on installation conditions

C = dimensionless coefficient that takes into account the effect of:

(a) the ratio of the height of fill to the width of trench of pipe (H/B),

(b) the shearing forces acting along the edges of the prism, and

(c) the relative settlement between the prism and the adjacent soil for embankment installations.

(a) Vertical earth load for trench condition

Under vertical load, a flexible metal pipe installed in a trench condition will deflect more than a well compacted side fills leading to a proportional share of the total load between the pipe and the side fills. The vertical' load, W, on a flexible pipe for trench condition is then expressed as:

$$W_c = Cd\ \omega\ B_c\ B_d \tag{3.5}$$

where

B_c = outside diameter of the pipe,

B_d = width of the trench,

C_d = load coefficient given by:

$$C_d = \frac{1 - e^{-2k\mu'(H/B_d)}}{2K\mu'} \tag{3.6}$$

where:

K = Rankine's ratio of lateral pressure to vertical pressure,

μ' = coefficient of friction between backfill material and side of the trench,

H = height of fill above top of pipe.

The load coefficient C_d can be determined from the computation diagram presented in Fig. 3.2. Vertical earth load, W, has also been expressed as a function of the prism load as follows (AASHTO LRFD, clause 12.10.2 for rigid pipe, Mc Grath, 1999, for flexible and rigid pipes):

$$W = VAF \times W_P \tag{3.7}$$

where W_P is the prism load (Eq. 3.3) and VAF is the vertical arching factor. Generally, VAF < 1.0 for flexible pipes and 1.0 < VAF < 1.4 for rigid pipes. However, for a conservative design, the prism load (i.e. VAF = 1.0) is usually considered for flexible pipes, whereas VAF = 1.4 is used for rigid pipes.

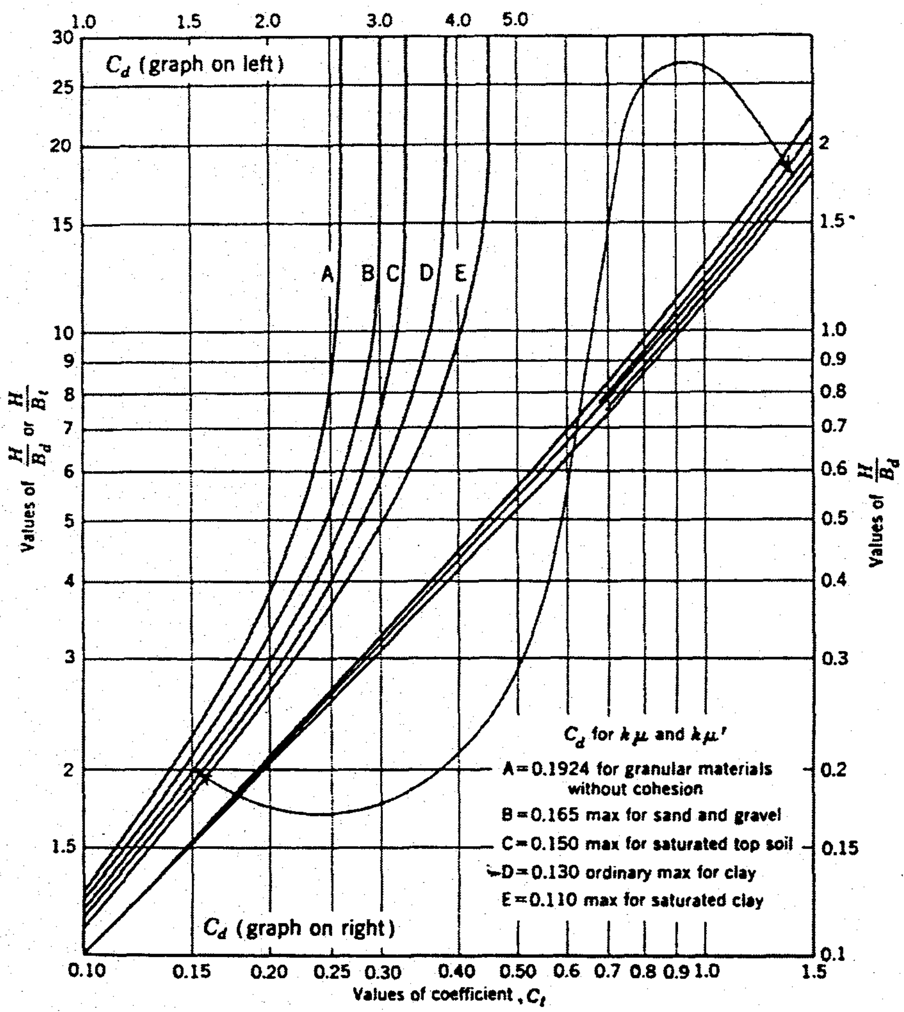


Figure 3.2 – Computation diagram for earth loads on trench conduits completely buried in trenches (Source : Moser, 1990)

(b) Vertical earth load for embankment conditions

The vertical earth load, W_c, on a flexible pipe installed in an embankment is given by

$$W_c = C_c \gamma B_c^2 \tag{3.8}$$

where C_c is a load coefficient expressed in terms of the followings:

- *Ratio* of *cover height to pipe diameter* (H/B_c): Its determination is straightforward.
- *Product* of *the settlement ratio and the protection ratio* ($r_{sd}p$): The projection ratio, p, is defined as the ratio of the vertical height of the top of the pipe above the embankment subgrade level to the outside pipe diameter B_c. Therefore, it is readily available from installation geometry. The settlement ratio, r_{sd}, indicates the direction and magnitude of the relative settlements of the prism of soil directly above the pipe and of the adjacent prisms of soil (see Fig. 3.3). It is given by

$$r_{sd} = \frac{(S_m + S_g) - (S_f + d_c)}{S_m} \tag{3.9}$$

where

S_m = compression of the columns of soil of height pB_c

S_g = settlement of the natural ground adjacent to the pipe

S_f = settlement of the bottom of the pipe

d_c = deflection of the pipe

The load coefficient C_c can be derived from Fig. 3.4.

In embankment installation, most pipes are installed above the natural ground surface. This type of installation is defined as a positive projecting pipe. Martson proposed two cases of positive projecting pipes depending on the settlement ratio r_{sd}:

- Projection condition (Fig. 3.3a), characterized by a positive settlement ration r_{sd}, where the sidefill settles more than the top of the pipe.

- Trench condition (Fig. 3.3b), characterized by a negative settlement ratio r_{sd}, where the top of the pipe settles more than the side fill.

It must be noted that the settlement ratio, r_{sd}, is difficult to determine even empirically. Recommend design values of the settlement ratio r_{sd} are given in Table 3.1. These values are based on measured settlements of a number of actual installations.

Table 3.1 – Recommended Design Values of r_{sd}

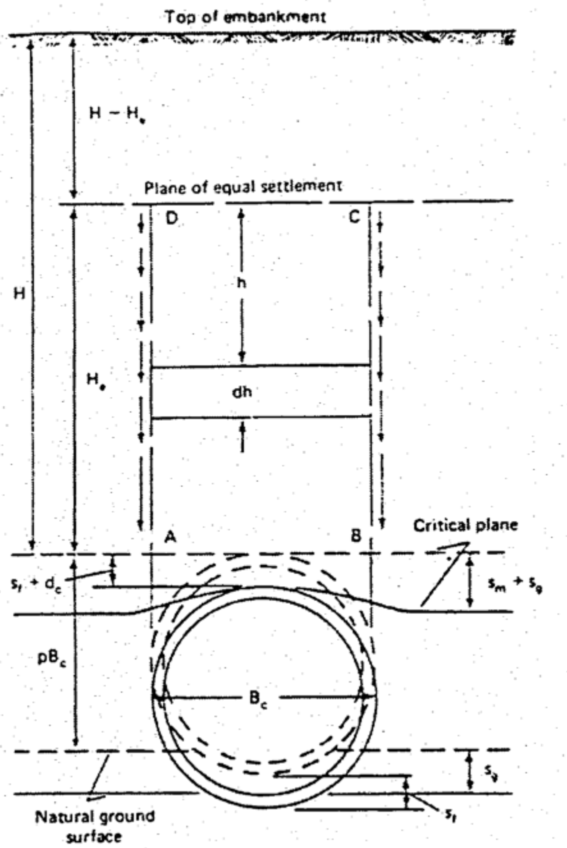
Type of Pipe	Soil Conditions	Settlement Ratio, r_{sd}
Rigid	Rock or unyielding foundation	+1.0
Rigid	Ordinary foundation	+0.5 to +0.8
Rigid	Yielding foundation	0 to +0.5
Rigid	Negative projecting installation	-0.3 to –0.5
Flexible	Poorly compacted side fills	-0.4 to 0
Flexible	Well compacted side fills	0

Note that the curves of Fig. 3.4 are plotted for both "incomplete ditch condition" and "incomplete projection condition" for which the plane of equal settlement is respectively located within, and above the top of the embankment (imaginary plane). The plane of equal settlement is defined as the plane where the shearing forces at the side of prism (see Fig. 3.3) are zero.

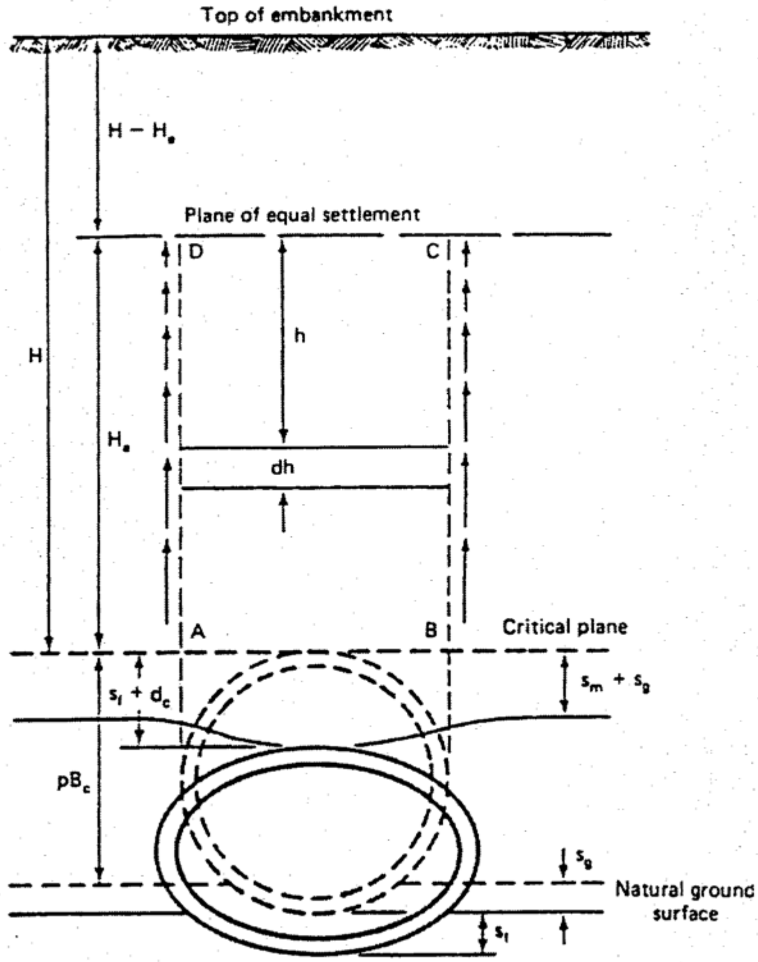
- *Products of Rankine 's constant and the coefficient of internal friction of backfill XM:* Recommended values of Kit are 0.19 for the projection condition: and 0.13 for the trench condition (see Fig. 3.4).

3.1.3 Surface live loads

Buried pipes are subjected to live loads: resulting from the weight and impact of surface vehicles or railroads. Standard highway loading, referred to as AASHTO HS20 live loads, and standard railroad loading known as AREA E80 live loads are usually used to standardize the design.



(a) Projection condition



(b) Trench condition

Figure 3.3 – Positive projecting pipes

(source: Moser, 1990)

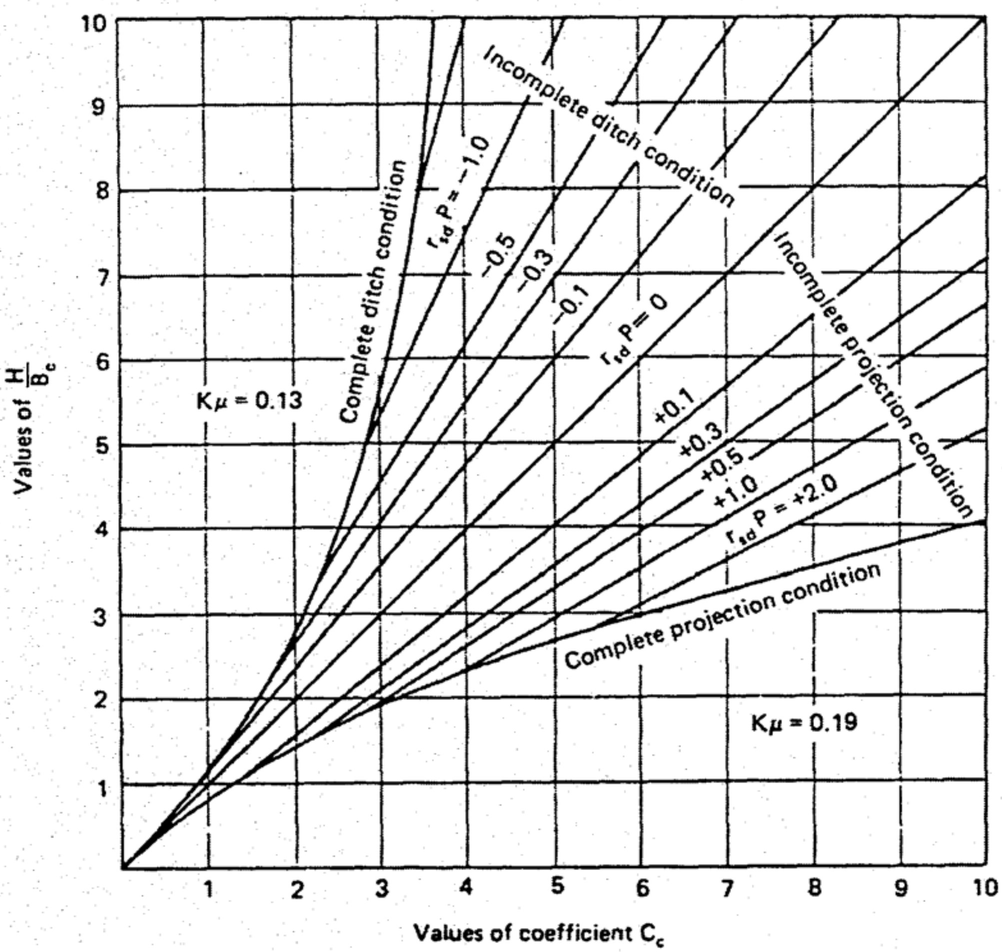


Figure 3.4 – Diagram for coefficient C_c for positive projection pipes

(source : Moser, 1990)

The Boussinesq solution for a semi-infinite elastic solid is usually used to obtain the resulting vertical stress distribution resulting from traffic loads with depth as follows:

$$q = \frac{3Q_s H^3}{2\pi R^5} \tag{3.10}$$

in which q is the vertical stress at the point considered, due to concentrated point load, Q_s; and H and R are the vertical depth and radial, distance, respectively, from the surface load to the point in question.

In current practice live loads for the design of buried pipes are generally computed through charts prepared by the Corrugated steel pipe industry. These charts are presented in Fig. 3.5 and include a 50 % impact factor to account for the dynamic effects of the traffic.

It is well known that surface live loads affect mainly shallow covers. Therefore, most of times it is not taken into consideration. The question that remains is related to the minimum cover beyond which effect of surface live loads on buried pipes can be neglected. From Fig. 3.5 it is clear that the surface live load plus the impact are of no effect when less than 100 psf. This corresponds to a minimum height of cover above the pipe of 8 feet and 30 feet for Highway HS20 and Railway E80 loading, respectively (see Table 3.2)

On the other hand, the AASHTO Highway: code recommends a minimum cover of 3 ft or pipe outside diameter, whichever is larger, above which the impact effect can be neglected. The AREA code recommends to neglect the impact effect when the cover exceeds 10 feet.

Table 3-2 Highway and Railway Live Loads Including 50% Impact

(Source: AISI's Manual)

Highway HS20 Loading

Height of Cover, ft	Load, psf
1	1800
2	800
3	600
4	400
5	250
6	200
7	175
8	100

Railway E 80 Loading

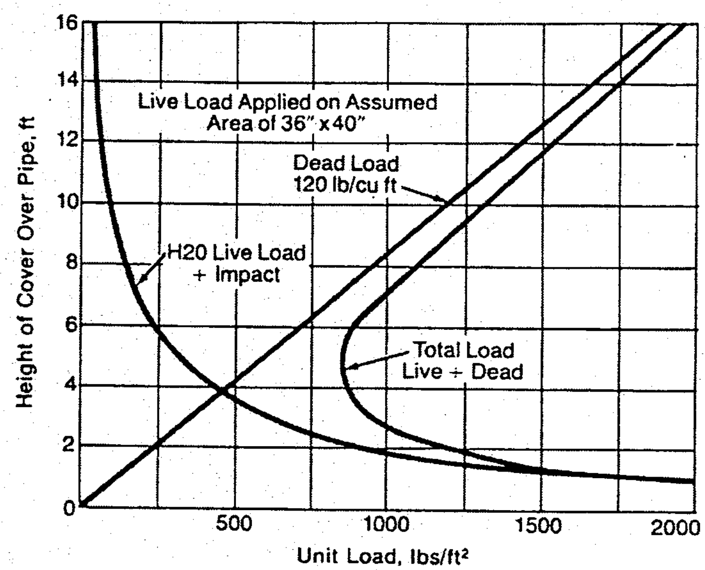
Height of Cover, ft	Load, psf
2	3800
5	2400
8	1600
10	1100
12	800
15	600
20	300
30	100

Note: Neglect live load when less than 100 psf, use dead load only.

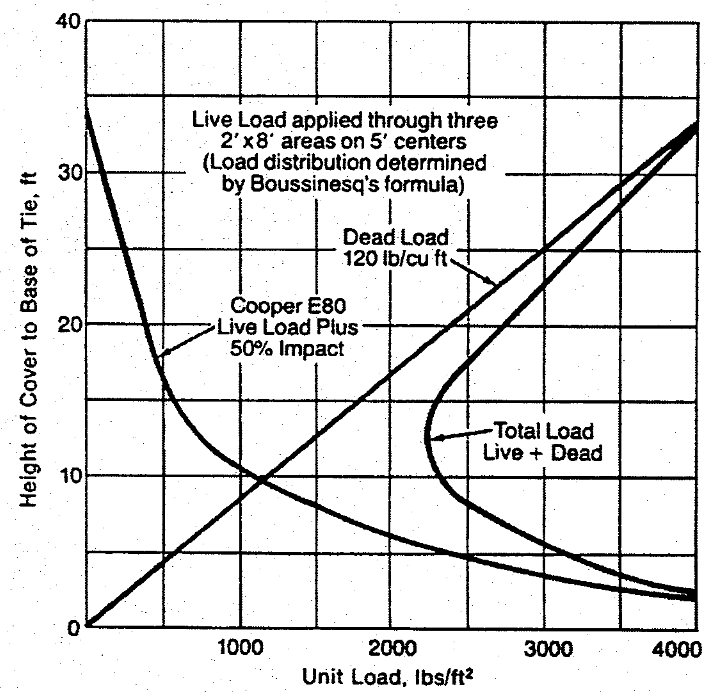
It must be noted that charts such as those of Fig. 3.5 present shortcomings in that they do not take the size of the pipe into consideration. Therefore, an alternative formula (Spangler 1960) was proposed to determine the live loads, as follows:

$$W_t = \frac{1}{l} I_c C_t Q_s \tag{3.11}$$

in which W_t is the average load, in pounds per linear foot, on the conduit due to wheel load; *l* is the length (or effective length) of the conduit; k is the impact factor; C_t is the load coefficient; and Q_s is the concentrated truck-wheel load, in pounds, on the surface of the fill.



(a) Combined HS20 highway live load and dead load is a minimum at about 5 ft cover, applied, through a pavement 1 ft thick



(b) Railroad live load, Cooper E80, combined with dead load is a minimum at about 12 ft. Load is applied though three 2×8 ft areas on 5 ft centers.

Figure 3.5 - Surface Traffic Live Load Combined with Dead Load
(Source : AISI's Handbook (Steel Drainage and Highway Constr.))

3.2 Performance limits

As presented earlier in chapter 2, in current AASHTO specifications, the structural capacity of metal pipes is evaluated on the basis of wall resistance to thrust (Eq. 2.2) and wall resistance to buckling (Eqs. 2.5 and 2.6). No indication is given on the deflection or strain limits. While this procedure can be appropriate for rigid pipes, where the above specified performance limits may always occur before deflection or strain limits are reached, it may not hold true for flexible pipes where deflection performance may govern the design. It may be worthwhile noting that the ASTM A796 specifies that the application of a deflection design criteria is optional arguing that long-term field experience and test results have demonstrated that corrugated metal pipe, properly installed using suitable fill material, will experience no significant deflection.

In general, however, the following performance limits corresponding to possible pipe response may be considered in design of metal pipes for gravity flow applications : (a) wall crushing, (b) wall buckling, (c) seam resistance, (d) longitudinal and shear stress (e) reversal of curvature, (f) deflection, (g) strain limit and (h) durability. Items (a) to (d) were addressed by code and are therefore discussed first, items (e) to (g) related to deformations and (h) to durability will be discussed later under Issues not covered by code.

3.2.1 Wall crushing

This performance limit is reached when the wall stress (Eq. 2.2) reaches the yield stress of the pipe (Eq 2.3) The latter is used to determine the minimum wall thickness required, hence the maximum burial height allowed. As: stated earlier, this situation is mainly of concern for rigid pipes. However; it may also be a governing: performance limit for stiffer flexible pipes installed in highly compacted backfill and subjected to very deep cover. It maybe worth noting that the AASHTO formula does not take into consideration the bending stress, which if important may influence wall crushing.

3.2.2 Wall buckling

Wall buckling is caused by: either insufficient pipe bending stiffness or/and by insufficient soil stiffness. While pipe bending stiffness of metal pipe can be determined fairly accurately, the determination of soil stiffness on the other hand is not straight forward. Stiffness is described by soil modulus E' and depends on the class and the degree of compaction of soil. Many attempts have been made through extensive laboratory and field tests to measure and quantify the soil modulus E'. However, considerable difficulty has been encountered and no consensus on the values of E' has been reached. The values of E' shown in Table 3.3 were suggested by the U.S. Bureau of Reclamation. Other values taking into consideration the soil depth were also suggested (Hartley and Duncan, 1987).

In AASHTO Standards, two formulae (Eqs. 2.4 and 2.5) are recommended depending on the diameter (slenderness). These formulae give the critical buckling pressure (f_c) mainly in terms of the pipe properties. The only soil parameter included in the equations is a soil stiffness factor K. In view of the difficulty in the determination of the soil modulus, constant value of 0.22 is recommended for the type of backfill material allowed for flexible metal pipe structures.

It is noted that AASHTO Equations for f_{cr} are expressed in terms of the radius of gyration of corrugations and no indications are given as to the use of these equations for non corrugated flexible metal pipes.

Meyerhof and Baike (1963) developed the following formula to determine the critical force required to cause buckling in a buried circular pipe:

$$p_{cr} = \frac{2}{R}\sqrt{\frac{KEI}{1-v^2}} \tag{3.12}$$

If the "sub-grade modulus" K is replaced by the soil stiffness modulus E', Eq. 3.12 becomes:

$$p_{cr} = 2\sqrt{\frac{E'}{1-v^2}\left(\frac{EI}{R^3}\right)} \tag{3.13}$$

where I = Moment of inertia of wall cross section per unit length, v =Poisson's ratio of pipe, R =

Radius of pipe, and E = Modulus of elasticity of the pipe.

Table 3.3 – Bureau of Reclamation Average Values of E' for Iowa Formula (for Initial Flexible Pipe Deflection)

	E' for Degree of Compaction of Bedding, in pounds per square inch			
Soil type-pipe bedding material (United Classification System) (1)	Dumped (2)	Slight, <85% Proctor, <40% relative density (3)	Moderate, 85%-95% Proctor, 40%-70% relative density (4)	High >95% Proctor, >70% relative density (5)
Fine-grained soils (LL > 50)[b] Soils with medium to high plasticity CH, MH, CH-MH	If no data is available; consult a competent soils engineer; otherwise use E' = 0			
Fine-grained soils (LL < 50) Soils with medium to no plasticity CL, ML, ML-CL, with less than 25% coarse-grained particles	50	200	400	1.000
Fine-grained soils (LL < 50) Soils with medium to no plasticity CL, ML, ML-CL, with more than 25% Coarse-grained particles Coarse-grained soils with fines GM, GC, SM, SC[c] contains more Than 12% fines	100	400	1,000	2,000
Coarse-grained soils with little or no fines GW, GP, SW, SP[c] contains Less than 12% fines	200	1,000	2,000	3,000
Crushed Rock	1,000	3,000	3,000	3,000
Accuracy in Terms of Percentage Deflection[d]	62	62	61	60.5

[a]ASTM Designation D-2487, USBR Designation E-3.
[b]LL = Liquid limit.
[c]Or any borderline soil beginning with one of these symbols (i.e., GM-GC, GC-SC).
[d]For 61% accuracy and predicted deflection of 3%, actual deflection would be between 2% and 4%

Note: Values applicable only for fills less than 50 ft (15 m). Table does not include any safety factor. For use in predicting initial deflections only, appropriate Deflection Lag Factor must be applied for long-term deflections. If bedding falls on the borderline between two compaction categories, select lower E' value or average the two values. Percentage proctor based on laboratory maximum dry density from test standards using about 12,500 ft-lb/cu ft (598,000 J/m^3) (ASTM D-698, AASHTO T-99. USBR Designation E-11. 1 psi = 6.9 KPa).

Actual tests show that Eq. 3.13 works fairly well for steel pipes. However, it assumes a constant external pressure (or internal vacuum) around the pipe and may therefore not be suitable for large diameter pipes installed below the water table in shallow burial.

A similar formula was also developed by Lusher (1966). This formula gives the critical uniform pressure, p_{cr}, required to cause buckling in a soil-surrounded tube.

$$p_{cr} = 1.73\sqrt{\frac{EIBM^*}{r^3}} \tag{3.14}$$

in which E is the modulus of elasticity of the pipe material; I is the moment of inertia of the longitudinal cross section of the conduit wall per unit length; B is the coefficient of elastic support; M* is the constrained modulus of the soil; and r is the nominal radius of the tube. For dense to medium-loose sand Eq. 3.14 was found to give a close correlation with laboratory test results.

3.2.3 Seam resistance

Fabrication and resistance for, seams are thoroughly described in AASHTO M36M-96 and ASTM A 760/A - 760M-956 for steel and in AASHTO 196M-92 for aluminum pipes. Following type of seams are addressed: (a) Riveted and spot welded seams, (b) Helical lock seams and (c) Helical continuous welded seams.

The longitudinal seam formed by bolting or riveting curved sheets together for corrugated metal pipe may have to be checked for crushing strength for heavy backfill loads. In flexible metal pipes welded seams may represent the weakest link of the chain. These regions can be of high residual stresses that can cause cracks leading to leaks when the pipe deflects.

Strength of lap welds may be less than that of the steel pipe. For example, tests on lap joints (Brockenbrough, 1990) show that longitudinal strengths of a single and a double weld is about 75% and 83% of pipe strength, respectively.

3.3 Installation consideration

3.3.1 Handling

For flexible metal pipes, a maximum flexibility factor FF (see Table 2.3) is recommended to avoid damage of the pipe during handling and installation. FF is function of stiffness factor EI (Eq. 2.6). Note that FF is not a true property for buried pipes, but it is fairly representative of concentrated forces on pipes which are typical of handling loads. The stiffness factor EI is related to the pipe stiffness (PS) as follows:

$$PS = \frac{F}{\Delta y} = \frac{EI}{0.149r^3} \tag{3.15}$$

where: E = modulus of elasticity, lb/in^2

I = moment of inertia of the wall cross-section length of pipe, in^4/in

r = mean radius of pipe, in

F = force, lb/in

Δy = vertical deflection, in

Pipe stiffness PS is determined in the laboratory by a parallel plate loading test according to ASTM D2412-96. It is defined as the load at an arbitrary 5% deflection divided by the sample length (usually longer than one diameter) and divided by the vertical deflection Δy, giving a typical unit of lb/in^2. The resulting stiffness factor EI is. used to determine the flexibility factor FF (Eq. 2.6) as well as the approximate field deflection by the modified Iowa Formula:

$$\Delta X = \frac{D_L K W_c r^3}{EI + 0.061E' r^3} \tag{3.16}$$

where : D_L = deflection lag factor

K = bedding constant

W_C = Marston's load per unit length of pipe, lb/in

r = mean radius of pipe, in

E	=	modulus of elasticity of the pipe material, lb/in^2
I	=	moment of inertia of the pipe wall per unit length, in^4/in
E'	=	soil modulus, lb/in^2
OX	=	horizontal deflection or change in diameter, in

The deflection lag factor was introduced to account for the consolidation at the sides of the pipe that continues after the installation and that could lead to an increase in long term deflections. Spangler recommended a deflection lag factor of 1.5. However, if the prism load is used for design, then a deflection lag factor of 1.0 is recommended.

3.3.2 Longitudinal and shear stresses

Most of pipes are not designed to resist high longitudinal stresses. Longitudinal stresses in buried pipes are produced mainly by longitudinal bending and thermal expansion or contraction. One of the major causes of longitudinal bending is the non-uniformity of the soil bedding. A-uniform bedding is usually very difficult to achieve in field despite appropriate specifications and design and therefore, longitudinal stresses can not be totally avoided. However they should be kept to a minimum by proper installation design and construction. Corrugated metal pipes are known to be flexible enough to relieve themselves of longitudinal stresses by changing length and by beam bending that conforms with uneven bedding.

Two basic longitudinal analysis of buried pipes, that follow classical procedures, are available : the axial and the flexural longitudinal analysis. The first one considers the effects of temperature changes and the second one considers the effects of beam bending. Shear loading often accompanies longitudinal bending. These shear forces must be eliminated or minimized by proper design and installation.

Limiting the irregularities of the bedding surface (grade control) to 1 % of a single section of pipe, which can reasonably be achieved in practice, should limit longitudinal and shear stresses.

3.3.3 Installation condition

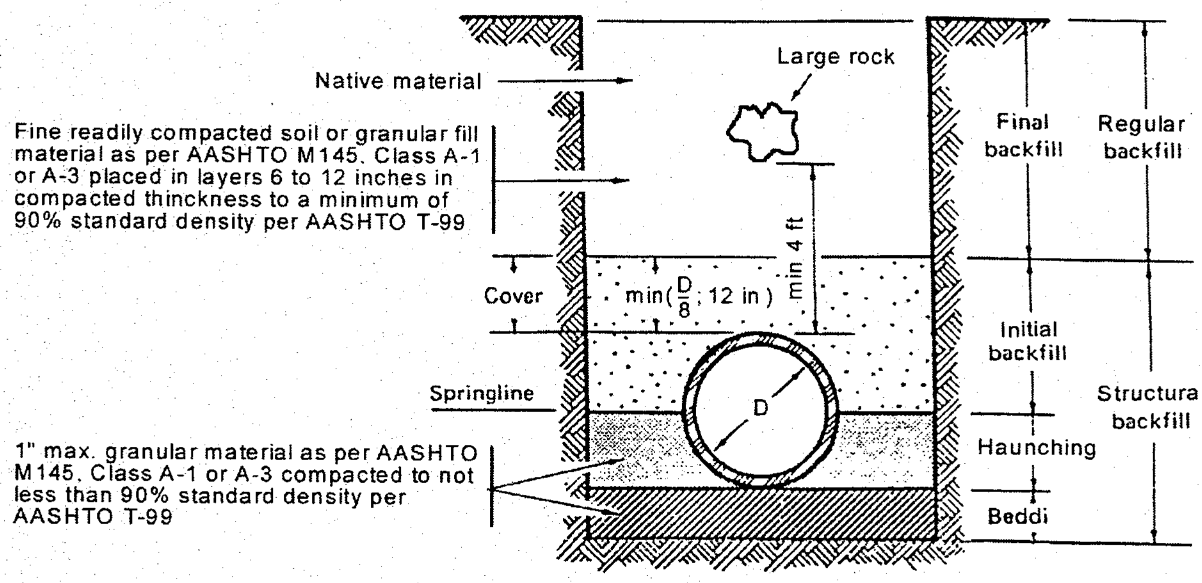
Flexible metal pipes are generally installed in a relatively narrow trench (dictated by installation) excavated in undisturbed soil or fill embankments. The narrower the trench, the lighter is the load on the pipe. However, a trench excavated in poor soil (the trench walls provide less horizontal support) may need a wider trench. The normal installation requirement for flexible metal pipes are given in ASTM A807/A 807M-96 and conveniently presented in Fig. 3.6 along with the appropriate terminology for both trench and embankment conditions. The soil types recommended for each of installation regions are also provided.

3.4 Safety factors

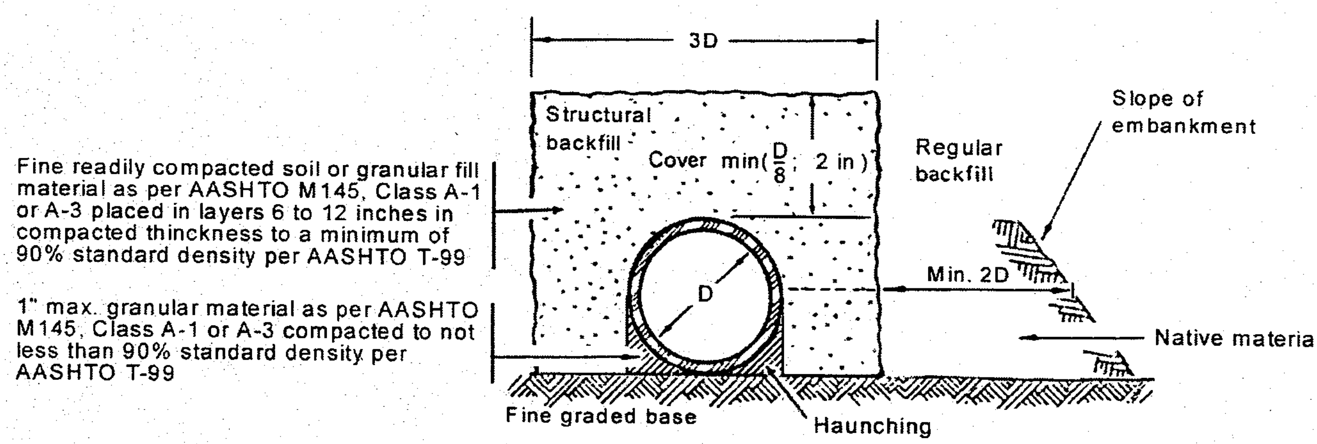
Safety factors against ultimate collapse of buried pipes are about the same as those used in the. design of most engineered structures. The need for selecting a design load that is less than the performance limit load arises mainly from uncertainties such as service conditions loads, uniformity materials and design assumptions along with unexpected construction deficiencies. Therefore, the application of a safety factor is aimed at providing adequate margin of safety against all possible .modes of failure.

Design performance limits for flexible metal pipes may be expressed in terms of stress and strain, crushing or buckling in the pipe wall or deflection. Safety factors depend therefore on uncertainties for the performance limit considered. Therefore, a safety factor is not necessarily unique but depends on uncertainties for the type of performance limit considered. Thus, a safety factor for buckling may be different from deflection. Safety factors ranging from 2 to 4 have been generally used for design performance limits of flexible metal pipes. A safety factor of 2 is recommended for buckling and wall area, while a safety factor of 3 is used for seam resistance (AASHTO - Standard Specifications, art. 12.4.1.2). On the other hand, a safety factor of 4 has been traditionally applied to the deflection limits associated with snap-through occurrence.

Some of these safety factors may seem somehow excessive, however, they may be justified given the uncertainties involved in the design of such structures, particularly those related to load values, backfill soil properties and compaction, and installation control.



(a) Trench condition



(b) Embankment condition

Figure 3.6 – Normal installation requirements for flexible metal pipes as per ASTM Standards

3.5 Issues not Covered by Code

Many issues that are important for design of flexible metal pipes are not covered by the code. Deflection, strain and reversal of curvature, as well as durability are some of these issues.

3.5.1 Deflection - Strain - Reversal of Curvature

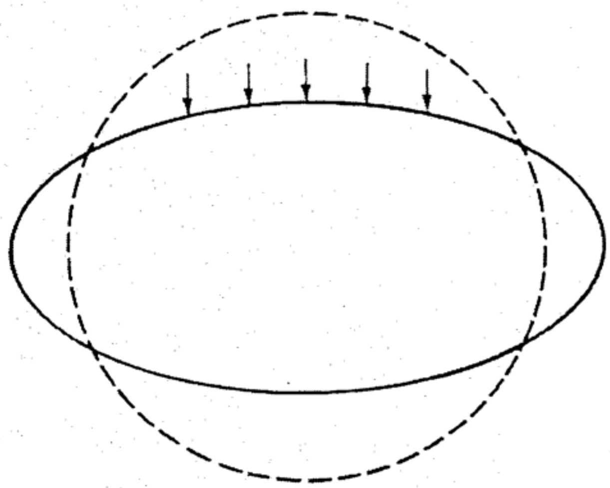
In flexible metal pipes, excessive deflection may occur before crushing strength limit of the pipe is reached. A flexible metal pipe will generally have a deflection design limit based on occurrence of reversal of curvature (Fig.3.7) The calculated design deflection must then be equal to or less then the design deflection limit with a safety factor.

The modified Iowa formula (Eq. 3.16) is generally used to determine the design deflection of flexible metal pipes. The maximum deflection prior to failure has been investigated by inspecting a number of large-diameter pipe installations. It was determined that a flexible metal pipe would begin to reverse curvature at a vertical deflection of about 20% of the nominal pipe diameter. The use of a conservative factor of safety of 4 established the design deflection at 5%. Strain is related to deflection, therefore, limiting the deflection amounts to limiting the strain. The total circumferential strain in the case of buried pipes is generally made up of bending strain, ring compression strain, hoop strain due to internal pressure, and strain due to Poisson's effect. For gravity flow application pipes, the bending strain is the predominant component and contributes for most of the total circumferential strain.

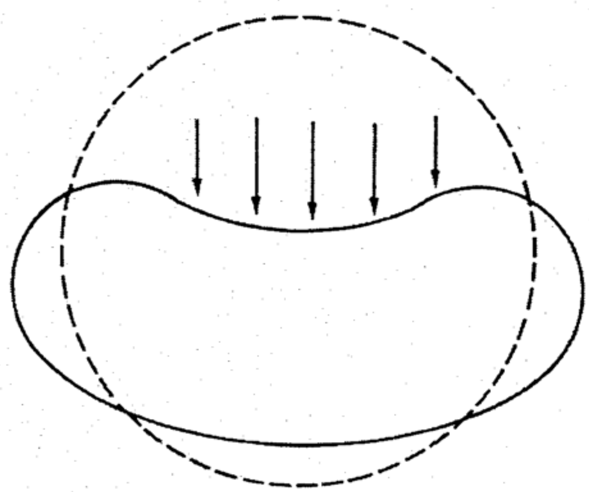
Research studies indicate that the bending strain ε_b may be expressed as:

$$\varepsilon_b = 6\left(\frac{t}{d}\right)\left(\frac{\Delta_y}{D}\right) \tag{3.17}$$

where t is the wall thickness, D is the pipe diameter, and Δ_y is the vertical deflection. The level of strain corresponding to 5% vertical deflection may be of interest. Three flexible metal pipes with diameters of 600, 1200, and 2400mm, were considered for analysis. The total strains at 5% vertical deflection, calculated from Eq. 3.17, were found to be 0.07%, 0.04% and 0.05%, respectively.



(a) Deflection



(b) Reversal of curvature due to over-deflection

Figure 3.7 – Ring deflection in a flexible pipe
(Source : Moser, 1990)

These simple calculations, show that the strains induced at a 5% deflection are very small compared to the yield strain of steel, which is around 0.2%.

3.5.2 Durability

Flexible metal pipes must be designed to have enough strength and/or stiffness to perform adequately their intended functions. In addition, they must also be durable to last for their design service life. This is generally achieved by designing the additional thickness required of the selected protective mean. However, relating metal loss with various physical and chemical properties of the soil is very complex and very limited data is available. Chapter 6 of MOT Topic No. 625-040-001-b (see Appendix E) gives useful diagrams for service life estimation for metal pipes, in terms of the PH and the resistivity of the prevailing water and soil conditions.

The statistical average corrosion rate of the type suggested by Haviland et al. (1967) for the state of New York (see Fig. 3.8) as well as the following recommendations can also be used as guidelines.

(a) Allowance should be made for abrasion wherever peak flow velocity is high and water contains significant amounts of sediment;

(b) When the water PH is less than 4.5, the use of metal pipe should be avoided. If the water PH is greater than 4.5, an additional metal thickness must be provided;

(c) Aluminum pipes can be used for $4.5 \leq PH < 9.0$

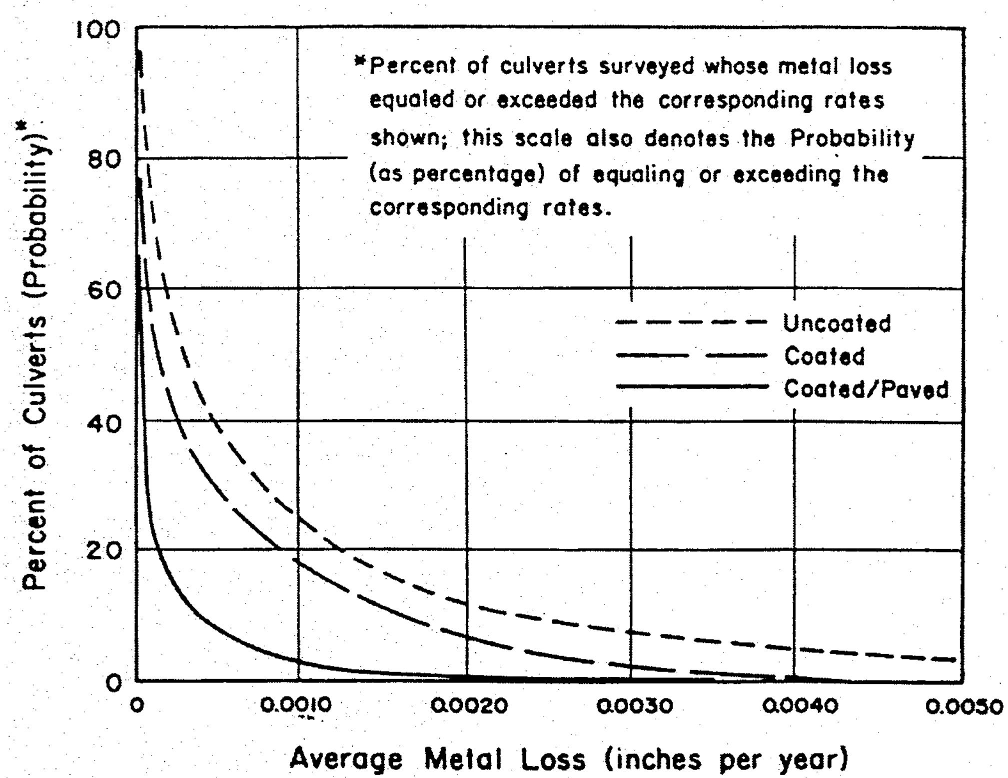


Figure 3.8 – Distribution of average metal loss for galvanized steel culverts
(Source : Haviland et al., 1967)

4.0 CONCLUSIONS AND RECOMMENDATIONS

The main objective of this research study was to evaluate the performance limits of flexible metal pipes, with particular emphasis on structural design including deflection, and service life expectancy. Specific objectives were set as follows: (a) Review the relevant technical documents gathered on the subject at hand; (b) Review AASHTO code requirements and DOT's practice regarding design of metal pipes; (c) Analyze and evaluate the current design requirements in terms of wall area, allowable deformations and strains, buckling, seam failure, and installation; and (d) Provide recommendations for appropriate application of flexible metal pipes as gravity flow conduits.

The study reviewed in addition to relevant standards and code, numerous publications and reports on the subject.

4.1 General Conclusions

In summary, the review and analysis of documents indicated that, although in current practice the design of flexible metal pipes is generally based on deflection limitation, it should consider each possible performance limit, including deflection, in succession to identify the one that occurs at the lowest load.

Flexible metal pipes have shown an excellent field performance for several decades, and very few cases of failure due to design short comings: were reported. That means that the design methods have withstood the test of time. It may also mean that the design is too conservative. However, one should also keep in mind that the design of flexible pipes is a soil-structure interaction problem and adequate construction control is difficult to achieve.

The review also indicated that the AASHTO Standard provides a reasonable basis for design of flexible metal pipe. However, it presents some shortcomings; particularly regarding the following important aspects:

(a) The loads: No indication is provided on how the loads including live loads, are calculated and hoe they can be affected by the flexibility of the pipes (flexible versus rigid) and by the installation conditions (trench versus embankment)

(b) Shallow Conditions: No guidelines are given for shallow installation conditions. Questions related to the minimum cover below which the traffic load is to be included need to be addressed.

(c) The vertical deflection: No indication is given on how to calculate deflection and what is a reasonable limit and related factor of safety.

(d) Large diameter Pipes: It appeared from the survey that large diameter pipes may warrant a different design approach.

(e) Durability and Service Life: No guidelines are provided for durability with relation to service life expectancy of flexible metal pipes.

(f) Safety Factors: Safety factors currently used for different performance limits lack of rationale and consistency. They should therefore be reviewed particularly in view of the introduction of new products into market.

(g) Acceptability Criteria: Realistic acceptability criteria consistent with current installation procedures should help achieve uniform quality control.

4.2 Preliminary Recommendations

Based on the evaluation of the listed documents and on a literature review, the following preliminary recommendations are offered. The bases of these recommendations are also provided. Further testing and verifications are necessary before these recommendations can be implemented.

1. Loads

Recommendation

- For flexible metal pipes, the vertical earth load can be conservatively assumed equal to prism load, $W_{p.}$

- Live load including impact load should be considered for shallow conditions, that is for covers smaller than 8 feet for HS20 vehicles. Impact effect can be neglected if the cover is higher than 3 feet or the pip diameter; whichever the greatest. If construction loads are higher than 3 feet or the pipe diameter; whichever the greatest. If construction loads are expected to be higher than HS20, then the minimum cover should be increased consequently.

Basis *for Recommendation*

- Vertical earth load can be expressed as VAF x W_p, where VAF = vertical arch factor and W_p = prism load. It has been shown that VAF can be in the range [0.2 - 1.0] for flexible pipes depending on the relative stiffness of pipe and backfill soil.
- From Fig. 3.5, it is clear that the surface load plus the impact are of no effect when less than 100 psf. The latter corresponds to a minimum cover of 8 ft above the pipe. The AASHTO LRFD code recommends a minimum cover of 3 ft or pipe diameter, whichever the largest, above which the impact effect can be neglected. Construction vehicles may be heavier than service traffic loads and a minimum cover, with due account of rut effect, should be designed to avoid damaging the pipe.

2. Resistance to Thrust

Recommendation

- Verification of thrust resistance should be carried out according to AASHTO (Eqs. 2.2 and 2.3)

Basis for recommendation

- AASHTO formula neglects bending stress, which is believed reasonably correct for flexible metal pipe, which are generally thin.

3. Resistance to Buckling *Recommendation*

- Resistance to buckling of corrugated metal pipe should be verified according to AASHTO. For non corrugated metal pipe, Eq. (3.14) may be used.

Basis for *recommendation*

- Field pipe and test showed that buckling is not the governing performance limit and therefore it is usually neglected altogether. AASHTO formula, although most likely quite conservative since it uses only one value for soil stiffness factor that conservatively covers all backfill soil materials allowed for flexible pipe installations, presents the advantage of being straightforward. In addition, it suggests a different formula for large diameters, which appears rational in view of the fact that large diameter pipes are more prone to buckling than small diameter pipes. Alternatively, the use Eq. 3.13 or Eq. 3.14 for corrugated and non-corrugated flexible metal pipes if the soil characteristics are known, is indicated. These equations have shown good correlation with laboratory tests.

4. Seam Resistance *Recommendation*

- Seams resistance should be verified as per AASHTO using a resistance factor of 0.67 as recommended by AASHTO LRFD (Table 12.5.5-1).

Basis for Recommendation

- Tests have shown that seam resistance may be 75% lower than the metal pipe resistance. However it is believed that the resistance factor of 0.67 will make up for any weakness in the welds.

5. Deflection Limitation *Recommendation*

- Limit of vertical deflection could be increased after further testing and verifications are made. Field verification test after installation should be maintained.

Basis for Recommendation

- The current practice limit of 5% of the diameter stem from the deflection corresponding to snap-through buckling, which was reported to be around 20% of the pipe diameter. A safety factor of 4 is currently used. However, it is believed that there is no rationale supporting such a high conservatism. In fact, this question of safety factor should be clarified for all, types of pipes. The degree of field control should be reflected in such an endeavor. A Safety factor of 3 appears reasonable. However, it should be backed by further testing and verifications. It is clear from review and simple calculations that the source of 5% deflection limitation does not come from the strain limitation. Therefore, the argument advanced in the Memorandum addressed by Jim Schluter to Paul Harkins (see Appendix F) to remove the 5% deflection limitation for flexible pipes, although correct in saying that the strains are very small, is fundamentally wrong.

6. Installation

Recommendation

- Flexural deflection limits during handling and installation as per AASHTO LRFD (Table 12.5.6.1-1) should be maintained
- The irregularities of the bedding surface (grade control) should be limited to 1 % of a single section.
- Installation geometry and materials should follow the current AASHTO and ASTM specifications, as conveniently summarized in Fig. 3.6.

Basis for Recommendation

- It has been shown that if the flexibility factor of a given pipe is less than that specified, the probability of transportation/installation damage is statistically low to be tolerated (Watkins and Anderson, 1999).
- In addition, frequently the additional wall thickness required for handling and installation provides sufficient metal to satisfy durability requirements.
- The limitation in bedding surface irregularities should limit longitudinal and shear stresses to acceptable levels.
- Good performance was reported for pipes installed on the basis of current specifications.

7. Durability and Service Life

Recommendation

- Durability of flexible metal pipe in relation to service life expectancy should be addressed during the design process. The document prepared by the FDOT and presented in Appendix E, provides good guidelines. Additionally, Fig. 3.8 as well as the considerations given in section 3.5.2 can provide some guidance on the additional metal thickness for the corrosion allowance per year of service.

Basis for Recommendation

- No reliable methods exist for prediction of durability performance in a given environment. A set of guidelines for taking the corrosion losses into consideration has been proposed on the basis of extensive survey (Haviland et al., 1967).

8. Coordination

Recommendation

- Coordination between the designer and the contractor should be reinforced.

Basis for Recommendation

- It appeared from the review that the principal reasons for culvert failures were related to inadequate relation between the design assumptions and the actual construction conditions.

APPENDIX A

REVIEW OF SELECTED PAPERS

A.1 Attenuation of Stresses for Buried Cylinders

by Jerome Q. Burns and Ralph M. Richard, Proceedings, Symposium of Soil Structure Interaction, University of Arizona, Engineering Research Lab. Tucson (Sept. 1964)

The paper presents two-dimensional elastic analytical equations in non-dimensional form which describe the thrusts, moments, and displacements in a deeply buried conduit as well as the stresses and displacements throughout the surrounding elastic medium due to the action of an overpressure applied at the surface of the medium. The. conduit and the medium are analyzed as a structural system. The determination of the stresses and deformations throughout this system gives the conduit thrusts, moments, and displacements, and the medium stresses and displacements, hence, the interaction loads and the arching phenomena are evaluated.

The analysis is made through the use of extensional shell theory for the shell and Mitchell's formulating of Airy's stress function or the medium. The analysis is applicable to conduits embedded in an elastic medium ranging from "Rigid conduits" to "Flexible conduits". The equations clearly show' the soil-shell interaction problem and the effect of the extensional flexibility of the shell relative to its bending flexibility on the arching effect, as well as of the slippage of the shell relative to the medium on the response.

The analytical study showed that the spatial attenuation of the stresses and displacements is quite rapid with the free-field conditions being essentially reached within about two diameters. This study of the linearly elastic soil case of the soil-pipe system is thought to be a necessary starting point and gives good insight into the actual soil problem. The authors concluded that the validity of this theory and the resulting slip-zone-arch modifications, which arise from it, should be verified experimentally.

A.2 E' and Ms Variation with Depth

By James D. Hartley and James M. Duncan, ASCE Journal of *Transportation Engineering., Vol. 113, No. 5; Sept. 1987.*

This paper investigated the variation with depth of embedment of the modulus of elasticity E' and the constrained modulus M_s of the soil. The modulus of soil reaction (E') characterizes the stiffness of the soil backfill at the sides of a buried pipe, and is an important factor in the Iowa formula for determining pipe deflections.

Numerous studies have clearly established experimentally and in practice that E' varies with soil type and compacted density. There have been conflicting opinions in the literature as to whether E' is indeed a function of depth, and that depth has a significant effect on the value of E'. This effect was examined empirically with sets of pipe deflections and pressures, and with a finite element computer program developed for the study of culverts during and after construction. Recommended design values of E' as a function of depth of embedment are presented in Table 1.

Table A2.1– Recommended Design Values of E', psi (source : Duncun et al. 1987)

Type of soil	Depth of cover (ft)	Standard AASHTO Relative Compaction			
		85%	90%	95%	100%
Fine-grained soils with less than 25% sand (CL, ML, CL-ML)	0-5	500	700	1,000	1,500
	5-10	600	1,000	1,400	2,000
	10-15	700	1,200	1,600	2,300
	15-20	800	1,300	1,800	2,600
Coarse-grained soils with (SM, SC)	0-5	600	1,000	1,200	1,900
	5-10	900	1,400	1,800	2,700
	10-15	1,000	1,500	2,100	3,200
	15-20	1,100	1,600	2,400	3,700
Coarse-grained soils with little or no fines (SP, SW, GP, GW)	0-5	700	1,000	1,600	2,500
	5-10	1,000	1,500	2,200	3,300
	10-15	1,050	1,600	2,400	3,600
	15-20	1,100	1,700	2,500	3,800

A.3 Flexibility Factor or Pipe Stiffness : Significant Stiffness Consideration

by James C *Schlutter and James W. Shade Transport Research Record 1656, 1999.*

This paper investigated the geometry, material and environmental factors that must be considered to evaluate functional stiffness and compare pipe performance through laboratory-measured "stiffness". Laboratory stiffness tests were conducted in conjunction with ASTM D2412 on a series of 68 x 13mm (2.67 x 0.5 in) corrugated steel pipes (CSP) as well as profile wall PVC and high-density polyethylene (HDPE) pipes to determine the effects of helix angle, material yielding, reverse curvature, strain rate, and temperature. Tests were limited to a maximum diameter of 900 mm (36 in) and a maximum length of 1.8 m (6 ft), mainly because of the size of the test equipment.

Stiffness test results are presented in figure 1 and compared with theoretical stiffness calculated using the following equation

$$PS = \frac{EI}{0.149R^3}$$

where

E = young's modulus - pipe material

I = moment of inertia, and

R = pipe radius:

Figure 2 represents a load deflection curve for a 450 mm 918 in) diameter CSP from a parallel plate test performed according to ASTM D2412 with a 1.8 m (6 ft) specimen length. Table 1 shows the results of flattering test and Figure 3 indicates the variation of PS with strain rate (head speed) in 600 mm pipes.

Following these results, the authors concluded, as far as SCP are concerned, that the consideration to have a significant effect on practical, in service stiffness include the followings:

- The actual stiffness of helical pipes is less than theoretical because of the orientation of the profile. At the same time, stiffness test results are significantly understated unless a suitable specimen length is used. For pipe diameters at least twice as large as the wrap width, a minimum specimen length of three times the wrap width appears to be appropriate. Pipe with larger helix angles require even longer test specimens to keep from understating stiffness.
- Excessively deep profiles cause high bending strains that can lead to yielding in metals.
- Reverse curvature occurred at deflections as low as 25 percent for CSP in the flattening test.

The stiffness of the steel pipe is unaffected by head speed.

Table A3.1 – Deflection Levels to Cause Reverse Curvature in the Flattening Test

Pipe	deflection (%)	approximate W/t
450mm CSP	25	--
300mm M294	31.7	10.5
375mm M294	21.8	13
600mm M294	38.6	10
900mm M294	23.5	14
300mm F949	34.6	9.2
600mm F949	33.6	9.2
900mm F949	34.7	8.5

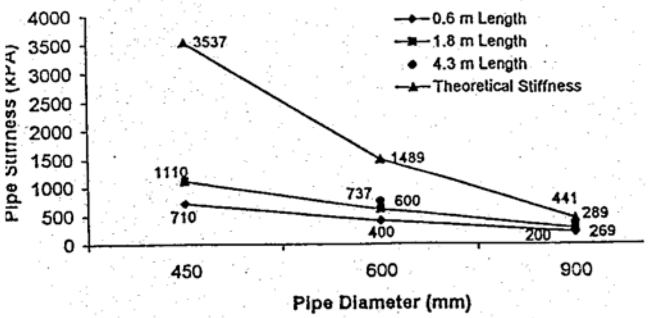


Figure A3.1 – CSP PS results showing helix angle effects

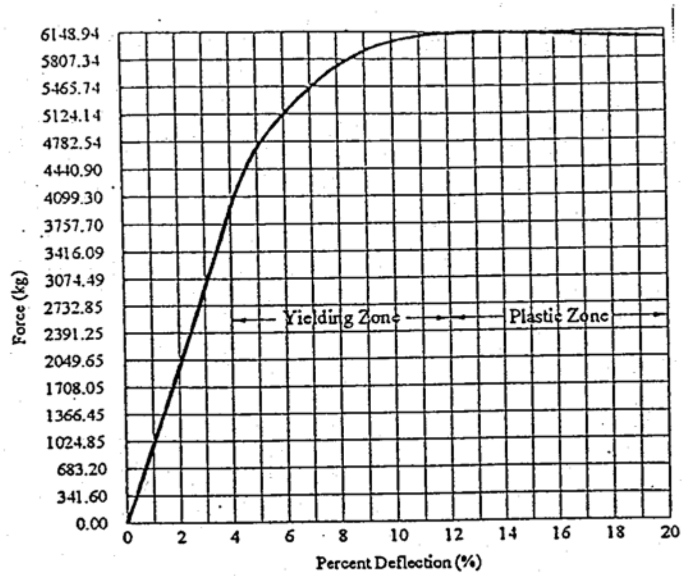


Figure A3.2 – Load-deflection curve (450 mm CSP)

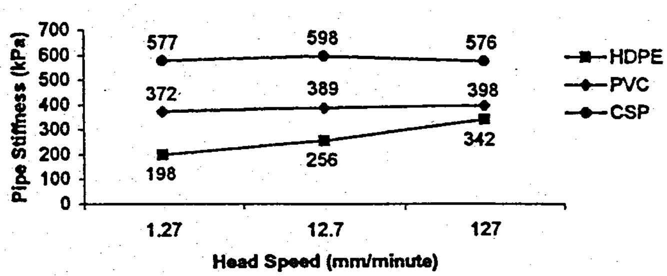


Figure A3.3 – Change in PS with strain rate (head speed) (600 mm pipes)

A.4 **Calculating Loads** on **Buried Culverts Based. on the Pipe Hoop Stiffness**

by Timothy J. McGrath, Transportation Research Record 1656, 1999

This paper investigated the significance of the hoop stiffness factor for determining load on flexible and rigid buried pipe and proposed a simplified design model for predicting loads based on the Burns and Richard theory.

Burns and Richard (1964) proposed a plane strain solution for stresses and deformations of an elastic circular tube and surrounding isotropic elastic continuum subjected to uniformly distributed loads (Figure 1). The solution uses the bending stiffness factor S_B, the hoop stiffness factor SH, and the Poisson's ratio of the soil as the principal parameters to define the problem. The load acting on a buried pipe W_p is generally expressed as function of the soil prism load W_{sp} as:

$$W_p = VAF \times W_{sp}$$

Where VAF is defined as the vertical arching factor.

The Burns and Richard theory offers two solutions for the condition of the interface between pipe and soil. The solution for the fully bonded interface where no shear displacement is allowed between the pipe and the soil is called the no-slip condition, and the solution for the frictionless interface where no shear stress is allowed to develop at the interface is called the full-slip condition.

The Burns and Richard equation for VAF based on thrust at the spring line with a no-slip interface is expressed as:

$$VAF = B(1 - a_0) + C(1 + a^2)$$

The Bums and Richard equation for VAF based on thrust at the spring line with a full-slip interface is expressed as:

$$VAF = B(1 - a_0) + \frac{C}{3}(1 + 3A_2 - 4B_2)$$

The coefficients used in these equations are defined in Appendix B.

Calculations were made to evaluate the possibility that a simpler equation could be derived without introducing significant error. These calculations were made with several types of pipe, and are summarized in Table 1.

The hypothesis that the hoop stiffness factor SH is the dominant term in evaluating the vertical arching factor was also tested by plotting the VAF computed with the Burns and Richard theory, versus the hoop stiffness factor SH (Figures 2 and 3). Results of these calculations and examination of the terms contributing to VAF indicates that reasonable accuracy can be obtained by setting the terms a_2, A_2 and B_2 to constant values and assuming that Poisson's ration of the soil is always 0.3 Following this study, the authors proposed a simplified design equations in the form of:

- No slip: $VAF = 1.06 - 0.96\left(\frac{S_H - 0.7}{S_H + 1.75}\right)$
- Full slip: $VAF = 0.76 - 0.71\left(\frac{S_H - 0.7}{S_H + 1.75}\right)$

The approximations were compared with calculations made by using the full Burns and Richard theory (Figures 2 and 3). The approximations showed good agreement with the full theory, even though the flexural stiffness of the pipe (pipe wall moment of inertia) was ignored as a variable.

Table A4.1 – Pipe Properties Used for VAF Analysis

Pipe Type	PS_B		PS_H		Modulus of elasticity	
	$\frac{E_0 I}{R^3}$ (kPa)	$\frac{E_{50} I}{R^3}$ (kPa)	$\frac{E_0 A}{R}$ (kPa)	$\frac{E_{50} A}{R}$ (kPa)	E_0 (kPa)	E_{50} (kPa)
Corrugated polyethylene	30	5.5	15,000	3,100	760,000	150,000
Ribbed polyethylene	28	6.9	23,000	5,900	550,000	140,000
Ribbed PVC	18	6.2	53,000	20,000	3×10^6	1.1×10^6
Corrugated metal	52		490,000		200×10^6	
Reinforced concrete	21,000		5.8×10^6		28×10^6	
Fiberglass	49	24	400,000	200,000	10×10^6	5×10^6

Notes:

1. Time dependence of thermoplastics is accounted for by computing parameters using both the initial modulus, E_0, and the 50 year modulus, E_{50}
2. Properties are typical values based on AASHTO and ASTM Standards but are not inclusive of all possible values for any given product.
3. 1 psi = 6.89 kPa

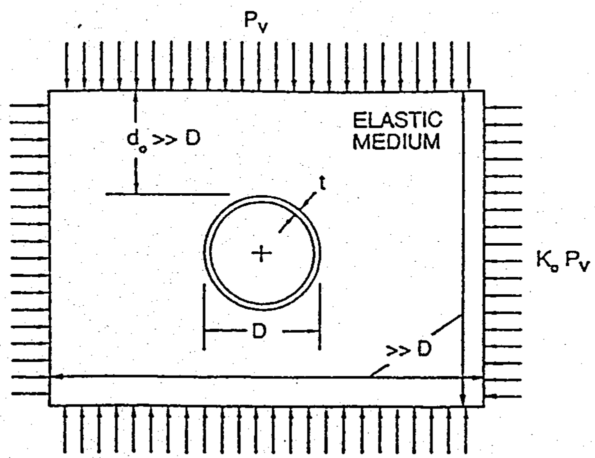


Figure A4.1 – Burns and Richard model for pipe embedded in an elastic plate.

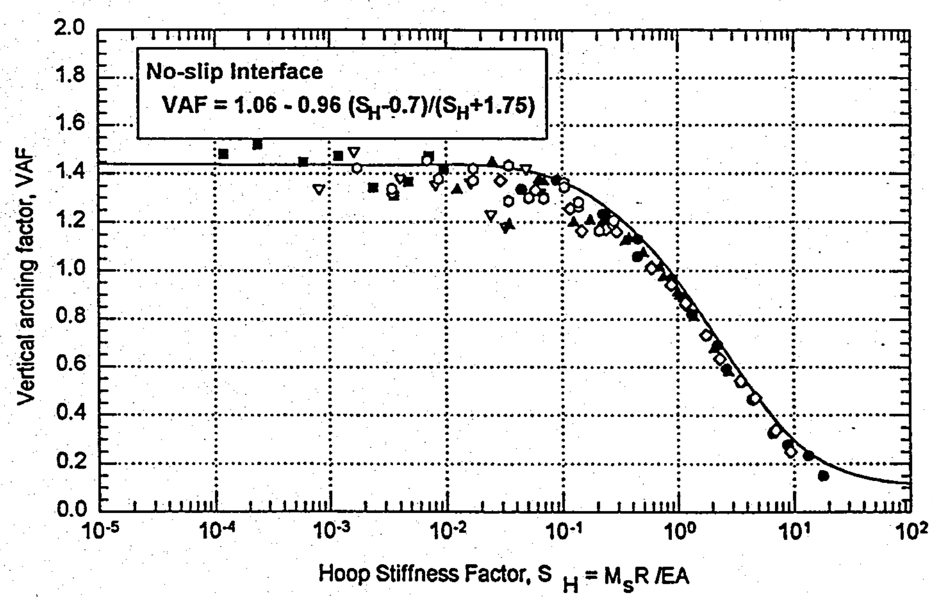


Figure A4.2 – Burns and Richard VAF : no-slip interface.

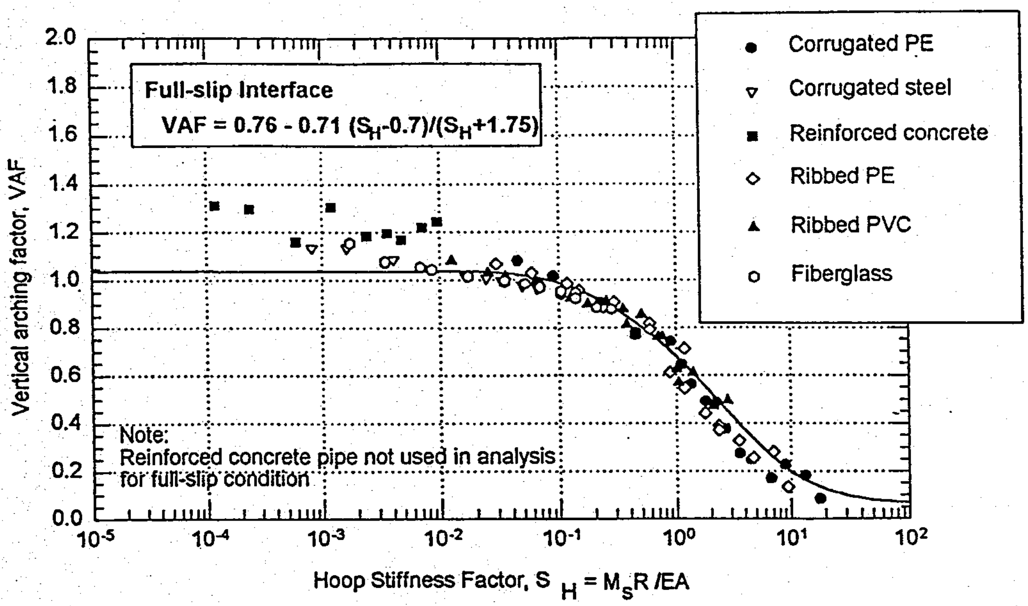


Figure A4.3 – Burns and Richard VAF : full-slip interface. PE = polyethylene; PVC = polyvinyl chloride.

A.5 Strength of Bell - and - Spigot Joints

by Roger L. Brockenbrough, Fellow, ASCE, Journal of Structural Engineering, Vol. 116, No. 7 (July 1990)

The paper first states that, for Bell - and - Spigot Joints (Fig. 1), axial (longitudinal) forces cause bending stresses in the joint region because of the geometric excentricity. Questions arise as how these stresses should be calculated and more importantly how they should be treated in design. Therefore, the paper presents a simple general - yielding approach that can be used to directly determine the strength of this type of steel - pipe joints.

The approach presented in this paper is based on the assumption that the weld is adequate to transmit the forces involved and that the steel, after fabrication, has the ductility and toughness necessary to allow the formation of a yield hinge. Based on these assumptions, the following equation for computing the axial - joint efficiency (F_a/F_y) has been derived

$$\frac{F_a}{F_y} = \left(k^2 + 1\right)^{\frac{1}{2}} - k$$

with: $$k = \frac{t+g}{t}$$

where:

- k= excentricity ratio, given as a function of the wall thickness (t) and the gap (g) between the bell and the spigot (see Fig. 1)
- F_Y = yield point
- F_a = average axial stress

The joint efficiency calculated using the above equation ranges from 0.41 for zero gap to 0.24 for a gap equal to the pipe thickness.

Comparison of the results to a finite-element analysis, to the ASME code, and to the results of tests conducted on specimens with double-fillet welds as well as single-fillet welds (Tables 1 and 2) shows that the equation is reasonable and conservative. Tests also show that a single full-thickness fillet weld can provide adequate strength.

Table A5.1 – Summary of Test Results on Fillet-Welded Bell-and-Spigot Pipe (61 in. I.D. by 5/16 in.), (Thompson Pipe and Steel Co., Unpublished 1984)

Test number	Calculated Pressure (psi)[a]			Test pressure (psi)	Experimental joint efficiency	Failure mode[b]	Radial gap (in.)	Weld Size (in.)	
	Longitudinal yield	Hoop yield	Hoop ultimate					I.D.	O.D.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
2	1,006	503	785	805	0.80	L[b]	0.05/0.08	5/16	1 /4
3	1,006	503	785	785	0.78	L[b]	0.03/0.10	1 /4	5/16
4	918	459	755	760	0.76	C[c]	0.05/0.08	5/16	--
5	918	459	755	695	0.76	C[c]	0.04/0.10	--	5/16
6	918	459	755	695	0.83	L[b]	0.09/0.11	5/16	--

[a]Based on measured tensile properites; biaxial effects not considered in calculations.
[b]Longitudinal rupture.
[c]Circumferential rupture.
Note : 1 psi = 6.89 kPa; 1 in. = 25.4 mm.

Table A5.2 – Summary of Test Results on Fillet-Welded Bell-and-Spigot Pipe (48 in. I.D. by 5/16 in.), (at consolidated Western Steel., Unpublished 1958)

Test number	Calculated Pressure (psi)[a]			Test pressure (psi)	Experimental joint efficiency	Failure mode[b]	Radial gap (in.)	Weld Size (in.)	
	Longitudinal yield	Hoop yield	Hoop ultimate					I.D.	O.D.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	860	430	781	800	0.93	C[b]	----	5/16	----
2	860	430	781	860	1.00	C[b]	----	5/16	----
3	860	430	781	850	0.99	X[c]	----	----	5/16
4	860	430	781	850	0.99	X[c]	----	----	5/16

[a]Based on specified minimum tensile properties; biaxial effects not considered in calculations.
[c]Circumferential rupture.
Note : 1 psi = 6.89 kPa; 1 in. = 25.4 mm.

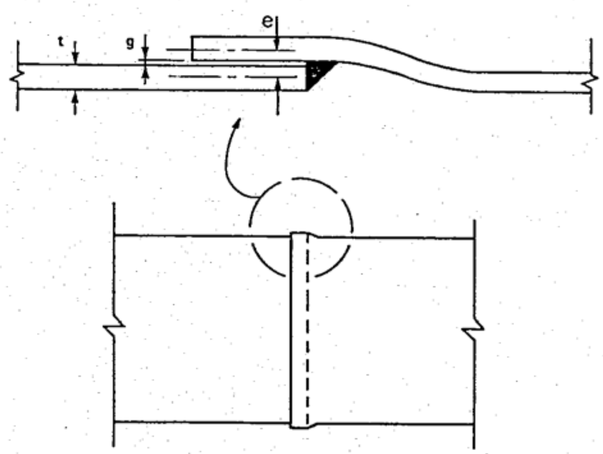


Figure A5.1 – Bell-and-Spigot Joint

A.6 Durability of corrugated Metal Culverts

by:Haviland et al. , *Report for Dept of Trans., State of New York (1967)*

as Summarized by

Raymond J. Krizek et al., Northwestern University, Evanston, Illinois.

The New York study by Haviland, Bellair, and Morrell is the outcome of two separate studies. One consists of a survey of 792 bituminous-coated and uncoated galvanized steel culverts installed between 1930 and 1963; a statistical evaluation of the measurable factors thought to control corrosion was made, and a design method was developed. The other is a comparative study of galvanized steel and alclad aluminum culvert exposed to similar conditions at 21 locations throughout the state.

Steel Culvert Survey

At each site pH, electrical resistivity, calcium carbonate content, and flow velocity were measured. The ranges of values encountered were as follows:

1. pH - varied from 3.8 to 9.4 with no apparent correlation between the values for water and soil at each site.
2. Resistivity - varied from 50 ohm-cm to 30,000 ohm-cm; with values for soil and water being fairly consistent at each site.
3. Calcium carbonate - qualitative determination at 148 sites indicated 76 saturated and 72 unsaturated conditions.
4. Flow velocity- of 291 sites tested, results indicated that 7 sites had a velocity of 5.0 to 7.9 fps (moderate); 113 sites, 2.0 to 4.9 fps (slow); and 171 sites, less than 2.0 fps (stagnant).

The distribution of surface treatment for the culverts was 11 uncoated, 238 bituminous coated, and 443 bituminous coated and paved.

Observation of the general condition of the culverts and of samples taken from the culverts indicated that:

(1) culvert extremities were far- more distressed than were interior portions (and conditions were not considered in the general evaluation),

(2) metal loss consistently originated on the interior surface and progressed outward,

(3) progressive corrosion was confined to the area below the waterline, and

(4) there was little evidence that abrasion was more than a minor contributor.

A statistical evaluation was made with the aid of an electronic computer on 146 installations for which complete data were available. The pH and resistivity of both soil and water and the age of each culvert were treated as independent variables, and metal loss in inches was treated as the `dependent variable. A stepwise regression technique was used to analyze the effect of sequentially eliminating each independent variable, and culvert age was found to be the only statistically significant factor. It could, therefore, be concluded that at least for the State of New York within the range of conditions tested, a culvert durability design based on the physical parameters measured at a particular site would be of little value. Apparently, other factors, such as oxygen concentration, temperature, and flow velocity, play a significant, but undetermined, role in the corrosion process. Unfortunately, the measurement of these parameters involves considerable difficulty, and prospects for including them in design criteria in the near future are small.

However, because a large quantity of data was available, it was possible to determine the degree of variability from the average straight-line relationship between metal loss and age. A corrosion design method, based on the probability of exceeding any given rate of metal loss, is suggested, and curves are shown in Figure 1 for the three cases of uncoated, coated, and coated/paved culverts. The following examples illustrate the use of these curves to determine the corrosion allowance to be made.

Example 1. - For a low-cover driveway pipe serving light traffic, a 30 to 40 percent probability of exceeding the determined corrosion rate is considered satisfactory. From the curve for uncoated pipe, one obtains a corrosion rate of approximately 0.0007 in./yr; if the required service life for the culvert is 25 years; the corrosion allowance should be 25 x 0.0007 = 0.002 in.

Example 2. - For a culvert under a high embankment on an Interstate Highway subjected to heavy traffic, it is desired to limit to 10 percent the probability of exceeding the determined corrosion rate. Use of the curve for coated pipe for a 50 year service life yields a calculated allowance for metal loss of 50 x 0.0017= 0.085 in.

Comparison Survey

The second study involved a comparison of aluminum and steel culverts exposed to similar conditions. Because the aluminum culverts were installed between 1961 and 1964, the results obtained from this study are considered only preliminary. In a few cases the exposure time for the steel culvert was considerably greater than that of its aluminum counterpart. The ranges of the pH, electrical resistivity, and stream velocity values agreed, in general, with those of the previous study. Because the aluminum :culverts showed no measurable metal loss, it is concluded from these limited results that bituminous coatings may be unnecessary for aluminum culverts "except in unusually aggressive chemical or abrasive environments." The performance of the steel culverts was consistant with the results of the previous statewide survey, and the average metal loss varied from zero to appreciable amounts.

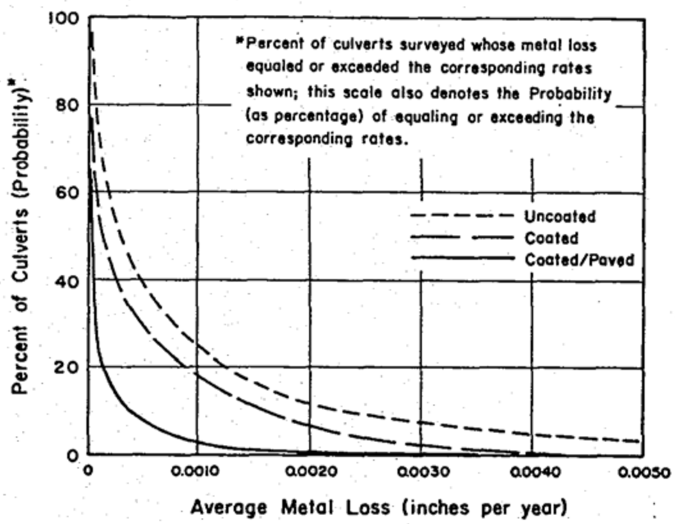


Figure A6.1 – Distribution of average metal loss for galvanized steel culverts (after Haviland, Bellair, and Morrell, 1967).

APPENDIX B

DERIVATION OF THE VERTICAL ARCHING FACTOR (VAF)

Calculating Loads on Buried Culverts Based on Pipe Hoop Stiffness

TIMOTHY J. MCGRATH

Evaluating the hoop compression capacity of buried pipe, whether for total stress, local buckling capacity, or general buckling capacity, requires an accurate design model to compute the compressive thrust in the pipe wall. Flexible pipe has traditionally been designed based on the assumption that vertical soil load is the weight of soil directly over the pipe, known as the "soil prism load." Field experience and research have shown that some pipe with low cross-sectional area and low modulus of elasticity can be buried at depths much greater than calculated by using the soil prism load, indicating that this load assumption is too conservative under some conditions. Investigation using the Burns and Richard elasticity solution for a circular tube embedded in an elastic medium shows that the ratio of the soil stiffness to the pipe hoop stiffness (EA/R) is often the controlling factor in determining the load on a buried pipe instead of the flexural stiffness of the pipe. The significance of the hoop stiffness factor for determining load on flexible and rigid buried pipe is explored here and development of a simplified design model for predicting loads based on the Burns and Richard theory is presented. The proposed equations are consistent with past practice and with tests showing that pipe with low hoop stiffness can carry far greater depths of fill than predicted by past practice.

Traditional design procedures for computing loads on buried pipe require classifying a pipe as either flexible or rigid. Load theories for rigid pipe were developed by Marston, Schlick, and others (*1,2*) and flexible pipe theories were developed by Spangler (*3*) and by White and Layer (*4*). Under typical embankment installation conditions, theories for flexible pipe generally predict loads to be less than or equal to the soil prism load and theories for rigid pipe generally predict loads to be greater than the soil prism load. The soil prism load is the weight of soil directly over the pipe, indicated in Figure 1 and calculated as follows:

$$W_{sp} = \gamma_s(H + 0.11D_o)D_o \qquad (1)$$

where

- W_{sp} = soil prism load, kN/m (lb/ft),
- γ_s = unit weight of soil, kN/m³ (lb/ft³),
- H = depth of fill over top of pipe, m (ft), and
- D_o = outside diameter of pipe, m (ft).

It is convenient to express the load on the pipe as a function of the soil prism load:

$$W_p = \text{VAF} \times W_{sp} \qquad (2)$$

where

- VAF = vertical arching factor, and
- W_p = load on the pipe, kN/m (lb/ft)

Simpson Gumpertz & Heger, Inc., 297 Broadway, Arlington, MA 02474.

If the load on a pipe is less than the soil prism load, the VAF is less than 1.0. The VAF for rigid pipe, installed under typical embankment installation conditions, is always approximately 1.4. Most flexible pipe is designed for a VAF of 1.0. VAF has been adopted as a load terminology for concrete pipe by AASHTO Specifications (*5,6*) and ASCE (*7*).

A pipe is generally classified as flexible or rigid based on the flexural stiffness of the pipe wall. In United States practice, the classification is made based on the pipe stiffness as determined from results of parallel plate testing (ASTM D 2412):

$$PS_B = \frac{F}{\Delta_y} = \frac{EI}{0.149R^3} \qquad (3)$$

where

- PS_B = pipe stiffness, kN/m/m (lb/in./in.), often determined at a deflection of 5 percent of the nominal inside diameter of the pipe,
- F = parallel plate load, kN/m (lb/in.),
- Δ_y = change in vertical diameter, m (in.),
- E = pipe material modulus of elasticity, kPa (psi),
- I = pipe wall moment of inertia, mm⁴/mm (in.⁴/in.), and
- R = radius to the centroid of the pipe wall, mm (in.).

Researchers evaluating soil structure interaction with continuum theories, such as finite-element analyses or the Burns and Richard (*8*) elasticity solution for a ring embedded in an elastic medium, have concluded that a pipe is actually classified as flexible or rigid based on the relative stiffness of the pipe and the soil in which it is embedded. This is expressed as follows:

$$S_B = \frac{M_sR^3}{EI} \qquad (4)$$

where

- S_B = bending stiffness factor, ratio of soil stiffness to pipe wall flexural stiffness, and
- M_s = constrained modulus of soil, kPa (psi).

M_s is used as the parameter to describe soil stiffness for buried pipe problems because soil around pipe is highly confined. It is a true elastic property that has been related by several researchers (*9–11*) to the empirical modulus of soil reaction, E', which is commonly used in flexible pipe design, and several researchers (*9,10*) have concluded that E' and M_s can be directly substituted for each other. The constrained modulus represents the stiffness of soil under uniaxial strain conditions as indicated in Figure 2, which demonstrates the use of the secant constrained modulus (average modulus) to represent the soil behavior over a stress range (0 to p_v) or the tan-

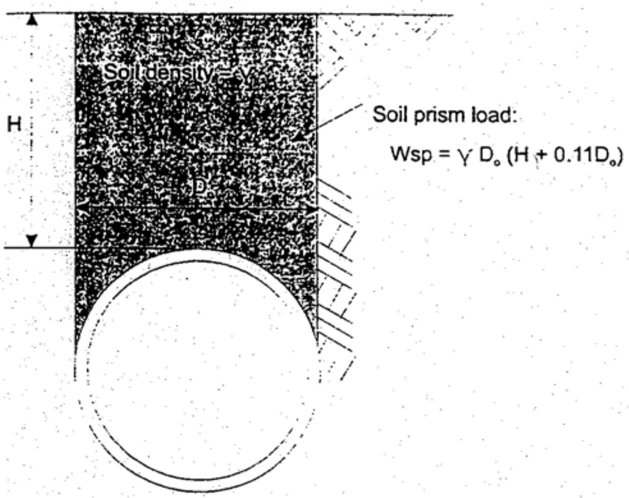


FIGURE 1 Definition of soil prism load.

gent modulus (instant modulus) to represent the soil behavior at a specific stress (p_s). The constrained modulus is related to the Young's modulus by the expression:

$$M_s = \frac{E_s(1-\nu)}{(1+\nu)(1-2\nu)} \tag{5}$$

where

E_s = Young's modulus of soil, kPa (psi), and
ν = Poisson's ratio of soil.

The other parameter that is significant in the solution of buried pipe problems is the pipe hoop stiffness:

$$PS_H = \frac{EA}{R} \tag{6}$$

where

PS_H = pipe hoop stiffness, kPa (psi), and
A = pipe wall area, mm²/mm (in.²/in.).

The pipe hoop stiffness can also be combined with the soil stiffness to form an interaction parameter:

$$S_H = \frac{M_s}{PS_H} = \frac{M_s R}{EA} \tag{7}$$

where S_H = hoop stiffness factor.

The pipe hoop stiffness has not received attention as a basis for design, because pipe traditionally has been relatively stiff in the hoop direction, and differences in flexural stiffness were sufficient to distinguish one type of pipe from another. Reinforced concrete, corrugated metal, clay, and other traditional pipe materials have pipe hoop stiffness values on the order of 500 to 5000 MPa (70,000 to 750,000 psi). Thermoplastic pipe has much lower hoop stiffnesses, as low as 3.5 MPa (500 psi) for profile wall polyethylene pipe under long-term loading. In this range it is no longer appropriate to disregard the hoop stiffness in pipe design.

LOAD REDUCTION DUE TO CIRCUMFERENTIAL SHORTENING

Katona and Akl (*12*) showed the benefit of pipe with low hoop stiffness by developing design recommendations for corrugated steel structural plate pipe with keyhole slotted connections. The slotted holes allow adjacent plates to slide over each other under earth load, effectively shortening the circumference of the pipe. This circumferential shortening results in substantial load reduction and, thus, substantial increases in allowable depth of fill for any given plate thickness. Hashash and Selig (*13*) reported a VAF of 0.23 and circumferential shortening of 1.5 percent for a corrugated polyethylene pipe test installation under 30 m (100 ft) of earth fill. This pipe was embedded in crushed stone compacted to 100 percent of maximum standard Proctor density.

BURNS AND RICHARD ELASTICITY SOLUTION

In 1964 Burns and Richard (*8*) proposed a plane strain solution for stresses and deformations of an elastic circular tube and surrounding isotropic elastic continuum subjected to uniformly distributed loads (Figure 3). This solution has received considerable attention (*14*) for use in pipe design and was incorporated as a Level 1 solution in the Federal Highway Administration's computerized culvert design program CANDE (*15,16*). The solution uses the bending stiffness factor S_B, the hoop stiffness factor S_H, and the

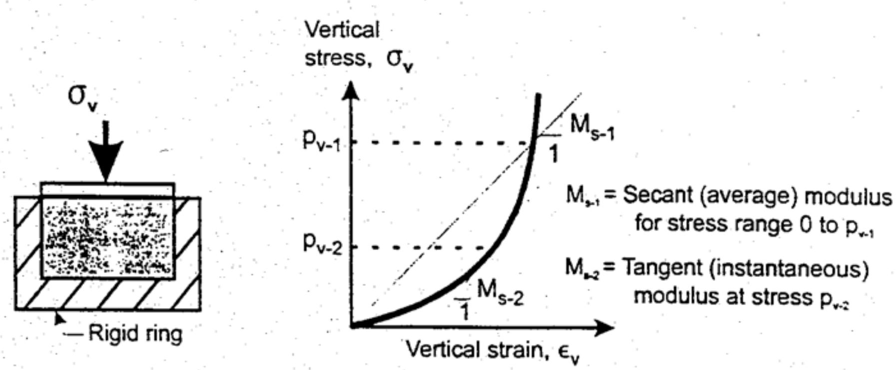


FIGURE 2 One-dimensional test and secant constrained modulus.

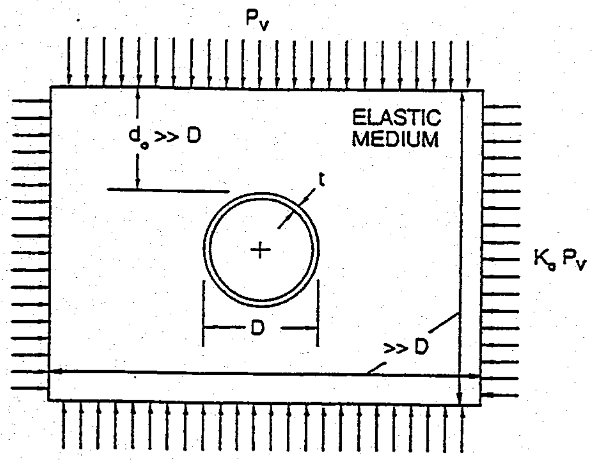


FIGURE 3 Burns and Richard model for pipe embedded in an elastic plate.

Poisson's ratio of the soil as the principal parameters to define the problem.

The Burns and Richard theory offers two solutions for the condition of the interface between pipe and soil. The solution for the fully bonded interface where no shear displacement is allowed between the pipe and the soil is called the no-slip condition, and the solution for the frictionless interface where no shear stress is allowed to develop at the interface is called the full-slip condition. The no-slip condition results in substantial variation of hoop compression forces around the pipe, with the maximum occurring at the spring line. The full-slip condition results in more uniform hoop compression forces around the circumference and lower peak forces relative to the no-slip condition.

The Burns and Richard equation for VAF based on thrust at the spring line with a no-slip interface is

$$\text{VAF} = B(1 - a_0) + C(1 + a_2) \tag{8}$$

The Burns and Richard equation for VAF based on thrust at the spring line with a full-slip interface is

$$VAF = B(1 - a_0) + \frac{C}{3}(1 + 3A_2 - 4B_2) \tag{9}$$

The coefficients used in these equations are defined as follows (ν is the Poisson's ratio of the soil):

$$C = \frac{1}{2}\left(\frac{1-2\nu}{1-\nu}\right) \tag{10}$$

$$B = \frac{1}{2}\left(\frac{1}{1-\nu}\right) \tag{11}$$

$$K = \frac{\nu}{1-\nu} \tag{12}$$

$$a_0 = \frac{\{(1+K)S_H\} - 1}{\{(1+K)S_H\} + \left(\frac{1}{1-2\nu}\right)} \tag{13}$$

$$a_2 = \frac{C[1 - \{(1+K)S_H\}]\left\{(1-K)\frac{S_B}{6}\right\} + [2B] - \left[\frac{C}{2}\frac{C}{B}\{(1+K)S_H\}\right]}{[1 + B + C\{(1+K)S_H\}]\left\{(1-K)\frac{S_B}{6}\right\} + 2(1+C) + \left[\left(1+\frac{C}{2}\right)\left(\frac{C}{B}\right)\{(1+K)S_H\}\right]} \tag{14}$$

$$B_2 = \frac{4C\frac{S_B}{6} - 1}{4C\frac{S_B}{6} - 1 + \frac{3}{B}} \tag{15}$$

$$A_2 = \frac{4C\frac{S_B}{6} - 1 + \frac{1}{B}}{4C\frac{S_B}{6} - 1 + \frac{3}{B}} \tag{16}$$

Equations 8 through 16 are cumbersome and calculations were made to evaluate the possibility that a simpler equation could be derived without introducing significant error. These calculations were made with several types of pipe, summarized in Table 1.

TABLE 1 Pipe Properties Used for VAF Analysis

	PS_B		PS_H		Modulus of elasticity	
Pipe Type	$\frac{E_0 I}{R^3}$ (kPa)	$\frac{E_{50} I}{R^3}$ (kPa)	$\frac{E_0 A}{R}$ (kPa)	$\frac{E_{50} A}{R}$ (kPa)	E_0 (kPa)	E_{50} (kPa)
corrugated polyethylene	30	5.5	15,000	3,100	760,000	150,000
ribbed polyethylene	28	6.9	23,000	5,900	550,000	140,000
ribbed PVC	18	6.2	53,000	20,000	3×10^6	1.1×10^6
corrugated metal	52		490,000		200×10^6	
reinforced concrete	21,000		5.8×10^6		28×10^6	
fiberglass	49	24	400,000	200,000	10×10^6	5×10^6

Notes:

1. Time dependence of thermoplastics is accounted for by computing parameters using both the initial modulus, E_0, and the 50 year modulus, E_{50}
2. Properties are typical values based on AASHTO and ASTM Standards but are not inclusive of all possible values for any given product.
3. 1 psi = 6.89 kPa

The constrained soil modulus was varied from 0.7 to 55 MPa (100 to 8,000 psi) and the Poisson's ratio of the soil was varied from 0.2 to 0.4.

The hypothesis that the hoop stiffness factor is the dominant term in evaluating the vertical arching factor was tested by plotting the VAF computed with the Burns and Richard theory, versus the hoop stiffness factor S_H. Results of these calculations (Figures 4 and 5) for the no-slip and full-slip conditions, respectively, indicate the following:

- The VAF drops significantly for high values of S_H, which occurs when the soil stiffness is high relative to the pipe hoop stiffness. Polyethylene and polyvinyl chloride pipes fall into this category.
- The values for VAF form a curved line with little scatter, except for concrete pipe in the full slip condition.
- The VAF for pipe with S_H values $<10^{-1}$ fall into ranges that are consistent with historical practice for computing load on pipe. Design VAF values for concrete pipe are between 1.2 and 1.4, and design VAF values for corrugated metal pipe are between 1.0 and 1.4.

Also of interest is that the predicted VAF for the traditional pipe (the flat portion of the curve) shows some scatter that disappears as the value of S_H increases and the VAF drops. The scatter is due to the variations in Poisson's ratio of the soil. The figure suggests that for pipe installations with low S_H the Poisson's ratio is not significant, which is logical because the pipe is shortening circumferentially and will be less sensitive to lateral soil pressure.

Examination of the terms contributing to VAF indicates that reasonable accuracy is obtained by setting the terms a_2, A_2, and B_2 to constant values and assuming that Poisson's ratio of the soil is always 0.3. Thus, the underlined terms in the following equations can be treated as constants:

No slip $$\mathrm{VAF} = B(1 - a_0) + \underline{C(1 + a_2)} \tag{17}$$

Full slip $$\mathrm{VAF} = B(1 - a_0) + \underline{\frac{C}{3}(1 + 3A_2 - 4B_2)} \tag{18}$$

To optimize the constants, the average and standard deviation of the error between the full Burns and Richard solution and the approximations were minimized.

- Percent error $$x = \left(\frac{\text{B \& R} - \text{Approx.}}{\text{B \& R}}\right)100 \tag{19}$$
- Average error $$\bar{x} = \frac{\sum x}{n} \tag{20}$$
- Standard deviation $$\sigma = \sqrt{\frac{\sum (x - \bar{x})^2}{n}} \tag{21}$$

The resulting best fit approximations are as follows:

No slip $$\mathrm{VAF} = 0.964(1 - a_0) + 0.095 \tag{22}$$

Full slip $$\mathrm{VAF} = 0.714(1 - a_0) + 0.05 \tag{23}$$

which, by substitution and rearranging terms, can be simplified to the proposed design equations:

No slip $$\mathrm{VAF} = 1.06 - 0.96\left(\frac{S_H - 0.7}{S_H + 1.75}\right) \tag{24}$$

Full slip $$\mathrm{VAF} = 0.76 - 0.71\left(\frac{S_H - 0.7}{S_H + 1.75}\right) \tag{25}$$

The approximations are compared with calculations made by using the full Burns and Richard theory in Figures 4 and 5. The approximations show good agreement with the full theory, even though the flexural stiffness of the pipe (pipe wall moment of inertia) was ignored as a variable. If pipes are designed using the hoop stiffness factor approach, then achieving the design soil stiffness in the field becomes a significant issue in controlling load.

Equations 24 and 25 for the no-slip and full-slip conditions are compared in Figure 6, with curves that show the sensitivity of the computed VAF to changes in the hoop stiffness factor. Moving vertically from

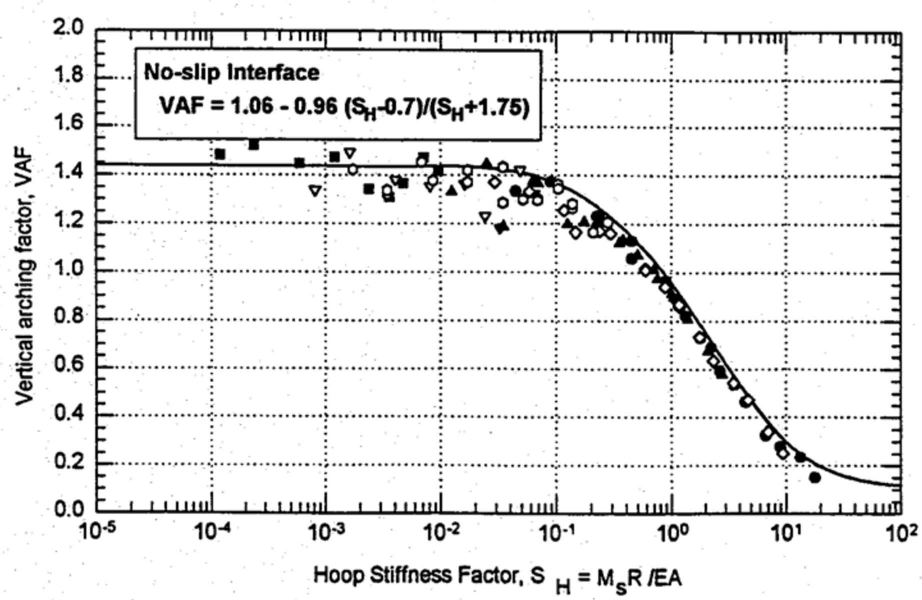


FIGURE 4 Burns and Richard VAF: no-slip interface.

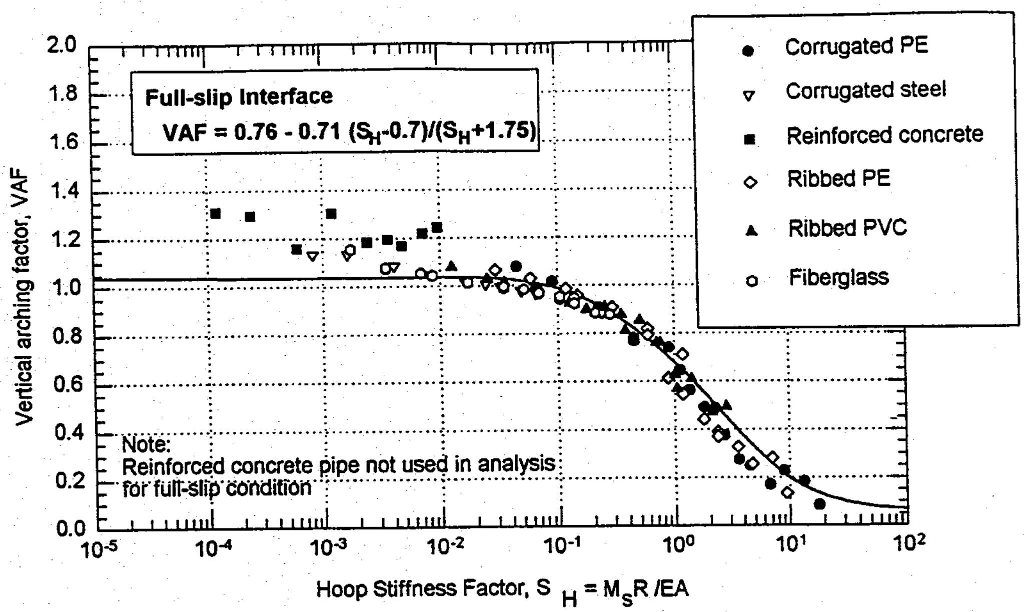


FIGURE 5 Burns and Richard VAF: full-slip interface. PE = polyethylene; PVC = polyvinyl chloride.

the line marked $\phi = 1$ to the line marked $\phi = 0.5$ gives the increase in VAF due to a 50 percent reduction in soil stiffness while holding pipe properties constant. Traditional pipe, such as concrete and corrugated steel, is in a region of the curve where changes in the hoop stiffness do not affect the load; however, the load on many of the thermoplastic pipe sections is significantly affected by the reduction in soil stiffness. In general, on the sloped portion of the curve, a 50 percent reduction in soil stiffness produces a 0.2 increase in the VAF. At a VAF of 0.2 this results in a 100 percent increase in load and at a VAF of 1.0 this results in a 20 percent increase in load.

EXAMPLE CALCULATIONS

Table 2 summarizes a calculation of the hoop compressive load and the hoop compressive capacity for a 600-mm (24-in.) inside diameter corrugated polyethylene pipe at a depth of 7 m (23 ft) and for two different soil conditions: M_s of 3.5 and 20 MPa (500 and 3,000 psi), and assuming pipe properties as stated in AASHTO design specifications (*5,6*). Because AASHTO requires design for a factor of safety of approximately 2, the design example shows that a pipe installed in soil with a M_s of 21 MPa (3, 000 psi), generally considered to be a good installation, is adequate for both long-term and short-term loads. In soil with a lower modulus, $M_s = 3.5$ MPa (500 psi), the pipe is adequate in the short term but not in the long term. This calculation demonstrates the importance of proper installation practices. This finding is the same for both the full-slip and no-slip solutions, even though each method predicts different values for the arching factor and load.

Figure 7 demonstrates that, even though the VAF, and hence the load, is larger as the wall thickness increases, the factor of safety also increases.

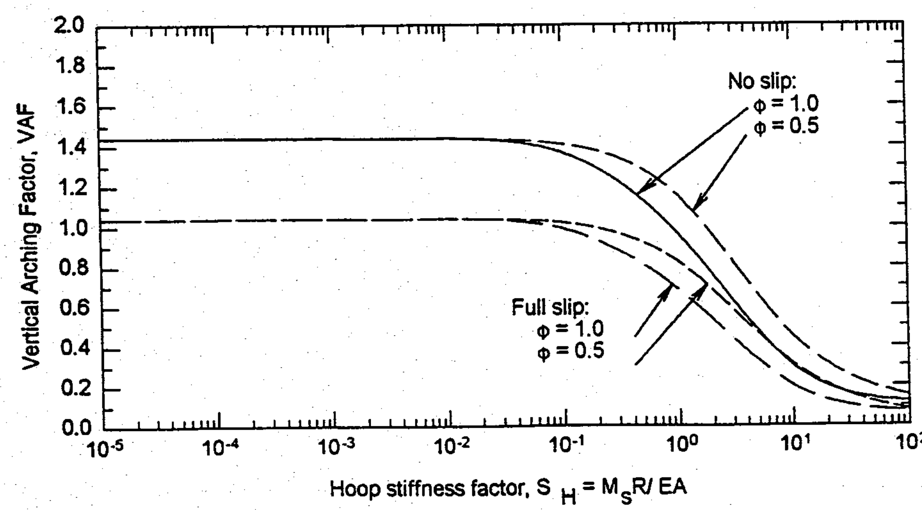


FIGURE 6 Sensitivity of VAF to variations in soil stiffness.

TABLE 2 Example Calculation for Hoop Compression Forces

			Short Term Properties		Long Term Properties	
Pipe and Soil Properties	A	mm²/mm	6.35	6.35	6.35	6.35
	R	mm	330	330	330	330
	R_o	mm	360	360	360	360
	Modulus	MPa	760	760	150	150
	Strength	MPa	21	21	6	6
	Soil unit weight	kN/m³	18.8	18.8	18.8	18.8
	Depth of fill	m	7	7	7	7
	M_s	MPa	3.5	21	3.5	21
	S_H		0.24	1.44	1.21	7.28
No-slip	VAF		1.28	0.84	0.89	0.36
	Wall thrust	kN/m	61	40	43	17
	Capacity	kN/m	133	133	38	38
	F of S		2.17	3.32	0.89	2.21
Full-slip	VAF		0.92	0.60	0.64	0.24
	Wall thrust	kN/m	44	29	31	12
	Capacity	kN/m	133	133	38	38
	F of S		3.01	4.67	1.25	3.28

DISCUSSION OF RESULTS

Application of the Burns and Richard theory to buried pipe design problems has received a great deal of attention since it was first proposed over 30 years ago; however, the equations are somewhat cumbersome and the concern that the Burns and Richard solution was too idealized has limited its use in actual practice. Figures 4 and 5 indicate that this concern is not necessary when the theory is used to predict loads. The evaluation presented here suggests that the simplified Burns and Richard equations to predict load on buried pipe are suitable for use in design. The VAF values are consistent with past practice for traditional pipe, with the keyhole slotted designs used in the corrugated steel pipe industry, and with recent research on corrugated polyethylene pipe under deep fills. Designers should be aware of the sensitivity of the load calculation to actual soil stiffness and design for anticipated installed soil stiffnesses.

Analysis reported elsewhere (*10,14*) suggests that the modulus of soil reaction, E', values proposed by Howard (*17*) can be used directly for the one-dimensional modulus (M_s) in the equations; however, research also shows that actual values of the one-dimensional modulus are variable with depth, and new design values have been

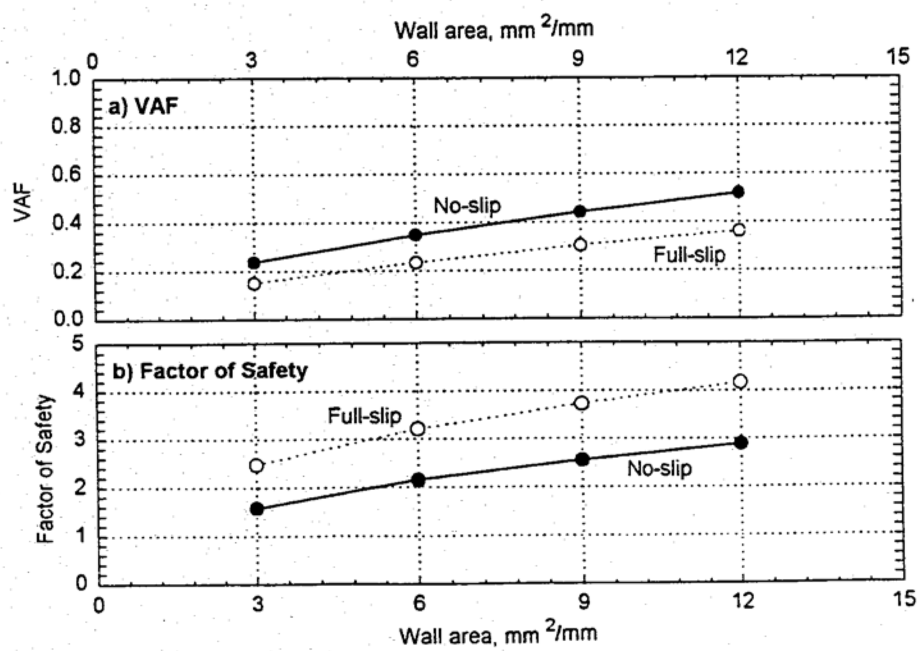


FIGURE 7 Effect of changing wall area on VAF and factor of safety.

proposed (*18*) based on the same nonlinear soil properties that were used to develop the new concrete pipe design methods recently adopted by AASHTO (*5,6*).

CONCLUSIONS

Traditional methods for computing loads on buried pipe are based on an assumption of high hoop stiffness, expressed as the term EA/R. Current thermoplastic pipe products have low hoop stiffnesses and the load predicted by traditional methods can substantially overestimate actual loads. The Burns and Richard elasticity solution has been shown to consider both the flexural and the hoop stiffness of buried pipe and predicts loads that are consistent with past practice for rigid and flexible pipe and with research on corrugated polyethylene pipe. A simplified version of the Burns and Richard method is proposed for computing loads based solely on the pipe hoop stiffness and the soil stiffness. Little accuracy is lost by disregarding the flexural stiffness of the pipe in the calculations.

REFERENCES

1. Marston, A. *The Theory of External Loads on Closed Conduits in the Light of the Latest Experiments*. Bulletin 96, Iowa State College, 1930.
2. Marston, A., and A. O. Anderson. *The Theory of Loads on Pipes in Ditches and Tests of Cement and Clay Drain Tile and Sewer Pipe*. Bulletin 31, Iowa State College, 1913.
3. Spangler, M. G. *The Structural Design of Flexible Pipe Culverts*. Iowa Engineering Experiment Station, Bulletin No. 153, Ames, IA, 1941.
4. White, H. L., and J. P. Layer. The Corrugated Metal Conduit as a Compression Ring. *HRB Proc.*, Vol. 39, 1960, pp. 389–397.
5. *LRFD Bridge Design Specifications*, 1st ed. AASHTO, Washington, D.C., 1994.
6. *Standard Specifications for Highway Bridges*, 16th ed. AASHTO, Washington, D.C., 1996.
7. *Standard Practice for Direct Design of Buried Precast Concrete Pipe Using Standard Installations*. ANSI/ASCE 15-93. ASCE, New York, 1994.
8. Burns, J. Q., and R. M. Richard. Attenuation of Stresses for Buried Cylinders. *Proc. Symposium on Soil Structure Interaction*, University of Arizona, Tucson, Arizona, 1964, pp. 378–392.
9. Chambers, R. E., T. J. McGrath, and F. J. Heger. *NCHRP Report 225: Plastic Pipe for Subsurface Drainage of Transportation Facilities*. TRB, National Research Council, Washington, D.C., Oct. 1980.
10. Hartley, J. P., and J. M. Duncan. E′ and its Variations with Depth. *Journal of Transportation Engineering*. Vol. 113, No. 5, 1987, pp. 538–553.
11. Selig, E. T. Soil Properties for Plastic Pipe Installations. In *Buried Plastic Pipe Technology, ASTM STP 1093* (G. S. Buczala and M. J. Cassady, eds.), American Society for Testing and Materials, Philadelphia, PA, 1990.
12. Katona, M. G., and A. Y. Akl. Structural Design of Buried Culverts and Slotted Joints. *Journal of Structural Engineering*, Vol. 113, No. 1, 1987, pp. 44–60.
13. Hashash, N., and E. T. Selig. Analysis of the Performance of Buried High Density Polyethylene Pipe. In *Structural Performance of Flexible Pipes*, Balkema, Rotterdam, 1990.
14. Krizek, R. J., R. A. Parmelee, N. J. Kay, and H. A. Elnaggar. *NCHRP Report 116: Structural Analysis and Design of Buried Culverts*. TRB, National Research Council, Washington, D.C., 1971.
15. Katona, M. G., et al. *CANDE: Engineering Manual—A Modern Approach for the Structural Design of Buried Culverts*. Report No. FHWA/RD-77. NCEL, Port Hueneme, CA, 1976.
16. Musser, S. C., M. G. Katona, and E. T. Selig. *CANDE-89 User Manual*, FHWA, Turner-Fairbank Highway Research Center, McLean, VA, 1989.
17. Howard, A. K. Modulus of Soil Reaction Values for Buried Flexible Pipe. *Journal of the Geotechnical Engineering Division*. Vol. 103, No. 1, New York, 1977.
18. McGrath, T. J. Replacing E′ with the Constrained Modulus in Buried Pipe Design. *Proc. Conference Pipelines in the Constructed Environment*, ASCE, 1998.

Publication of this paper sponsored by Committee on Subsurface Soil-Structure Interaction.

APPENDIX C

EXTRACT FORM ASSHTO LRFD BRIDGE DESIGN SPECIFICATIONS

SECTION 12 - TABLE OF CONTENTS

LRFD Design spec Section 12

TABLE OF CONTENTS (Continued)

SPECIFICATIONS

12.1 SCOPE

This section provides requirements for the selection of structural properties and dimensions of buried structures, e.g., culverts, and steel plate used to support tunnel excavations in soil.

Buried structure systems considered herein are metal pipe, structural plate pipe, long-span structural plate, structural plate box, reinforced concrete pipe, reinforced concrete cast-in-place and precast arch, box and elliptical structures, and thermoplastic pipe.

The type of liner plate considered is cold-formed steel panels.

COMMENTARY

C12.1

For buried structures, refer to Article 2.6.6 for hydraulic design considerations and FHWA (1985) for design methods related to location, length, and waterway openings.

12.2 DEFINITIONS

Abrasion - Loss of section or coating of a culvert by the mechanical action of water conveying suspended bed load of sand, gravel, and cobble-size particles at high velocities with appreciable turbulence.

Buried Structure - A generic term for a structure built by embankment or trench methods.

Corrosion - Loss of section or coating of a buried structure by chemical and/or electrochemical processes.

Culvert - A curved or rectangular buried conduit for conveyance of water, vehicles, utilities, or pedestrians.

FEM - Finite Element Method

Narrow Trench Width - The outside span of rigid pipe, plus 1.0 FT.

Projection Ratio - Ratio of the vertical distance between the outside top of the pipe and the ground or bedding surface to the outside vertical height of the pipe, applicable to reinforced concrete pipe only.

Soil Envelope - Zone of controlled soil backfill around culvert structure required to ensure anticipated performance based on soil-structure interaction considerations.

Soil-Structure Interaction System - A buried structure whose structural behavior is influenced by interaction with the soil envelope.

Tunnel - A horizontal or near horizontal opening in soil excavated to a predesigned geometry by tunneling methods exclusive of cut-and-cover methods.

12.3 NOTATION

A = wall area (IN^2/FT); constant corresponding to the shape of the pipe (12.7.2.3)
A_L = sum of all axle loads in an axle group (KIP); total axle load on single axle or tandem axles (KIP) (12.9.4.2) (12.9.4.3)
A_s = tension reinforcement area on width b (IN^2/FT) (C12.10.4.2.4a)
A_{smax} = minimum flexural reinforcement area without stirrups (IN^2/FT) (12.10.4.2.4c)
A_T = area of the top portion of the structure above the springline (FT^2) (12.8.4.2)
A_{vr} = stirrup reinforcement area to resist radial tension forces on cross-section width b in each line of stirrups at circumferential spacing s (IN^2/FT) (12.10.4.2.6)
A_{vs} = required area of stirrups for shear reinforcement (IN^2/FT) (12.10.4.2.6)
B = width of culvert (FT) (C12.6.2.2.4)

$_c$ = outside diameter or width of the structure (FT) (12.6.6.3)
$'_c$ = out-to-out vertical rise of pipe (FT) (12.6.6.3)
$_d$ = horizontal width of trench at top of pipe (FT) (12.10.2.1.2)
$_{FE}$ = earth load bedding factor (12.10.4.3.1)
$_{FLL}$ = live load bedding factor (12.10.4.3.1)
$_1$ = crack control coefficient for effect of cover and spacing of reinforcement (C12.10.4.2.4d)
= width of section resisting M, N, and V; usually b = 12.0 IN (12.10.4.2.4)
$_A$ = constant corresponding to the shape of the pipe (12.10.4.3.2a)
$_c$ = load coefficient for positive pipe projection (12.10.4.3.2a)
$_d$ = load coefficient for trench installation (12.10.2.1.2)
$_{dt}$ = load coefficient for tunnel installation (12.13.2.1)
$_H$ = adjustment factor for shallow cover heights over metal box culverts (12.9.4.4)
$_l$ = live load adjustment coefficient for axle loads, tandem axles, and axles with other than four wheels; C_1 C_2 A_L (12.9.4.2)
= parameter that is a function of the vertical load and vertical reaction (12.10.4.3.2a)
= construction stiffness for tunnel liner plate (K/IN) (12.5.6.4)
= 1.0 for single axles and 0.5 + S/50 $\leq$ 1.0 for tandem axles; adjustment coefficient for number of axles; crack control coefficient for various types of reinforcement (12.9.4.2) (12.9.4.3) (C12.10.4.2.4d)
= adjustment factor for number of wheels on a design axle as specified in Table 1; adjustment coefficient for number of wheels per axle (12.9.4.2) (12.9.4.3)
= distance from inside face to neutral axis of thermoplastic pipe (IN); distance from inside surface to neutral axis (IN) (12.12.3.7) (12.12.3.6)
= straight leg length of haunch (IN); pipe diameter (IN); required D-load capacity of reinforced concrete pipe (KLF) (12.9.4.1) (12.6.6.2) (12.10.4.3.1)
oad = resistance of pipe from three-edge bearing test load to produce a 0.01-IN crack (KLF) (12.10.4.3)
= effective diameter of thermoplastic pipe (IN) (12.12.3.7)
= inside diameter of pipe, IN (12.10.4.3.1)
= required envelope width adjacent to the structure (FT); distance from compression face to centroid of tension reinforcement (IN) (12.8.5.3) (12.10.4.2.4a)
= width of warped embankment fill to provide adequate support for skewed installation (FT) (C12.6.8.2)
= distance from the structure (FT) (12.8.5.3)
= long-term, i.e., 50-year, modulus of elasticity of the plastic (KSI) (12.12.3.3)
= modulus of elasticity of metal (KSI) (12.7.2.4)
) = lateral unbalanced distributed load on culvert below sloping ground and skewed at end wall (LBS) (C12.6.2.2.4)
= concentrated load acting at the crown of a culvert (KIP) (C12.6.2.2.5)
= factor for the effect of curvature on diagonal tension, shear, strength in curved components (12.10.4.2.5)
= factor for adjusting crack control relative to average maximum crack width of 0.01 IN corresponding to F_{cr} = 1.0 (12.10.4.2.4d)
= factor for crack depth effect resulting in increase in diagonal tension, shear, and strength with decreasing d (12.10.4.2.5)
= soil-structure interaction factor for embankment installations (12.10.2.1)
= flexibility factor (IN/KIP) (12.5.6.3) (12.7.2.6)
= coefficient for effect of thrust on shear strength (12.10.4.2.5)
= factor for process and local materials affecting radial tension strength of pipe (12.10.4.2.3)
= factor for pipe size effect on radial tension strength (12.10 4.2.4c)
= soil-structure interaction factor for trench installations (12.10.2.1)
= specified minimum tensile strength (KSI) (12.7.2.4)
= factor for process and local materials that affect the shear strength of the pipe (12.10.4.2.3)
= yield strength of metal (KSI) (12.7.2.3)
= compressive strength of concrete (KSI) (12.4.2.2)
= critical buckling stress (KSI) (12.7.2.4)
= specified minimum yield point for reinforcing steel (KSI) (12.10.4.2.4a)
= rise of culvert (FT); height of cover from the box culvert rise to top of pavement (FT); height of cover over crown (FT); height of fill above top of pipe (FT) (C12.6.2.2.5) (12.9.4.2) (12.9.4.4) (12.10.2.1)
= horizontal arching factor (12.10.2.1)
$_n$ = design height of cover above top of culvert or above crown of arches or pipes (FT) (C12.6.2.2.5)

H_L = headwall strip reaction (KIP) (C12.6.2.2.5)
H_1 = depth of crown of culvert below ground surfaces (FT); height of cover above the footing to traffic surface (FT) (C12.6.2.2.5) (12.8.4.2)
H_2 = actual height of cover above top of culvert or above crown of arches or pipes (FT); height of cover from the structure springline to traffic surface (FT) (C12.6.2.2.5) (12.8.4.2)
h = vertical distance from the top of cover for design height to point of horizontal load application (FT); wall thickness of pipe (IN); height of ground surface above top of pipe (FT) (C12.6.2.2.5) (12.10.4.2.4a)
h_w = height of water surface above top of pipe (FT) (12.12.3.6)
I = moment of inertia (IN^4/IN) (12.7.2.6)
ID = inside diameter (IN) (12.6.6.3)
K = ratio of the unit lateral effective soil pressure to unit vertical effective soil pressure, i.e., Rankine coefficient of active earth pressure (12.10.4.2)
K_h = lateral earth pressure for culvert under sloping ground (PSF/LF) (C12.6.2.2.5)
K_{h1} = lateral earth pressure distribution acting on upslope surface of culvert (PSF/LF) (C12.6.2.2.5)
K_{h2} = lateral earth pressure distribution acting on downslope surface of culvert (PSF/LF) (C12.6.2.2.5)
k = soil stiffness factor (12.7.2.4) (12.13.3.3)
L = distance along length of culvert from expansion joint to the centerline of the headwall (FT); length of stiffening rib on leg (IN) (C12.6.2.2.5) (12.9.4.1)
L_w = lane width (FT) (12.8.4.2)
M_{dl} = dead load moment (K-FT/FT); sum of the nominal crown and haunch dead load moments (K-FT/FT) (12.9.4.2)
M_{dlu} = factored dead load moment as specified in Article 12.9.4.2 (K-FT) (12.9.4.3)
M_{ll} = live load moment (K-FT/FT); sum of the nominal crown and haunch live load moments (K-FT/FT) (12.9.4.2)
M_{llu} = live load moment as specified in Article 12.9.4.2 (K-FT) (12.9.4.3)
M_{nu} = factored moment acting on cross-section width "b" as modified for effects of compressive or tensile thrust (K-FT/FT) (12.10.4.2.5)
M_{pc} = crown plastic moment capacity (K-FT/FT) (12.9.4.3)
M_{ph} = haunch plastic moment capacity (K-FT/FT) (12.9.4.3)
M_s = soil modulus (KSI); bending moment at service limit state (KIP-IN/FT) (12.12.3.6) (12.10.4.2.4d)
M_u = ultimate moment acting on cross-section width b (KIP-IN/FT) (12.10.4.2.4a)
N_s = axial thrust acting on cross-section of width b at service limit state (KIP/FT) (12.10.4.2.4d)
N_u = axial thrust acting on cross-section width b at strength limit state (KIP/FT) (12.10.4.2.4a)
n = number of adjoining traffic lanes (12.8.4.2)
P_{Brg} = allowable bearing pressure to limit compressive strain in the trench wall or embankment (KSF) (12.8.5.3)
P_c = proportion of total moment carried by crown of metal box culvert (12.9.4.3)
P_L = factored design crown pressure (KSF) (12.7.2.2)
P_1 = horizontal pressure from the structure at a distance d_1 (KSF) (12.8.5.3)
p = positive projection ratio (12.10.4.3.2a)
p' = negative projection ratio (12.10.4.3.2a)
q = ratio of the total lateral pressure to the total vertical pressure (12.10.4.3.2a)
R = rise of structure (FT); rise of box culvert or long-span structural plate structures (FT); radius of pipe (IN) (12.8.4.1) (12.9.4.1) (12.12.3.6)
R_{AL} = axle load correction factor (12.9.4.6)
R_c = corner radius of the structure (FT); concrete strength correction factor (12.8.5.3) (12.9.4.6)
R_d = ratio of resistance factors specified in Article 5.5.4.2 for shear and moment (12.10.4.2.4c)
R_f = factor related to required relieving slab thickness, applicable for box structures where the span is less than 26.0 FT (12.9.4.6)
R_H = horizontal reaction component (K/FT) (12.8.4.2)
R_h = haunch moment reduction factor (12.9.4.3)
R_n = nominal resistance (KLF) (12.5.1)
R_r = factored resistance (KLF) (12.5.1)
R_T = top arc radius of long-span structural plate structures (FT) (12.8.3.2)
R_V = vertical footing reaction component (K/FT) (12.8.4.2)
r = radius of gyration (IN); radius to centerline of concrete pipe wall (IN) (12.7.2.4) (12.10.4.2.5)
r_c = radius of crown (FT) (12.9.4.1)
r_h = radius of haunch (FT) (12.9.4.1)

SPECIFICATIONS | COMMENTARY

- = radius of the inside reinforcement (IN) (12.10.4.2.4c)
- d = settlement ratio parameter (12.10.4.3.2a)
- = 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)
- = internal diameter or horizontal span of the pipe (IN) (12.10.4.2.4b)
- = spacing of circumferential reinforcement (IN) (12.10.4.2.4d)
- 1, S_2 = shear forces acting along culvert bearing lines (LBS) (C12.6.2.2.5)
- = spacing of stirrups (IN) (12.10.4.2.6)
- = total dead load and live load thrust in the structure (KIP/FT) (12.8.5.3)
- L = factored thrust (KIP/FT) (12.7.2.2)
- = required thickness of cement concrete relieving slab (IN) (12.9.4.6)
- = basic thickness of cement concrete relieving slab (IN); clear cover over reinforcement (IN) (12.9.4.6) (12.10.4.2.4d)
- = unfactored footing reaction (K/FT) (12.9.4.5)
- AF = vertical arching factor (12.10.2.1)
- = factored shear force acting on cross-section width b which produces diagonal tension failure without stirrup reinforcement (KIP/FT) (12.10.4.2.6)
- L = $[H_2(S)\ A_T]\ \gamma_s/2$ (K/FT) (12.8.4.2)
- = headwall strip reaction (KIP) (C12.6.2.2.5)
- L = $n(A_L)/(8 + 2\ H_1)$ (K/FT) (12.8.4.2)
- = nominal shear resistance of pipe section without radial stirrups per unit length of pipe (KIP/FT) (12.10.4.2.5)
- = factored shear resistance per unit length (KIP/FT) (12.10.4.2.5)
- = ultimate shear force acting on cross-section width b (KIP/FT) (12.10.4.2.5)
- = total earth load on pipe or liner (KIP/FT) (12.10.2.1)
- = fluid load in the pipe (KIP/FT) (12.10.4.3.1)
- = total live load on pipe or liner (KIP/FT) (12.10.4.3.1)
- = total dead and live load on pipe or liner (KIP/FT) (12.10.4.3.1)
- = parameter which is a function of the area of the vertical projection of the pipe over which active lateral pressure is effective (12.10.4.3.2a)
- = skew angle between the highway centerline or tangent thereto and the culvert headwall (DEG) (C12.6.2.2.5)
- = angle of fill slope measured from horizontal (DEG) (C12.6.2.2.5)
- = unit weight of backfill (KCF) ; soil unit weight (KCF) (12.9.2.2) (12.9.4.2)
- = return angle of the structure (DEG); haunch radius included angle (DEG) (12.8.4.2) (12.9.4.1)
- = coefficient of friction between the pipe and soil (12.10.2.1.2)
- = resistance factor (12.5.1)
- = resistance factor for flexure (12.10.4.2.4c)
- = coefficient of friction between the fill material and the sides of the trench (12.10.4.3.2a)
- = resistance factor for radial tension (12.10.4.2.4c)
- = central angle of pipe subtended by assumed distribution of external reactive force (DEG) (12.10.4.2.1)

SOIL AND MATERIAL PROPERTIES

.1 Determination of Soil Properties

.1.1 GENERAL

Subsurface exploration shall be carried out to rmine the presence and influence of geologic and ironmental conditions that may affect the ormance of buried structures. For buried structures orted on footings and for pipe arches and large neter pipes, a foundation investigation should be lucted to evaluate the capacity of foundation erials to resist the applied loads and to satisfy the ement requirements of the structure.

C12.4.1.1

The following information may be useful for design:

- Strength and compressibility of foundation materials;
- Chemical characteristics of soil and surface waters, e.g., pH, resistivity, and chloride content of soil and pH, resistivity, and sulfate content of surface water;

SPECIFICATIONS

COMMENTARY

- Stream hydrology, e.g., flow rate and velocity, maximum width, allowable headwater depth, and scour potential; and
- Performance and condition survey of culverts in the vicinity.

12.4.1.2 FOUNDATION SOILS

The type and anticipated behavior of the foundation soil shall be considered for stability of bedding and settlement under load.

C12.4.1.2

Refer to Article 10.4 for general guidance regarding foundation soil properties. The performance of rigid pipes is dependent on foundation and bedding stability.

12.4.1.3 ENVELOPE BACKFILL SOILS

The type, compacted density and strength properties of the soil envelope adjacent to the buried structure shall be established. The backfill soils comprising the soil envelope shall conform to the requirements of AASHTO M 145 as follows:

- For standard flexible pipes and concrete structures: A-1, A-2, or A-3 (GW, GP, SW, SP, GM, SM, SC, GC),
- For metal box culverts and long-span structures with cover less than 12.0 FT: A-1, A-2-4, A-2-5, or A-3 (GW, GP, SW, SP, GM, SM, SC, GC), and
- For long-span metal structures with cover not less than 12.0 FT: A-1 or A-3 (GW, GP, SW, SP, GM, SM).

C12.4.1.3

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

Wall stresses in buried structure are sensitive to the relative stiffness of the soil and pipe. Buckling stability of flexible culverts is dependant on soil stiffness.

In the selection of a type of backfill for the envelope, the quality of the material and its suitability for achieving the requirements of the design should be considered. The order of preference for selecting envelope backfill based on quality may be taken as follows:

- Angular, well-graded sand and gravel;
- Nonangular, well-graded sand and gravel;
- Flowable materials, e.g., cement-soil-fly ash mixtures, which result in low density/low strength backfill, for trench applications only;
- Uniform sand or gravel, provided that placement is confirmed to be dense and stable, but which may require a soil or geofabric filter to prevent the migration of fines;
- Clayey sand or gravel of low plasticity; and
- Stabilized soil, which should be used only under the supervision of an Engineer familiar with the behavior of the material.

12.4.2 Materials

12.4.2.1 ALUMINUM PIPE AND STRUCTURAL PLATE STRUCTURES

Aluminum for corrugated metal pipe and pipe-arches shall comply with the requirements of AASHTO M 196 (ASTM B 745). Aluminum for structural plate pipe,

SPECIFICATIONS

COMMENTARY

pipe-arch, arch, and box structures shall meet the requirements of AASHTO M 219 (ASTM B 746).

12.4.2.2 CONCRETE

Concrete shall conform to Article 5.4, except that f'_c may be based on cores.

12.4.2.3 PRECAST CONCRETE PIPE

Precast concrete pipe shall comply with the requirements of AASHTO M 170 (ASTM C 76) and M 242 (ASTM C 655). Design wall thickness, other than the standard wall dimensions, may be used, provided that the design complies with all applicable requirements of Section 12.

12.4.2.4 PRECAST CONCRETE STRUCTURES

Precast concrete arch, elliptical, and box structures shall comply with the requirements of AASHTO M 206 (ASTM C 506), M 207 (ASTM C 507), M 259 (ASTM C 789), and M 273 (ASTM C 850).

12.4.2.5 STEEL PIPE AND STRUCTURAL PLATE STRUCTURES

Steel for corrugated metal pipe and pipe-arches shall comply with the requirements of AASHTO M 36 (ASTM A 760). Steel for structural plate pipe, pipe-arch, arch, and box structures shall meet the requirements of AASHTO M 167 (ASTM A 761).

12.4.2.6 STEEL REINFORCEMENT

Reinforcement shall comply with the requirements of Article 5.4.3, and shall conform to one of the following AASHTO M 31 (ASTM A 615), M 32 (ASTM A 82), M 55 (ASTM A 185), M 221 (ASTM A 497), or M 225 (ASTM A 496).

For smooth wire and smooth welded wire fabric, the yield strength may be taken as 65.0 KSI. For deformed welded wire fabric, the yield strength may be taken as 70.0 KSI.

12.4.2.7 THERMOPLASTIC PIPE

Plastic pipe may be solid wall, corrugated, or profile wall and may be manufactured of polyethylene (PE) or polyvinyl chloride (PVC).

PE pipe shall comply with the requirements of ASTM F 714 for solid wall pipe, AASHTO M 294 for corrugated pipe, and ASTM F 894 for profile wall pipe.

SPECIFICATIONS

PVC pipe shall comply with the requirements of AASHTO M 278 for solid wall pipe, ASTM F 679 for solid wall pipe, and AASHTO M 304 for profile wall pipe.

12.5 LIMIT STATES AND RESISTANCE FACTORS

12.5.1 General

Buried structures and their foundations shall be designed by the appropriate methods specified in Articles 12.7 through 12.12 so that they resist the factored loads given by the load combinations specified in Articles 12.5.2 and 12.5.3.

The factored resistance, R_r, shall be calculated for each applicable limit state as:

$$R_r = \varphi R_n \quad (12.5.1\text{-}1)$$

where:

R_n = the nominal resistance

φ = the resistance factor specified in Table 12.5.5-1

12.5.2 Service Limit State

Buried structures shall be investigated at Service Load Combination I, as specified in Table 3.4.1-1.

- Deflection of metal structures, tunnel liner plate, and thermoplastic pipe, and
- Crack width in reinforced concrete structures.

12.5.3 Strength Limit State

Buried structures and tunnel liners shall be investigated for construction loads and at Strength Load Combinations I and II, as specified in Table 3.4.1-1, as follows:

- For metal structures:
  - wall area
  - buckling
  - seam failure
  - flexibility limit for construction
  - flexure of box structures only

COMMENTARY

C12.5.1

Procedures for determining nominal resistance are provided in Articles 12.7 through 12.12 for:

- Metal pipe, pipe arches, and arch structures;
- Long-span structural plate;
- Structural plate box structures;
- Reinforced precast concrete pipe;
- Reinforced concrete cast-in-place and precast box structures; and
- Thermoplastic pipe.

C12.5.2

Deflection of a tunnel liner depends significantly on the amount of overexcavation of the bore and is affected by delay in backpacking or inadequate backpacking. The magnitude of deflection is not primarily a function of soil modulus or the liner plate properties, so it cannot be computed with usual deflection formulae.

Where the tunnel clearances are important, the designer should oversize the structure to allow for deflection.

C12.5.3

Strength Load Combinations III and IV and the extreme event limit state do not control due to the relative magnitude of loads applicable to buried structures as indicated in Article 12.6.1. Buried structures have been shown not to be controlled by fatigue.

SPECIFICATIONS

- For concrete structures:
  - flexure
  - shear
  - thrust
  - radial tension
- For thermoplastic pipe:
  - wall area
  - buckling
  - flexibility limit
- For tunnel liner plate
  - wall area
  - buckling
  - seam strength
  - construction stiffness

12.5.4 Load Modifiers and Load Factors

Load modifiers shall be applied to buried structures and tunnel liners as specified in Article 1.3, except that the load modifiers for construction loads should be taken as 1.0. For strength limit states, buried structures shall be considered nonredundant under earth fill and redundant under live load and dynamic load allowance loads. Operational importance shall be determined on the basis of continued function and/or safety of the roadway.

12.5.5 Resistance Factors

Resistance factors for buried structures shall be taken as specified in Table 12.5.5-1. Values of resistance factors for the geotechnical design of foundations for buried structures shall be taken as specified in Section 10.

COMMENTARY

C12.5.5

The standard installations for direct design of concrete pipe were developed based on extensive parameter studies using the soil structure interaction program, SPIDA. Although past research validates that SPIDA soil structure models correlate well with field measurements, variability in culvert installation methods and materials suggests that the design for Type I installations be modified. This revision reduces soil structure interaction for Type I installations by 10 percent until additional performance documentation on installation in the field is obtained.

Table 12.5.5-1 - Resistance Factors for Buried Structures

STRUCTURE TYPE	RESISTANCE FACTOR
Metal Pipe, Arch, and Pipe Arch Structures	
Helical pipe with lock seam or fully welded seam:	
• Minimum wall area and buckling	1.00
Annular pipe with spot-welded, riveted, or bolted seam:	
• Minimum wall area and buckling	0.67
• Minimum seam strength	0.67
Structural plate pipe:	
• Minimum wall area and buckling	0.67
• Minimum seam strength	0.67
• Bearing resistance of pipe arch foundations	refer to Section 10
Long-Span Structural Plate and Tunnel Liner Plate Structures	
• Minimum wall area	0.67
• Minimum seam strength	0.67
• Bearing resistance of pipe arch foundations	refer to Section 10
Structural Plate Box Structures	
• Plastic moment strength	1.0
• Bearing resistance of pipe arch foundations	refer to Section 10
Reinforced Concrete Pipe	
Direct design method:	
Type 1 installation:	
• Flexure	0.90
• Shear	0.82
• Radial tension	0.82
Other type installations:	
• Flexure	1.00
• Shear	0.90
• Radial tension	0.90
Reinforced Concrete Cast-in-Place Box Structures	
• Flexure	0.90
• Shear	0.85
Reinforced Concrete Precast Box Structures	
• Flexure	1.00
• Shear	0.90
Reinforced Concrete Precast Three-Sided Structures	
• Flexure	0.95
• Shear	0.90
Thermoplastic Pipe	
PE and PVC pipe:	
• Minimum wall area and buckling	1.00

SPECIFICATIONS — COMMENTARY

2.5.6 Flexibility Limits and Construction Stiffness

2.5.6.1 CORRUGATED METAL PIPE AND STRUCTURAL PLATE STRUCTURES

Flexibility factors for corrugated metal pipe and tructural plate structures shall not exceed the values pecified in Table 1.

Table 12.5.6.1-1 - Flexibility Factor Limit

TYPE OF CONSTRUCTION MATERIAL	CORRUGATION SIZE (IN)	FLEXIBILITY FACTOR (IN/KIP)
Steel Pipe	0.25	43
	0.5	43
	1.0	33
Aluminum Pipe	0.25 and 0.50	
	0.060 Material Thk.	31
	0.075 Material Thk.	61
	All Others	92
	1.0	60
Steel Plate	6.0 x 2.0	
	Pipe	20
	Pipe-Arch	30
	Arch	36
Aluminum Plate	9.0 x 2.5	
	Pipe	25
	Pipe-Arch	36
	Arch	36

C12.5.6.1

Limits on construction stiffness and plate flexibility are construction requirements that do not represent any limit state in service.

.5.6.2 SPIRAL RIB METAL PIPE AND PIPE ARCHES

Flexibility factors for spiral rib metal pipe and pipe ches shall not exceed the values, specified in Table 1, embankment installations conforming to the visions of Articles 12.6.6.2 and 12.6.6.3 and for ich installations conforming to the provisions of icles 12.6.6.1 and 12.6.6.3.

SPECIFICATIONS

COMMENTARY

Table 12.5.6.2-1 - Flexibility Factor Limits

MATERIAL	CONDITION	CORRUGATION SIZE (IN)	FLEXIBILITY FACTOR (IN/KIP)
Steel	Embankment	0.75 x 0.75 x 7.5 0.75 x 1.0 x 11.5	$173\ I^{1/3}$ $140\ I^{1/3}$
	Trench	0.75 x 0.75 x 7.5 0.75 x 1.0 x 11.5	$200\ I^{1/3}$ $163\ I^{1/3}$
Aluminum	Embankment	0.75 x 0.75 x 7.5 0.75 x 1.0 x 11.5	$250\ I^{1/3}$ $175\ I^{1/3}$
	Trench	0.75 x 0.75 x 7.5 0.75 x 1.0 x 11.5	$300\ I^{1/3}$ $215\ I^{1/3}$

Values of inertia, I, for steel and aluminum pipes and pipe arches shall be taken as tabulated in Tables A12-2 and A12-5.

12.5.6.3 THERMOPLASTIC PIPE

Flexibility factor, FF, of thermoplastic pipe shall not exceed 95.0 IN/KIP.

C12.5.6.3

PE and PVC are thermoplastic materials that exhibit higher flexibility factors at high temperatures and lower flexibility factors at low temperatures. The specified flexibility factor limits are defined in relation to pipe stiffness values in accordance with ASTM D 2412 at 73.4°F.

12.5.6.4 STEEL TUNNEL LINER PLATE

Construction stiffness, C_s, in K/IN, shall not be less than the following:

- Two-flange liner plate

  $C_s \geq 0.050$ (K/IN)

- Four-flange liner plate

  $C_s \geq 0.111$ (K/IN)

C12.5.6.4

Assembled liner using two- and four-flange liner plates does not provide the same construction stiffness as a full steel ring with equal stiffness.

12.6 GENERAL DESIGN FEATURES

12.6.1 Loading

Buried structures shall be designed for force effects resulting from horizontal and vertical earth pressure, pavement load, live load, and vehicular dynamic load allowance. Earth surcharge, live load surcharge, and downdrag loads shall also be evaluated where construction or site conditions warrant. Water buoyancy

C12.6.1

Buried structures benefit from both earth shelter and support that reduce or eliminate from concern many of the loads and load combinations of Article 3.4. Wind, temperature, vehicle braking, and centrifugal forces typically have little effect due to earth protection. Structure dead load, pedestrian live load, and ice loads

PECIFICATIONS

ads shall be evaluated for buried structures with inverts ɘlow the water table to control flotation, as indicated in rticle 3.7.2. Earthquake loads should be considered ıly where buried structures cross active faults.

For vertical earth pressure, the maximum load factor ɔm Table 3.4.1-2 shall apply.

Wheel loads shall be distributed through earth fills ;cording to the provisions of Article 3.6.1.2.6.

.6.2 Service Limit State

.6.2.1 TOLERABLE MOVEMENT

Tolerable movement criteria for buried structures all be developed based on the function and type of ucture, anticipated service life, and consequences of acceptable movements.

.6.2.2 SETTLEMENT

.6.2.2.1 General

Settlement shall be determined as specified in Article 6.2. Consideration shall be given to potential ıvements resulting from:

Longitudinal differential settlement along the length of the pipe,

Differential settlement between the pipe and backfill, and

Settlement of footings and unbalanced loading of skewed structures extending through embankment slopes.

COMMENTARY

are insignificant in comparison with force effects due to earth fill loading.

Vehicular collision forces are applicable to appurtenances such as headwalls and railings only. Water, other than buoyancy and vessel collision loads, can act only in the noncritical longitudinal direction of the culvert.

Due to the absence or low magnitude of these loadings, Service Load Combination I, Strength Load Combinations I and II, or construction loads control the design.

The finite element analyses used in the preparation of these metal box structure provisions are based on conservative soil properties of low plasticity clay (CL) compacted to 90 percent density as specified in AASHTO T 99. Although low plasticity clay is not considered an acceptable backfill material, as indicated in Article 12.4.1.3, the FEM results have been shown to yield conservative, upperbound moments.

The loading conditions that cause the maximum flexural moment and thrust are not necessarily the same, nor are they necessarily the conditions that will exist at the final configuration.

SPECIFICATIONS

12.6.2.2.2 Longitudinal Differential Settlement

Differential settlement along the length of buried structures shall be determined in accordance with Article 10.6.2.2.3. Pipes and culverts subjected to longitudinal differential settlements shall be fitted with positive joints to resist disjointing forces meeting the requirements of Sections 26 and 27, AASHTO LRFD Bridge Construction Specifications.

Camber may be specified for an installation to ensure hydraulic flow during the service life of the structure.

12.6.2.2.3 Differential Settlement Between Structure and Backfill

Where differential settlement of arch structures is expected between the structure and the side fill, the foundation should be designed to settle with respect to the backfill.

Pipes with inverts shall not be placed on foundations that will settle much less than the adjacent side fill, and a uniform bedding of loosely compacted granular material should be provided.

12.6.2.2.4 Footing Settlement

Footings shall be designed to provide uniform longitudinal and transverse settlement. The settlement of footings shall be large enough to provide protection against possible downdrag forces caused by settlement of adjacent fill. If poor foundation materials are encountered, consideration shall be given to excavation of all or some of the unacceptable material and its replacement with compacted acceptable material.

Footing design shall comply with the provisions of Article 10.6.

Footing reactions for metal box culvert structures shall be determined as specified in Article 12.9.4.5.

The effects of footing depth shall be considered in the design of arch footings. Footing reactions shall be taken as acting tangential to the arch at the point of connection to the footing and to be equal to the thrust in the arch at the footing.

12.6.2.2.5 Unbalanced Loading

Buried structures skewed to the roadway alignment and extending through an embankment fill shall be designed in consideration of the influence of unsymmetrical loading on the structure section.

COMMENTARY

C12.6.2.2.3

The purpose of this provision is to minimize downdrag loads.

C12.6.2.2.4

Metal pipe arch structures, long-span arch structures, and box culvert structures should not be supported on foundation materials that are relatively unyielding compared with the adjacent sidefill. The use of massive footings or piles to prevent settlement of such structures is not recommended.

In general, provisions to accommodate uniform settlement between the footings are desirable, provided that the resulting total settlement is not detrimental to the function of the structure.

C12.6.2.2.5

Disregard of the effect of lateral unbalanced forces in the headwall design can result in failure of the headwall and adjacent culvert sections.

Due to the complexity of determining the actual load distribution on a structure subjected to unbalanced loading, the problem can be modeled using numerical

PECIFICATIONS

COMMENTARY

methods or the following approximate method. The approximate method consists of analyzing 1.0-FT wide culvert strips for the unbalanced soil pressures wherein the strips are limited by planes perpendicular to the culvert centerline. Refer to Figure C1 for this method of analysis for derivation of force F. For semicomplete culvert strips, the strips may be assumed to be supported as shown in the lower part of the plan. The headwall shall be designed as a frame carrying the strip reactions, V_L and $H_L \cos\alpha$, in addition to the concentrated force, F, assumed to be acting on the crown. Force F is determined using the equations given herein.

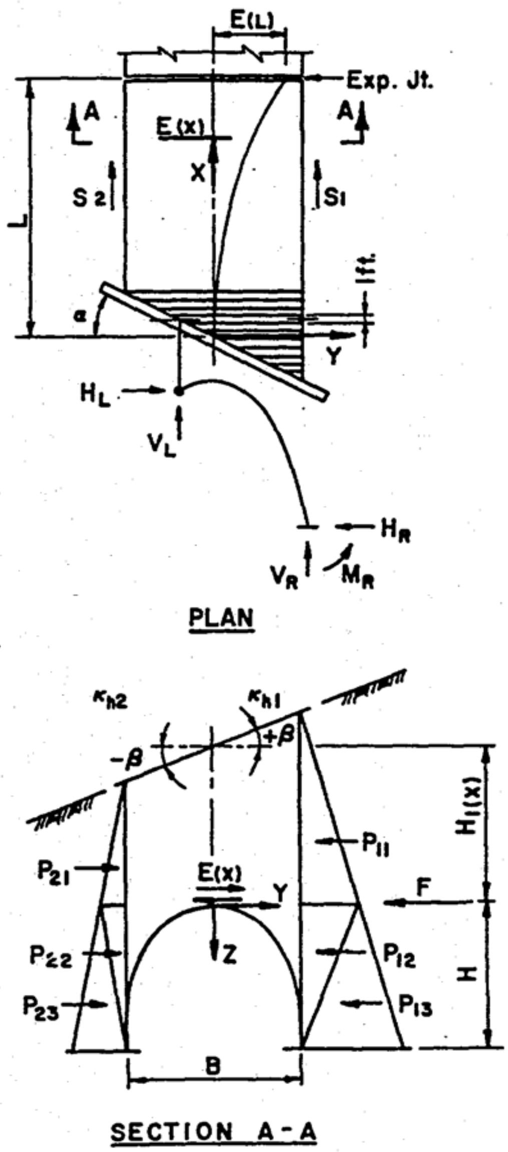


Figure C12.6.2.2.5-1 - Forces on Culvert - Approximate Analysis

SPECIFICATIONS

COMMENTARY

The unbalanced distributed load may be estimated by the following relationships:

$$E(x) = (P_{11} - P_{21}) + \frac{2}{3}(P_{12} - P_{22}) + \frac{1}{3}(P_{13} - P_{23}) \quad \text{(C12.6.2.2.5-1)}$$

for which:

$$\begin{aligned}
P_{11} &= \frac{1}{2}K_{h1}\left(H_{1(x)} + \frac{B}{2}\tan\beta\right)^2 \\
P_{21} &= \frac{1}{2}K_{h2}\left(H_{1(x)} - \frac{B}{2}\tan\beta\right)^2 \\
P_{12} &= \frac{1}{2}K_{h1}H\left(H_{1(x)} + \frac{B}{2}\tan\beta\right) \\
P_{22} &= \frac{1}{2}K_{h2}H\left(H_{1(x)} - \frac{B}{2}\tan\beta\right) \\
P_{13} &= \frac{1}{2}K_{h1}H\left(H + H_{1(x)} + \frac{B}{2}\tan\beta\right) \\
P_{23} &= \frac{1}{2}K_{h2}H\left(H + H_{1(x)} - \frac{B}{2}\tan\beta\right)
\end{aligned} \quad \text{(C12.6.2.2.5-2)}$$

When the pressures are substituted into Equation C1, the following results:

$$E(x) = A_2x^2 + A_1x + A_0 \quad \text{(C12.6.2.2.5-3)}$$

for which:

$$\begin{aligned}
A_2 &= \frac{1}{2}\left(\frac{H_{1(L)}}{L}\right)^2 (K_{h1} - K_{h2}) \\
A_1 &= \frac{1}{2}\left(\frac{H_{1(L)}}{L}\right) [B(K_{h1} + K_{h2})\tan\beta + H(K_{h1} - K_{h2})] \\
A_0 &= \frac{1}{24}[(3B^2\tan^2\beta + 4H^2)(K_{h1} - K_{h2}) \\
&\quad + 6HB(K_{h1} + K_{h2})\tan\beta]
\end{aligned}$$

(C12.6.2.2.5-4)

The support forces for the unbalanced distribution load, E(x), are:

$$F = \frac{1}{6} L\sec\alpha\,(2A_2L^2 + 3A_1L + 6A_0)$$

$$S_1 = -\frac{1}{12}\frac{L}{B}[A_2L^2(3L - 2B\tan\alpha) + A_1L(4L - 3B\tan\alpha + 6A_0(L - B\tan\alpha)]$$

$$S_2 = \frac{1}{12}\frac{L}{B}[A_2L^2(3L + 2B\tan\alpha) + A_1L(4L + 3B\tan\alpha + 6A_0(L + B\tan\alpha)]$$

(C12.6.2.2.5-5)

For values of K_h, see Figure 2.

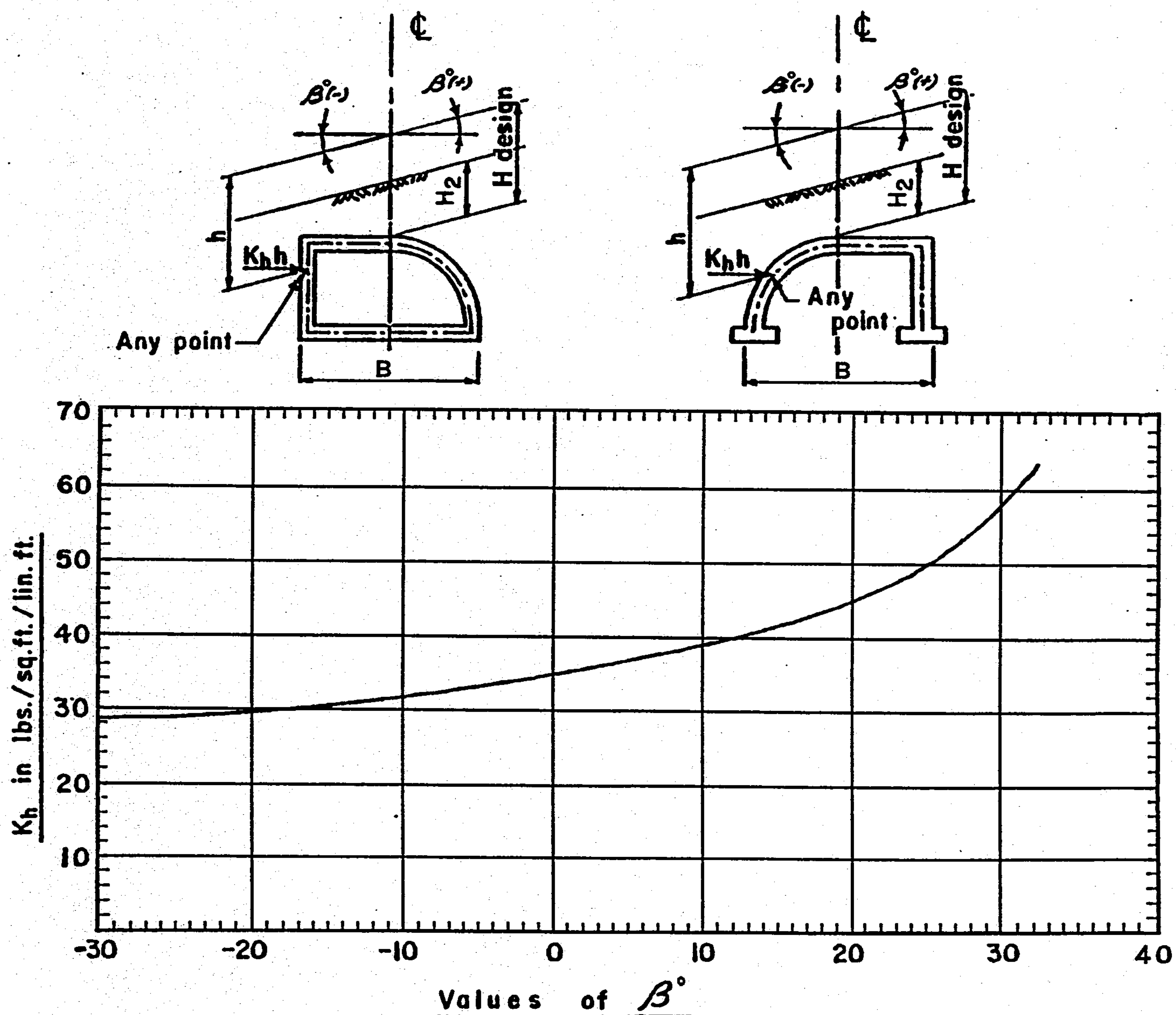


Figure C12.6.2.2.5-2 - Lateral Earth Pressure as a Function of Ground Slope

SPECIFICATIONS

12.6.2.3 UPLIFT

Uplift shall be considered where structures are installed below the highest anticipated groundwater level.

COMMENTARY

C12.6.2.3

To satisfy this provision, the dead load on the crown of the structure should exceed the buoyancy of the culvert, using load factors as appropriate.

12.6.3 Safety Against Soil Failure

12.6.3.1 BEARING RESISTANCE AND STABILITY

Pipe structures and footings for buried structures shall be investigated for bearing capacity failure and erosion of soil backfill by hydraulic gradients.

12.6.3.2 CORNER BACKFILL FOR METAL PIPE ARCHES

The corner backfill for metal pipe arches shall be designed to account for corner pressure taken as the arch thrust divided by the radius of the pipe-arch corner. The soil envelope around the corners of pipe arches shall resist this pressure. Placement of select structural backfill compacted to unit weights higher than normal may be specified.

12.6.4 Hydraulic Design

Design criteria, as specified in Article 2.6 and "Hydraulic Design of Highway Culverts," FHWA (1985), for hydraulic design considerations shall apply.

12.6.5 Scour

Buried structures shall be designed so that no movement of any part of the structure will occur as a result of scour.

In areas where scour is a concern, the wingwalls shall be extended far enough from the structure to protect the structural portion of the soil envelope surrounding the structure. For structures placed over erodible deposits, a cutoff wall or scour curtain, extending below the maximum anticipated depth of scour or a paved invert, shall be used. The footings of structures shall be placed not less than 2.0 FT below the maximum anticipated depth of scour.

12.6.6 Soil Envelope

12.6.6.1 TRENCH INSTALLATIONS

The minimum trench width shall provide 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

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.

PECIFICATIONS

The contract documents shall require that stability of e trench be ensured by either sloping the trench walls providing support of steeper trench walls in onformance with OSHA or other regulatory quirements.

COMMENTARY

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.

2.6.6.2 EMBANKMENT INSTALLATIONS

The minimum width of the soil envelope shall be ufficient to ensure lateral restraint for the buried ructure. The combined width of the soil envelope and nbankment beyond shall be adequate to support all e loads on the culvert and to comply with the ovement requirements specified in Article 12.6.2.

C12.6.6.2

As a guide, the minimum width of the soil envelope on each side of the buried structure should not be less than the widths specified in Table C1:

Table C12.6.6.2-1 - Minimum Width of Soil Envelope

Diameter, S (IN)	Minimum Envelope Width (FT)
< 24	S/12
24 - 144	2.0
> 144	5.0

2.6.6.3 MINIMUM SOIL COVER

The cover of a well-compacted granular subbase, ken from the top of rigid pavement or the bottom of exible pavement, shall not be less than that specified in able 1, where:

= diameter of pipe (IN)

$_c$ = outside diameter or width of the structure (FT)

$'_c$ = out-to-out vertical rise of pipe (FT)

) = inside diameter (IN)

SPECIFICATIONS

Table 12.6.6.3-1 - Minimum Soil Cover

TYPE	CONDITION	MINIMUM COVER
Corrugated Metal Pipe	-	S/8 ≥ 12.0 IN
Spiral Rib Metal Pipe	Steel Conduit	S/4 ≥ 12.0 IN
	Aluminum Conduit where S ≤ 48.0 IN	S/2 ≥ 12.0 IN
	Aluminum Conduit where S > 48.0 IN	S/2.75 ≥ 24.0 IN
Structural Plate Pipe Structures	-	S/8 ≥ 12.0 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
	Compacted granular fill under rigid pavement	9.0 IN
Thermoplastic Pipe	-	ID/8 ≥ 12.0 IN

If soil cover is not provided, the top of precast or cast-in-place reinforced concrete box structures shall be designed for direct application of vehicular loads.

12.6.7 Minimum Spacing Between Multiple Lines of Pipe

The spacing between multiple lines of pipe shall be sufficient to permit the proper placement and compaction of backfill below the haunch and between the structures.

Contract documents should require that backfilling be coordinated to minimize unbalanced loading between multiple, closely spaced structures. Backfill should be kept level over the series of structures when possible. The effects of significant roadway grades across a series of structures shall be investigated for the stability of flexible structures subjected to unbalanced loading.

COMMENTARY

C12.6.7

As a guide, the minimum spacing between pipes should not be less than that shown in Table 1.

PECIFICATIONS

COMMENTARY

Table C12.6.7-1 - Minimum Pipe Spacing

Type of Structure	Minimum Distance Between Pipes (FT)
Round Pipes Diameter, D (FT)	
< 2.0	1.0
2.0 - 6.0	D/2
> 6.0	3.0
Pipe Arches Span, S (FT)	
< 3.0	1.0
3.0 - 9.0	S/3
9.0 - 16.0	3.0
Arches Span, S (FT)	
All Spans	2.0

The minimum spacing can be reduced if a flowable backfill material, as specified in Article 12.4.1.3, is placed between the structures.

:.6.8 End Treatment

:.6.8.1 GENERAL

Protection of end slopes shall be given special nsideration where backwater conditions occur or iere erosion or uplift could be expected. Traffic safety atments, such as a structurally adequate grating that nforms to the embankment slope, extension of the lvert length beyond the point of hazard, or provision of ide rail, should be considered.

C12.6.8.1

Culvert ends may represent a major traffic hazard.

When backwater conditions occur, pressure flow at the outlet end of culverts can result in uplift of pipe sections having inadequate cover and scour of erosive soils due to high water flow velocities. Measures to control these problems include anchoring the pipe end in a concrete headwall or burying it in riprap having sufficient mass to resist uplift forces as well as lining outlet areas with riprap or concrete to prevent scour.

.6.8.2 FLEXIBLE CULVERTS CONSTRUCTED ON (EW

The end treatment of flexible culverts skewed to the adway alignment and extending through embankment shall be warped to ensure symmetrical loading along her side of the pipe or the headwall shall be designed support the full thrust force of the cut end.

C12.6.8.2

For flexible structures, additional reinforcement of the end is recommended to secure the metal edges at inlet and outlet against hydraulic forces. Reinforcement methods include reinforced concrete or structural steel

SPECIFICATIONS

COMMENTARY

collars, tension tiebacks or anchors in soil, partia headwalls, and cut-off walls below invert elevation.

As a guide in Figure 1, limits are suggested fo skews to embankments unless the embankment is warped. It also shows examples of warping ar embankment cross-section to achieve a square-endec pipe for single and multiple flexible pipe installations where the minimum width of the warped embankment d', is taken as 1.50 times the sum of the rise of the culvert and the cover or three times the span of the culvert, whichever is less..

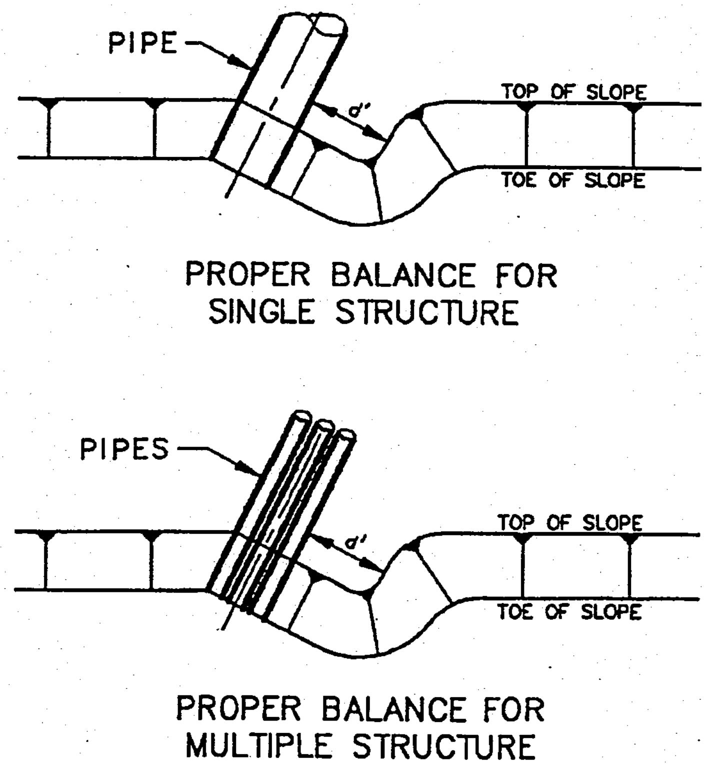


Figure C12.6.8.2-1 - End Treatment of Skewed Flexible Culvert

12.6.9 Corrosive and Abrasive Conditions

The degradation of structural resistance due to corrosion and abrasion shall be considered.

If the design of a metal or thermoplastic culvert is controlled by flexibility factors during installation, the requirements for corrosion and/or abrasion protection may be reduced or eliminated, provided that it is demonstrated that the degraded culvert will provide

C12.6.9

Several long-term tests of the field performance of buried structures have resulted in development of empirical guidelines for estimating the effects of corrosion and abrasion. A representative listing includes Bellair and Ewing (1984), Koepf and Ryan (1986), Hurd (1984), Meacham et al. (1982), Potter (1988), NCHRP Synthesis No. 50 (1978), and Bushman (1991).

For highly abrasive conditions, a special design may be required. Protective coatings may be shop- or field-applied in accordance with AASHTO M 190, M 224, M 243, and M 245 (ASTM A 762).

SPECIFICATIONS

adequate resistance to loads throughout the service life of the structure.

12.7 METAL PIPE, PIPE ARCH, AND ARCH STRUCTURES

12.7.1 General

The provisions herein shall apply to the design of buried corrugated and spiral rib metal pipe and structural plate pipe structures.

Corrugated metal pipe and pipe-arches may be of riveted, welded, or lockseam fabrication with annular or helical corrugations. Structural plate pipe, pipe-arches, and arches shall be bolted with annular corrugations only.

The rise-to-span ratio of structural plate arches shall not be less than 0.3.

The provisions of Article 12.8 shall apply to structures with a radius exceeding 13.0 FT.

12.7.2 Safety Against Structural Failure

Corrugated and spiral rib metal pipe and pipe arches and structural plate pipe shall be investigated at the strength limit state for:

- Wall area of pipe,
- Buckling strength, and
- Seam resistance for structures with longitudinal seams.

12.7.2.1 SECTION PROPERTIES

Dimensions and properties of pipe cross-sections, minimum seam strength; mechanical and chemical requirements for aluminum corrugated and steel corrugated pipe and pipe-arch sections; and aluminum and steel corrugated structural plate pipe, pipe-arch, and arch sections, may be taken as given in Appendix A12.

12.7.2.2 THRUST

The factored thrust, T_L, per unit length of wall shall be taken as:

$$T_L = P_L\left(\frac{S}{24}\right) \qquad (12.7.2.2\text{-}1)$$

COMMENTARY

C12.7.1

These structures become part of a composite system comprised of the metal pipe section and the soil envelope, both of which contribute to the structural behavior of the system.

For information regarding the manufacture of structures and structural components referred to herein, AASHTO M 196 (ASTM B 745) for aluminum, M 36 (ASTM A 760) for steel corrugated metal pipe and pipe-arches, and M 167 (ASTM A 761) for steel and M 219 (ASTM B 746) for aluminum structural plate pipe may be consulted.

SPECIFICATIONS

where:

T_L = factored thrust per unit length (K/FT)

S = pipe span (IN)

P_L = factored crown pressure (KSF)

12.7.2.3 WALL RESISTANCE

The factored axial resistance, R_n, per unit length of wall, without consideration of buckling, shall be taken as:

$$R_n = \varphi F_y A \quad (12.7.2.3\text{-}1)$$

where:

A = wall area (IN^2/FT)

F_y = yield strength of metal (KSI)

φ = resistance factor as specified in Article 12.5.5

12.7.2.4 RESISTANCE TO BUCKLING

The wall area, calculated using Equation 12.7.2.3-1, shall be investigated for buckling. If $f_{cr} < F_y$, A shall be recalculated using f_{cr} in lieu of F_y.

$$If\ S < \left(\frac{r}{k}\right)\sqrt{\frac{24E_m}{F_u}}, then;$$

$$f_{cr} = F_u - \frac{\left(\frac{F_u k S}{r}\right)^2}{48E_m} \quad (12.7.2.4\text{-}1)$$

$$If\ S > \left(\frac{r}{k}\right)\sqrt{\frac{24E_m}{F_u}}, then;$$

$$f_{cr} = \frac{12E_m}{\left(\frac{kS}{r}\right)^2} \quad (12.7.2.4\text{-}2)$$

where:

S = diameter of pipe or span of plate structure (IN)

E_m = modulus of elasticity of metal (KSI)

COMMENTARY

C12.7.2.4

The use of 0.22 for the soil stiffness is thought to be conservative for the types of backfill material allowed for pipe and arch structures. This lower bound on soil stiffness has a long history of use in previous editions of the Standard Specifications.

SPECIFICATIONS

u = tensile strength of metal (KSI)

= radius of gyration of corrugation (IN)

= soil stiffness factor taken as 0.22

2.7.2.5 SEAM RESISTANCE

For pipe fabricated with longitudinal seams, the ominal resistance of the seam shall be sufficient to evelop the factored thrust in the pipe wall, T_L.

2.7.2.6 HANDLING AND INSTALLATION EQUIREMENTS

Handling flexibility shall be indicated by a flexibility ictor determined as:

$$FF = \frac{S^2}{E_m I} \qquad (12.7.2.6\text{-}1)$$

here:

= diameter of pipe or span of plate structure (IN)

= moment of inertia of wall (IN^4/IN)

Values of the flexibility factors for handling and stallation shall not exceed the values for steel and uminum pipe and plate pipe structures as specified in ticle 12.5.6.

.7.3 Smooth Lined Pipe

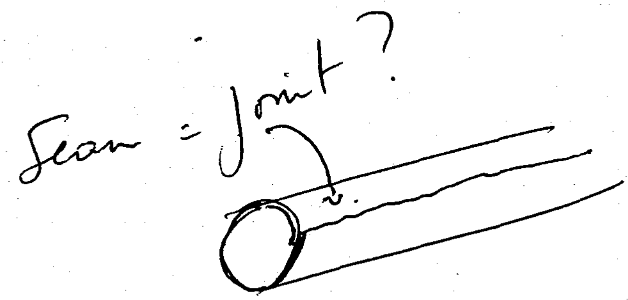
Corrugated metal pipe composed of a smooth liner id corrugated shell attached integrally at helical seams, aced not more than 30.0 IN apart, may be designed the same basis as a standard corrugated metal pipe iving the same corrugations as the shell and a weight r FT not less than the sum of the weights per FT of er and helically corrugated shell.

The pitch of corrugations shall not exceed 3.0 IN, id the thickness of the shell shall not be less than 60 rcent of the total thickness of the equivalent standard oe.

.7.4 Stiffening Elements for Structural Plate ructures

The stiffness and flexural resistance of structural ate structures may be increased by adding cumferential stiffening elements to the crown. iffening elements shall be symmetrical and shall span

COMMENTARY



C12.7.2.6

Transverse stiffeners may be used to assist corrugated structural plate structures to meet flexibility factor requirements.

C12.7.4

Acceptable stiffening elements are:

- Continuous longitudinal structural stiffeners connected to the corrugated plates at each side of

SPECIFICATIONS

from a point below the quarter-point on one side of the structure, across the crown, and to the corresponding point on the opposite side of the structure.

COMMENTARY

the top arc: metal or reinforced concrete, either singly or in combination; and

- Reinforcing ribs formed from structural shapes, curved to conform to the curvature of the plates, fastened to the structure to ensure integral action with the corrugated plates, and spaced at such intervals as necessary.

Section 12

SOIL-CORRUGATED METAL STRUCTURE INTERACTION SYSTEMS

12.1 GENERAL

12.1.1 Scope

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

Only Article 12.7 is applicable to structural plate box culverts.

12.1.2 Notations

A = required wall area (Article 12.2.1)
A = area of pipe wall (Article 12.3.1)
AL = total axle load on single axle or tandem axles (Articles 12.8.4.3.2 and 12.8.4.4)
C_1 = number of axles coefficient (Article 12.8.4.3.2)
C_2 = number of wheels per axle coefficient (Article 12.8.4.3.2)
C_{dl} = dead load adjustment coefficient (Article 12.8.4.3.2)
C_{ll} = live load adjustment coefficient (Article 12.8.4.3.2)
D = straight leg of haunch (Article 12.8.2)
E_m = modulus of elasticity of metal (Articles 12.2.2 and 12.3.2)
E_m = modulus of elasticity of pipe material (Articles 12.2.4 and 12.3.4)
FF = flexibility factor (Articles 12.2.4 and 12.3.4)
f_a = allowable stress—specified minimum yield point divided by safety factor (Article 12.2.1)
f_{cr} = critical buckling stress (Articles 12.2.2 and 12.3.2)
f_u = specified minimum tensile strength (Articles 12.2.2 and 12.3.2)
f_y = specified minimum yield point (Article 12.3.1)
H = height of cover above crown (Article 12.8.4.4)
I = moment of inertia, per unit length, of cross section of the pipe wall (Articles 12.2.4 and 12.3.4)
k = soil stiffness factor (Articles 12.2.2 and 12.3.2)
M_{dl} = dead load factored moment (Article 12.8.4.3.3)
M_{ll} = live load factored moment (Article 12.8.4.3.3)
M_{pc} = crown plastic moment capacity (Article 12.8.4.3.3)
M_{ph} = haunch plastic moment capacity (Article 12.8.4.3.3)
P = design load (Article 12.1.4)
P = proportion of total moment carried by the crown. Limits for P are given in Table 12.7.4D (Article 12.8.4.3.3)
r = radius of gyration of corrugation (Articles 12.2.2 and 12.3.2)
r_c = radius of crown (Table 12.8.2A)
r_h = radius of haunch (Table 12.8.2A)
R = rise of box culvert (Articles 12.7.2 and 12.8.4.4)
R_h = haunch moment reduction factor (Article 12.8.4.3.3)
S = diameter of span (Articles 12.1.4, 12.2.2, 12.8.2, and 12.8.4.4)
s = pipe diameter or span (Articles 12.2.4, 12.3.2, and 12.3.4)
SF = safety factor (Article 12.2.3)
SS = required seam strength (Articles 12.2.3 and 12.3.3)
T = thrust (Article 12.1.4)
T_L = thrust, load factor (Articles 12.3.1 and 12.3.3)
T_s = thrust, service load (Articles 12.2.1 and 12.2.3)
t = length of stiffening rib on leg (Article 12.8.2)
V = reaction acting in leg direction (Article 12.8.4.4)
Δ = haunch radius included angle (Table 12.8.2A)
γ = unit weight of backfill (Articles 12.8.4.3.2 and 12.8.4.4)
ϕ = capacity modification factor (Articles 12.3.1 and 12.3.3)

12.1.3 Loads

Design load, P, shall be the pressure acting on the structure. For earth pressures, see Article 3.20. For live load, see Articles 3.4 to 3.7, 3.11, 3.12, and 6.4, except that the words "When the depth of fill is 2 feet or more" in Article 6.4.1 need not be considered. For loading combinations, see Article 3.22.

12.1.4 Design

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

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

12.1.4.2 The thrust in the wall is:

$$T = P \times \frac{S}{2} \tag{12-1}$$

where

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

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

12.1.5 Materials

The materials shall conform to the AASHTO specifications referenced herein.

12.1.6 Soil Design

12.1.6.1 Soil Parameters

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

The following must be considered:

(a) Soils

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

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

Good side fill is obtained from a granular material with little or no plasticity and free of organic material, i.e., AASHTO classification groups A-1, A-2, and A-3, compacted to a minimum 90 percent of standard density based on AASHTO Specifications T 99 (ASTM D 698).

(3) The density of the embankment material above the pipe must be determined. See Article 6.2.

(b) Dimensions of soil envelope

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

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

(2) *Embankment installations*—one diameter or span each side of culvert.

(3) The minimum upper limit of the soil envelope is one foot above the culvert.

12.1.6.2 Pipe Arch Design

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

12.1.6.3 Arch Design

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

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

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

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

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

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

12.1.7 Abrasive or Corrosive Conditions

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

12.1.8 Minimum Spacing

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

12.1.9 End Treatment

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

12.1.10 Construction and Installation

The construction and installation shall conform to Section 23—Division II.

12.2 SERVICE LOAD DESIGN

Service Load Design is a working stress method, as traditionally used for culvert design.

12.2.1 Wall Area

$$A = T_s/f_a \qquad (12\text{-}2)$$

where

- A = required wall area in square inches per foot;
- T_s = thrust, service load in pounds per foot;
- f_a = allowable stress-specified minimum yield point, pounds per square inch, divided by safety factor, f_y/SF.

12.2.2 Buckling

Corrugations with the required wall area, A, shall be checked for possible buckling. If the allowable buckling stress, f_{cr}/SF, is less than f_a, the required area must be recalculated using f_{cr}/SF in lieu of f_a. Formulae for buckling are:

$$\text{If } S < \frac{r}{k}\sqrt{\frac{24E_m}{f_u}} \quad \text{then } f_{cr} = f_u - \frac{f_u^2}{48E_m}\left(\frac{kS}{r}\right)^2 \qquad (12\text{-}3)$$

$$\text{If } S > \frac{r}{k}\sqrt{\frac{24E_m}{f_u}} \quad \text{then } f_{cr} = \frac{12E_m}{(kS/r)^2} \qquad (12\text{-}4)$$

where

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

12.2.3 Seam Strength

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

The required seam strength shall be:

$$SS = T_s(SF) \qquad (12\text{-}5)$$

where

- SS = required seam strength in pounds per foot;
- T_s = thrust in pipe wall in pounds per foot;
- SF = safety factor.

12.2.4 Handling and Installation Strength

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

$$FF = s^2/E_m I \qquad (12\text{-}6)$$

where

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

12.3 LOAD FACTOR DESIGN

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

12.3.1 Wall Area

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

where

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

12.3.2 Buckling

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

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

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

where

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

12.3.3 Seam Strength

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

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

where

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

12.3.4 Handling and Installation Strength

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

$$FF = s^2/E_mI \qquad (12\text{-}11)$$

where

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

12.4 CORRUGATED METAL PIPE

12.4.1 General

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

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

12.4.1.2 Service Load Design—safety factor, SF:

Seam Strength = 3.0
Wall area = 2.0
Buckling = 2.0

12.4.1.3 Load Factor Design—capacity modification factor, ϕ.

Helical pipe with lock seam or fully welded seam

$$\phi = 1.00$$

Annular pipe with spot welded, riveted or bolted seam

$$\phi = 0.67$$

12.4.1.4 Flexibility Factor

(a) For steel conduits, FF should generally not exceed the following values:
1/4-in. and 1/2-in. depth corrugation FF = 4.3×10^{-2}
1-in. depth corrugation, FF = 3.3×10^{-2}
(b) For aluminum conduits, FF should generally not exceed the following values:
1/4-in. and 1/2-in. depth corrugation, FF = 9.5×10^{-2}
1-in. depth corrugation, FF = 6×10^{-2}

12.4.1.5 Minimum Cover

The minimum cover for design loads shall be Span/8 but not less than 12 inches. (The minimum cover shall be measured from the top of a rigid pavement or the bottom of a flexible pavement.) For construction requirements, see Article 23.10—Division II.

12.4.2 Seam Strength

Minimum Longitudinal Seam Strength

2 × 1/2 and 2-2/3 × 1/2 Corrugated Steel Pipe—Riveted or Spot Welded				3 × 1 Corrugated Steel Pipe—Riveted or Spot Welded		
Thickness (in.)	Rivet Size (in.)	Single Rivets (kips/ft.)	Double Rivets (kips/ft.)	Thickness (in.)	Rivet Size (in.)	Double Rivets (kips/ft.)
0.064	5/16	16.7	21.6	0.064	3/8	28.7
0.079	5/16	18.2	29.8	0.079	3/8	35.7
0.109	3/8	23.4	46.8	0.109	7/16	53.0
0.138	3/8	24.5	49.0	0.138	7/16	63.7
0.168	3/8	25.6	51.3	0.168	7/16	70.7

2 × 1/2 and 2-2/3 × 1/2 Corrugated Aluminum Pipe—Riveted			
Thickness (in.)	Rivet Size (in.)	Single Rivets (kips/ft.)	Double Rivets (kips/ft.)
0.060	5/16	9.0	14.0
0.075	5/16	9.0	18.0
0.105	3/8	15.6	31.5
0.135	3/8	16.2	33.0
0.164	3/8	16.8	34.0

3 × 1 Corrugated Aluminum Pipe—Riveted			6 × 1 Corrugated Aluminum Pipe—Riveted		
Thickness (in.)	Rivet Size (in.)	Double Rivets (kips/ft.)	Thickness (in.)	Rivet Size (in.)	Double Rivets (kips/ft.)
0.060	3/8	16.5	0.060	1/2	16.0
0.075	3/8	20.5	0.075	1/2	19.9
0.105	1/2	28.0	0.105	1/2	27.9
0.135	1/2	42.0	0.135	1/2	35.9
0.164	1/2	54.5	0.167	1/2	43.5

12.4.3 Section Properties

12.4.3.1 Steel Conduits

Thickness (in.)	1-1/2 × 1/4 Corrugation A_s (sq.in./ft.)	r (in.)	$I \times 10^{-3}$ (in.^{4}/in.)	2-2/3 × 1/2 Corrugation A_s (sq.in./ft.)	r (in.)	$I \times 10^{-3}$ (in.^{4}/in.)
0.028	0.304					
0.034	0.380					
0.040	0.456	0.0816	0.253	0.465	0.1702	1.121
0.052	0.608	0.0824	0.344	0.619	0.1707	1.500
0.064	0.761	0.0832	0.439	0.775	0.1712	1.892
0.079	0.950	0.0846	0.567	0.968	0.1721	2.392
0.109	1.331	0.0879	0.857	1.356	0.1741	3.425
0.138	1.712	0.0919	1.205	1.744	0.1766	4.533
0.168	2.098	0.0967	1.635	2.133	0.1795	5.725

Thickness (in.)	3 × 1 Corrugation A_s (sq.in./ft.)	r (in.)	$I \times 10^{-3}$ (in.^{4}/in.)	5 × 1 Corrugation A_s (sq.in./ft.)	r (in.)	$I \times 10^{-3}$ (in.^{4}/in.)
0.064	0.890	0.3417	8.659	0.794	0.3657	8.850
0.079	1.113	0.3427	10.883	0.992	0.3663	11.092
0.109	1.560	0.3448	15.459	1.390	0.3677	15.650
0.138	2.008	0.3472	20.183	1.788	0.3693	20.317
0.168	2.458	0.3499	25.091	2.186	0.3711	25.092

12.4.3.2. Aluminum Conduits

Thickness (in.)	1-1/2 × 1/4 Corrugation A_s (sq.in./ft.)	r (in.)	$I \times 10^{-3}$ (in.^{4}/in.)	2-2/3 × 1/2 Corrugation A_s (sq.in./ft.)	r (in.)	$I \times 10^{-3}$ (in.^{4}/in.)
0.048	0.608	0.0824	0.344			
0.060	0.761	0.0832	0.349	0.775	0.1712	1.892
0.075	....	....	....	0.968	0.1721	2.392
0.105	....	....	....	1.356	0.1741	3.425
0.135	....	....	....	1.745	0.1766	4.533
0.164	....	....	....	2.130	0.1795	5.725

Thickness (in.)	3 × 1 Corrugation A_s (sq.in./ft.)	r (in.)	$I \times 10^{-3}$ (in.^{4}/in.)	6 × 1 A_s (sq.in./ft.)	Effective Area (sq.in./ft.)	r (in.)	$I \times 10^{-3}$ (in.^{4}/in.)
0.060	0.890	0.3417	8.659	0.775	0.387	0.3629	8.505
0.075	1.118	0.3427	10.883	0.968	0.484	0.3630	10.631
0.105	1.560	0.3448	15.459	1.356	0.678	0.3636	14.340
0.135	2.088	0.3472	20.183	1.744	0.872	0.3646	19.319
0.164	2.458	0.3499	25.091	2.133	1.066	0.3656	23.760

12.4.4 Chemical and Mechanical Requirements

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

Mechanical properties for design

Minimum Tensile Strength (psi)	Minimum Yield Point (psi)	Mod. of Elast. (psi)
31,000	24,000	10×10^6

12.4.4.2 Steel-corrugated metal pipe and pipe-arch material requirements—AASHTO M 218
M 246

Mechanical properties for design

Minimum Tensile Strength (psi)	Minimum Yield Point (psi)	Mod. of Elast. (psi)
45,000	33,000	29×10^6

12.4.5 Smooth Lined Pipe

Corrugated metal pipe composed of a smooth liner and corrugated shell attached integrally at helical seams spaced not more than 30 inches apart may be designed in accordance with Article 12.1 on the same basis as a standard corrugated metal pipe having the same corrugations as the shell and a weight per foot equal to the sum of the weights per foot of liner and helically corrugated shell. The shell shall be limited to corrugations having a maximum pitch of 3 inches and a thickness of not less than 60 percent of the total thickness of the equivalent standard pipe.

12.5 SPIRAL RIB METAL PIPE

12.5.1 General

12.5.1.1 Spiral Rib metal pipe and pipe-arches are helically formed from a single thickness of steel or aluminum with outwardly projecting ribs and a lockseam. The specifications are:

Aluminum: AASHTO M196, M190
Steel: AASHTO M36, M245, M190

12.5.2 Soil Design

12.5.2.1 Spiral Rib pipe and pipe-arches installed in embankment conditions shall have a granular soil backfill envelope extending to a minimum of one span on each side of the pipe and one foot above the pipe. This granular soil envelope shall meet the material and compaction requirements of Section 12.1.6.1 (a).

12.5.2.2 Spiral Rib pipe and pipe-arches installed in standard trench conditions shall have a backfill envelope that:

(a) Meets the material and compaction requirements of Section 12.1.6.1 (a).
(b) Extends a minimum of 2 feet each side of the pipe to the trench wall. To account for variable conditions, this recommendation shall be increased as required for poor in situ soils. It may be decreased for trenches in rock or high bearing strength in situ soils to the limits required for backfill compaction. In this condition, the use of cementitious grouts allows the envelope to be decreased to 2 inches, each side of the pipe.
(c) Extends a minimum of one foot above the crown of the pipe.

12.5.2.3 Pipe-Arch Design

The design of the corner backfill shall meet the requirements of Section 12.1.6.2.

12.5.2.4 Special Conditions

Design and installation shall meet the requirements of Section 12.1.7 for abrasive or corrosive conditions; Section 12.1.8 for minimum spacing of multiple runs; and Section 12.1.9 for end treatment.

12.5.2.5 Construction and Installation

Construction and installation shall conform to Section 23—Division II.

12.5.3 Design

12.5.3.1 Service load design shall conform to the requirements of Section 12.2—Safety Factor (SF) shall be:

Wall Area = 2.0
Buckling = 2.0

12.5.3.1 Load factor design shall conform to the requirements of Section 12.3—Capacity modification factor, Ø, shall be:

Ø = 1.00

12.5.3.2 Flexibility Factor

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

(1) For installation conforming to Section 12.5.2.1:

FF = 0.173 $I^{0.33}$ for 3/4 × 3/4 × 7 1/2 configurations.

FF = 0.140 $I^{0.33}$ for ¾ × 1 × 11½ configurations.

(2) For installations conforming to Section 12.5.2.2:

FF = 0.200 $I^{0.33}$ for ¾ × ¾ × 7½ configurations.

FF = 0.163 $I^{0.33}$ for ¾ × 1 × 11½ configurations.

Note: I is the applicable moment of inertia value from Section 12.5.4.1.

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

(1) For installations conforming to Section 12.5.2.1:

FF = 0.250 $I^{0.33}$ for ¾ × ¾ × 7½ configurations.

FF = 0.175 $I^{0.33}$ for ¾ × 1 × 11½ configurations.

(2) For installations conforming to Section 12.5.2.2:

FF = 0.300 $I^{0.33}$ for ¾ × ¾ × 7½ configurations.

FF = 0.215 $I^{0.33}$ for ¾ × 1 × 11½ configurations.

Note: I is the applicable moment of inertia value from Section 12.5.4.2.

12.5.3.3 Minimum Cover

The minimum cover for design loads shall be measured from the top of rigid pavement or the bottom of flexible pavement such that:

(a) For steel conduits the minimum cover shall be span/4, but not less than 12 inches

(b) For aluminum conduits with spans of 48 inches or less, the minimum cover shall be span/2, but not less than 12 inches. For aluminum conduits with spans greater than 48 inches, the minimum cover shall be span/2.75, but not less than 24 inches.

For construction requirements, see Article 23.10—Division II.

12.5.4 Section Properties

12.5.4.1 Steel Conduits

Thickness (in)	¾ × ¾ × 7½ Configuration A_s (sq in/ft)	r (in)	$I \times 10^{-3}$ (in⁴/in)
0.064	0.511	0.290	3.590
0.079	0.715	0.282	4.740
0.109	1.192	0.268	7.150

¾ × 1 × 11½ Configuration A_s (sq in/ft)	r (in)	$I \times 10^{-3}$ (in⁴/in)
0.374	0.383	4.580
0.524	0.373	6.080
0.883	0.355	9.260

Note: Effective section properties at full yield stress.

12.5.4.2 Aluminum Conduits

Thickness (in)	¾ × ¾ × 7½ Configuration A_s (sq in/ft)	r (in)	$I \times 10^{-3}$ (in⁴/in)
0.060	0.417	0.303	3.200
0.075	0.572	0.299	4.260
0.105	0.922	0.290	6.460
0.135	1.302	0.284	8.740

¾ × 1 × 11½ Configuration A_s (sq in/ft)	r (in)	$I \times 10^{-3}$ (in⁴/in)
0.312	0.396	4.080
0.427	0.391	5.450
0.697	0.380	8.390
1.009	0.369	11.480

Note: Effective section properties at full yield stress.

12.5.5 Chemical and Mechanical Requirements

12.5.5.1 Steel Spiral Rib Pipe and Pipe-Arch Requirements—AASHTO M218

Mechanical Properties for Design

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

12.5.5.2 Aluminum Spiral Rib Pipe and Pipe-Arch Requirements—AASHTO M197

Mechanical Properties for Design

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

12.6 STRUCTURAL PLATE PIPE STRUCTURES

12.6.1 General

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

The specifications are:

Aluminum	Steel
AASHTO M 219	AASHTO M 167

12.6.1.2 Service Load Design—safety factor, SF

Seam strength = 3.0
Wall area = 2.0
Buckling = 2.0

12.6.1.3 Load Factor Design—capacity modification factor, ϕ

$$\varnothing = 0.67$$

12.6.1.4 Flexibility Factor

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

6 in. × 2 in. corrugation FF = 2.0×10^{-2} (pipe)
6 in. × 2 in. corrugation FF = 3.0×10^{-2} (pipe-arch)
6 in. × 2 in. corrugation FF = 3.0×10^{-2} (arch)

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

9 in. × 2-1/2 in. corrugation FF = 2.5×10^{-2} (pipe)
9 in. × 2-1/2 in. corrugation FF = 3.6×10^{-2} (pipe-arch)
9 in. × 2-1/2 in. corrugation FF = 7.2×10^{-2} (arch)

12.6.1.5 Minimum Cover

The minimum cover for design loads shall be Span/8 but not less than 12 inches. (The minimum cover shall be measured from the top of a rigid pavement or the bottom of a flexible pavement.) For construction requirements see Article 23.10—Division II.

12.6.2 Seam Strength

Minimum Longitudinal Seam Strengths

	6″ × 2″ Steel Structural Plate Pipe			
Thickness (in.)	Bolt Size (in.)	4 Bolts/ft. (kips/ft.)	6 Bolts/ft. (kips/ft.)	8 Bolts/ft. (kips/ft.)
0.109	3/4	43.0		
0.138	3/4	62.0		
0.168	3/4	81.0		
0.188	3/4	93.0		
0.218	3/4	112.0		
0.249	3/4	132.0		
0.280	3/4	144.0	180	194

	9″ × 2-1/2″ Aluminum Structural Plate Pipe		
Thickness (in.)	Bolt Size (in.)	Steel Bolts 5-1/2 Bolts Per ft. (kips/ft.)	Aluminum Bolts 5-1/2 Bolts Per ft. (kips/ft.)
0.100	3/4	28.0	26.4
0.125	3/4	41.0	34.8
0.150	3/4	54.1	44.4
0.175	3/4	63.7	52.8
0.200	3/4	73.4	52.8
0.225	3/4	83.2	52.8
0.250	3/4	93.1	52.8

12.6.3. Section Properties

12.6.3.1. Steel Conduits

	6″ × 2″ Corrugations		
Thickness (in.)	A_s (sq.in./ft.)	r (in.)	$I \times 10^{-3}$ ($in.^4/in.$)
0.109	1.556	0.682	60.411
0.138	2.003	0.684	78.175
0.168	2.449	0.686	96.163
0.188	2.739	0.688	108.000
0.218	3.199	0.690	126.922
0.249	3.650	0.692	146.172
0.280	4.119	0.695	165.836

12.6.3.2 Aluminum Conduits

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

12.6.4 Chemical and Mechanical Properties

12.6.4.1 Aluminum structural plate pipe, pipe-arch, and arch material requirements — AASHTO M 219, Alloy 5052.

Mechanical Properties for Design

Thickness (in.)	Minimum Tensile Strength (psi)	Minimum Yield Point (psi)	Mod. of Elast. (psi)
0.100 to 0.175	35,000	24,000	10×10^6
0.176 to 0.250	34,000	24,000	10×10^6

12.6.4.2 Steel structural plate pipe, pipe-arch, and arch material requirements —AASHTO M167

Mechanical Properties for Design

Minimum Tensile Strength (psi)	Minimum Yield Point (psi)	Mod. of Elast. (psi)
45,000	33,000	29×10^6

12.6.5 Structural Plate Arches

The design of structural plate arches should be based on ratios of a rise to span of 0.3 minimum.

12.7 LONG SPAN STRUCTURAL PLATE STRUCTURES

12.7.1 General

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

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

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

12.7.1.3 Wall strength and chemical and mechanical properties shall be in accordance with Article 12.6. The construction and installation shall conform to Section 26—Division II.

12.7.2 Design

12.7.2.1 General

Long span structures shall be designed in accordance with Articles 12.1 and 12.6, and 12.2 or 12.3 except that the requirements for buckling and flexibility factor shall not apply. The span in the formulae for thrust shall be replaced by twice the top arc radius. Long span structures shall include acceptable special features. Minimum requirements are detailed in Table 12.7.1A.

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

I. TOP ARC MINIMUM THICKNESS

	Top Radius (ft.)				
	15	15-17	17-20	20-23	23-25
6″ × 2″ Corrugated Steel Plates	0.109 in.	0.138 in.	0.168 in.	0.218 in.	0.249 in.

II. MINIMUM COVER IN FEET

	TOP RADIUS (FT.)				
Steel Thickness[a] in inches	15	15-17	17-20	20-23	23-25
.109	2.5				
.138	2.5	3.0			
.168	2.5	3.0	3.0		
.188	2.5	3.0	3.0		
.218	2.0	2.5	2.5	3.0	
.249	2.0	2.0	2.5	3.0	4.0
.280	2.0	2.0	2.5	3.0	4.0

III. GEOMETRIC LIMITS

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

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

IV. SPECIAL DESIGNS

Structures not described herein shall be regarded as special designs.

[a]When reinforcing ribs are used the moment of inertia of the composite section shall be equal to or greater than the moment of inertia of the minimum plate thickness shown.

12.7.2.2 Acceptable Special Features

(a) Continuous longitudinal structural stiffeners connected to the corrugated plates at each side of the top arc. Stiffeners may be metal or reinforced concrete either singly or in combination.
(b) Reinforcing ribs formed from structural shapes curved to conform to the curvature of the plates, fastened to the structure as required to ensure integral action with the corrugated plates, and spaced at such intervals as necessary to increase the moment of inertia of the section to that required by the design.

12.7.2.3 Design for Deflection

Soil design and placement requirements for long span structures limit deflection satisfactorily. However, construction procedures must be such that severe deformations do not occur during construction.

12.7.2.4 Soil Design

12.7.2.4.1 Granular type soils shall be used as structure backfill (the envelope next to the metal structure). The order of preference of acceptable structure backfill materials is as follows:

(a) Well-graded sand and gravel; sharp, rough, or angular if possible.
(b) Uniform sand or gravel.
(c) Approved stabilized soil shall be used only under direct supervision of a competent, experienced soils Engineer. Plastic soils shall not be used.

12.7.2.4.2 The structure backfill material shall conform to one of the following soil classifications from AASHTO Specification M 145, Table 2: for height of fill less than 12 feet, A-1, A-3, A-2-4, and A-2-5; for height of fill of 12 feet and more, A-1, A-3. Structure backfill shall be placed and compacted to not less than 90 percent density per AASHTO T 180.

12.7.2.4.3 The extent of the select structural backfill about the barrel is dependent on the quality of the adjacent embankment. For ordinary installations, with good quality, well-compacted embankment or in situ soil adjacent to the structure backfill, a width of structural backfill 6 feet beyond the structure is sufficient. The structure backfill shall also extend to an elevation 2 to 4 feet over the structure.

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

12.7.3 Structural Plate Shapes

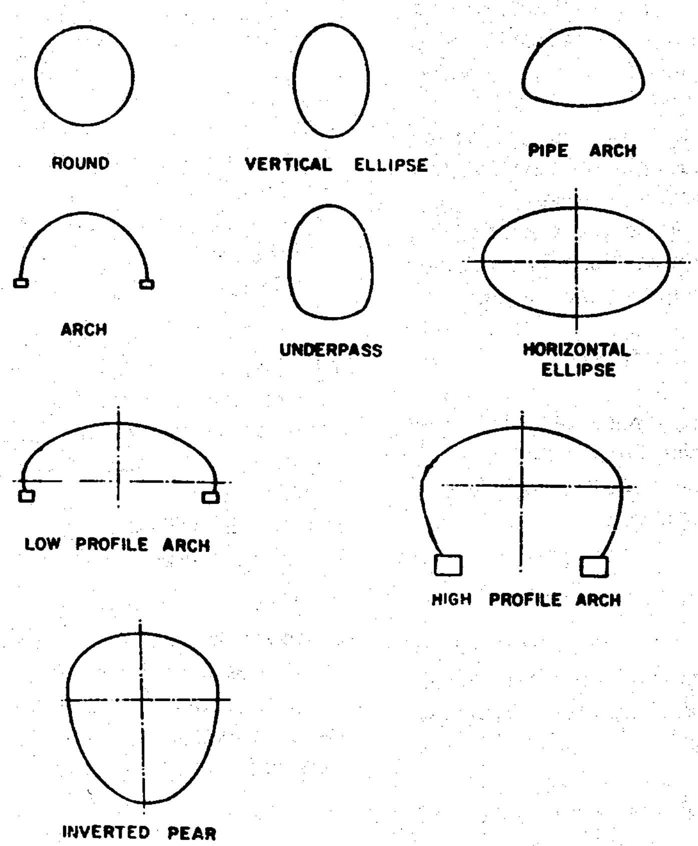


Figure 12.7.1A. Standard Terminology of Structural Plate Shapes Including Long-Span Structures

12.7.4 End Treatment

When headwalls are not used, special attention may be necessary at the ends of the structure. Severe bevels and skews are not recommended. For hydraulic structures, additional reinforcement of the end is recommended to secure the metal edges at inlet and outlet against hydraulic forces. Reinforced concrete or structural steel collars, tension tiebacks or anchors in soil, partial headwalls and cut-off walls below invert elevation are some of the methods which can be used. Square ends may have side plates beveled up to a maximum 2:1 slope. Skew ends up to 15° with no bevel are permissible, but when this is done on spans over 20 feet the cut edge must be reinforced with a reinforced concrete or structural steel collar. When full headwalls are used and they are skewed, the offset portion of the metal structure shall be supported by the headwall. A special headwall shall be designed for skews exceeding 15°. The maximum skew shall be limited to 35°.

12.7.5 Multiple Structures

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

12.8 STRUCTURAL PLATE BOX CULVERTS

12.8.1 General

Structural plate box culverts (hereafter "box culverts") are composite reinforcing rib-plate structures of approximate rectangular shape. Box culverts are intended for shallow covers and low wide waterway openings. The shallow covers and extreme shapes of box culverts require special design procedures. Requirements of Articles 12.1 through 12.7 are not applicable to box culvert designs unless included in Article 12.8 by specific reference.

12.8.1.1 Scope

Article 12.8 presents structural capacity requirements for box culverts based on the load factor method. Standard shapes, soil requirements, and permissible product details for box culverts in compliance with this specification are defined.

12.8.2 Structural Standards

The design criteria presented in subsequent articles are applicable only to structures in compliance with the standards described in Article 12.8.

12.8.2.1 Structural plate box culverts shall be bolted.

The box culvert materials specifications are:

Aluminum	Steel
AASHTO M 219	AASHTO M 167

12.8.2.2 Reinforcing ribs shall be an aluminum or steel structural section curved to fit the structural plates. Ribs shall be bolted to the plates so as to develop the plastic moment capacity required. Spacing between ribs shall not exceed 2 feet on the crown and 4.5 feet on the haunch. Rib splices shall develop the plastic moment capacity required at the location of the splice.

TABLE 12.8.2A Geometric Requirements for Box Culverts

I. Span, (S), may vary from 8 ft.-9 in. to 25 ft.-5 in.
II. Rise, (R), may vary from 2 ft.-6 in. to 10 ft.-6 in.
III. Radius of crown, (r_c) = 24 ft.-9½ in maximum
IV. Radius of haunch, (r_h) = 2 ft.-6 in. minimum
V. Δ may vary from 50° to 70°
VI. Length of leg, (D), may vary from 0.5 ft. to 5.2 ft.
VII. Minimum length of rib on leg, (t), is either 19 in. or the length of leg, (D), minus 3 in., whichever is less.

12.8.2.3 Plastic moment capacities of ribbed sections may be computed using minimum yield strength values for both rib and corrugated shell. Such computed values may be used for design only after they have been confirmed by representative flexural test data. (Reference Article 10.48.1)

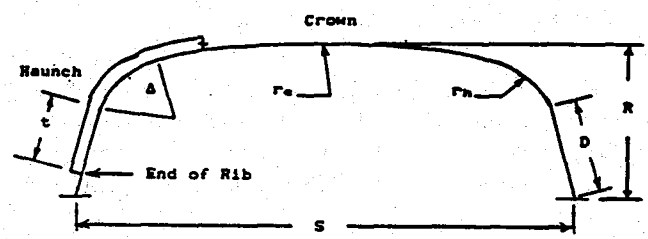


Figure 12.8.2A Standard Terminology of Structural Plate Box Culvert Shapes

12.8.3 Structure Backfill

12.8.3.1 Structure backfill material shall conform to the requirements of Article 12.7.2.4, compacted to a minimum 95 percent of standard density based on AASHTO Specifications T-99 or 90 percent of standard density based on AASHTO Specifications T-180.

12.8.3.2 Specified structure backfill material shall be 3 feet wide, minimum, at the footing and shall extend upward to the road base elevation.

12.8.4 Design

12.8.4.1 Analytical Basis for Design

Structural requirements for box culverts have been developed from finite element analyses covering the range of structures allowed by Article 12.8.2.

12.8.4.1.1 Structural requirements are based on analyses using two dimensional live loads equivalent to HS-20, 4 wheel, single axle vehicles. Dead load of soil equals 120 pounds per cubic foot. Coefficients to adjust for other load conditions are contained in Article 12.8.4.3.2.

12.8.4.1.2 Backfill required in Article 12.8.3 is dense granular material. The analyses that provide the basis for this specification were based on conservative soil properties of low plasticity clay (CL) compacted to 90 percent of standard AASHTO Specifications T-99.

12.8.4.2 Load Factor Method

Actual moments from the analyses have been load factored to obtain the total plastic moment capacities required for box culverts. Load factors applied and included in Tables 12.8.4A and 12.8.4B are:

Dead load, load factor = 1.5
Live load, load factor = 2.0

12.8.4.3 Plastic Moment Requirements

Analyses covering the range of box culvert shapes described in Article 12.8.2 have shown moment requirements govern the design in all cases. Effects of thrust were found to be negligible when combined with moment.

Metal box culverts act similar to rigid frames, distributing moment between the crown and haunch on the basis of their relative stiffness. Within limits, increasing the stiffness of one component of the box (either crown or haunch) reduces the portion of the total moment carried by the other.

Article 12.8 provides for this moment distribution within the allowable limits of the moment proportioning factor (P). P represents the proportion of the total moment that can be carried by the crown of the box culvert and varies with the relative moment capacities of the crown and haunch components. Limits for P are given in Table 12.8.4D.

12.8.4.3.1 The sum of the factored crown and haunch dead and live load moments are given in Tables 12.8.4A and 12.8.4B for standard dead and live load conditions. Moments for intermediate spans and covers may be linearly interpolated.

TABLE 12.8.4A $C_{d1}M_{d1}$, Load Factored Dead Load Moment for Soil Density of 120 lb./ft.^{3}, ($C_{d1}=1.0$), kip-ft./ft.

Span	Cover Depth, ft.				
ft.	1.40*	2.00	3.00	4.00	5.00
8	0.58	0.94	1.55	2.16	2.77
10	1.04	1.61	2.57	3.52	4.47
12	1.65	2.47	3.85	5.22	6.59
14	2.38	3.50	5.37	7.24	9.11
16	3.20	4.67	7.11	9.55	11.99
18	4.05	5.91	9.00	12.09	15.18
20	4.87	7.16	10.97	14.79	18.60
22	5.56	8.33	12.95	17.56	22.18
24	6.02	9.32	14.81	20.31	25.80
26	6.14	10.01	16.46	22.91	29.35

* Minimum cover depth from box culvert rise to top of pavement.

12.8.4.3.2 Dead and live load crown and haunch moments are adjusted for other loading conditions using the following adjustment coefficients:

$$C_{d1} = \gamma/120 \quad (12\text{-}12)$$

$$C_{\ell\ell} = C_1C_2(AL/32) \quad (12\text{-}13)$$

where

C_{d1} = Dead load adjustment coefficient;

γ = Backfill unit weight in pounds per cubic foot;

$C_{\ell\ell}$ = Live load adjustment coefficient for axle loads other than 32 kips, loads on tandem axles, and axles with other than 4 wheels;

AL = Total axle load on single axle or tandem axles in kips;

C_1 = Adjustment coefficient for number of axles;

C_1 = 1.0, for single axle;

C_1 = (0.5 + S/50), for tandem axles, ($C_1 \geq 1.0$);

S = Box culvert span in feet;

C_2 = Adjustment coefficient for number of wheels per axle. (Values for C2 are given in Table 12.8.4C.)

TABLE 12.8.4B $C_{\ell\ell}M_{\ell\ell}$, Load Factored Live Load Moment for HS-20, 4 Wheel Single Axle, ($C_{\ell\ell}=1.0$), kip-ft./ft.

Span	Cover Depth, ft.				
ft.	1.40*	2.00	3.00	4.00	5.00
8	10.44	8.44	5.73	4.44	3.60
10	13.64	11.04	7.49	5.80	4.71
12	16.98	13.74	9.32	7.22	5.86
14	20.43	16.53	11.21	8.69	7.05
16	23.98	19.40	13.16	10.20	8.27
18	27.62	22.35	15.16	11.75	9.53
20	31.35	25.36	17.20	13.33	10.81
22	33.39	27.01	18.32	14.20	11.51
24	35.11	28.40	19.27	14.93	12.11
26	36.51	29.53	20.03	15.52	12.59

* Minimum cover depth from box culvert rise to top of pavement.

TABLE 12.8.4C C_2, Adjustment Coefficient Values for Number of Wheels per Axle

Wheels per	Cover Depth, ft.			
Axle	1.4	2.0	3.0	5.0
2	1.18	1.21	1.24	1.02
4	1.00	1.00	1.00	1.00
8	0.63	0.70	0.82	0.93

12.8.4.3.3 Crown plastic moment capacity, (Mpc), and haunch plastic moment capacity, (Mph), must be equal to or greater than the proportioned sum of load adjusted dead and live load moments.

$$M_{pc} \geq P[(C_{d1}M_{d1}) + (C_{11}M_{11})] \quad (12\text{-}14)$$

$$M_{ph} \geq (1.0 - P)[(C_{d1}M_{d1}) + (R_hC_{11}M_{11})] \quad (12\text{-}15)$$

where

P = Proportion of total moment carried by the crown. Limits for P are given in Table 12.8.4D.

TABLE 12.8.4D P, Crown Moment Proportioning Values

Span ft.	Allowable Range of P
Less Than 10	0.55 to 0.70
10–15	0.50 to 0.70
15–20	0.45 to 0.70
20–26	0.45 to 0.60

R_h = Haunch moment reduction factor from Table 12.8.4E.

12.8.4.3.4 Article 12.8 can be used to check the adequacy of manufactured products for compliance with the requirements of this specification. Using the actual crown moment capacity (Mpc) provided by the box culvert under consideration and the loading requirements of the application, Equation 12-14 is solved for the factor P. This factor should fall within the allowable range of Table 12.8.4D. Knowing the factor P, equation 12-15 is then solved for Mph, which should be less than or equal to the actual haunch moment capacity provided.

If Equation 12-14 indicates a higher P factor than permitted by the ranges of Table 12.8.4D, the actual crown is over designed, which is acceptable. However, in this case only the maximum value of P allowed by the table shall be used to calculate the required Mph from Equation 12-15.

12.8.4.4 Footing Reactions

The reaction at the box culvert footing may be computed using the following equation:

$$V = \gamma(HS/2000 + S^2/40000) + AL/[8 + 2(H + R)] \quad (12\text{-}16)$$

TABLE 12.8.4E R_h, Haunch Moment Reduction Values

Cover Depth, ft.			
1.4	2	3	4 to 5
0.66	0.74	0.87	1.00

where

V = Reaction in kips per foot acting in the direction of the box culvert straight side;
γ = Backfill unit weight in pounds per cubic foot;
H = Height of cover over the crown in feet;
S = Span of box culvert in feet;
AL = Axle load in kips;
R = Rise of box culvert in feet.

12.8.5 Manufacturing and Installation

12.8.5.1 Manufacture and assembly of structural plates shall be in accordance with Articles 23.2.1, and 23.3.1.4. Reinforcing ribs shall be attached as shown by the manufacturer. Bolts connecting plates, plates to ribs and rib splices shall be torqued to 150 foot pounds.

12.8.5.2 Sidefill and overfill per Article 12.8.3 shall be placed in uniform layers not exceeding 8 inches in compacted thickness at near optimum moisture with equipment and methods which do not damage or distort the box culvert.

12.8.5.3 Following completion of roadway paving, crown deflection due to live load may be checked. After a minimum of 10 loading cycles with the design live load, the change in rise loaded with the design live load relative to the rise unloaded, should not exceed 1/200 of the box culvert span.

Section 13

TIMBER STRUCTURES

13.1 GENERAL AND NOTATIONS

13.1.1 General

The following information on timber design is based on the National Design Specification for Wood Construction (NDS), 1982 Edition. See the latest edition of the NDS for additional information.

All wood used in timber structures shall be preservatively treated as provided in Section 20—Division II unless otherwise specified.

The hardware for structures on the seacoast shall be galvanized or cadmium plated.

13.1.2 Notations

"a" = fixity condition in which the centroid of connectors or a connector group lies within one-twentieth of ℓ_1, from the column end (Article 13.6.3)
"b" = fixity condition in which the centroid of connectors or a connector group lies between one-twentieth and one-tenth of ℓ_1 from the column end (Article 13.6.3)
b = width of beam or glued laminated deck panel (Article 13.3.1)
b = width of cross section (Article 13.3.2.2)
b = breadth (width) of rectangular member (Article 13.3.4)
C_F = size factor (Article 13.3.7)
C_k = limiting value of slenderness factor (Article 13.3.8.3)
C_s = slenderness factor (Article 13.3.8)
C_x = constant for fixity condition "a" or "b" (Article 13.6.4)
d = depth of beam or glued laminated deck panel (Article 13.3.1)
d = depth of cross section (Article 13.3.2.2)
d = depth of beam above notch (Article 13.3.4)
d = depth of member (Article 13.3.7)
d = depth of beam (Article 13.3.8)
d = least dimension of a compression member (Article 13.4.6)
d_1 = dimension of column in plane of lateral support corresponding to length ℓ_1 (Article 13.5)
d_2 = dimension of column in plane of lateral support corresponding to length ℓ_2 (Article 13.5)
E = modulus of elasticity (Article 13.2)
F_b = allowable unit stress in bending (Article 13.3.8.3)
F'_b = allowable unit stress in bending based on slenderness considerations (Article 13.3.8.3)
$F_{c\perp}$ = allowable unit stress in compression parallel to grain (Article 13.5.2)
F_c = allowable unit stress in compression perpendicular to grain (Article 13.2)
F'_c = allowable unit stress in compression parallel to grain adjusted for slenderness ratio (Article 13.4.4)
F_t = allowable unit stress in tension parallel to grain (Article 13.2)
F_v = allowable unit stress in horizontal shear (Article 13.3.4)
f_r = actual radial stress (Article 13.3.2.2)
f_v = actual horizontal shear stress (Article 13.3.1)
h = total depth of beam (Article 13.3.4)
K = limiting value of slenderness ratio (Article 13.5.2)
L = length of bearing measured along the grain of the wood (Article 13.3.3)
ℓ = unsupported length (Articles 13.3.8 and 13.5)
ℓ_e = effective length of beam (Article 13.3.8)
ℓ_i = distance between points of lateral support of column in plane 1 (Article 13.5)
ℓ_2 = distance between points of lateral support of column in plane 2 (Article 13.5)
ℓ_1 & ℓ_2 = distance from center to center of lateral supports of continuous spaced columns from end to end of simple spaced columns (Article 13.6)
ℓ_3 = distance from center to center of connectors in end blocks to center of spacer block (Article 13.6)
M = bending or resisting moment (Article 13.3.2.2)

STANDARD SPECIFICATIONS
for
HIGHWAY BRIDGES

FIFTEENTH EDITION

1992

Adopted and Published by the
American Association of State Highway
and Transportation Officials, Inc.

444 North Capitol Street, N.W., Suite 249
Washington, D.C. 20001

ISBN 1-56051-014-5

Section 26
METAL CULVERTS

26.1 GENERAL

26.1.1 Description

This work shall consist of furnishing, fabricating, and installing metal pipe, metal structural plate pipe, arches, pipe arches, and box structures in conformance with these specifications, the special provisions, and the details shown on the plans. As used in this specification, long-span structures are metal plate horizontal ellipse, inverted pear and multiple radius arch shapes as well as special shape culverts as defined in Division I, Section 12, "Soil-Corrugated Metal Structure Interaction Systems." The terms "metal pipe" and "metal structural plate pipe" shall include both circular pipe arch, underpass and elliptical shapes. "Metal structural plate arches" consist of a metal plate arch supported on reinforced concrete footings at its base (ends) with or without a paved invert slab. "Pipe arches" are constructed to form a pipe having an arch-shaped crown and a relatively flat invert. "Metal structural plate box structures" are conduits, rectangular in cross section, constructed of metal plates.

26.2 WORKING DRAWINGS

Whenever specified or requested by the Engineer, the Contractor shall provide manufacturer's assembly instructions or working drawings with supporting data in sufficient detail to permit a structural review. Sufficient copies shall be furnished to meet the needs of the Engineer and other entities with review authority. The working drawings shall be submitted sufficiently in advance of proposed use to allow for their review, revision, if needed, and approval without delay to the work.

The Contractor shall not start the construction of any metal culvert for which working drawings are required until the drawings have been approved by the Engineer. Such approval will not relieve the Contractor of responsibility for results obtained by use of these drawings or any of his or her other responsibilities under the contract.

26.3 MATERIALS

26.3.1 Corrugated Metal Pipe

Steel pipe shall conform to the requirements of AASHTO M 36.

Aluminum pipe shall conform to the requirements of AASHTO M 196.

26.3.2 Structural Plate

Steel structural plate shall conform to the requirements of AASHTO M 167.

Aluminum alloy structural plate shall conform to the requirements of AASHTO M 219.

26.3.3 Nuts and Bolts

Nuts and bolts for steel structural plate pipe, arches, pipe arches, and box structures shall conform to the requirements of AASHTO M 167. Nuts and bolts for aluminum structural plate shall be aluminum conforming to ASTM Specification F 468 or standard strength steel conforming to ASTM A 307.

26.3.4 Mixing of Materials

Aluminum and steel materials shall not be mixed in any installation unless they are adequately separated or protected to avoid galvanic reactions. Hot-dip galvanizing provides such protection. Hot-dip galvanized steel and stainless steel bolts and nuts are acceptable for aluminum structural plate.

26.3.5 Fabrication

Plates at longitudinal and circumferential seams shall be connected by bolts with the seams staggered so that not more than three plates come together at any one point.

26.3.6 Welding

Welding of steel, if required, shall conform to the *ANSI/AASHTO/AWS Bridge Welding Code D1.5.* All welding of steel plates, other than fittings, shall be performed prior to galvanizing.

Welding of aluminum, if required, shall conform to the AWS D1.2, "Structural Welding Code."

26.3.7 Protective Coatings

When required by the plans or the special provisions, metal pipes and structural plate shall be protected with bituminous coating or have the invert paved with bituminous material. Bituminous coatings shall be applied as provided in AASHTO M 190, Type A, unless otherwise specified. Bituminous pavings, if required, shall be applied over the bituminous coatings to the inside bottom portion of pipe as provided in AASHTO M 190, Type C, unless otherwise specified. The portion of all nuts and bolts used for assembly of coated structural plate projecting outside the pipe, shall be coated after installation. The portions of the nuts and bolts projecting inside the pipe need not be coated.

Polymeric coatings, when called for on the plans or in the special provisions, shall conform to the requirements of AASHTO M 246. The polymeric coating shall be applied to the galvanized sheet prior to corrugating and, unless otherwise specified, the thickness shall be not less than 0.010 inch. Any pinholes, blisters, cracks, or lack of bond shall be cause for rejection. Polymeric coatings will not be permitted on structural plate pipes.

26.3.8 Bedding and Backfill Materials

26.3.8.1 General

Bedding material shall be loose native or granular material with a maximum particle (or clump) size not to exceed one-half the corrugation depth. Backfill for metal culverts shall be granular material as specified in the plans and specifications and shall be free of organic material, stones larger than 3 inches in the greatest dimension, frozen lumps, or moisture in excess of that permitting thorough compaction. As a minimum, backfill materials shall meet the requirements of AASHTO M 145 for A-1, A-2, or A-3.

26.3.8.2 Long-Span Structures

Bedding and backfill materials shall meet the general requirements of Article 26.3.8.1. As a minimum backfill materials for structures with less than 12 feet of cover shall meet the requirements of AASHTO M 145 for A-1, A-2-4, A-2-5, or A-3. Minimum backfill requirements for structures with 12.0 feet or more cover shall meet AASHTO M 145 requirements for A-1 or A-3.

26.3.8.3 Box Culverts

Bedding and backfill materials shall meet the general requirements of Article 26.3.8.1. As a minimum, backfill shall meet the requirements of AASHTO M 145 for A-1, A-2-4, A-2-5, or A-3.

26.4 ASSEMBLY

26.4.1 General

Corrugated metal pipe and structural plate pipe shall be assembled in accordance with the manufacturer's instructions. All pipe shall be unloaded and handled with reasonable care. Pipe or plates shall not be rolled or dragged over gravel or rock and shall be prevented from striking rock or other hard objects during placement in trench or on bedding.

Corrugated metal pipe shall be placed in the bed starting at the downstream end. Pipes with circumferential seams shall be installed with their inside circumferential sheet laps pointing downstream.

Bituminous coated pipe, polymer coated pipe, and paved invert pipe shall be installed in a similar manner to corrugated metal pipe with special care in handling to avoid damage to coatings. Paved invert pipe shall be installed with the invert pavement placed and centered on the bottom.

Structural plate shall be assembled and installed in accordance with the plans and detailed erection instructions. Copies of the manufacturer's assembly instructions shall be furnished as specified in Article 26.2. Bolted longitudinal seams shall be well fitted with the lapping plates parallel to each other. The applied bolt torque for ¾-inch diameter high-strength steel bolts (A 449) for the assembly of steel structural plate shall be a minimum of 100 ft-lbs and a maximum of 300 ft-lbs. Aluminum structural plate shall be assembled using ¾-inch diameter aluminum bolts (F 468) or standard strength steel bolts (A 307) which shall be torqued to a minimum of 100 ft-lbs and a maximum of 150 ft-lbs. When seam sealant tape or a shop applied asphalt coating is used, bolts should be retightened no more than once. Generally, retightening is done within 24 hours. There is no structural requirement for residual torque; the important factor is the seam fit-up.

26.4.2 Joints

Joints for corrugated metal culvert and drainage pipe shall meet the following performance requirements.

26.4.2.1 Field Joints

Transverse field joints shall be of such design that the successive connection of pipe sections will form a continuous line free from appreciable irregularities in the flow line. In addition, the joints shall meet the general performance requirements described in Articles 26.4.2.2 and 26.4.2.3. Suitable transverse field joints, which satisfy the requirements for one or more of the subsequently defined joint performance categories can be obtained with the following types of connecting bands furnished with the suitable band-end fastening devices:

(a) Corrugated bands.
(b) Bands with projections.
(c) Flat bands.
(d) Bands of special design that engage factory reformed ends of corrugated pipe.
(e) Other equally effective types of field joints may be used with the approval of the Engineer.

26.4.2.2 Joint Types

Applications may require either "Standard" or "Special" joints. Standard joints are for pipe not subject to large soil movements or disjointing forces; these joints are satisfactory for ordinary installations, where simple slip type joints are typically used. Special joints are for more adverse requirements such as the need to withstand soil movements or resist disjointing forces. Special designs must be considered for unusual conditions as in poor foundation conditions. Downdrain joints are required to resist longitudinal hydraulic forces. Examples of this are steep slopes and sharp curves.

26.4.2.3 Soil Conditions

(a) The requirements of the joints are dependent on the soil conditions at the construction site. Pipe backfill which is not subject to piping action is classified as "nonerodible." Such backfill typically includes granular soil (with grain sizes equivalent to coarse sand, small gravel, or larger) and cohesive clays.

(b) Backfill that is subject to piping action, and would tend to either infiltrate the pipe or to be easily washed by exfiltration of water from the pipe, is classified as "Erodible." Such backfill typically includes fine sands and silts.

(c) Special joints are required when poor soil conditions are encountered such as when the backfill or foundation material is characterized by large soft spots or voids. If construction in such soil is unavoidable, this condition can only be tolerated for relatively low fill heights, because the pipe must span the soft spots and support imposed loads. Backfills of organic silt, which are typically semi-fluid during installation, are included in this classification.

26.4.2.4 Joint Properties

The requirements for joint properties are divided into the six categories given on Table 26.4. Properties are defined and requirements are given in the following paragraphs (a) through (f). The values for various types of pipe can be determined by a rational analysis or a suitable test.

(a) Shear Strength—The shear strength required of the joint is expressed as a percent of the calculated shear strength of the pipe on a transverse cross-section remote from the joint.

(b) Moment Strength—The moment strength required of the joint is expressed as a percent of the calculated mo-

TABLE 26.4 Categories of Pipe Joints

	Soil Condition				
	Nonerodible Joint Type		Erodible Joint Type		
	Standard	Special	Standard	Special	Downdrain
Shear	2%	5%	2%	5%	2%
Moment[a]	5%	15%	5%	15%	15%
Tensile 0 in.–42 in. dia.	0	5,000 lbs	—	5,000 lbs	5,000 lbs
48 in.–84 in. dia.	—	10,000 lbs	—	10,000 lbs	10,000 lbs
Joint Overlap[b] (min.)	10-1/2 in.	NA	10-1/2 in.	NA	NA
Soiltightness[c]	NA	NA	0.3 or 0.2	0.3 or 0.2	0.3 or 0.2
Watertightness	See Article 26.4.2.4(f)				

[a] Article 26.4.2.4(b).
[b] Alternate requirement. See Article 26.4.2.4(e).
Structural plate pipe, pipe-arches, and arches shall be installed in accordance with the plans and detailed erection instructions.
[c] Minimum ratio of D_{85} soil size to size of opening 0.3 for medium to fine sand and 0.2 for uniform sand.

ment capacity of the pipe on a transverse cross section remote from the joint.

(c) Tensile Strength—Tensile strength is required in a joint when the possibility exists that a longitudinal load could develop which would tend to separate adjacent pipe sections.

(d) Joint Overlap—Standard joints which do not meet the moment strength alternatively shall have a minimum sleeve width overlapping the abutting pipes. The minimum total sleeve width shall be as given in Table 26.4. Any joint meeting the requirements for a special joint may be used in lieu of a standard joint.

(e) Soiltightness—Soiltightness refers to openings in the joint through which soil may infiltrate. Soil tightness is influenced by the size of the opening (maximum dimension normal to the direction that the soil may infiltrate) and the length of the channel (length of the path along which the soil may infiltrate). No opening may exceed 1 inch. In addition, for all categories, if the size of the opening exceeds ⅛ inch, the length of the channel must be at least four times the size of the opening. Furthermore, for nonerodible or erodible soils, the ratio of D_{85} soil size to size of opening must be greater than 0.3 for medium to fine sand or 0.2 for uniform sand; these ratios need not be met for cohesive backfills where the plasticity index exceeds 12. As a general guideline, a backfill material containing a high percentage of fine grained soils requires investigation for the specific type of joint to be used to guard against soil infiltration. Alternatively, if a joint demonstrates its ability to pass a 2-psi hydrostatic test without leakage, it will be considered soil tight.

NOTE: Joints that do not meet these requirements may be made soil tight by wrapping with a suitable geotextile.

(f) Watertightness—Watertightness may be specified for joints of any category where needed to satisfy other criteria. The leakage rate shall be measured with the pipe in place or at an approved test facility. The adjoining pipe ends in any joint shall not vary more than 0.5 inch in diameter or more than 1.5 inches in circumference for watertight joints. These tolerances may be attained by proper production controls or by match-marking pipe ends.

26.4.3 Assembly of Long-Span Structures

Long-span structures may require deviation from the normal good practice of loose bolt assembly. Unless held in shape by cables, struts, or backfill, longitudinal seams should be tightened when the plates are hung. Care must be taken to align plates to ensure properly fitted seams prior to bolt tightening. This may require temporary shoring. Follow the manufacturer's instructions. The variation before backfill shall not exceed 2 percent of the span or rise, whichever is greater, but shall not exceed 5 inches except for horizontal ellipse shapes having a ratio of top to side radii of 3 or less where only the 2-percent restriction shall apply. The rise of arches with a ratio of top to side radii of three or more should not deviate from the specified dimensions by more than 1 percent of the span.

Reinforcing ribs, when required to satisfy the structural design, shall be attached to the structural plate corrugation crown prior to backfilling using a bolt spacing of not more than 12 inches. Legible identifying letters or numbers shall be placed on each rib to designate its proper position in the finished structure.

Reinforcing ribs, when required only as a means of controlling structure shape during installation, shall be spaced and attached to the corrugated plates at the discretion of the manufacturer with the approval of the Engineer.

26.5 INSTALLATION

26.5.1 Placing Culverts—General

For trench conditions, the trench shall be excavated to the width, depth, and grade shown on the plans and approved by the Engineer.

Proper preparation of foundation, placement of foundation material where required, and placement of bedding material shall precede the installation of all culvert pipe. This shall include necessary leveling of the native trench bottom or the top of the foundation material as well as placement and compaction of required bedding material to a uniform grade so that the entire length of pipe will be supported on a uniform base. The backfill material shall be placed and compacted around the pipe in a manner to meet the requirements specified.

All pipes shall be protected by sufficient cover before permitting heavy construction equipment to pass over them during construction.

Soil migration can weaken or destroy the support capabilities of the soils around the pipe. Materials used for foundation improvements, bedding and structure backfill must have gradations compatible with adjacent soils to avoid migration. Where material gradations can not be properly controlled, adjacent materials must be separated with a suitable geotextile.

26.5.2 Foundation

The foundation under the pipe and structure backfill shall be investigated for its ability to support the loads. A foundation shall be provided such that the structure backfill does not settle more than the pipe to avoid dragdown loads on the pipe.

The foundation must provide uniform support for the pipe invert. Boulders or rock under the pipe or soft spots

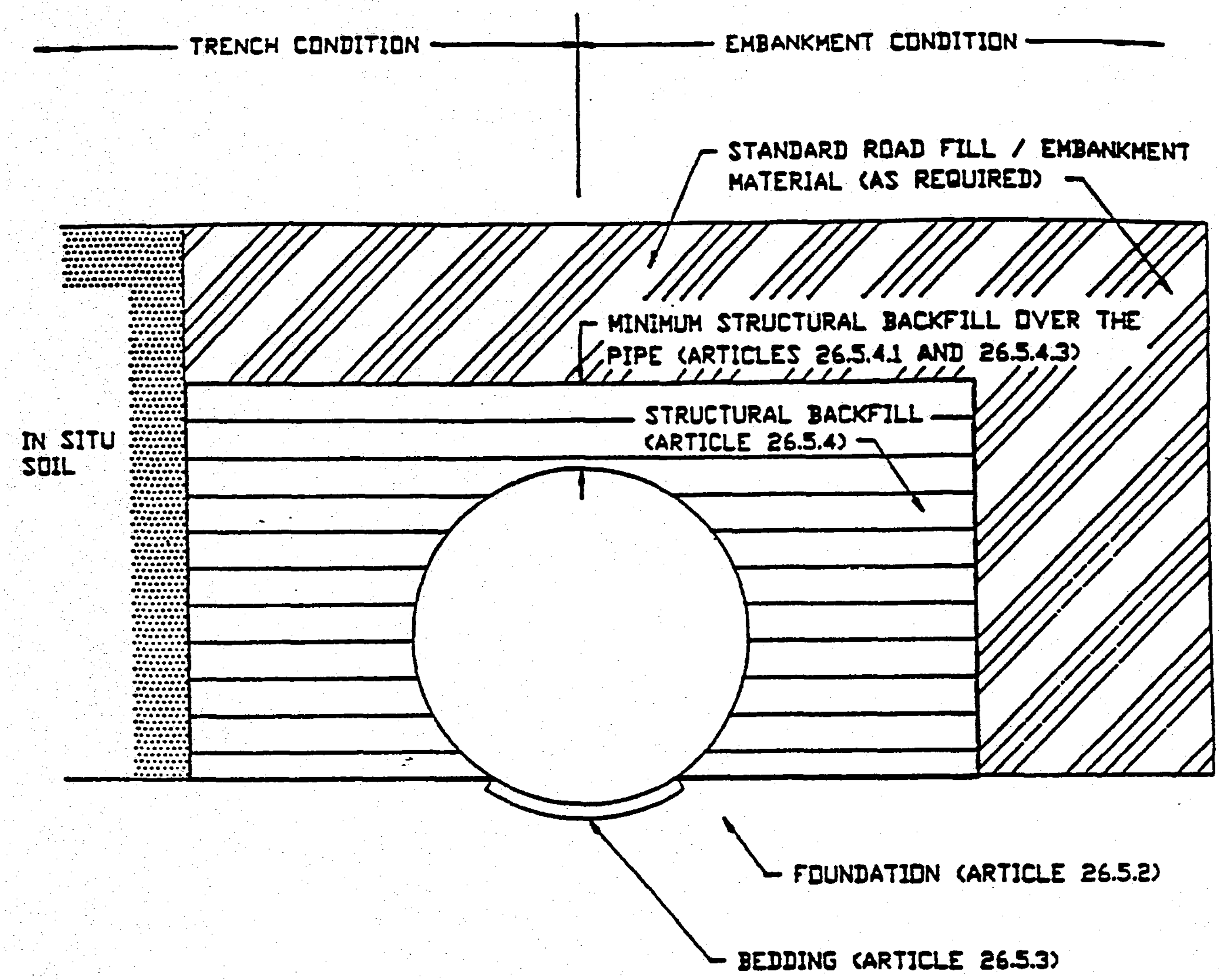


FIGURE 26.5 Typical Cross-Section Showing Materials Around the Pipe

shall be excavated to a suitable depth and filled with backfill material compacted sufficiently to provide uniformity as shown in Figure 26.5.2A.

Where the natural foundation is judged inadequate by the Engineer to support the pipe or structure backfill, it shall be excavated to a suitable depth and replaced by backfill material as shown in Figure 26.5.2B.

For shapes such as pipe arches, horizontal ellipses or underpasses, where relatively large radius inverts adjoin small radius corners or sides, the foundation must support the radial pressures exerted by the smaller radius portions of the pipe. These pressures, quantified in Division I, Section 12, "Soil-Corrugated Metal Structure Interaction Systems," may be two to five times the loading pressures on top of the pipe, depending on the specific pipe shape. The principal foundation support must be provided in the areas extending radially outward from the smaller radius areas.

The larger radius inverts exert proportionately lower pressures. When corrective measures are necessary, providing less support under the invert allows the pipe to maintain its shape as minor settlements occur. (See Figure 26.5.2C.)

Under high fills, where pipe settlements will not maintain the necessary grade, pipe may be cambered to an amount sufficient to prevent excessive sag or back slope. The amount of camber must be determined by the engineer based on considerations including the flow line gradient, fill height, the compressive characteristics of the foundation materials and the depth to rock or other incompressible materials. A camber detail is provided in Figure 26.5.2D.

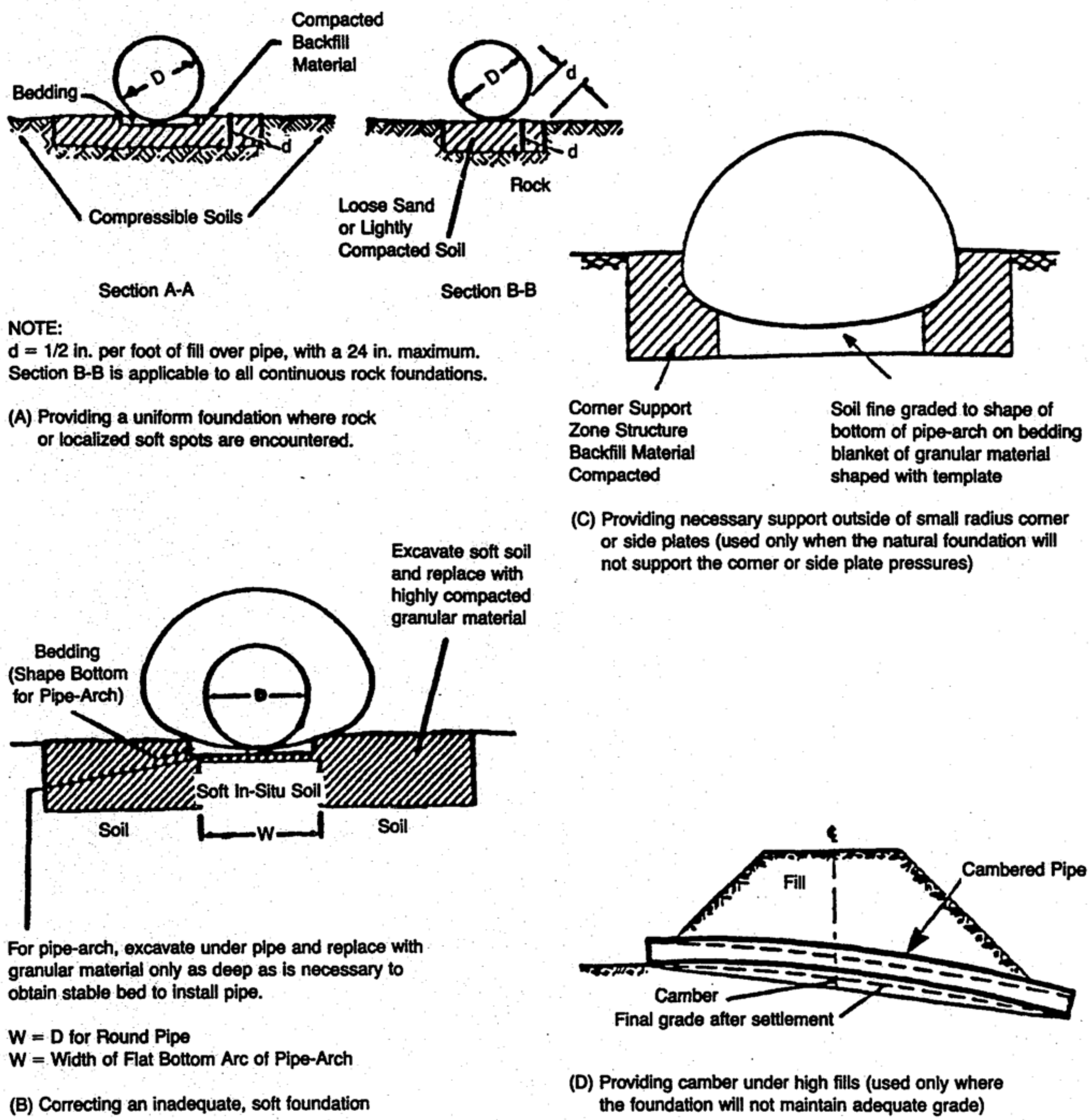


FIGURE 26.5.2 A-D: Foundation Improvement Methods when Required

26.5.3 Bedding

The pipe bedding is a relatively thin layer of loosely placed material to cushion the pipe invert and allow the corrugation to rest or seat into it, thus supporting the corrugation. When, in the opinion of the Engineer, the natural soil does not provide a suitable bed, a bedding blanket with a minimum thickness of twice the corrugation depth shall be provided.

Pipe arch, horizontal ellipse and underpass shapes with spans exceeding 12 feet should be placed on a shaped bed. The shaped area, centered beneath the pipe should have a minimum width of ½ the span for pipe arch and underpass shapes and ⅓ the span for horizontal ellipse shapes.

Preshaping may consist of a simple "V" graded into the soil as shown in Figure 26.5.3.

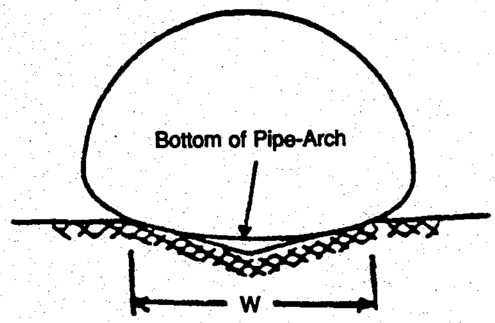


FIGURE 26.5.3 "V" Shaped Bed (Foundation) for Larger Pipe Arch, Horizontal Ellipse and Underpass Structures

26.5.4 Structural Backfill

26.5.4.1 General

Correct placement of materials of the proper quality and moisture content is essential. Sufficient field testing must be used to verify procedures, but is no substitute for inspection that ensures that the proper procedures are followed. This is of extreme importance because the structural integrity of the corrugated metal structure is vitally affected by the quality of construction in the field.

Backfill material shall meet the requirements of Article 26.3.8 and shall be placed as shown in Figure 26.5.1D in layers not exceeding 8-inch loose lift thickness to a minimum 90-percent standard density per AASHTO T 99. Equipment used to compact backfill within 3 feet from sides of pipe or from edge of footing for arches and box culverts shall be approved by the Engineer prior to use. Except as provided below for long-span structures, the equipment used for compacting backfill beyond these limits may be the same as used for compacting embankment.

The backfill shall be placed and compacted with care under the haunches of the pipe and shall be brought up evenly on both sides of the pipe by working backfill operations from side to side. The side to side backfill differential shall not exceed 24 inches or ⅓ of the size of the structure, whichever is less. Backfill shall continue to not less than 1 foot above the top for the full length of the pipe. Fill above this elevation may be material for embankment fill or other materials as specified to support the pavement. The width of trench shall be kept to the minimum width required for placing pipe, placing adequate bedding and sidefill, and safe working conditions. Ponding or jetting of backfill will not be permitted except upon written permission by the Engineer.

Where single or multiple structures are installed at a skew to the embankment (i.e. cross the embankment at other than 90 degrees), proper support for the pipe must be provided. This may be done with a rigid, reinforced concrete head wall or by warping the embankment fill to provide the necessary balanced side support. Figure 26.5.4 provides guidelines for warping the embankment.

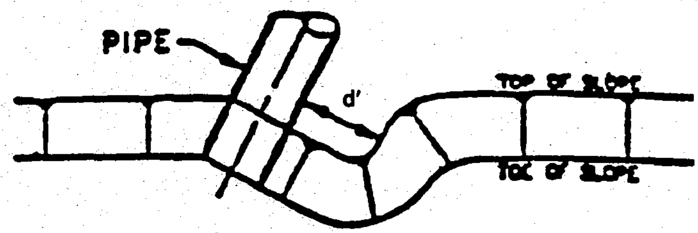
26.5.4.2 Arches

Arches may require special shape control considerations during the placement and compaction of structure backfill. Pin connections at the footing restrict uniform shape change. Arches may peak excessively and experience curvature flattening in their upper quadrants. Using lighter compaction equipment, more easily compacted structure backfill, or top loading (placing a small load of structure backfill on the crown) will aid installation.

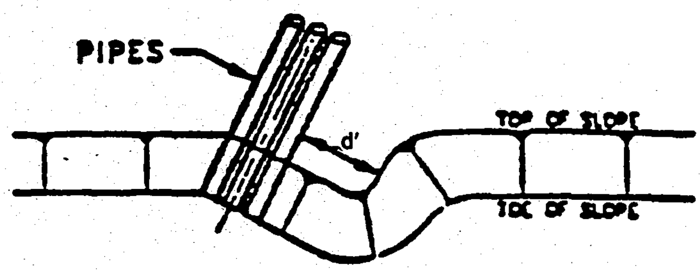
26.5.4.3 Long-Span Structures

Backfill requirements for long-span structural-plate structures are similar to those for smaller structures. Their size and flexibility require special control of backfill and continuous monitoring of structure shape. Prior to beginning construction, the manufacturer shall provide a preconstruction conference to advise the Contractor(s) and Engineer of the more critical functions to be performed.

Equipment and construction procedures used to backfill long-span structural plate structures shall be such that excessive structure distortion will not occur. Structure shape shall be checked regularly during backfilling to verify acceptability of the construction methods used. Magnitude of allowable shape changes will be specified by the manufacturer (fabricator of long-span structures). The manufacturer shall provide a qualified shape control inspector to aid the Engineer during the placement of all structural backfill to the minimum cover level over the structure (as required by the design to carry full highway loads). The Inspector shall advise the Engineer on the acceptability of all backfill material and construction methods and the proper monitoring of the shape. Structure backfill material shall be placed in horizontal uniform layers not exceeding an 8-inch loose lift thickness and shall be brought up uniformly on both sides of the structure. Each layer shall be compacted to a density not less than 90 percent per AASHTO T 180. The structure backfill shall be constructed to the minimum lines and grades shown on the plans, keeping it at or below the level of adjacent soil or embankment. Permissible exceptions to required structure backfill density are: the area under the invert, the 12-inch to 18-inch width of soil immediately adjacent to the large radius side plates of high-profile



PROPER BALANCE FOR SINGLE STRUCTURE



PROPER BALANCE FOR MULTIPLE STRUCTURE

d' = 1.5 (Rise + Cover)

FIGURE 26.5.4 End Treatment of Skewed Flexible Culvert

arches and inverted pear shapes, and the lower portion of the first horizontal lift of overfill carried ahead of and under the small, tracked vehicle initially crossing the structure.

26.5.4.4 Box Culverts

Metal box culverts are not long-span structures in that they are relatively stiff, semi-rigid frames. They do not require a preconstruction conference or shape control considerations beyond those of a standard metal culvert.

Structural backfill material shall be placed in uniform horizontal layers not exceeding an 8-inch maximum loose lift thickness and compacted to a density not less than 90 percent per AASHTO T 180. The structural backfill shall be constructed to the minimum lines and grades shown on the plans, keeping it at or below the level of the adjacent soil or embankment.

26.5.4.5 Bracing

When required, temporary bracing shall be installed and shall remain in place as long as necessary to protect workmen and to maintain structure shape during erection.

For long-span structures which require temporary bracing or cabling to hold the structure in shape, the supports shall not be removed until backfill is placed to an adequate elevation to provide the necessary support. In no case shall internal braces be left in place when backfilling reaches the top quadrant of the pipe or the top radius arc portion of a long span.

26.5.5 Arch Substructures and Headwalls

Substructures and headwalls shall be designed in accordance with the requirements of Division I.

The ends of the corrugated metal arch shall rest in a keyway formed into continuous concrete footings, or shall rest on a metal bearing surface, usually an angle or channel shape, which is securely anchored to or embedded in the concrete footing.

The metal bearing when specified may be a hot-rolled or cold-formed galvanized steel angle or channel, or an extruded aluminum angle or channel. These shapes shall be not less than 3/16 inch in thickness and shall be securely anchored to the footing at a maximum spacing of 24 inches. When the metal bearing member is not completely embedded in a groove in the footing, one vertical leg shall be punched to allow the end of the corrugated plates to be bolted to this leg of the bearing member.

Where an invert slab is provided which is not integral with the arch footing, the invert slab shall be continuously reinforced.

26.6 CONSTRUCTION PRECAUTIONS

These structures can carry legal highway loads once the backfill is placed and compacted to the minimum cover level over the pipe as defined by Division I, Section 12, "Soil-Corrugated Metal Structure Interaction." For heavier construction loads, additional cover may be required. Table 26.6 provides guidance for smaller structures. Consult the Engineer or the manufacturer for guidance on structures or axle loads not listed.

TABLE 26.6 Minimum Cover for Construction Loads
(Round, Pipe-Arch, Ellipse and Underpass Shapes)

	Minimum Cover (ft) for Indicated Axle Loads (thousands of pounds)*			
Pipe Span, in.	18–50	50–75	75–110	110–150
12–42	2.0	2.5	3.0	3.0
48–72	3.0	3.0	3.5	4.0
78–120	3.0	3.5	4.0	4.0
126–144	3.5	4.0	4.5	4.5

* Minimum cover may vary, depending on local conditions. The contractor must provide the additional cover required to avoid damage to the pipe. Minimum cover is measured from the top of the pipe to the top of the maintained construction roadway surface.
* In unpaved situation, the surface must be maintained.

The structure must be protected from hydraulic forces during construction, prior to the completion of permanent erosion control and end protection. Hydraulic forces may cause erosion, shape distortion, flotation or washout.

Backfill and other earth loads must be kept balanced. (See Article 26.5.4.)

26.7 MEASUREMENT

Corrugated metal and structural plate pipe, pipe arches, arches and box culverts shall be measured in lineal feet installed in place, completed and accepted. The number of lineal feet shall be the average of the top and bottom center line lengths for pipe, the bottom center line length for pipe arches and box culverts, and the average of springing line lengths for arches.

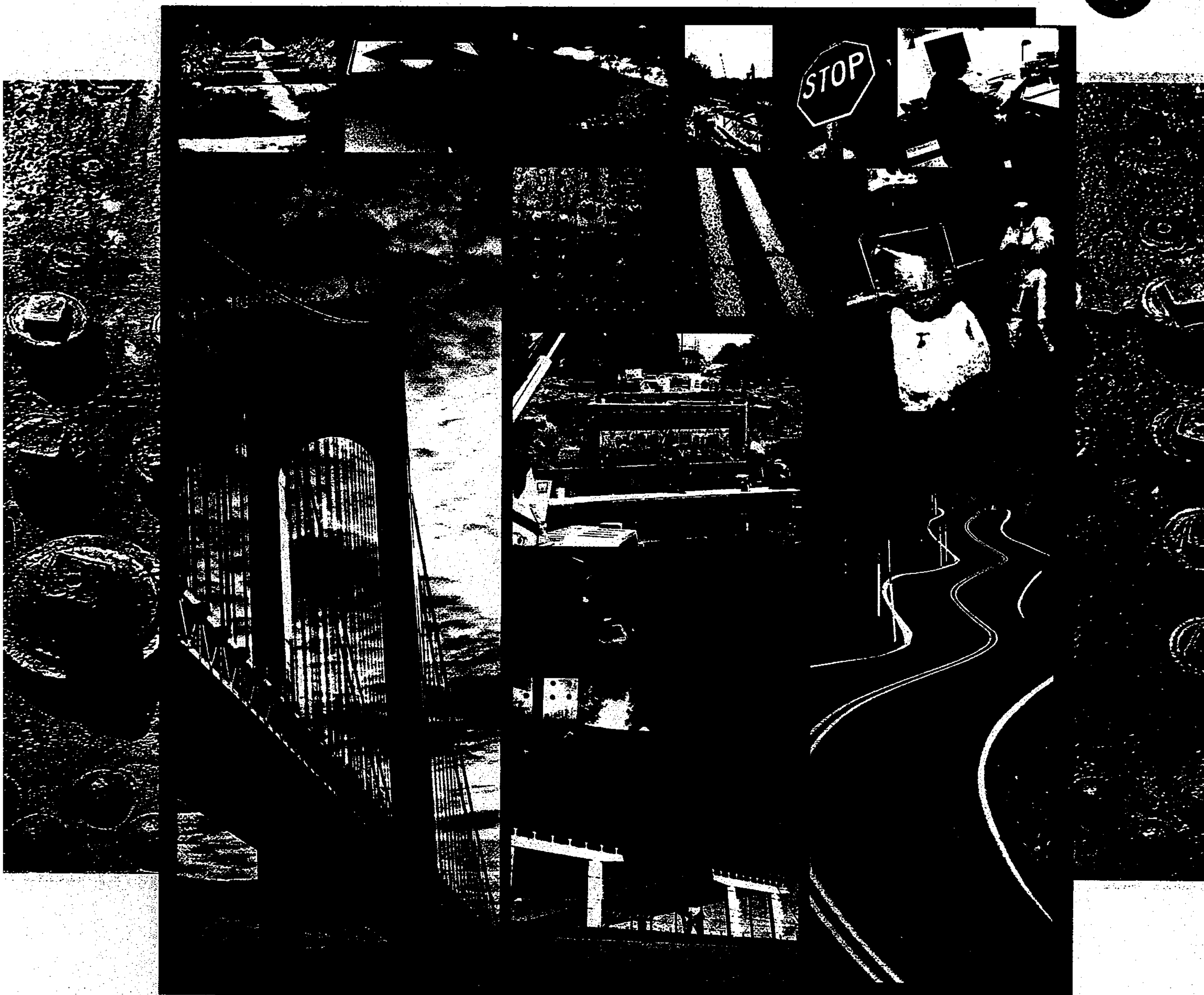
26.8 PAYMENT

Separate pay items or provision for including excavation, backfill, and concrete for arches must be provided for in the contract.

The lengths as measured above will be paid for at the contract prices per lineal foot bid for corrugated metal and structural plate pipe, pipe-arch, arch or box culvert of the sizes specified. Such price and payment shall constitute full compensation for furnishing, handling, erecting, and installing the pipe, pipe-arches, arches or box culverts, and for all materials, labor, equipment, tools and incidentals necessary to complete this item. Such price and payment shall also include excavation, bedding material, backfill, concrete headwalls, endwalls and foundations for pipe, pipe-arches and box culverts. Separate payment will be made for excavation, backfill, and concrete or masonry headwalls and foundations for arches.

APPENDIX D

AASHTO and ASTM- SPECIFICATIONS



Standard Specifications for Transportation Materials and Methods of Sampling and Testing

1999 Interim Edition

American Association of State Highway and Transportation Officials

Standard Specification
for

Corrugated Steel Pipe, Metallic-Coated, for Sewers and Drains

AASHTO DESIGNATION: M 36M-98[1]
(ASTM DESIGNATION: A 760/A 760M-95b)

1. SCOPE

1.1 This specification covers corrugated steel pipe intended for use for storm water drainage, underdrains, the construction of culverts, and similar uses. Pipe covered by this specification is not normally used for the conveyance of sanitary or industrial wastes. The steel sheet used in fabrication of the pipe has a protective metallic coating of zinc (galvanizing), aluminum Type 2, 55 percent aluminum-zinc alloy, zinc-5 percent aluminum-mischmetal alloy or aluminum Type 1.

1.1.1 Steel sheet with zinc and aramid fiber composite coating may be specified for fabrication of pipe. Pipe made from sheet with this composite coating is always furnished with an asphalt coating. Therefore, the requirements in this specification should be considered as applying to a semi-finished pipe; the finished pipe must include provisions of M 190M.

NOTE 1—Pipe fabricated with zinc and aramid fiber composite coated sheet and asphalt post-coating may be used for sanitary sewers and industrial applications. Petroleum products or similar materials in the sewer effluent may affect the performance of the asphalt coating.

1.2 The several different metallic coatings may not provide equal protection of the base metal against corrosion and/or abrasion in all environments. Some environments may be so severe that none of the metallic coatings included in this specification will provide adequate protection. Additional protection for corrugated steel pipe can be provided by use of coatings applied after fabrication of the pipe as described in M 190M, or by use of polymer precoated corrugated steel pipe as described in M 245M.

1.3 This specification does not include requirements for bedding, backfill, or the relationship between earth cover load and sheet thickness of the pipe. Experience has shown that the successful performance of this product depends upon the proper selection of sheet thickness, type of bedding and backfill, controlled manufacture in the plant, and care in the installation. The installation procedure is described in AASHTO *Standard Specifications for Highway Bridges*, Division II, Section 26.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards:*

2.1.1 M 190M Bituminous Coated Corrugated Metal Culvert Pipe and Pipe Arches
- M 198 Joints for Circular Concrete Sewer and Culvert Pipe Using Flexible Watertight Gaskets
- M 218M Steel Sheet, Zinc-Coated (Galvanized) for Corrugated Steel Pipe
- M 232M/M 232 Zinc Coating (Hot-Dip) on Iron and Steel Hardware
- M 245M Corrugated Steel Pipe, Polymer Precoated, for Sewers and Drains
- M 274M Steel Sheet, Aluminum-Coated (Type 2), for Corrugated Steel Pipe
- M 289M Aluminum-Zinc Alloy Coated Sheet Steel for Corrugated Steel Pipe
- M 291M Carbon and Alloy Steel Nuts (Metric)
- M 298 Coatings of Zinc Mechanically Deposited on Iron and Steel
- T 65M/T 65 Mass [Weight] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings
- T 213M/T 213 Mass [Weight] of Coating on Aluminum-Coated Iron or Steel Articles
- T 241M Helical Continuously Welded Seam Corrugated Steel Pipe
- T 249M Helical Lock Seam Corrugated Pipe

2.1.2 *Standard Specifications for Highway Bridges*

2.2 *ASTM Standards:*
- A 780 Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings
- A 796/A 796 M Structural Design of Corrugated Steel Pipe, Pipe-Arches, and Arches for Storm and Sanitary Sewers and Other Buried Applications
- A 885 Steel Sheet, Zinc and Aramid Fiber Composite Coated for Corrugated Steel Sewer, Culvert, and Underdrain Pipe

[1] This specification is technically identical to ASTM A 760/A 760M-95b.

A 929/A 929M Steel Sheet, Metallic-Coated by the Hot-Dip Process for Corrugated Steel Pipe
B 633 Electrodeposited Coatings of Zinc on Iron and Steel
D 1056 Flexible Cellular Materials—Sponge or Expanded Rubber
F 568M Carbon and Alloy Steel Externally Threaded Metric Fasteners

3. TERMINOLOGY

3.1 *Description of Terms Specific to This Standard:*

3.1.1 *Fabricator*—the producer of the pipe.

3.1.2 *Manufacturer*—the producer of the sheet.

3.1.3 *Minimized Coating Structure*—a coating characterized by a finer metallurgical coating structure obtained by a treatment designed to restrict the formation of the normal coarse-grain structure formed during solidification of the Zn-5 Al-MM alloy coating.

3.1.4 *Purchaser*—the purchaser of the finished product.

3.1.5 *Regular Couting Structure*—the normal coating structure resulting from unrestricted grain gowth during normal solidification of the Zn-5 Al-MM alloy coating.

3.2 *Abbreviations:*

3.2.1 *55 Al-Zn*—55 percent aluminum-zinc,

3.2.2 *MM*—mischmetal,

3.2.3 *Zn-5 Al-MM*—zinc-5 percent aluminum-mischmetal,

3.2.4 *AlT2* — aluminum-coated Type 2, and

3.2.5 *AlT1* — aluminum-coated Type 1.

4. PIPE CLASSIFICATION

4.1 The corrugated steel pipe covered by this specification is classified as follows:

4.1.1 *Type I*—This pipe shall have a full circular cross section, with a single thickness of corrugated sheet, fabricated with annular (circumferential) or helical corrugations.

4.1.2 *Type IA*—This pipe shall have a full circular cross section, with an outer shell of corrugated sheet and an inner liner of smooth (uncorrugated) sheet, fabricated with helical corrugations and lock seams.

4.1.3 *Type IR*—This pipe shall have a full circular cross section with a single thickness of smooth sheet, fabricated with helical ribs projecting outwardly.

4.1.4 *Type II*—This pipe shall be a Type I pipe which has been reformed into a pipe-arch, having an approximately flat bottom.

4.1.5 *Type IIA*—This pipe shall be a Type IA pipe which has been reformed into a pipe-arch, having an approximately flat bottom.

4.1.6 *Type IIR*—This pipe shall be a Type IR pipe which has been reformed into a pipe-arch having an approximately flat bottom.

4.1.7 *Type III*—This pipe, intended for use as underdrains or for underground disposal of water, shall be a Type I pipe which has been perforated to permit the inflow or outflow of water.

4.1.8 *Type IIIA*—This pipe, intended for use as underdrains, shall consist of a semicircular cross section, having a smooth (uncorrugated) bottom with a corrugated top shield.

4.2 Perforations in Type III pipe are included in three classes as described in Section 8.3.2.

4.3 Zn-5 Al-MM alloy-coated material is available in two coating classes, or structures, as follows:

4.3.1 *Class A*—Minimized coating structure.

4.3.2 *Class B*—Regular coating structure.

5. ORDERING INFORMATION

5.1 Orders for material to this specification shall include the following information as necessary, to adequately describe the desired product.

5.1.1 Name of material (corrugated steel pipe);

5.1.2 Type of metallic coating (zinc, aluminum-coated Type 2, aluminum-coated Type 1, 55 Al-Zn alloy, Zn-5 Al-MM alloy, or zinc and aramid fiber composite coating) (Section 6.1);

5.1.2.1 For Zn-5 Al-MM alloy, class of coating structure (class A, minimized, etc.);

5.1.3 AASHTO designation and date of issue (M 36M-98);

5.1.4 Type of pipe (Section 4.1);

5.1.5 Diameter of circular pipe (Table 6), or span and rise of pipe-arch section (Tables 8, 9, or 10);

5.1.6 Length, either total length or length of each piece and number of pieces;

5.1.7 Description of corrugations (Section 7.2);

5.1.8 Sheet thickness (Section 8.1.2);

5.1.9 For Type I and Type II pipe, the pipe fabrication method, whether with annular corrugations or helical corrugations (Section 7.1.1) (Note 2);

NOTE 2—Pipe manufactured with annular corrugations may have an element of weakness in the longitudinal seams as compared to pipe with helical corrugations. Therefore, consideration of the method of fabrication is important when pipe is installed under certain conditions of loading.

5.1.10 When zinc and aramid fiber composite coated sheet is used for fabrication of pipe, the type of asphalt coating (Sections 1.1.1 and 8.5);

NOTE 3—See M 190M for additional information appropriate to bituminous post-coatings on pipe.

5.1.11 Coupling bands, number, and type (Section 9.1) if special type is required;

5.1.12 Gaskets for coupling bands, if required (Section 9.3);

5.1.13 For Type III pipe, class of perforations, if other than Class I (Section 8.3.2);

5.1.14 Certification, if required (Section 14.1); and

5.1.15 Special requirements.

6. MATERIALS

6.1 *Steel Sheet for Pipe*—All pipe fabricated under this specification shall be formed from zinc-coated sheet conforming to M 218M, or aluminum-coated Type 2 sheet conforming to M 274M, 55 percent aluminum-zinc alloy-coated sheet conforming to M 289M or zinc-5 percent aluminum-mischmetal alloy-coated sheet conforming to ASTM A 929/A 929M or aluminum-coated Type 1 conforming to ASTM A 929/A 929M. If the type of metallic coating is not stated in the order, zinc-coated sheet conforming to M 218M shall be used. All pipe furnished on the order shall have the same metallic coating, unless otherwise specified.

6.2 *Steel Sheet for Coupling Bands*—The sheet used in fabricating coupling bands shall have the same coating and shall conform to the same specification listed in Section 6.1 as that used for fabrication of the pipe furnished under the order.

6.3 *Rivets*—The rivets used in riveted pipe shall be of the same material as the base metal specified for the corrugated sheets. They shall be thoroughly galvanized or sherardized. If bolts and nuts are substituted for rivets (Section 7.3.1), they shall meet the following requirements:

Bolts	Nuts
F 568, Cl. 8.8	M 291M, Cl. 12

The bolts and nuts shall be hot-dip galvanized in conformance with M 232M/M 232, or be mechanically galvanized in conformance with M 298, Class 40.

6.4 *Hardware for Coupling Bands*—Bolts and nuts for coupling bands shall conform to the following requirements:

Bolts	Nuts
F 568, Cl. 4.6	M 291M, Cl. 5

Bolts, nuts, and other threaded items used with coupling bands shall be zinc coated by one of the following processes: hot-dip process as provided in M 232M/M 232; electroplating process as provided in ASTM B 633, Class Fe/Zn 8; or mechanical process as provided in M298, Class 8. Other hardware items used with coupling bands shall be zinc coated by one of the following processes: hot-dip process as provided in M 232M/M 232; electroplating process as provided in ASTM B 633, Class Fe/Zn 25; or mechanical process as provided in M 298M, Class 25.

6.5 *Gaskets*—If gaskets are used in couplings, they shall be a band of expanded rubber meeting the requirements of ASTM D 1056 for the "RE" closed cell grades, or O-rings meeting the requirements of M 198.

7. FABRICATION

7.1 *General Requirements*—Pipe shall be fabricated in full circular cross section except for Type IIIA which is described in Section 8.4.

7.1.1 Type I pipe shall have annular corrugations with lap joints fastened with rivets or resistance spot welds, or shall have helical corrugations with a continuous lock seam or welded seam extending from end to end of each length of pipe. The type of fabrication used shall be the option of the fabricator unless otherwise specified, except that the pipe fabricated from zinc and aramid fiber composite coated sheet shall be fabricated by riveted or lock seam fabrication only.

7.1.2 Type IA pipe shall be fabricated with a smooth liner and helically corrugated shell integrally attached at helical lock seams extending from end to end of each length of pipe. The shell shall have corrugations of nominal 68- or 75-mm pitch. Zinc and aramid fiber composite coated sheet shall not be used for fabrication of Type IA pipe.

7.1.3 Type IR pipe shall be fabricated with helical ribs projecting outward with a continuous lock seam extending from end to end of each length of pipe.

7.2 *Corrugations*—The corrugations shall be either annular or helical as provided in Section 7.1. The direction of the crests and valleys of helical corrugations shall not be less than 60 degrees from the axis of the pipe for pipe diameters larger than 525 mm, and not less than 45 degrees from the axis for pipe diameters of 525 mm and smaller.

7.2.1 For Type I and IA pipe, corrugations shall form smooth continuous curves and tangents. The dimensions of the corrugations shall be in accordance with Table 1 for the size indicated in the order, except if the depth measurement of one or more corrugations is less than the minimum depth in Table 1, the depth of all corrugations between adjacent seams shall be measured and the values of Table 2 for minimum average depth and minimum corrugation depth shall apply.

NOTE 4—Inspection frequently consists of measurement of the depth of one or a few corrugations. If such measurement indicates insufficient depth, application of the requirements in Table 2 provides for acceptance where greater depth of some corrugations compensates for lack of depth of others. These measurements would normally be made at one location between seams on a length of pipe.

7.2.2 For Type IR pipe, the corrugations shall be essentially rectangular ribs projecting outward from the pipe wall. The dimensions and spacing of the ribs shall be in accordance with Table 3 for the size indicated on the order. For the 292-mm rib spacing, if the sheet between the ribs does not include a lock seam, a stiffener shall be included midway between the ribs. This stiffener shall have a nominal radius of 6.4 mm and a minimum height of 5.1 mm toward the outside of the pipe. N/A

NOTE 5—The nominal dimensions and properties for smooth corrugations and for ribs are given in AASHTO *Standard Specifications for Highway Bridges,* Division I, Section 12, and in ASTM A 796.

7.3 *Riveted Seams*—The longitudinal seams shall be staggered to the extent that no more than three thicknesses of sheet are fastened by any rivet. Pipe to be reformed into pipe-arch shape shall have seams meeting the longitudinal seam requirement of Section 8.2.2. (See also Note 6.)

NOTE 6—Fabrication of pipe without longitudinal seams in 120 degrees of arc, so that the pipe may be installed without longitudinal seams in the invert, is subject to negotiation between the purchaser and fabricator.

7.3.1 The size of rivets, number per corrugation, and width of lap at the longitudinal seam shall be as stated in Table 4, depending on sheet thickness, corrugation size, and diameter of pipe. For pipe with 25-mm deep corrugations, M 12 diameter bolts and nuts may be used in lieu of rivets on a one-for-one replacement ratio. Circumferential seams shall be riveted using rivets of the same size as for longitudinal seams and shall have a maximum rivet spacing of 150 mm, measured on centers, except that six riv-

TABLE 1 Corrugation Requirements for Type I, IA, II, IIA, and III Pipe

Nominal Size	Maximum Pitch[A]	Minimum Depth[B]	Inside Radius[C] Nominal	Inside Radius[C] Minimum
		M 36M—All values in millimeters		
38 by 6.5[D]	48	6.0	7	6.5
68 by 13	73	12	17	12
75 by 25	83	24	14	12
125 by 25	135	24	40	36

[A] Pitch is measured from crest to crest of corrugations, at 90 degrees to the direction of the corrugation.
[B] Depth is measured as the vertical distance from a straightedge resting on the corrugation crests parallel to the axis of the pipe to the bottom of the intervening valley. If the depth measurement of one or more corrugations is less than the value indicated herein, the depth of all corrugations between seams shall be measured, and the requirements of Table 2 shall be applied (see Section 7.2.1).
[C] Minimum inside radius requirement does not apply to a corrugation containing a helical lock seam.
[D] The corrugation size of 38 by 6.5 mm is available only in helically corrugated pipe.

TABLE 2 Referee Requirements for Corrugation Depth[A]

Nominal Size	Diameter	Minimum Average Depth	Minimum Corrugation Depth
	All values in millimeters		
38 by 6.5	all	6.1	5
68 by 13	300 thru 525	12.1	10
68 by 13	over 525	12.4	11
75 by 25	all	24.9	23
125 by 25	all	24.9	23

[A] See Section 7.2.1 for application of Table 2.

TABLE 3 Rib Requirements for Types IR and IIR Pipe

Nominal Size	Rib Width,[A] Min.	Rib Depth,[B] Min.	Rib Spacing[C] Max.	Bottom Outside Radius, Min.	Bottom[D] Outside Radius, Max. Avg.	Top Outside Radius, Min.	Top[D] Outside Radius, Max. Avg.
			Millimeters				
19 by 19 by 190	17	19	197	2.5	6.0	2.5+t	6.0+t
19 by 25 by 292	17	24	298	2.5	6.0	2.5+t	6.0+t

[A] Width is a dimension of the inside of the rib, but is measured on the outside of the pipe (outside of the rib) and shall meet or exceed the stated minimum width plus two times the wall thicknesses, that is, 2t + 17 mm.
[B] Depth is an average of three ribs (one sheet width) measured from the inside by placing a straightedge across the open rib and measuring to the bottom of the rib.
[C] Spacing is an average of three ribs (one sheet width) measured center-to-center of the ribs at 90° to the direction of the ribs.
[D] The average of the four rib radii (Top and Bottom) shall be within the minimum and maximum tolerances. The outside radius refers to the surface outside of the pipe.

ets will be sufficient in 300-mm diameter pipe.

7.3.2 All rivets shall be driven cold in such a manner that the sheets shall be drawn tightly together throughout the entire lap. The center of a rivet shall be no closer than twice its diameter from the edge of the sheet. All rivets shall have neat, workmanlike, and full hemispherical heads or heads of a form acceptable to the purchaser, shall be driven without bending, and shall completely fill the hole.

7.4 *Resistance Spot Welded Seams*—The longitudinal seams shall be staggered to the extent that no more than three thicknesses of sheet are fastened by any spot weld. Pipe to be reformed into pipe-arch shape shall also meet the longitudinal seam requirement of Section 8.2.2 (Note 6).

7.4.1 The size of spot welds, number per corrugation, and width of lap at the longitudinal seam shall be as stated in Table 4, depending on sheet thickness, corrugation size, and diameter of pipe. Circumferential seams shall be welded using spot welds of the same size as for longitudinal seams and shall have a maximum weld spacing of 150 mm, except that six welds will be sufficient in 300-mm diameter pipe.

7.4.2 All spot welds shall be made in such a manner that the sheets will be drawn tightly together throughout the lap. The outside edge of each spot weld shall be at least 6.5 mm from the edge of the sheet. The welding shall be performed in such a manner that the exterior surfaces of 90 percent or more of the spot welds on a length of pipe shall show no evidence of melting or burning of the base metal, and the base metal shall not be exposed when the area adjacent to the electrode contact surface area is wire brushed. Discoloration of the spot weld surfaces will not be cause for rejection.

7.4.3 Welding equipment shall be qualified before use, and the qualification shall be verified before each work shift and when changing sheet thickness, all as described in Annex A1. If use of the equipment at the approved machine settings fails to produce satisfactory welds, fabrication shall be stopped until adjustments are made and the equipment is requalified.

7.5 *Helical Lock Seams*—The lock seam for Type I pipe shall be formed in the tangent element of the corrugation profile with its center near the neutral axis of the corrugation profile. The lock seam for Type IA pipe shall be in the valley of the corrugation, shall be spaced not more than 760 mm apart, and shall be formed from both the liner and the shell in the same general manner as Type I helical lock seam pipe. The lock seam for Type IR pipe shall be formed in the flat zone of the pipe wall, midway between two ribs.

7.5.1 The edges of the sheets within the cross section of the lock seam shall lap at least 4.0 mm for pipe 250 mm or less in diameter and at least 7.9 mm for pipe greater than 250 mm in diameter, with an occasional tolerance of minus 10 percent of lap width allowable. The lapped surfaces shall be in tight contact. The profile of the sheet shall include a retaining offset adjacent to the 180-degree fold (as described in T 249M) of one sheet thickness on one side of the lock seam, or one-half sheet thickness on both sides of the lock seam, at the fabricator's option. There shall be no visible cracks in the metal, loss of metal-

TABLE 4 Riveted and Spot-Welded Longitudinal Seams

Specified Sheet Thickness	68 × 13 mm[A,D]	75 × 25 mm[B,E]	125 × 25 mm[C,E]
	Rivet or Spot-Weld Diameters, min		
mm	mm	mm	mm
1.32	8.0	—	—
1.63	8.0	9.5	9.5
2.01	8.0	9.5	9.5
2.77	9.5	11.0	11.0
3.51	9.5	11.0	11.0
4.27	9.5	11.0	11.0

[A] One rivet or spot weld each valley for pipe diameters 900 mm and smaller. Two rivets or spot welds each valley for pipe diameters 1050 mm and larger.
[B] Two rivets or spot welds each valley for all pipe diameters.
[C] Two rivets or spot welds each crest and valley for all pipe diameters.
[D] Minimum width of lap: 38 mm for pipe diameters 900 mm and smaller, and 75 mm for pipe diameters 1050 mm and larger.
[E] Minimum width of lap: 75 mm for pipe of all diameters.

to-metal contact, or excessive angularity on the interior of the 180-degree fold of metal at the completion of forming the lock seam.

7.5.2 Specimens cut from production pipe normal to and across the lock seam shall develop the tensile strength as provided in Table 5, when tested according to T 249M. For Type IA pipe, the lock seam strength shall be as tabulated based on the thickness of the corrugated shell.

7.5.3 When the ends of helically corrugated lock seam pipe have been rerolled to form annular corrugations, either with or without a flanged end finish, the lock seam in the rerolled end shall not contain any visible cracks in the base metal and the tensile strength of the lock seam shall be not less than 60 percent of that required in Section 7.5.2.

7.6 *Helical Continuous Welded Seams*—The seam shall be parallel to the corrugations and shall have a continuous weld extending from end to end of each length of pipe. Welding shall be done utilizing ultra high frequency resistance equipment. Seams shall be welded in such a manner that they will develop the full strength of the pipe and not affect shape or nominal diameter of the pipe. Welded seams shall be controlled such that the combined width of weld and adjacent coating burned by welding does not exceed three times the metal thickness. Damage outside this width shall be repaired as required in Section II. The fabricator shall certify that the welds have been tested and found satisfactory.

7.6.1 Continuous welded seams shall be tested in accordance with the cup test procedure (Section 3) of T 241M. The welded seam shall be acceptable if the sum of the length of cracks or other defects on either side of the cup does not exceed 6.5 mm, basing the result on the second test if the first shows greater defects. The provisions of the referee test method of Section 4 of T 241M shall be applicable in the event of disagreement between the purchaser and the fabricator.

7.6.1.1 Tests of continuous welded seams shall be made as follows:

7.6.1.2 Pipe lengths of 7.3 m or less shall be tested on one end of each length, normally the trailing end.

7.6.1.3 If a length of pipe having a diameter greater than 1200 mm and length of 7.3 m or less is rejected, the following length of pipe produced shall be tested on both ends. If the test on either end fails, this entire length shall also be rejected.

7.6.1.4 Pipe lengths greater than 7.3 m shall be tested on each end of each length of pipe. If either end fails, the entire length shall be rejected.

7.6.2 The requirement for conducting quality control tests in accordance with Section 7.6.1 shall not apply for pipe in which the ends have been rerolled to form annular corrugations. The manufacturer shall maintain visual evaluation of the quality of the weld after rerolling and any indication of weld or base metal failure will be cause for rejection of the pipe.

7.6.3 Any indication of cracks, skips, or deficient welds found through visual inspection will be cause for rejection unless repaired. It is the option of the fabricator to remove the defective portion of the length of pipe or to manually repair defects in the automatically welded seam. Altered or repaired pipe shall meet the applicable requirements of Section 7.6. Where a manual repair occurs within 400 mm of the end of the length of pipe, a test shall be conducted on both the manually repaired section and on the immediately adjacent automatically welded section. If either test results in failure under the criterion of Section 7.6.1, the length of pipe shall be rejected.

7.7 *End Finish:*

7.7.1 To facilitate field jointing, the ends of the individual pipe sections with helical corrugations or ribs may be rerolled to form annular corrugations extending at least two corrugations from the pipe end, or to form an upturned flange meeting the requirements in Section 7.7.2, or both. The diameter of ends shall not exceed that of the pipe barrel by more than the depth of the corrugation. All types of pipe ends, whether

TABLE 5 Lock Seam Tensile Strength

Specified Sheet Thickness[A]	Lock Seam Tensile Strength, per Unit Width, min
mm	kN/m
1.02	30
1.32	42
1.63	60
2.01	91
2.77	122
3.50	154
4.27	210

[A] For Type IA pipe, the thickness shall be that of the corrugated shell.

rerolled or not, shall be matched in a joint such that the maximum difference in the diameter of abutting pipe ends is 13 mm.

7.7.1.1 When pipe with any size helical corrugation or rib is rerolled to form annular corrugations in the ends, the usual size of the annular corrugation is 68 by 13 mm.

7.7.2 If a flanged finish is used on the ends of individual pipe sections to facilitate field jointing, the flange shall be uniform in width, be not less than 13 mm wide, and shall be square to the longitudinal axis of the pipe.

7.7.3 The ends of all pipe which will form the inlet and outlet of culverts, fabricated of sheets having nominal thicknesses of 2.01 mm and less, shall be reinforced in a manner approved by the purchaser, when specified.

8. PIPE REQUIREMENTS

8.1 *Type I, Type IA, and Type IR Pipe:*

8.1.1 *Pipe Dimensions*—The nominal diameter of the pipe shall be as stated in the order, selected from the size listed in Table 6. The size of corrugations which are standard for each size of pipe are also shown in Table 6. The average inside diameter of circular pipe and pipe to be reformed into pipe-arches shall not vary more than 1 percent or 13 mm, whichever is greater, from the nominal diameter when measured on the inside crest of the corrugations. Alternately, for pipe having annular corrugations, conformance with the inside diameter requirement may be determined by measuring the outside circumference, for which minimum values are given in Table 6.

NOTE 7—The outside circumference of helically corrugated pipe is influenced by the corrugation size and the angle of the corrugation, affecting the number of corrugations crossed; therefore, no minimum measurement can be specified.

8.1.2 *Sheet Thickness*—Sheet thickness shall be specified by the purchaser from the specified sheet thicknesses listed in Table 7 (Notes 8 and 9). For Type IA pipe, the thickness of both the shell and the liner shall be given; the

TABLE 6 Pipe Sizes

Nominal Inside Diameter	Corrugation Sizes[A]					Minimum Outside Circumference[B]
	38 by 6.5	68 by 13	75 by 25	125 by 25	Ribbed	
mm	mm	mm	mm	mm	Pipe[C]	mm
100	x					284
150	x					441
200	x					598
250	x					755
300	x	x				912
375	x	x				1148
450	x	x			x	1383
525		x			x	1620
600		x			x	1854
675		x			x	2091
750		x			x	2483
825		x		x	x	2561
900		x	x	x	x	2797
1050		x	x	x	x	3269
1200		x	x	x	x	3739
1350		x	x	x	x	4209
1500		x	x	x	x	4675
1600		x	x	x	x	4987
1650		x	x	x	x	5142
1800		x	x	x	x	5609
1950		x	x	x	x	6075
2100		x	x	x	x	6542
2250			x	x	x	7006
2400			x	x	x	7475
2550			x	x	x	7941
2700			x	x	x	8408
2850			x	x		8874
3000			x	x		9341
3150			x	x		9807
3300			x	x		10274
3450			x	x		10740
3600			x	x		11207

[A] An "X" indicates standard corrugation sizes for each nominal diameter of pipe.
[B] Measured in valley of annular corrugations. Not applicable to helically corrugated pipe.
[C] Rib sizes 19 × 19 × 190 mm and 19 × 25 × 292 mm.

TABLE 7 Thicknesses of Metallic Coated Steel Sheet[A]

Specified Thickness	Specification Designation					
mm	M 218 Zinc Coated	M 274 AlT2 Aluminum Coated	M 289 55 percent Aluminum-Zinc Alloy Coated	A 885 Zinc and Aramid Fiber Coated	A 929M Zn-5 Al-MM Alloy Coated	A 929M AlT1 Aluminum Coated
1.02	x		x		x	
1.32	x	x	x		x	x
1.63	x	x	x	x	x	x
2.01	x	x	x	x	x	x
2.77	x	x	x	x	x	x
3.51	x	x	x	x	x	x
4.27	x			x	x	

[A] An "X" indicates sheet thicknesses included in the applicable specification for coating types listed.

thickness of the corrugated shell shall not be less than 60 percent of the thickness of the equivalent Type I pipe; the liner shall have a nominal thickness of at least 1.02 mm; and the sum of the specified thicknesses of shell and liner shall equal or exceed the specified thickness of an equivalent pipe of identical corrugations as the shell according to the design criteria in AASHTO *Standard Specifications for Highway Bridges.*

NOTE 8—The sheet thicknesses indicated in Table 7 are the thicknesses listed as available in M 218M, M 274M, M 289M and ASTM A 929M.

NOTE 9—The purchaser should determine the required thickness for each of the types of pipe described in Sections 4.1.1 through 4.1.6 according to the design criteria in AASHTO *Standard Specifications for Highway Bridges,* Division 1, Section 12, or other appropriate guidelines.

8.1.3 When specified by the purchaser, the finished pipe shall be factory elongated to the extent specified. The elongation shall be accomplished by the use of a mechanical apparatus which will produce a uniform deformation throughout the length of the section.

8.2 *Type II, IIA, and IIR Pipe:*

8.2.1 *Pipe-Arch Dimensions*—Pipe furnished as Type II, IIA, or IIR shall be made from Type I, IA, or IR pipe respectively, and shall be reformed to provide a pipe-arch shape. All applicable requirements for Types I, IA, and IR pipe shall be met by finished Types II, IIA, and IIR pipe, respectively. Pipe-arches shall conform to the dimensional requirements of Tables 8, 9, or 10. All dimensions shall be measured from the inside crests of corrugations for Type II pipe or from the inside liner or surface for Types IIA or IIR, respectively.

8.2.2 *Longitudinal Seams*—Longitudinal seams of riveted or spot-welded pipe-arches shall not be placed in the corner radius.

8.2.3 Reforming Type IR into Type IIR pipe shall be done in such a manner as to avoid damage to the external ribs.

8.3 *Type III Pipe:*

8.3.1 Type III pipe shall have a full circular cross-section and shall conform to the requirements for Type I pipe and, in addition, shall contain perforations conforming to one of the classes described in Section 8.3.2.

8.3.2 *Perforations*—The perforations shall conform to the requirements for Class I, unless otherwise specified in the order. Class I perforations are for pipe intended to be used for subsurface drainage. Class 2 and 3 perforations are for pipe intended to be used for subsurface disposal of water, but pipe containing Class 2 and 3 perforations may also be used for subsurface drainage.

8.3.2.1 *Class I Perforations*—The perforations shall be approximately circular and cleanly cut; shall have nominal diameters of not less than 4.8 mm nor greater than 9.5 mm; and shall be arranged in rows parallel to the axis of the pipe. The perforations shall be located on the inside crests or along the neutral axis of the corrugations, with one perforation in each row for each corrugation. Pipe connected by couplings or bands may be unperforated within 100 mm of each end of each length of pipe. The rows of perforations shall be arranged in two equal groups placed symmetrically on either side of a lower unperforated segment cor-

TABLE 8 (M 36M) Pipe Arch Requirements 68 by 13 mm Corrugations

Pipe Arch Size, mm	Equivalent Diam., mm	Span[A] mm	Rise[A] mm	Minimum Corner Radius, mm	Maximum B[B] mm
430 by 330	375	430	330	75	135
530 by 380	450	530	380	75	155
610 by 460	525	610	460	75	185
710 by 510	600	710	510	75	205
780 by 560	675	780	560	75	225
885 by 610	750	870	610	75	240
970 by 690	825	970	690	75	255
1060 by 740	900	1060	740	90	265
1240 by 840	1050	1240	840	100	290
1440 by 970	1200	1440	970	130	345
1620 by 1100	1350	1620	1100	155	380
1800 by 1200	1500	1800	1200	180	420
1950 by 1320	1650	1950	1320	205	460
2100 by 1450	1800	2100	1450	230	510

[A] A tolerance of 25 mm or 2 percent of equivalent diameter, whichever is greater, will be permissible in span and rise.

[B] B is defined as the vertical dimension from a horizontal line across the widest portion of the arch to the lowest portion of the base.

TABLE 9 (M 36M) Pipe Arch Requirements 75 by 25 mm or 125 by 25 mm Corrugations

Pipe Arch Size, mm	Equivalent Diam., mm	Span[A] mm	Rise[A] mm	Minimum Corner Radius, mm
1010 by 790	900	1010 − 45	790 + 45	130
1160 by 920	1050	1160 − 55	920 + 55	155
1340 by 1050	1200	1340 − 60	1050 + 60	180
1520 by 1350	1350	1520 − 70	1170 + 70	205
1670 by 1300	1500	1670 − 75	1300 + 75	230
1850 by 1400	1650	1850 − 85	1400 + 85	305
2050 by 1500	1800	2050 − 95	1500 + 95	355
2200 by 1620	1950	2200 − 110	1620 + 110	355
2400 by 1720	2100	2400 − 120	1720 + 120	410
2600 by 1820	2250	2600 − 130	1820 + 130	410
2840 by 1920	2400	2840 − 145	1920 + 145	460
2970 by 2020	2550	2970 − 150	2020 + 150	480
3240 by 2120	2700	3240 − 165	2120 + 165	480
3470 by 2220	2850	3470 − 175	2220 + 175	480
3600 by 2320	3000	3600 − 180	2320 + 180	480

[A] Negative and positive numbers listed with span and rise dimensions are negative and positive tolerances; no tolerance in opposite direction.

TABLE 10 Pipe-Arch Requirements—19 × 19 × 190 mm or 19 × 25 × 292 mm Rib Corrugations

Pipe Arch Size, mm	Equivalent Diameter, mm	Span[A] mm	Rise[A] mm	Minimum Corner Radius, mm
500 × 410	450	500 − 25	410 + 25	130
580 × 490	525	550 − 25	490 + 25	130
680 × 540	600	680 − 40	540 + 40	130
750 × 620	675	750 − 40	620 + 40	130
830 × 670	750	830 − 40	670 + 40	130
900 × 750	825	900 − 45	750 + 45	130
1010 × 790	900	1010 − 45	790 + 45	130
1160 × 920	1050	1160 − 55	920 + 55	155
1340 × 1050	1200	1340 − 60	1050 + 60	180
1520 × 1170	1350	1520 − 70	1170 + 70	205
1670 × 1300	1500	1670 − 75	1300 + 75	230
1850 × 1400	1650	1850 − 85	1400 + 85	305
2050 × 1500	1800	2050 − 95	1500 + 95	355

[A] Negative and positive numbers listed with span and rise dimensions are negative and positive tolerances; no tolerance in opposite direction.

responding to the flow line of the pipe. The spacing of the rows shall be uniform. The distance between the center lines of rows shall be not less than 25 mm. The minimum number of longitudinal rows of perforations, the maximum heights of the centerlines of the uppermost rows above the bottom of the invert, and the inside chord lengths of the unperforated segments illustrated in Figure 1 shall be as specified in Table 11.

NOTE 10—Pipe with Class I perforations is generally available in diameters from 100 to 525 mm inclusive, although perforated pipe in larger sizes may be obtained.

8.3.2.2 *Class 2 Perforations*—The perforations shall be circular holes with nominal diameters of 8.0 to 9.5 mm, or slots with nominal widths of 4.8 to 8.0 mm and not to exceed 13 mm in length. The perforations shall be uniformly spaced around the full periphery of the pipe. The perforations shall provide an opening area of not less than 230 square centimeters per square meter of pipe surface based on nominal diameter and length of pipe.

NOTE 11—323 perforations, 9.5-mm diameter, per square meter satisfies this requirement.

8.3.2.3 *Class 3 Perforations*—The perforations shall be slots with a width of 2.5 ± 1.0 mm and length of 25 ± 6.5 mm, spaced 45 to 65 mm on centers around the circumference and staggered on the outside crests of the corrugations of the pipe. No metal shall be removed in making the slot. Slots shall be made from the inside of the pipe.

8.4 *Type IIIA Pipe:*

8.4.1 Type IIIA pipe shall be fabricated of an unperforated semicircular bottom section with a top shield of corrugated steel, both of nominal 1.32 mm thickness or greater. The smooth semicircular bottom section shall be approximately 120 mm in diameter and shall have a continuous lip extending outward along each side; the corrugated top shield shall be approximately 160 mm wide including a 19 mm sloping overhang on each side and shall be secured to the lip of the bottom section by integral tabs spaced at about 90 mm center to center. The top shield shall have corrugations approximately 22 mm center to center and approximately 8.0 mm depth.

8.5 *Pipe Fabricated From Zinc and Aramid Fiber Composite Coated Sheet*—Pipe which has been fabricated from zinc and aramid fiber composite coated sheet shall be coated with asphalt as described in AASHTO M 190M, Type A, Fully Bituminous Coated. If full or partial smooth lining is desired, it shall be specified by the purchaser. (See Section 1.1.1 and AASHTO M 190M.)

9. COUPLING BANDS

9.1 *Types of Coupling Bands*—Field joints for each type of corrugated steel pipe shall maintain pipe alignment during construction and prevent infiltration of fill material during the life of the installation. Coupling bands may be of the following types:

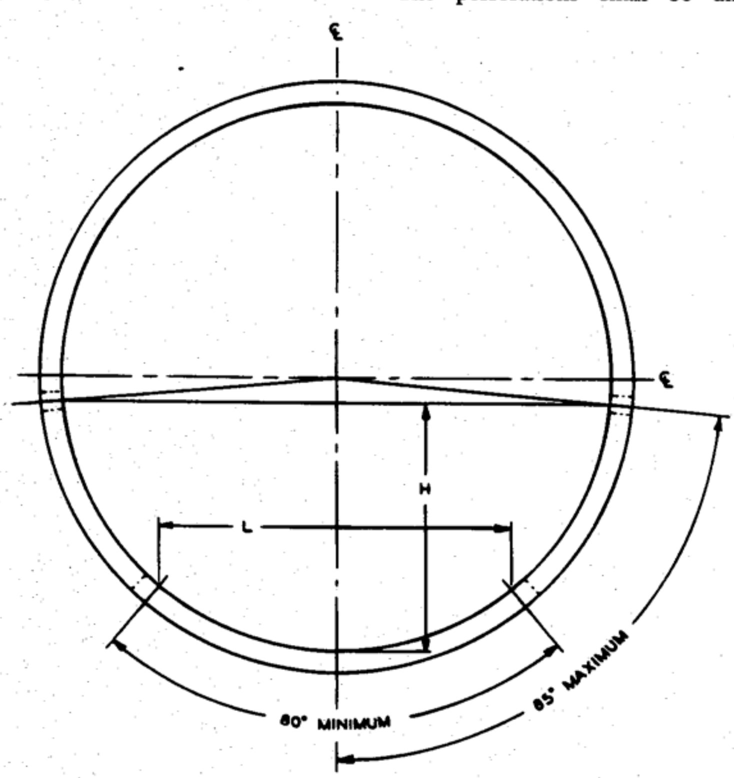


FIGURE 1 Requirements for Perforations

TABLE 11 Rows of Perforations, Height "H" of the Centerline of the Uppermost Rows Above the Invert, and Chord Length "L" of Unperforated Segment, for Class 1 Perforations

Internal Diameter of Pipe		H, max[B]	L, min[B]
mm	Rows of Perforations[A]	mm	mm
100	2	46	64
150	4	69	96
200	4	92	128
250	4	115	160
300	6[C]	138	192
375	6[C]	172	240
450	6[C]	207	288
525	6	241	336
600 and larger	8	(D)	(D)

[A] Minimum number of rows. A greater number of rows for increased inlet area shall be subject to agreement between purchaser and fabricator. Note that the number of perforations per unit length in each row (and inlet area) is dependent on the corrugation pitch.
[B] See Figure 1 for location of dimensions "H" and "L".
[C] Minimum of 4 rows permitted in pipe with 38 by 6.5-mm corrugations.
[D] H(max) = 0.46D; L(min) = 0.64D, where D = internal diameter of pipe, millimeters or inches as appropriate.

TABLE 12 Coupling Band Thickness

Nominal Pipe Thickness	Nominal Coupling Band Thickness, Minimum
mm	mm
2.77 and thinner	1.32
3.51	1.63
4.27	2.01

Bands with annular corrugations,
Bands with helical corrugation,
Bands with projections (dimples),
Channel bands for upturned flanges, with or without annular corrugations,
Flat bands, and
Smooth sleeve-type couplers.

Except as provided in Sections 9.1.1 through 9.1.4, the type of coupling furnished shall be at the option of the fabricator unless the type is specified in the order.

NOTE 12—Bands are classified according to their ability to resist shear, moment, and tensile forces as described in AASHTO *Standard Specifications for Highway Bridges*, Division II, Section 26, and identified as "standard joints" and "special joints." The first four types of bands listed in Section 9.1 and meeting the requirements of Section 9.2 are expected to meet the requirements for "standard joints." Some may also be able to meet the requirements for "special joints," but such capability should be determined by analysis or test.

9.1.1 Coupling bands with annular corrugations shall be used only with pipe with annular corrugations, or helical pipe in which the ends have been rerolled to form annular corrugations. The corrugations in the band shall have the same dimensions as the corrugations in the pipe end, or may be of a special design to engage only the first or second corrugation from the end of each pipe. The band may also include a U-shaped channel to accommodate upturned flanges on the pipe.

9.1.2 Coupling bands with helical corrugations shall be used only with pipe with helically corrugated ends. The corrugations in the bands shall be designed to properly mesh with the corrugations in the pipe.

9.1.3 Coupling bands with projections (dimples) may be used with pipe with either annular or helical corrugations. The bands shall be formed with the projections in annular rows with one projection for each corrugation of helical pipe. Bands 265 or 300 mm wide shall have two annular rows of projections and bands 415 or 560 mm wide shall have four annular rows of projections.

9.1.4 Channel bands may be used only with pipe having upturned flanges on the pipe ends.

9.1.5 Smooth sleeve-type couplers and flat bands may be used only with Type III and IIIA pipe of 300 mm diameter or smaller.

9.2 *Requirements*—Coupling bands shall be fabricated to lap on an equal portion of each of the pipe sections to be connected. The ends of the bands shall lap or be fabricated to form a tightly closed joint upon installation. Coupling band thickness shall conform to the requirements in Table 12, based on the sheet thickness of the pipe to be connected, except as provided in Sections 9.2.1 and 9.2.2. The band width shall be not less than as shown in Table 13. The bands shall be connected in a manner approved by the purchaser with suitable galvanized devices such as: angles, or integrally or separately formed and attached flanges, bolted with zinc-coated bolts; bars and straps; wedge lock and straps; or lugs. Coupling bands shall be fastened with the following size of bolts:

Pipe diameters 450 mm and less—M 10 diameter
Pipe diameters 525 mm and greater—M 12 diameter
Type IIIA pipe—M 8 diameter

9.2.1 If flanges are provided on the pipe ends, the coupling may also be made by interlocking the flanges with a preformed channel band or other band incorporating a locking channel not less than 19 mm in width. The depth of the channel shall be not less than 13 mm. The channel band shall have a minimum nominal thickness of 2.01 mm.

9.2.2 Smooth sleeve type couplings and flat bands shall be steel having a nominal thickness of not less than 1.02 mm, or as an option, may be a plastic sleeve to provide equivalent strength. The coupling shall be close-fitting, to hold the pipe firmly in alignment without the use of sealing compounds or gaskets. The coupling or flat band shall contain a device so that the band or coupling will lap equally on the two pipes being joined. The overall length of the coupling shall be equal to or greater than the nominal diameter of the pipe.

9.3 *Gaskets*—Where infiltration or exfiltration is a concern, the couplings may be required to have gaskets. The closed-cell expanded rubber gaskets shall be a continuous band, approximately 180 mm wide and approximately 9.5 mm thick. Rubber O-ring gaskets shall be 20-mm diameter for pipe diameters of 900 mm or smaller, and 22-mm diameter for larger pipe diameters, having 13-mm

TABLE 13 Coupling Band Width Requirements

Nominal Corrugation Size[A]	Nominal Pipe Inside Diameter,[B]	Coupling Band Width, min		
		Annular Corrugated Bands	Helically Corrugated Bands	Bands With Projections
M 36M—All values in millimeters				
38 by 6.5	100 to 450	265	180	265
68 by 13	300 to 900	180	300	265
	1000 to 1800	265	300	265
	1950 to 2100[C]	265	300	415
75 by 25	900 to 1800	300	350	265
	1950 to 3600	300	350	415
125 by 25	900 to 1800	500	560	300
	1950 to 3600	500	560	560

[A] For helically corrugated pipe with rerolled ends, the nominal corrugation size refers to the dimensions of the end corrugations in the pipe.
[B] Equivalent diameter for Type II, IIA, and IIR pipe.
[C] Diameters through 3600 mm for annular corrugated bands used on rerolled ends of helically corrugated pipe.

deep-end corrugations. Rubber O-ring gaskets shall be 35-mm diameter for pipe having 25-mm deep-end corrugations.

NOTE 13—Riveted and spot-welded pipe is not water tight, having small openings at the intersection of longitudinal and circumferential seams. Therefore, these types of fabrication should not be used where water tightness is a concern unless the pipe is bituminous coated or lined prior to installation.

9.4 Other types of coupling bands or fastening devices which are equally effective as those described, and which comply with the joint performance criteria of AASHTO *Standard Specifications for Highway Bridges*, Division II, Section 26 may be used when approved by purchaser.

10. WORKMANSHIP

10.1 The complete pipe shall show careful, finished workmanship in all particulars. Pipe which has been damaged, either during fabrication or in shipping, may be rejected unless repairs are made which are satisfactory to the purchaser. Among others, the following defects shall be considered as constituting poor workmanship:

Variation from a straight centerline;
Elliptical shape in pipe intended to be round;
Dents or bends in the metal;
Metallic coating which has been bruised, broken, or otherwise damaged;
Lack of rigidity;
Illegible markings on the steel sheet;
Ragged or diagonal sheared edges;
Uneven laps in riveted or spot-welded pipe;
Loose, unevenly lined, or unevenly spaced rivets;
Defective spot welds or continuous welds; and
Loosely formed lockseams.

11. REPAIR OF DAMAGED COATINGS

11.1 Pipe on which the metallic coating has been burned by welding beyond the limits provided in Sections 7.4.2 and 7.6, or has been otherwise damaged in fabricating or handling, shall be repaired. The repair shall be done so that the completed pipe shall show careful finished workmanship in all particulars. Pipe which, in the opinion of the purchaser, has not been cleaned or coated satisfactorily may be rejected. If the purchaser so elects, the repair shall be done in his presence.

11.2 The damaged area shall be repaired in conformance with ASTM A 780 (Note 14), except as described herein. The damaged area shall be cleaned to bright metal by blast cleaning, power disk sanding, or wire brushing. The cleaned area shall extend at least 13 mm into the undamaged section of the coating. The cleaned area shall be coated within 24 hours and before any rusting or soiling.

NOTE 14—While ASTM A 780 specifically refers to repair of damaged zinc coatings, the same procedures are applicable to repair of other metallic coatings except as described in this section.

11.3 *Zinc-Rich Paint Coating*—Zinc-rich paint shall be applied to a dry film thickness of at least 0.13 mm over the damaged section and surrounding cleaned area. Zinc-rich paint shall be used for repair of damage to all types of metallic coating—zinc, aluminum, and aluminum-zinc alloy.

11.4 *Metallizing Coating*—The damaged area shall be cleaned as described in Section 11.2, except it shall be cleaned to the near-white condition. The repair coating applied to the cleaned section shall have a thickness of not less than 0.13 mm over the damaged section and shall taper off to zero thickness at the edges of the cleaned undamaged section.

11.4.1 Where zinc coating is to be metallized, it shall be done with zinc wire containing not less than 99.98-percent zinc.

11.4.2 Where aluminum coating is to be metallized, it shall be done with aluminum wire containing not less than 99-percent aluminum.

11.4.3 Where aluminum-zinc alloy coating is to be metallized, it shall be done by using the materials described in Sections 11.4.1 or 11.4.2, or by using an alloy wire of 55-percent aluminum and 45-percent zinc by mass.

11.4.4 When Zn-5 Al-MM alloy coating is to be metallized, it shall be done using the materials described in 11.4.1 or by using an alloy wire of 85-percent zinc and 15-percent aluminum by weight.

11.5 Pipe on which zinc and aramid fiber composite coating is damaged by welding during fabrication of fittings, or otherwise damaged during handling or shipping, shall be repaired as described in Sections 11.2 through 11.4.

11.6 Materials used to repair damaged bituminous coating shall be compatible with the previous coating. Repair coatings shall be of equal thickness to the original coating as a minimum and shall have equal adherence.

12. INSPECTION

12.1 The purchaser or his representative shall have free access to the fabricating plant for inspection, and every facility shall be extended to him for this purpose. This inspection shall include an examination of the pipe for the items in Section 10.1 and the specific requirements of this specification applicable to the type of pipe and method of fabrication.

12.2 On a random basis, samples may be taken for chemical analysis and metallic coating measurements for check purposes. These samples will be secured from fabricated pipe or from sheets or coils of the material used in fabrication of the pipe. The weight of metallic coating shall be determined in accordance with T 65M/T 65 for zinc, T 213M/T 213 for aluminum, and the dilute hydrochloric acid method of T 65M/T 65 for 55 Al-Zn alloy and T 65M/T 65 for Zn-5 Al-MM alloy.

13. REJECTION

13.1 Pipe that fails to conform to the specific requirements of this specification, or that shows poor workmanship, may be rejected. This requirement applies not only to the individual pipe, but to any shipment as a whole where a substantial number of pipe are defective. If the average deficiency in length of any shipment of pipe is greater than 1 percent, the shipment may be rejected.

12. CERTIFICATION

14.1 When specified in the purchase order or contract, a manufacturer's or fabricator's certification, or both, shall be furnished to the purchaser stating that samples representing each lot have been tested and inspected in accordance with this specification and have been found to meet the requirements for the material described in the order. When specified in the order, a report of the test results shall be furnished.

TABLE A1.1 Shear Strength of Spot Welds

Specified Sheet Thickness mm (M 36M)	Minimum Shear Strength kN (M 36M)
1.63	18.2
2.01	23.1
2.77	31.1
3.51	37.8
4.27	44.5

ANNEX

A1. QUALIFICATION OF RESISTANCE SPOT WELDING EQUIPMENT

A1.1 *General*—Welding equipment shall be of sufficient capacity, of such design, and in such condition as to make possible the production of first-class welds. Before being permitted to perform welding on corrugated steel pipe, resistance spot welding machines and operations shall be qualified by means of the test prescribed in Section A1.2. Tests shall be performed by the fabricator's shop or by a recognized independent laboratory at no expense to the purchaser. Qualification tests performed by the fabricator's shop shall be made in the presence of the representative of the purchaser.

A1.2 *Qualification*—Perform three tension shear tests representing each thickness of sheet to be used in the fabrication of the pipe. Prepare specimens by lapping two strips of corrugated steel sheet 38-mm minimum width by 125-mm minimum length and joining them together by a single spot weld duplicating the size to be used in production. The length of lap shall be 38 mm. The longer axis of specimen shall be parallel to the direction of rolling. Test the specimens in tension to destruction in a standard calibrated testing machine. The minimum shear strength in kilonewtons as determined by this test shall be not less than that shown in Table A1.1 for nominal thickness of sheet used in the test.

A1.3 *Verification*—After a machine and operator have been qualified by the foregoing procedure, to insure that qualification is maintained, make three tension shear tests at the start of each work shift, and make three tension shear tests for each change in sheet thickness.

A1.4 *Machine Setting*—One copy of the approved machine setting shall be posted on the machine for use by the machine operator. No settings shall be varied, except weld phase shift and pressure which may be varied by 10-percent plus or minus.

Standard Specification
for

Corrugated Steel Structural Plate, Zinc-Coated, for Field-Bolted Pipe, Pipe-Arches, and Arches

AASHTO DESIGNATION: M 167M-98
(ASTM DESIGNATION: A 761/A 761M-92)

1. SCOPE

1.1 This specification covers corrugated steel structural plate, zinc-coated, used in the construction of pipe, pipe-arches, arches, underpasses, and special shapes for field assembly. Appropriate fasteners and accessory materials are also described. The pipe, arches, and other shapes are generally used for drainage purposes, pedestrian and vehicular underpasses, and utility tunnels.

1.2 This specification does not include requirements for bedding, backfill, or the relationship between earth cover load and plate thickness of the pipe. Experience has shown that the successful performance of this product depends upon the proper selection of plate thickness, type of bedding and backfill, manufacture in the plant, and care in the installation. The purchaser must correlate the above factors and also the corrosion and abrasion requirements of the field installation with the plate thickness. The structural design of corrugated steel structural plate pipe and the proper installation procedures are described in AASHTO *Standard Specifications for Highway Bridges*, Division I, Section 12 and Division II, Section 26, respectively.

1.3 This specification is applicable to orders in SI units (as M 167M).

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards:*

2.1.1 M 111M/M 111 Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products
- M 120 Zinc
- M 183/M 183M Structural Steel
- M 232M/M 232 Zinc Coating (Hot-Dip) on Iron and Steel Hardware
- M 291 Carbon and Alloy Steel Nuts
- M 291M Carbon and Alloy Steel Nuts (Metric)
- R 11 Indicating Which Places of Figures Are to Be Considered Significant in Specified Limiting Values
- T 65M/T 65 Mass [Weight] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings
- T 244 Mechanical Testing of Steel Products

2.1.2 *Standard Specifications for Highway Bridges*

2.2 *ASTM Standards:*
- A 307 Standard Specification for Carbon Steel Bolts and Studs, 60 000 psi Tensile Strength
- A 449 Standard Specification for Quenched and Tempered Steel Bolts and Studs
- A 751 Standard Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products
- A 754/A 754M Standard Test Method for Coated Weight (Mass) of Metallic Coatings on Steel by X-ray Fluorescence
- A 780 Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings
- E 376 Standard Practice for Measuring Coating Thickness by Magnetic-Field or Eddy-Current (Electromagnetic) Test Methods
- F 568M Standard Specification for Carbon and Alloy Steel Externally Threaded Metric Fasteners

2.3 *American National Standards:*
- B18.2.1 Square and Hex Bolts and Screws, Inch Series
- B18.2.2 Square and Hex Nuts
- B18.2.3.6M Bolts, Metric Heavy Hex
- B18.2.4.6M Hex Nuts, Heavy, Metric

3. DESCRIPTIONS OF TERMS SPECIFIC TO THIS STANDARD

3.1 *Arch*—a part circle shape spanning an open invert between the footings on which it rests.

3.2 *Box culvert*—a rectangular box with a long-radius crown and either short radius corners or welded corners. It can be with full invert or with footings.

3.3 *Fabricator*—the producer of the components for the finished product.

3.4 *Flat plate*—sheet or plate used to fabricate structural plate.

3.5 *Manufacturer*—the producer of the flat plate and accessories.

3.6 *Pipe*—a conduit having full circular shape; also, in a general context, all structural shapes covered by this specification.

3.7 *Pipe-arch*—an arch shape with an approximate semicircular crown, small-radius corners, and large-radius invert.

3.8 *Pipe, horizontal ellipse*—an elliptically shaped pipe with the horizontal diameter approximately 25 percent greater than the nominal diameter.

3.9 *Pipe, vertically elongated*—an elliptically shaped pipe with the vertical diameter up to 10 percent greater than the nominal diameter.

3.10 *Purchaser*—the purchaser of the finished product.

3.11 *Special shape*—a shape, other than described elsewhere in this section, suitable for fabrication with structural plate.

3.12 *Structural plate*—a corrugated and curved plate which is field assembled with other structural plates to form the required structure.

3.13 *Vehicular underpass*—a high arch shape with an approximate semicircular crown, large-radius sides, small-radius corners between sides and invert, and large-radius invert.

4. ORDERING INFORMATION

4.1 Orders for material under this specification shall include the following information as necessary to adequately describe the desired product:

4.1.1 Name of material (corrugated steel structural plate and accessories);

4.1.2 Description of structure (Section 3);

4.1.3 Number of structures;

4.1.4 AASHTO designation and year of issue;

4.1.5 Dimensions of structure (diameter or span and rise, and length, etc.) (Section 8.2 and Note 7);

4.1.6 Thickness of plate (Section 8.1);

4.1.7 Description of corrugations (Section 6.2);

4.1.8 End treatment (bevel, skew, grade or slope corrections, or other special provision if required by the project plans or specifications);

4.1.9 Seam bolt size and number per corrugation, if different than the minimums indicated by Tables 3 and 5 (Section 6.3);

4.1.10 Special requirements (including reinforcement locations, shapes, and thicknesses), if required; and

4.1.11 Certification, if required (Section 12.1).

NOTE 1—A typical ordering description is as follows: Structural plates and fasteners for two corrugated steel plate pipe-arch, per AASHTO M 167M-______, 3860-mm span by 2460-mm rise, 5.54-mm plate thickness, 150 by 50-mm corrugations, 27.0-m nominal centerline length with square ends, longitudinal seams with four M20 bolts per corrugation.

5. MATERIALS

5.1 *Flat Plate:*

5.1.1 *Manufacture*—The base steel shall be made by any of the following processes: open-hearth, basic-oxygen, or electric-furnace.

5.1.2 *Chemical Composition*—The base metal cast or heat (formerly ladle) analysis shall conform to the chemical requirements of Table 1. The requirements of this specification shall be met in continuous mass production during which the manufacturer has made analysis of individual heats so as to ensure that material is controlled within the specified limits.

5.1.3 *Mechanical Requirements*—The mechanical properties of the flat plate material prior to corrugating shall conform to the requirements in Table 2.

NOTE 2—The properties enumerated in Table 2 for the flat plate normally provide the minimum yield strength of 230 MPa used in structural design of structural plate after the plate is corrugated.

5.2 *Bearings for Arches*—When specified, metal bearings for arches may be cold-formed channels made from flat plate material conforming to Section 5.1, and not less than 4.78 mm in specified thickness.

5.3 *Members for Structural Reinforcement*—Steel members for circumferential or longitudinal stiffeners, or secondary structural components, shall be fabricated from rolled shapes conforming to M 183M, or from flat plate material conforming to Section 5.1.

NOTE 3—Steel transverse structural reinforcing members when used are part of long span or box corrugated steel structural plate structures. The structural reinforcement for either of these types of structures can be designed using AASHTO *Standard Specifications for Highway Bridges*. The structural design of long-span structures is given in AASHTO *Standard Specifications for Highway Bridges*, Division I, Section 12. The structural design of beams is under development by the AASHTO Subcommittee on Bridges and Structures.

5.4 *Assembly Fasteners*—Except as provided elsewhere in this section, bolts and nuts shall conform to the requirements specified in Table 3. The bearing surface of both bolts and nuts for use with 150 by 50-mm corrugations shall be shaped to a 25-mm radius spherical surface. In lieu of bolts and nuts with the special

TABLE 1 Chemical Composition by Cast Analysis

	Composition, percent	Tolerance Over the Maximum Limit by Product Analysis, percent
Sulfur, max	0.05	+0.01
Sum of carbon, manganese, phosphorus, silicon, and sulfur, max	0.70	+0.04

TABLE 2 Mechanical Requirements for Flat Plate[A]

Yield Point,[B]	Tensile Strength[B] min, MPa	Elongation in 50 mm[C] min, percent
190	290	30

[A] To determine conformance with this specification, each value for tensile strength and for yield point shall be rounded to the nearest 1 MPa and each value for elongation to the nearest 1 percent, both in accordance with the rounding-off method of AASHTO R 11.

[B] Yield point and tensile strength are based on thickness of the base metal. If tests are made after coating, determine the base metal thickness after stripping the coating from the ends of the specimen contacting the grips of the tension testing machine.

[C] Elongation requirement does not apply to material tested after corrugating.

TABLE 3 Bolt and Nut Requirements

	Bolts	Nuts
General dimensions[A]	ANSI B18.2.3.6M Heavy Hex	ANSI B18.2.4.6 M Heavy Hex
Seam bolts and nuts[B]	F 568 Class 8.8	M 291M Class 12
Anchorage bolts and nuts	F 568 Class 4.6	M 291M Class 5
Zinc coating	M 232	M 232
Nominal diameter, min, metric size[C]	M 20	M 20

[A] See Section 5.4 for permissible modifications to bearing surface.
[B] Bolts and nuts also used for connecting arch plates to bearings and structural reinforcement to structural plates.
[C] Bolt size of M 22, M 24, or M 27 may be required with thicker plates, especially with 380- by 140-mm corrugation, and shall be furnished when specified in the order.

TABLE 4 Corrugation Requirements

Nominal Size	Maximum Pitch[A]	Minimum Depth[B]	Inside Radius Nominal	Inside Radius Minimum
		All values in mm		
150 by 50	158	48	28	25
380 by 140	394	133	75	68

[A] Pitch is measured from crest to crest of corrugations, at 90° to the direction of the corrugations.
[B] Depth is measured as the vertical distance from a straightedge resting on the corrugation crests parallel to the axis of the pipe to the bottom of the intervening valley.

TABLE 5 Bolt Hole Patterns in Structural Plate[A]

Corrugation Size, mm	150 by 50	380 by 140
Longitudinal Seams		
Number of rows	2	3
Holes per corrugation, each row, min:		
For 7.11-mm and thinner plates	1[B]	2[C]
For 7.87-mm and thicker plates	2[C]	N.A.
Spacing between rows, min, mm	50	75
Circumferential Seams		
Number of rows	1	1
Spacing in rows, max, mm	250	400
Arch Anchorage Seams		
Number of rows	1	1
Spacing in rows, nominal max, mm	600	380

[A] All bolt holes shall be located 1.75 × bolt diameter minimum, center of hole to edge of sheet.
[B] For minimum of one hole per corrugation, holes shall be staggered with holes in one row in valleys and holes in the other row in crests of corrugations.
[C] One hole each crest and valley of all corrugations for each row.

bearing surface, standard type bolts and nuts with special washers providing comparable bearing surface may be used. Bolts and nuts with standard bearing surfaces shall be used with 380- by 140-mm corrugations. The number of bolts and nuts of each size and length furnished shall be 2 percent in excess of the theoretical number required to field erect the structure or structures. Bolt lengths shall be such as to result in at least "full nut" engagement when tightened in place.

5.5 *Head Wall and Bearing Anchorage*—Bolts and nuts for head wall anchorage and for anchoring arch bearings to foundations shall be fabricated as shown on the plans and shall conform to the requirements specified in Table 3.

6. FABRICATION

6.1 *Structural Plates*—Structural plates shall be fabricated from flat sheets or plates, corrugated in accordance with Section 6.2, punched for bolted lap seams in accordance with Section 6.3, and curved to the required radius.

6.2 *Corrugations*—Corrugations shall form smooth continuous curves and tangents. Corrugations shall form annular rings (complete or partial) about the axis of the structure. The dimensions of the corrugations shall be in accordance with Table 4 for the size specified in the order.

6.3 *Bolt Holes*—The bolt holes shall be punched so that all plates having like dimensions, curvature, and same size and number of bolts per meter [foot] of seam shall be interchangeable. Except as otherwise specified, the location and number of seam bolt holes shall conform to the requirements of Table 5 for the size of bolts indicated in Table 3 (Note 4). The diameter of bolt holes in the longitudinal seams shall not exceed the bolt diameter by more than 3 mm except those in plate corners. Bolt holes in circumferential seams, including plate corners, shall not exceed the bolt diameter by more than 6 mm or may be slotted with a width equal to the bolt diameter plus 3 mm and a length equal to the bolt diameter plus 10 mm. Holes shall be provided as required for connecting headwall anchors, structural reinforcement, and miscellaneous attachments.

NOTE 4—The purchaser should determine the appropriate bolt size and number of bolts per corrugation for longitudinal seams according to the design criteria in AASHTO *Standard Specifications for Highway Bridges*, Division I, Section 12, or other appropriate guidelines.

6.3.1 *Bolt Holes in Bearings for Arches*—Bolt holes for anchoring bearings to foundation shall be punched as shown on the plans, with spacing at not more than 600 mm on centers. Bolt holes shall be punched in the vertical leg of bearings to match corresponding bolt holes in the bottom arch plate.

6.4 *Special Plates*—Plates for forming skewed ends, beveled ends, or curved alignment shall be accurately cut to fit the order plans. Cut edges of plates shall be free of notches, gouges, or burrs, and shall present a workmanlike finish. Legible identification shall be placed on each special plate to designate its proper position in the finished structure and referenced to the approved erection drawings.

6.5 *Structural Reinforcement*—Members for longitudinal or circumferential reinforcing, if required, shall be as sized and located on the order plans and fabricated from materials described in Section 5.3.

7. ZINC COATING

7.1 All structural plates including fittings and cut ends shall be zinc coated after cutting, corrugating, punching of holes, and welding (when required), but they may be curved to the required radius either before or after zinc coating when it has been demonstrated that this fabrication can be done on specific tooling and equipment without damage to the zinc coating. All arch bearings and structural reinforcement shall be zinc coated after all fabrication is completed. The zinc used for the coating shall conform to M 120 and shall be at least equal to the grade designated as "Prime Western."

7.2 *Coating Mass (Plates)*—Plates shall be zinc coated to provide an average coating mass of 910 g/m^2 of sheet (total both surfaces), and a minimum coating mass for any single specimen of 820 g/m^2 of sheet.

7.2.1 To determine conformance with this specification, each single value for coating mass and the average of all values shall be rounded to the nearest 10 g/m^2 in accordance with the rounding-off method of R 11.

7.3 *Coating Mass (Structural Reinforcement and Arch Bearings)*—Members fabricated from rolled shapes shall be zinc-coated to conform to M 111M/M 111. Members fabricated from plate material shall be zinc-coated as specified in Section 7.2.

7.4 *Repair of Damaged Zinc Coating*—Plate or accessory material on which the metallic coating has been burned by welding, or has been otherwise damaged in fabricating or handling, shall be repaired. The repair shall be done so the completed material shall show careful finished workmanship in all particulars. Material which, in the opinion of the purchaser, has not been cleaned or coated satisfactorily may be rejected. If the purchaser so elects, the repair shall be done in his presence.

7.4.1 The damaged area shall be cleaned to bright metal by blast cleaning, power disk sanding, or wire brushing. The cleaned area shall extend at least 13 mm into the undamaged section of the coating. The cleaned area shall be coated within 24 hours and before any rusting or soiling, using either the procedure in Sections 7.4.2 or 7.4.3, unless specified otherwise.

7.4.2 *Zinc-Rich Paint Coating*—Zinc-rich paint shall be applied to a dry film thickness of at least 0.13 mm over the damaged section and surrounding cleaned area.

7.4.3 *Metallizing Coating*—The damaged area shall be cleaned as described in Section 7.4.1 except it shall be cleaned to the near-white condition. The repair coating applied to the cleaned section shall have a thickness of not less than 0.13 mm over the damaged section and shall taper off to zero thickness at the edges of the cleaned undamaged section. Metallizing shall be performed using zinc wire containing not less than 99.98 percent zinc.

NOTE 5—ASTM A 780 contains additional information on repair of damaged zinc coatings.

7.5 *Coating Adherence*—The coating shall adhere to the base metal so that no peeling or flaking occurs during normal handling.

8. DIMENSIONS AND TOLERANCES

8.1 *Plate Thickness*—Plate thickness shall conform to the requirements of Table 6 as specified by the purchaser from the specified plate thicknesses listed in that table (Note 6). For corrugated plate, the thickness shall be measured on the tangents of the corrugations. The thickness shall include both the base metal and the coating.

TABLE 6 Thickness for Zinc-Coated Plates[A]

Specified Thickness	Minimum Thickness
mm	mm
2.82	2.51
3.56	3.25
4.32	4.01
4.78	4.47
5.54	5.23
6.32	6.02
7.11	6.81
7.87[B]	7.57
9.65[B]	9.35

[A] Thickness is measured at any point on the plate not less than 10 mm from an edge, and if corrugated, on the tangents of corrugations. There is no limit on over-thickness.

[B] For the 150- by 50-mm corrugation only.

NOTE 6—The purchaser should determine the required thickness according to the design criteria in AASHTO *Specifications for Highway Bridges,* Division I, Section 12 or other appropriate guidelines.

8.2 *Cross Section Dimensions*—Cross section dimensions, such as diameter, span and rise, and radius of curvature, shall be measured to the inside crest of corrugations. Tolerances herein specified apply to the as erected shape before backfill placement. The diameter of circular pipe, based on two measurements at 90 degrees to each other, shall not vary more than ±2 percent from the calculated inside diameter shown in Tables 7 and 8. The span and rise of pipe-arch, arch, underpass, and other non-circular structures shall be as specified within ±2 percent.

NOTE 7—The purchaser should consult the fabricator to determine the standard dimensions for the various types of structures, other than circular structures.

9. WORKMANSHIP

9.1 Plates, fasteners, and accessories shall be of uniform quality consistent with good manufacturing and inspection practices.

10. SAMPLING AND TESTING

10.1 Sampling and testing of plate for chemical composition shall be according to ASTM A 751, and for mechanical requirements shall be according to the procedure for sheet-type specimens in T 244. The manufacturer shall make adequate tests and measurements to ensure that the material produced complies with this specification.

10.2 *Coating Mass Determination*—Except as provided herein, coating mass shall be determined according to T 65M/T 65, using a specimen with an area of 3000 mm^2 or greater. The average coating mass shall be the average of

TABLE 7 Diameter of Circular Pipe 150 by 50 mm Corrugation

Nominal Diameter Specified	Calculated Inside Diameter
mm	mm
1525	1500
1675	1655
1830	1810
1980	1965
2135	2120
2285	2275
2440	2430
2590	2585
2745	2470
2895	2895
3050	3055
3200	3205
3355	3365
3505	3515
3660	3675
3810	3825
3960	3980
4115	4140
4265	4290
4420	4450
4570	4600
4725	4760
4875	4910
5030	5070
5180	5225
5335	5380
5485	5535
5640	5690
5790	5845
5945	6000
6095	6155
6250	6315
6400	6465
6555	6625
6705	6775
6860	6935
7010	7085
7165	7245
7315	7395
7470	7555
7620	7710
7770	7860
7925	8020

TABLE 8 Diameter of Circular 1380 by 140 mm Corrugation

Nominal Diameter Specified	Calculated Inside Diameter
mm	mm
6095	6050
6475	6435
6860	6830
7240	7215
7620	7600
8000	7990
8380	8375
8765	8770
9145	9155
9525	9545
9905	9930
10285	10315
10670	10710
11050	11095
11430	11485
11810	11870
12190	12255
12575	12650
12955	13035
13335	13425
13715	13810
14095	14200
14480	14590
14860	14975
15240	15365
15620	15750
16000	16140
16385	16530
16765	16915
17145	17305
17525	17690
17905	18080
18290	18470
18670	18860
19050	19245

three or more single-spot tests, each taken from different plates in the order. Instead of using the stripping procedure in T 65M/T 65, the mass may be converted from the sum of the readings on both surfaces of the plate by a magnetic coating-thickness gage suitably checked and demonstrated for accuracy (Note 8) 1 μm = 7.1 g/m². Alternately, the coating mass may be determined by the x-ray fluorescence procedure according to ASTM A 754/A 754M. In case of dispute, results of testing according to T 65M/T 65 shall govern.

NOTE 8—Several magnetic and electromagnetic types of coating-thickness gages are commercially available and are a satisfactory basis for acceptance when properly calibrated just prior to inspection use. (See ASTM E 376.)

10.3 Mechanical properties shall be determined on plate prior to corrugating or other fabricating, except tests may be made after fabrication by the purchaser for tensile and yield strengths.

10.4 Test results including chemical composition and mechanical properties shall be maintained by the manufacturer for 7 years. Test results for coating mass or other tests, and a copy of the plate manufacturer's certified test results for chemical composition and mechanical properties shall be maintained by the fabricator for 7 years. Such results shall be made available to the purchaser upon request.

11. REJECTION AND REHEARING

11.1 Material that fails to conform to the requirements of this specification may be rejected. Rejection should be reported to the manufacturer or fabricator promptly and in writing. In case of dissatisfaction with the results of the test, the manufacturer or fabricator may make claim for a rehearing.

12. CERTIFICATION

12.1 When specified in the purchase order or contract, a manufacturer's or fabricator's certification, or both, shall be furnished to the purchaser stating that samples representing each lot have been tested and inspected in accordance with this specification and have been found to meet the requirements for the material described in the order. When specified in the purchase order or contract, a report of the test results shall be furnished.

13. PRODUCT MARKING

13.1 Each plate shall be identified by showing the following:

13.1.1 Name of fabricator;

13.1.2 Specified zinc-coated plate thickness;

13.1.3 Specified coating mass;

13.1.4 Identification showing heat number and coating lot number; the heat number may be omitted if the fabricator's records tie the coating lot number to a specific heat number and manufacturer; and

13.1.5 AASHTO designation.

13.2 The marking shall be so placed that when the structure is erected, the identification will appear on the inside.

Standard Specification
for

Corrugated Aluminum Pipe for Sewers and Drains

AASHTO DESIGNATION: M 196M-92 (1995)
(ASTM DESIGNATION: B 745/B 745M-95)

1. SCOPE

1.1 This specification covers corrugated aluminum pipe intended for use for storm water drainage, underdrains, the construction of culverts, and similar uses. Pipe covered by this specification is not normally used for the conveyance of sanitary or industrial wastes.

1.2 This specification does not include requirements for bedding, backfill, or the relationship between earth cover load and sheet thickness of the pipe. Experience has shown that the successful performance of this product depends upon the proper selection of sheet thickness, type of bedding and backfill, controlled manufacture in the plant, and care in the installation. The purchaser must correlate the above factors and also the corrosion and abrasion requirements of the field installation with the sheet thickness. The structural design of corrugated aluminum pipe and the proper installation procedures are given in AASHTO *Standard Specifications for Highway Bridges*.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards:*

2.1.1 M 197M Aluminum Alloy Sheet for Corrugated Aluminum Pipe
M 198 Joints for Circular Concrete Sewer and Culvert Pipe Using Flexible Watertight Gaskets
M 232M/M 232 Zinc Coating (Hot-Dip) on Iron and Steel Hardware
M 291M Carbon and Alloy Steel Nuts (Metric)
M 298 Coatings of Zinc Mechanically Deposited on Iron and Steel
T 249M Helical Lock Seam Corrugated Pipe

2.1.2 *Standard Specifications for Highway Bridges*

2.2 *ASTM Standards:*
B 221M Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes [Metric]
B 316/B 316M Standard Specification for Aluminum and Aluminum-Alloy Rivet and Cold-Heading Wire and Rods
B 633 Specification for Electrodeposited Coatings of Zinc on Iron and Steel
B 666/B666M Standard Practice for Identification Marking of Aluminum and Magnesium Products
D 1056 Standard Specification for Flexible Cellular Materials—Sponge or Expanded Rubber
F 467M Standard Specification for Nonferrous Nuts for General Use [Metric]
F 468M Standard Specification for Nonferrous Bolts, Hex Cap Screws, and Studs for General Use [Metric]
F 568M Standard Specification for Carbon and Alloy Steel Externally Threaded Metric Fasteners
F 593 Standard Specification for Stainless Steel Bolts, Hex Cap Screws, and Studs
F 594 Standard Specification for Stainless Steel Nuts
F 738M Standard Specification for Stainless Steel Metric Bolts, Screws, and Studs
F 836M Standard Specification for Style 1 Stainless Steel Metric Nuts

3. DESCRIPTIONS OF TERMS SPECIFIC TO THIS STANDARD

3.1 *Fabricator*—the producer of the pipe.

3.2 *Manufacturer*—the producer of the sheet.

3.3 *Purchaser*—the purchaser of the finished product.

4. CLASSIFICATION

4.1 The corrugated aluminum pipe covered by this specification is classified as follows:

4.1.1 *Type I*—This pipe shall have a full circular cross-section, with a single thickness of corrugated sheet, fabricated with annular (circumferential) or helical corrugations.

4.1.2 *Type IA*—This pipe shall have a full circular cross-section, with an outer shell of corrugated sheet and an inner liner of smooth (uncorrugated) sheet, fabricated with helical corrugations and lock seams.

4.1.3 *Type IR*—This pipe shall have a full circular cross-section with a single thickness of smooth sheet, fabricated with helical ribs projecting outwardly.

4.1.4 *Type II*—This pipe shall be a Type I pipe which has been reformed into a pipe-arch, having an approximately flat bottom.

4.1.5 *Type IIA*—This pipe shall be a Type IA pipe which has been reformed into a pipe-arch, having an approximately flat bottom.

4.1.6 *Type IIR*—This pipe shall be a Type IR pipe which has been reformed into a pipe-arch, having an approximately flat bottom.

4.1.7 *Type III*—This pipe, intended for use as underdrains or for underground disposal of water, shall be a Type I pipe which has been perforated to permit the in-flow or out-flow of water.

4.1.8 *Type IIIR*—This pipe, intended for the underground disposal of water or for subsurface drainage, shall be a Type IR pipe which has been perforated to permit the outflow or inflow of water.

4.2 Perforations in Type III pipe are classified as Class 1 or Class 2 and perforations in Type IIIR pipe are classified as Class 4, as described in Section 8.3.2.

5. ORDERING INFORMATION

5.1 Orders for material to this specification shall include the following information as necessary, to adequately describe the desired product:

5.1.1 Name of material (corrugated aluminum pipe),

5.1.2 AASHTO designation and year of issue,

5.1.3 Type of pipe (Section 4.1),

5.1.4 Method of fabrication for Type I and Type II pipe (Section 7.1),

5.1.5 Diameter of circular pipe (Section 8.1.1), or span and rise of pipe-arch section (Section 8.2.1).

5.1.6 Length, either total length or length of each piece and number of pieces,

5.1.7 Description of corrugations (Section 7.2),

5.1.8 Sheet thickness (Section 8.1.2),

5.1.9 Coupling bands, number, and type (Section 9.1) if special type is required,

5.1.10 Gaskets for coupling bands, if required (Section 9.3),

5.1.11 For perforated pipe, the class of perforations. If no class is specified for Type III pipe, Class 1 perforations will be furnished. Type IIIR pipe is furnished with Class 4 perforations only (Section 8.3.2),

5.1.12 Certification, if required (Section 13.1), and

5.1.13 Special requirements.

6. MATERIALS

6.1 *Aluminum Sheet for Pipe*—All pipe fabricated under this specification shall be formed from aluminum-alloy sheet conforming to AASHTO M 197M.

6.2 *Aluminum Sheet for Coupling Bands*—The sheet used in fabricating coupling bands shall conform to AASHTO M 197M.

6.3 *Rivets*—The material used for rivets in riveted pipe shall conform to the requirements of ASTM B 316/B 316M for alloy 6053-T4, with the following mechanical properties:

Tensile strength, min, MPa	170
Yield strength, min, MPa	95
Shear strength, min, MPa	105
Elongation in 50 mm, or 4 X diameter, min percent	16

If bolts and nuts are substituted for rivets (see Section 7.3.1), they shall meet the following requirements for either steel bolts and nuts, stainless steel bolts and nuts, or aluminum alloy bolts and nuts:

	Bolts	Nuts
For M 196M pipe:		
(Steel)	F 568, C1.4.6	M 291M, C1.5
(Stainless steel)	F 738, Alloy Grp A1, A2, or A4	F 836, Alloy Grp A1, A2, or A4
(Aluminum alloy)	F 468M, Alloy 6061-T6	F 467M, Alloy 6061-T6

The steel bolts and nuts shall be hot-dip galvanized in conformance with AASHTO M 232M/M 232, or be mechanically galvanized in conformance with AASHTO M 298 Class 40.

6.4 *Hardware for Coupling Bands*—Bolts and nuts for coupling bands shall conform to the requirements shown in Section 6.3 except for the coating on steel bolts and nuts. Steel bolts, nuts, and other threaded steel items used with coupling bands shall be zinc coated by one of the following processes: hot-dip process as provided in AASHTO M 232M/M 232; electroplating process as provided in ASTM B 633, Class Fe/Zn 8; or mechanical process as provided in AASHTO M 298, Class 8. Other steel hardware items used with coupling bands shall be zinc coated by one of the following processes: hot-dip process as provided in AASHTO M 232M/M 232; electroplating process as provided in ASTM B 633 Class Fe/Zn 25; or mechanical process as provided in AASHTO M 298 Class 25. Aluminum angles and lugs shall conform to the requirements of ASTM B 221M for alloy 6063-T6.

6.5 *Gaskets*—If gaskets are used in couplings, they shall be a band of expanded rubber meeting the requirements of ASTM D 1056 for the "RE" closed cell grades, or O-rings meeting the requirements of AASHTO M 198.

7. FABRICATION

7.1 *General Requirements*—Pipe shall be fabricated in full circular cross-section.

7.1.1 Type I pipe shall have annular corrugations with lap joints fastened with rivets or shall have helical corrugations with a continuous lock seam extending from end to end of each length of pipe. As there are important differences in the structural characteristics of annular, riveted pipe versus helical pipe, it is important for the purchaser to stipulate, for Type I and Type II pipe, the method of fabrication desired. If the method of fabrication is not stated in the ordering information, the fabrication method shall be at the option of the fabricator.

7.1.2 Type IA pipe shall be fabricated with a smooth liner and helically corrugated shell integrally attached at helical lock seams extending from end to end of each length of pipe. The shell shall have corrugations of nominal 68 or 75 mm pitch.

7.1.3 Type IR pipe shall be fabricated with helical ribs projecting outward with a continuous lock seam extending from end to end of each length of pipe.

7.2 *Corrugations*—The corrugations shall be either annular or helical as provided in Section 7.1. The direction of the crests and valleys of helical corrugations shall not be less than 60 degrees from the axis of the pipe for pipe diameters larger than 525 mm, and not less than

TABLE 1 Corrugated Requirements for Types I, IA, II, IIA, and III Pipe

			Inside Radius[C]	
Nominal Size	Maximum Pitch[A]	Minimum Depth[B]	Nominal	Minimum
		M 196M—All values in mm		
38 by 6.5[D]	48	6.0	7	6.5
68 by 13	73	12[E]	17	12
75 by 25	83	24	14	12
150 by 25	160	24	56	51

[A] Pitch is measured from crest to crest of corrugations, at 90 degrees to the direction of the corrugations.
[B] Depth is measured as the vertical distance from a straightedge resting on the corrugation crests parallel to the axis of the pipe, to the bottom of the intervening valley.
[C] Minimum inside radius requirements does not apply to a corrugation containing a helical lock seam.
[D] The corrugation size of 38 by 6.5 mm is available only in helically corrugated pipe.
[E] For pipe 300- to 525-mm diameter inclusive, the minimum corrugation depth shall be 11 mm.

45 degrees from the axis for pipe diameters of 525 mm and smaller.

7.2.1 For Type I and IA pipe, corrugations shall form smooth continuous curves and tangents. The dimensions of the corrugations shall be in accordance with Table 1 for the size indicated in the order.

7.2.2 For Type IR pipe, the corrugations shall be essentially rectangular ribs projecting outward from the pipe wall. The dimensions and spacings of the ribs shall be in accordance with Table 2 for the size indicated in order. For the 292-mm rib spacing, a stiffener shall be included midway between the ribs if the sheet between the ribs does not include a lock seam. This stiffener shall have a nominal radius of 6.4 mm and a minimum height of 5.1 mm toward the outside of the pipe.

NOTE 1—The nominal dimensions and properties for smooth corrugations and for ribs are given in AASHTO *Standard Specifications for Highway Bridges*, Division I, Section 12.

7.3 *Riveted Seams*—The longitudinal seams shall be staggered to the extent that no more than three thicknesses of sheet are fastened by any rivet. Pipe to be reformed into pipe-arch shape shall have seams meeting the longitudinal seam requirement of Section 8.2.2.

NOTE 2—Fabrication of pipe without longitudinal seams in 120 degrees of arc, so that the pipe may be installed without longitudinal seams in the invert, is subject to negotiation between the purchaser and fabricator.

7.3.1 The size of rivets, number per corrugation, and width of lap at the longitudinal seam shall be as stated in Table 3, depending on sheet thickness, corrugation size, and diameter of pipe. For pipe with 25-mm deep corrugations, M12 diameter bolts and nuts may be used in lieu of rivets on a one-for-one replacement ratio. Circumferential seams shall be riveted using rivets of the same size as for longitudinal seams and shall have a maximum rivet spacing of 150 mm measured on centers, except that six rivets will be sufficient in 300-mm diameter pipe.

7.3.2 All rivets shall be driven cold in such a manner that the sheets shall be drawn tightly together throughout the entire lap. The center of a rivet shall be no closer than twice its diameter from the edge of the sheet. The distance between the centerlines of the two rows of rivets, where two rows are required, shall not be less than 38 mm. All rivets shall have neat, workmanlike, and full hemispherical heads or heads of a form acceptable to the purchaser, shall be driven without bending, and shall completely fill the hole.

7.4 *Helical Lock Seams*—The lock seam for Type I pipe shall be formed in the tangent element of the corrugation profile with its center near the neutral axis of the corrugation profile. The lock seam for Type IA pipe shall be in the valley of the corrugation, shall be spaced not more than 760 mm apart, and shall be formed from both the liner and the shell in the same general manner as Type I helical lock seam pipe. The lock seam for Type IR pipe shall be formed in the flat zone of the pipe wall, midway between two ribs.

7.4.1 The edges of the sheets within the cross section of the lock seam shall lap at least 4.0 mm for pipe 250 mm or less in diameter and at least 7.9 mm for pipe greater than 250 mm in diameter, with an occasional tolerance of minus 10 percent of lap width allowable. The lapped surfaces shall be in tight contact. The profile of the sheet shall include a retaining offset adjacent to the 180-degree fold (as described in T 249M) of one sheet thickness on one side of the lock seam, or one-half sheet thickness on both sides of the lock seam, at the fabricator's option. There shall be no visual cracks in the metal, loss of metal-to-metal contact, or excessive angularity on the interior of the 180-degree fold of metal at the completion of forming the lock seam. The lock seam shall be mechanically staked (indented) at periodic intervals, or otherwise specially constructed to prevent slippage.

7.4.2 Specimens cut from production pipe normal to and across the lock seam shall develop the tensile strength as provided in Table 4, when tested according to T 249M. For Type IA pipe, the lock seam strength shall be as tabulated

TABLE 2 Rib Requirements for Type IR Pipe

	Rib						
Nominal Size	Width,[A] Min	Depth,[B] Min	Spacing,[C] Max	Bottom Outside Radius, Min.	Bottom[D] Outside Radius, Max. Avg.	Top Outside Radius, Min.	Top[D] Outside Radius, Max. Avg.
			Millimeters				
19 × 19 × 190	17	19	197	2.5	6.0	2.5+t	6.0+t
19 × 25 × 292	17	24	298	2.5	6.0	2.5+t	6.0+t

[A] Width is a dimension of the inside of the rib, but is measured on the outside of the pipe (outside of the rib) and shall meet or exceed the stated minimum width plus two times the wall thickness, that is, 2t + 17 mm.
[B] Depth is an average of three ribs (one sheet width) measured from the inside by placing a straightedge across the open rib and measuring to the bottom of the rib.
[C] Spacing is an average of three ribs (one sheet width) measured center-to-center of the ribs at 90° to the direction of the ribs.
[D] The average of the four rib radii (Top and Bottom) shall be within the minimum and maximum tolerances. The outside radius refers to the surface outside of the pipe.

TABLE 3 Riveted Longitudinal Seams

Specified Sheet Thickness	Nominal Corrugation Size		
	68 × 13 mm[A,B]	75 × 25 mm[C,D]	150 × 25 mm[E,D]
	Rivet Diameters, min		
mm	mm	mm	mm
1.52	8.0	9.5	12.7
1.91	8.0	9.5	12.7
2.67	9.5	12.7	12.7
3.43	9.5	12.7	12.7
4.17	9.5	12.7	12.7

[A] One rivet each valley for pipe diameters 900 mm and smaller. Two rivets each valley for pipe diameters 1050 mm and larger.
[B] Minimum width of lap 38 mm for pipe diameters 900 mm and smaller, and 75 mm for pipe diameters 1050 mm and larger.
[C] Two rivets each valley for all pipe diameters.
[D] Minimum width of lap: 75 mm for pipe of all diameters.
[E] Two rivets each crest and valley for all pipe diameters.

TABLE 4 Specified Aluminum Alloy Sheet Thicknesses and Lock Seam Tensile Strength

Specified Sheet Thickness[A,B]	Lock Seam Tensile Strength, min
mm	kN/mm
0.91	17
1.22	25
1.52	30
1.91	43
2.67	74
3.43	96
4.17	122

[A] Thicknesses listed are those included in AASHTO M 197M.
[B] For Type IA pipe, the lock seam tensile strength requirements shall be based on the thickness of the corrugated shell.

based on the thickness of the corrugated shell.

7.4.3 When the ends of helically corrugated lock seam pipe have been rerolled to form annular corrugations, either with or without a flanged end finish, the lock seam in the rerolled end shall not contain any visible cracks in the base metal and the tensile strength of the lock seam shall be not less than 60 percent of that required in Section 7.4.2.

7.5 *End Finish:*

7.5.1 To facilitate field jointing, the ends of individual pipe sections with helical corrugations or ribs may be rerolled to form annular corrugations extending at least two corrugations from the pipe end, or to form an upturned flange meeting the requirements in Section 7.5.3, or both. The diameter of ends shall not exceed that of the pipe barrel by more than the depth of the corrugation. All types of pipe ends, whether rerolled or not, shall be matched in a joint such that the maximum difference in the diameter of abutting pipe ends is 13 mm.

7.5.2 When pipe with helical corrugations or ribs is rerolled to form annular corrugations in the ends, the usual size of annular corrugations is 68 by 13 mm.

7.5.3 If a flanged finish is used on the ends of individual pipe sections to facilitate field jointing, the flange shall be uniform in width, be not less than 13 mm wide, and shall be square to the longitudinal axis of the pipe.

7.5.4 The ends of all pipe which will form the inlet and outlet of culverts, fabricated of sheets having nominal thicknesses of 1.91 mm and less, shall be reinforced in a manner approved by the purchaser, when specified.

8. PIPE REQUIREMENTS

8.1 *Type I, Type IA, and Type IR Pipe:*

8.1.1 *Pipe Dimensions*—The nominal diameter of the pipe shall be as stated in the order, selected from the sizes listed in Table 5. The size of corrugations which are standard for each size of pipe are also shown in Table 5. The average inside diameter of circular pipe and pipe to be reformed into pipe-arches shall not vary more than 1 percent or 13 mm, whichever is greater, from the nominal diameter when measured on the inside crest of the corrugations. Alternately, for pipe having annular corrugations, conformance with the inside diameter requirement may be determined by measuring the outside circumference, for which minimum values are given in Table 5.

NOTE 3—The outside circumference of helically corrugated pipe is influenced by the corrugation size and the angle of the corrugations, affecting the number of corrugations crossed, therefore no minimum circumferential measurement can be specified.

8.1.2 *Sheet Thickness*—Sheet thickness shall be specified by the purchaser from the specified sheet thicknesses listed in Table 4 (Notes 4 and 5). For Type IA pipe, the thickness of both the shell and the liner shall be given; the thickness of the corrugated shell shall be at least 60 percent of the thickness of the equivalent Type I pipe; the liner shall have a nominal thickness of at least 0.91 mm; and the sum of the specified thicknesses of shell and liner shall equal or exceed the specified thickness of an equivalent pipe of identical corrugations as the shell according to the design criteria in the AASHTO *Standard Specifications for Highway Bridges.*

NOTE 4—The sheet thicknesses indicated in Table 4 are the thicknesses listed as available in AASHTO M 197M.

NOTE 5—The purchaser should determine the required thickness for Type I, IA, or IR pipe, or Type I, IA, or IR pipe to be reformed into Type II, IIA, or IIR pipe according to the design criteria in AASHTO *Standard Specifications for Highway Bridges*, or other appropriate guidelines. Specified thickness of 0.91 mm is generally used only for Type IA pipe.

8.1.3 When specified by the purchaser, the finished pipe shall be factory elongated to the extent specified. The elongation shall be accomplished by the use of a mechanical apparatus which will

TABLE 5 Pipe Sizes

Nominal Inside Diameter	Corrugation Sizes[A]					Minimum Outside Circumference[B]
	38 by 6.5	68 by 13	75 by 25	150 by 25	Ribbed	
mm	mm	mm	mm	mm	Pipe[C]	mm
100	X					284
150	X					441
200	X					598
250	X					755
300		X				912
375		X			X	1226
450		X			X	1383
525		X			X	1540
600		X			X	1854
675		X			X	2169
750		X	X		X	2483
825		X	X		X	2561
900		X	X		X	2797
1050		X	X		X	3269
1200		X	X	X	X	3739
1350		X	X	X	X	4209
1500		X	X	X	X	4875
1600		X	X	X	X	4987
1650		X	X	X	X	5142
1800		X	X	X	X	5609
1950			X	X	X	6075
2100			X	X	X	6542
2250			X	X		7008
2400			X	X		7475
2550			X	X		7941
2700			X	X		8408
2850			X	X		8874
3000			X			9341

[A] An "X" indicates standard corrugation sizes for each nominal diameter of pipe.
[B] Measured in valley of annular corrugations. Not applicable to helically corrugated pipe.
[C] Rib sizes 19 by 19 by 190 mm and 19 by 25 by 292 mm.

produce a uniform deformation throughout the length of the section.

NOTE 6—When corrugated aluminum pipe is designed and installed according to AASHTO *Standard Specifications for Highway Bridges,* vertical elongation (factory or field) is not required for structural purposes.

8.2 *Type II, IIA, and IIR Pipe:*

8.2.1 *Pipe-Arch Dimensions*—Pipe furnished as Type II, IIA, or IIR shall be made from Type I, IA, or IR pipe respectively, and shall be reformed to provide a pipe-arch shape. All applicable requirements for Types I, IA, or IR pipe shall be met by finished Types II, IIA, and IIR respectively. Pipe-arches shall conform to the dimensional requirements of Tables 6, 7, or 8. All dimensions shall be measured from the inside crest of corrugations for Type II pipe or from the inside liner or surface for Types IIA or IIR pipe, respectively.

8.2.2 *Longitudinal Seams*—Longitudinal seams of riveted pipe-arches shall not be placed in the corner radius.

8.2.3 Reforming Type IR pipe into Type IIR pipe—and shall be done in such a manner as to avoid damage to the external ribs.

8.3 *Type III and IIIR Pipe:*

8.3.1 Type III and IIIR pipe shall have a full circular cross-section and shall conform to the requirements for Type I or Type IR pipe, and in addition shall contain perforations conforming to one of the classes described in Section 8.3.2.

8.3.2 *Perforations*—The perforations in Type III pipe shall conform to the requirements for Class 1 or Class 2 as specified in the order and described in Section 8.3.2.1 and Section 8.3.2.2, respectively. The perforations in Type IIIR pipe shall conform to the requirements for Class 4 as described in Section 8.3.2.3. Class 1 perforations are for pipe intended to be used for subsurface drainage. Class 2 and Class 4 perforations are for pipe intended to be used for subsurface disposal of water, but pipe containing these classes of perforations may also be used for subsurface drainage.

8.3.2.1 *Class I Perforations*—The perforations shall be approximately circular and cleanly cut; shall have nominal diameters of not less than 4.8 mm nor

TABLE 6 Pipe-Arch Requirements—68 by 13-mm Corrugations

Pipe Arch Size, mm	Equiv. Dia., mm	Span[A] mm	Rise[A] mm	Min Corner Radius, mm	Max B[B] mm
430 by 330	375	430	330	75	135
530 by 380	450	530	380	75	155
610 by 460	525	610	460	75	185
710 by 510	600	710	510	75	205
780 by 560	675	780	560	75	225
885 by 610	750	870	610	75	240
970 by 690	825	970	690	75	255
1060 by 740	900	1060	740	90	265
1240 by 840	1050	1240	840	100	290
1440 by 970	1200	1440	970	130	345
1620 by 1100	1350	1620	1100	155	380
1800 by 1200	1500	1800	1200	180	420
1950 by 1320	1650	1950	1320	205	460
2100 by 1450	1800	2100	1450	230	510

[A] A tolerance of ±25 mm or 2 percent of equivalent diameter, whichever is greater, is permissible in span and rise.
[B] B is defined as the vertical dimension from a horizontal line across the widest portion of the arch to the lowest portion of the base.

TABLE 7 Pipe-Arch Requirements—75 by 25-mm Corrugations

Pipe Arch Size, mm	Equiv. Dia., mm	Span[A] mm	Rise[A] mm	Min Corner Radius, mm
1340 by 1050	1200	1340 − 60	1050 + 60	180
1520 by 1170	1350	1520 − 70	1170 + 70	205
1670 by 1300	1500	1670 − 75	1300 + 75	230
1850 by 1400	1650	1150 − 85	1400 + 85	305
2050 by 1500	1800	2050 − 90	1500 + 95	355
2200 by 1620	1950	2200 − 110	1620 + 110	355
2400 by 1720	2100	2400 − 120	1720 + 120	410
2600 by 1820	2250	2600 − 130	1820 + 130	410
2840 by 1920	2400	2840 − 145	1920 + 145	460
2970 by 2020	2550	2970 − 150	2020 + 150	460
3240 by 2120	2700	3240 − 165	2120 + 165	460
3470 by 2220	2850	3470 − 175	2220 + 175	460
3600 by 2320	3000	3600 − 180	2320 + 180	460

[A] Negative and positive numbers listed with span and rise dimensions are negative and positive tolerances, zero tolerance in opposite direction.

TABLE 8 Pipe-Arch Requirements—19 by 19 by 190 mm and 19 by 25 by 292 mm Rib Corrugations

Pipe Arch Size, mm	Equiv. Dia., mm	Span[A] mm	Rise[A] mm	Min Corner Radius, mm
500 × 410	450	500 − 25	410 + 25	130
580 × 490	525	580 − 25	490 + 25	130
680 × 540	600	680 − 40	540 + 40	130
750 × 620	675	750 − 40	620 + 40	130
830 × 670	750	830 − 40	670 + 40	130
900 × 750	825	900 − 45	750 + 45	130
1010 × 790	900	1010 − 45	790 + 45	130
1160 × 920	1050	1160 − 55	920 + 55	155
1340 × 1050	1200	1340 − 60	1050 + 60	180
1520 × 1170	1350	1520 − 70	1170 + 70	205
1670 × 1300	1500	1670 − 75	1300 + 75	230
1850 × 1400	1650	1850 − 85	1400 + 85	305
2050 × 1500	1800	2050 − 95	1500 + 95	355

[A] Negative and positive numbers listed with span and rise dimensions are negative and positive tolerances, zero tolerance in opposite direction.

greater than 9.5 mm; and shall be arranged in rows parallel to the axis of the pipe. The perforations shall be located on the inside crests or along the neutral axis of the corrugations, with one perforation in each row for each corrugation. Pipe connected by couplings or bands may be unperforated within 100 mm of each end of each length of pipe. The rows of perforations shall be arranged in two equal groups placed symmetrically on either side of a lower unperforated segment corresponding to the flow line of the pipe. The spacing of the rows shall be uniform. The distance between the center lines of rows shall be not less than 25 mm. The minimum number of longitudinal rows of perforations, the maximum heights of the center lines of the uppermost rows above the bottom of the invert, and the inside chord lengths of the unperforated segments illustrated in Figure 1 shall be as specified in Table 9.

NOTE 7—Pipe with Class 1 perforations is generally available in diameters from 100 to 500 mm inclusive, although perforated pipe in larger sizes may be obtained.

8.3.2.2 *Class 2 Perforations*—The perforations shall be circular holes with nominal diameters of 8.0 to 9.5 mm, or slots with nominal width of 4.8 to 8.0 mm and maximum length of 13 mm. The perforations shall be uniformly spaced around the full periphery of the pipe. The perforations shall provide an opening area of not less than 230 square centimeters per square meter of pipe surface based on nominal diameter and length of pipe.

NOTE 8—323 perforations, 9.5-mm diameter per square meter satisfies the inlet area requirement for Class 2 perforations.

8.3.2.3 *Class 4 Perforations*—The perforations shall be circular holes with nominal diameters of 8.0 to 9.5 mm, or slots with nominal width of 4.8 to 8.0 mm and maximum length of 12.7 mm. All perforations shall occur in the flat sheet between spiral ribs or lockseam with the center of any hole no closer than 19.0 mm from the outside edge of a rib. The perforations shall be uniformly spaced around the full periphery of the pipe. The perforations shall provide an opening area of not less than 140 square centimeters per square meter of pipe surface based on nominal diameter and length of pipe.

NOTE 9—There is no provision for Class 3 perforations in this specification.

9. COUPLING BANDS

9.1 *Types of Coupling Bands*—Field joints for each type of corrugated aluminum pipe shall maintain pipe alignment during construction and prevent infiltration of fill material during the life of the installation.

9.1.1 Coupling bands may be of the following types:

9.1.1.1 Bands with annular corrugations;

9.1.1.2 Bands with helical corrugations;

9.1.1.3 Bands with projections (dimples);

9.1.1.4 Channel bands for upturned flanges, with or without annular corrugations;

9.1.1.5 Flat bands; and

9.1.1.6 Smooth sleeve-type couplers.

9.1.2 Except as provided in Sections 9.1.3 through 9.1.7, the type of coupling furnished shall be at the option of the fabricator unless the type is specified in the order.

NOTE 10—Bands are classified according to their ability to resist shear, moment, and tensile forces as described in AASHTO *Standard Specifications for Highway Bridges*, and identified as "standard joints" and "special joints." The four types of bands listed in Sections 9.1.1.1 through 9.1.1.4, and meeting

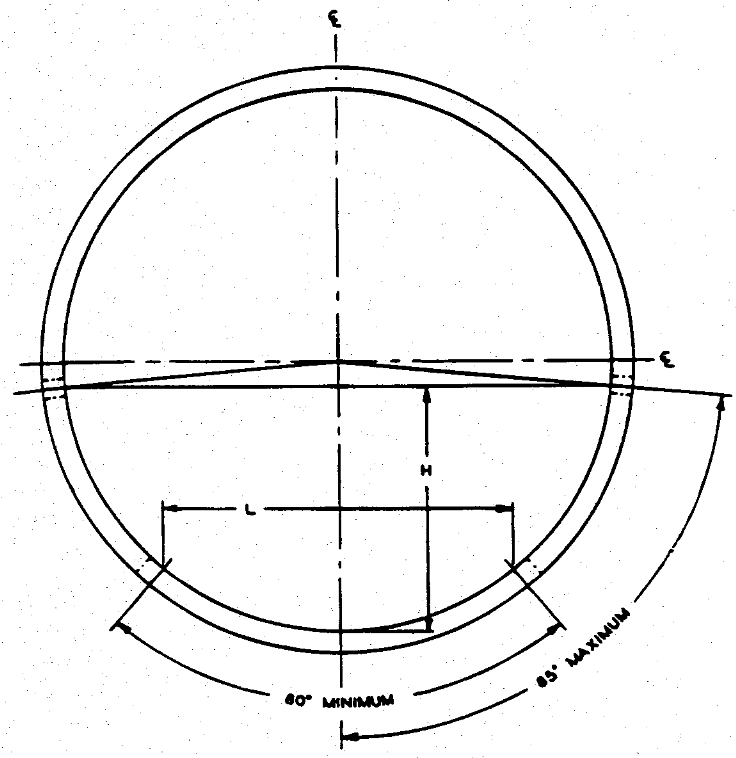


FIGURE 1 Circumferential Location of Class 1 Perforations

TABLE 9 Rows of Perforations, Height *H* of the Center line of the Uppermost Rows Above the Invert, and Chord Length *L* of Unperforated Segment, for Class I Perforations

Internal Diameter of Pipe mm	Rows of Perforations[A]	*H*, max[B] mm	*L*, min[B] mm
100	2	46	64
150	4	69	96
200	4	92	128
250	4	115	160
300	6	138	192
375	6	172	240
450	6	207	288
525	6	241	338
600 and larger	8	[C]	[C]

[A] Minimum number of rows. A greater number of rows for increased inlet area shall be subject to agreement between purchaser and fabricator. Note that the number of perforations per unit length in each row (and inlet area) is dependent on the corrugation pinch.

[B] See Figure 1 for location of dimensions *H* and *L*.

[C] *H* (max) = 0.46*D*: *L* (min) = 0.64*D*, where *D* = internal diameter of pipe, millimeters.

TABLE 10 Coupling Band Thickness

Nominal Pipe Thickness mm	Nominal Coupling Band Thickness, minimum mm
2.67 and thinner	1.22
3.43	1.52
4.17	1.91

the requirements of Section 9.2, are expected to meet the requirements for "standard joints." Some may also be able to meet the requirements for "special joints," but such capability should be determined by analysis or test.

9.1.3 Coupling bands with annular corrugations shall be used only with pipe with annular corrugations, or helical pipe in which the ends have been rerolled to form annular corrugations. The corrugations in the band shall have the same dimensions as the corrugations in the pipe end, or may be of a special design to engage either the first or second corrugation from the end of each pipe. The band may also include a U-shaped channel to accommodate upturned flanges on the pipe.

9.1.4 Coupling bands with helical corrugations shall be used only with pipe with helically corrugated ends. The corrugations in the bands shall be designed to properly mesh with the corrugations in the pipe.

9.1.5 Coupling bands with projections (dimples) may be used with pipe with either annular or helical corrugations. The bands shall be formed with the projections in annular rows with one projection for each corrugation of helical pipe. Bands 265 mm wide shall have two annular rows of projections, and bands 415 and 660 mm wide shall have four annular rows of projections.

9.1.6 Channel bands may be used only with pipe having upturned flanges on the pipe ends.

9.1.7 Smooth sleeve-type couplers and flat bands may be used with Type III pipe of 300-mm diameter or smaller.

9.2 *Requirements*—Coupling bands shall be fabricated to lap on an equal portion of each of the pipe sections to be connected. The ends of the bands shall lap or be fabricated to form a tightly closed joint upon installation. Coupling band thickness shall conform to the requirements in Table 10, based on the sheet thickness of the pipe to be connected, except as provided in Sections 9.2.1 and 9.2.2. The band width shall be not less than as shown in Table 11. The bands shall be connected in a manner approved by the purchaser with suitable aluminum or galvanized steel devices such as: angles, or integrally or separately formed and attached flanges, bolted with bolts as described in Section 6.4; bars and straps; wedge lock and straps; or lugs. Coupling bands shall be fastened with the following size of bolts: pipe diameters 450 mm and less—M10 diameter; pipe diameters 525 mm and greater—M12 diameter.

9.2.1 If flanges are provided on the pipe ends, the coupling may also be made by interlocking the flanges with a preformed channel band or other band incorporating a locking channel not less than

TABLE 11 Coupling Band Width Requirements

		Coupling Band Width, min		
Nominal Corrugation Size[A]	Nominal Pipe Inside Dia.[B]	Annular Corrugated Bands	Helically Corrugated Bands	Bands With Projections
M 196M—All values in millimeters				
38 by 65	100 to 250	265	180	265
68 by 13	300 to 900	180	300	265
	1000 to 1800	265	300	265
	2000 to 3000[C]	265	300	415
75 by 25	800 to 1800	300	350	265
	2000 to 3000	300	350	415
150 by 25	1200 to 2700	600	600	660

[A] For helically corrugated pipe with rerolled ends, the nominal corrugation size refers to the dimensions of the end corrugations in the pipe.
[B] Equivalent diameter of Type II, Type IIA, and Type IIR pipe.
[C] Diameters through 3000 mm for annular corrugated bands used on rerolled ends of helically corrugated pipe.

19 mm in width. The depth of the channel shall be not less than 13 mm. The channel band shall have a minimum nominal thickness of 1.91 mm.

9.2.2 Smooth sleeve type couplings and flat bands shall be aluminum sheet having a nominal thickness of not less than 0.91 mm or, as an option, may be a plastic sleeve to provide equivalent strength. The coupling shall be close fitting to hold the pipe firmly in alignment without the use of sealing compounds or gaskets. The coupling or flat band shall contain a device so that the band or coupling will lap equally on the two pipes being joined. The overall length of the coupling shall be equal to or greater than the nominal diameter of the pipe.

9.3 *Gaskets*—Where infiltration or exfiltration is a concern, the couplings may be required to have gaskets. The closed-cell expanded rubber gaskets shall be a continuous band, approximately 180 mm wide and approximately 9.5 mm thick. Rubber O-ring gaskets shall be 20-mm diameter for pipe diameters of 900 mm or smaller, and 22-mm diameter for larger pipe diameters, having 13 mm deep end corrugations. Rubber O-ring gaskets shall be 35-mm diameter for pipe having 25-mm deep end corrugations.

NOTE 11—Riveted pipe is not watertight, having small openings at the intersection of longitudinal and circumferential seams. Therefore, this type of fabrication should not be used where watertightness is a concern unless the pipe is bituminous coated or lined prior to installation.

9.4 Other types of coupling bands or fastening devices that are equally effective as those described, and which comply with the joint performance criteria of AASHTO *Standard Specifications for Highway Bridges*, may be used when approved by the purchaser.

10. WORKMANSHIP

10.1 The completed pipe shall show careful, finished workmanship in all particulars. Pipe which has been damaged, either during fabrication or in shipping, may be rejected unless repairs are made which are satisfactory to the purchaser. Among others, the following defects shall be considered as constituting poor workmanship:

10.1.1 Variation from a straight center line;

10.1.2 Elliptical shape in pipe intended to be round;

10.1.3 Dents or bends in the metal;

10.1.4 Lack of rigidity;

10.1.5 Illegible markings on the aluminum sheet;

10.1.6 Ragged or diagonal sheared edges;

10.1.7 Uneven laps in riveted pipe;

10.1.8 Loose, unevenly lined, or unevenly spaced rivets; and

10.1.9 Loosely formed lockseams.

11. INSPECTION

11.1 When agreement is made as part of the purchase contract, the purchaser or representative shall have free access to the fabricating plant for inspection, and every facility shall be extended for this purpose. This inspection shall include an examination of the pipe for the items in Section 10.1 and the specific requirements of this specification applicable to the type of pipe and method of fabrication.

11.2 On a random basis, samples may be taken for chemical analysis and mechanical property determination for check purposes. These samples will be secured from fabricated pipe or from sheets or coils of the material used in fabrication of the pipe. Testing shall be as described in M 197M.

12. REJECTION

12.1 Pipe failing to conform to the requirements of this specification may be rejected. This requirement applies not only to the individual pipe, but to any shipment as a whole where a substantial number of pipe are defective. If the average deficiency in length of any shipment of pipe is greater than 1 percent, the shipment may be rejected.

13. CERTIFICATION

13.1 When specified in the purchase order or contract, a manufacturer's or fabricator's certification, or both, shall be furnished to the purchaser stating that samples representing each lot have been tested and inspected in accordance with this specification and have been found to meet the requirements for the material described in the order. When specified in the order, a report of the mechanical test results and chemical composition limits shall be furnished.

NOTE 12—As the identity of the sheet is not maintained from the original ingot production, if numerical results are required by the purchaser, tests should be performed on the finished sheet.

14. PRODUCT MARKING

14.1 If the aluminum alloy sheet was not marked by the manufacturer as indicated in M 197M, it shall be marked by the fabricator as described in Section 14.2, during the course of corrugating the sheet and fabricating the pipe.

14.2 Each corrugated sheet used in annular corrugated pipe, and each 0.6 to 1.5 m of coiled sheet used in helically corrugated pipe, shall be identified by the fabricator showing the following:

14.2.1 Name of sheet manufacturer,

14.2.2 Identification of the pipe fabricator, if different than the sheet manufacturer,

14.2.3 Alloy and temper,

14.2.4 Specified thickness,

14.2.5 Fabricator's date of corrugating or forming into pipe by a six-digit number indicating in order the year, month, and day of the month, and

14.2.6 AASHTO designation number.

14.3 The marking shall be applied to the sheet by a permanent method such as coining in accordance with ASTM B 666/B 666M. This identification shall appear on the outside of the pipe.

Standard Specification
for

Corrugated Steel Pipe, Polymer Precoated, for Sewers and Drains

AASHTO DESIGNATION: M 245M-91 (1995)
(ASTM DESIGNATION: A 762/A 762M-95a)

1. SCOPE

1.1 This specification covers polymer precoated corrugated steel pipe intended for use for storm water drainage, underdrains, the construction of culverts, and similar uses. Pipe covered by this specification is not normally used for the conveyance of sanitary or industrial wastes. The steel sheet used in fabrication of the pipe has a polymer protective coating over a metallic coating of zinc (galvanizing), 55 aluminum-zinc alloy, or zinc-5 percent aluminum-Mischmetal alloy.

1.2 The polymer coating provides a degree of extra protection for the pipe against abrasion and corrosion as compared to metallic-coated pipe without polymer coating. Some severe environments may cause corrosion problems to accessory items such as rivets or coupling band hardware that does not have a polymer coating. Additional protection for polymer precoated corrugated steel pipe can be provided by use of coatings applied after fabrication of the pipe as described in M 190M.

1.3 This specification does not include requirements for bedding, backfill, or the relationship between earth cover load and sheet thickness of the pipe. Experience has shown that the successful performance of this product depends upon the proper selection of sheet thickness, type of bedding and backfill, controlled manufacture in the plant, and care in the installation. The installation procedure is described in AASHTO *Standard Specifications for Highway Bridges,* Division II, Section 26.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards:*

2.1.1 M 190M Bituminous Coated Corrugated Metal Culvert Pipe and Pipe Arches
M 198 Joints for Circular Concrete Sewer and Culvert Pipe Using Flexible Watertight Gaskets
M 218M Steel Sheet, Zinc-Coated (Galvanized) for Corrugated Steel Pipe
M 232M/M 232 Zinc Coating (Hot-Dip) on Iron and Steel Hardware
M 243M Field Applied Coating of Corrugated Metal Structural Plate for Pipe, Pipe-Arches, and Arches
M 246M Steel Sheet, Metallic-Coated and Polymer Precoated, for Corrugated Steel Pipe
M 289M Aluminum-Zinc Alloy Coated Steel Sheet for Corrugated Steel Pipe
M 291M Carbon and Alloy Steel Nuts (Metric)
M 298 Coatings of Zinc Mechanically Deposited on Iron and Steel
T 65M/ T 65 Mass [Weight] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings
T 249M Helical Lock Seam Corrugated Pipe

2.1.2 *Standard Specifications for Highway Bridges*

2.2 *ASTM Standards:*
A 493 Stainless Steel Wire and Wire Rods for Cold Heading and Cold Forging
A 780 Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings
A 796/A 796M Structural Design of Corrugated Steel Pipe, Pipe-Arches, and Arches for Storm and Sanitary Sewers
A 929/A 929M Sheet Steel, Metallic-Coated by the Hot-Dip Process for Corrugated Steel Pipe
B 633 Electrodeposited Coatings of Zinc on Iron and Steel
D 1005 Measurement of Dry Film Thickness of Organic Coatings Using Micrometers
D 1056 Flexible Cellular Materials—Sponge or Expanded Rubber
F 568M Carbon and Alloy Steel Externally Threaded Metric Fasteners

3. DESCRIPTIONS OF TERMS SPECIFIC TO THIS STANDARD

3.1 *Fabricator*—the producer of the pipe.

3.2 *Manufacturer*—the producer of the sheet.

3.3 *Purchaser*—the purchaser of the finished product.

4. CLASSIFICATION

4.1 The corrugated steel pipe covered by this specification is classified as follows:

4.1.1 *Type I*—This pipe shall have a full circular cross-section, with a single thickness of corrugated sheet, fabricated with annular (circumferential) or helical corrugations.

4.1.2 *Type IA*—This pipe shall have a full circular cross-section with an outer shell of corrugated sheet fabricated with helical corrugations and an inner liner of smooth (uncorrugated) sheet attached to the shell at helical lock seams.

4.1.3 *Type IR*—This pipe shall have a full circular cross-section, with a single thickness of smooth sheet, fabricated with helical ribs projecting outwardly.

4.1.4 *Type II*—This pipe shall be a Type I pipe which has been reformed into a pipe-arch, having an approximately flat bottom.

4.1.5 *Type IIA*—This pipe shall be a Type IA pipe which has been reformed into a pipe-arch, having an approximately flat bottom.

4.1.6 *Type IIR*—This pipe shall be a Type IR pipe which has been reformed into a pipe-arch having an approximately flat bottom.

4.1.7 *Type III*—This pipe, intended for use as underdrains or for underground disposal of water, shall be a Type I pipe which has been perforated to permit the in-flow or out-flow of water.

4.1.8 *Type IIIA*—This pipe, intended for use as underdrains, shall consist of a semi-circular cross-section, having a smooth (uncorrugated) bottom with a corrugated top shield.

4.2 Perforations in Type III pipe are included in two classes as described in Section 8.3.2.

5. ORDERING INFORMATION

5.1 Orders for material to this specification shall include the following information as necessary, to adequately describe the desired product:

5.1.1 Name of material (polymer-coated corrugated steel pipe);

5.1.2 Grade of polymer coating indicating thickness on inside and outside (Section 6.1.1);

5.1.3 Type of metallic coating (zinc or aluminum-zinc alloy) (Section 6.1.2);

5.1.4 AASHTO designation and date of issue;

5.1.5 Type of pipe (Section 4.1);

5.1.6 Diameter of circular pipe (Table 6), or span and rise of pipe-arch section (Tables 8, 9, or 10);

5.1.7 Length, either total length or length of each piece and number of pieces;

5.1.8 Description of corrugations (Section 7.2);

5.1.9 Sheet thickness (Section 8.1.2);

5.1.10 For Type I and Type II pipe, the pipe fabrication method, whether with annular corrugations or helical corrugations (Section 7.1.1) (Note 1);

5.1.11 Coupling bands, number, and type (Section 9.1) if special type is required;

5.1.12 Gaskets for coupling bands, if required (Section 9.3);

5.1.13 For Type III pipe, class of perforations, if other than Class I (Section 8.3.2);

5.1.14 Certification, if required (Section 14.1); and

5.1.15 Special requirements.

NOTE 1—Pipe manufactured with annular corrugations may have an element of weakness in the longitudinal seams as compared to pipe with helical corrugations. Therefore, consideration of the method of fabrication is important when pipe is installed under certain conditions of loading.

6. MATERIALS

6.1 *Steel Sheet for Pipe*—All pipe fabricated under this specification shall be formed from polymer precoated sheet conforming to M 246M.

6.1.1 The grade of coating shall be stated in the order, and the polymer coating thickness on both inside and outside of the pipe. The polymer coating is classified by grade corresponding to the thickness in micrometers on each side in SI units. The following grades are usually available. (See table entitled "Grades".)

Grades

Grade	Previous Designation	Coating Thickness µm
250/0	Type A	250/0
250/75	Type B	250/75
250/250		250/250

Bolts and Nuts

	Bolts	Nuts
For pipe fabrication:		
For M 245M pipe	F 568, Cl. 8.8	M 291M, Cl. 12
For coupling bands:		
For M 245M pipe	F 568, Cl. 4.6	M 291M, Cl. 5

6.1.1.1 Any combination of polymer coating thicknesses or other than shown above is subject to agreement between the manufacturer and purchaser or fabricator.

6.1.2 The polymer coating is applied to steel sheet having a metallic coating of zinc or aluminum-zinc alloy, as described in M 218M, M 289M, or ASTM A 929M, respectively. The type of metallic coating should be stated in the order, consistent with thickness availability as shown in Table 7. If the type of metallic coating is not stated, zinc-coated sheet conforming to M 218M shall be used. All pipe furnished on the order shall have the same metallic coating unless otherwise specified.

6.2 *Steel Sheet for Coupling Bands*—The sheet used in fabricating coupling bands shall conform to M 246M with the same polymer coating grade as that used for fabrication of the pipe furnished under the order, and having the same metallic coating.

6.2.1 As an alternate, the steel sheet for coupling bands shall conform to M 218M, M 289M, or ASTM A 929M (with the same metallic coating as the pipe), with the sheet having a bituminous coating according to M 190M, except the thickness requirement shall not apply.

6.2.2 When specifically permitted by the purchaser, coupling bands shall be made of steel sheet conforming to the specification listed in Section 6.2.1 having the same metallic coating as the pipe, but without bituminous coating.

6.3 *Rivets*—The rivets used in riveted pipe shall be of the same material as the base metal specified for the corrugated sheets. They shall be thoroughly galvanized or sherardized. If bolts and nuts are substituted for rivets (Section 7.3.1), they shall meet the following requirements. (See table entitled "Bolts and Nuts".)

The bolts and nuts shall be hot-dip galvanized in conformance with M 232M/M 232, or be mechanically galvanized in conformance with M 298 Class 40.

6.3.1 When specified in the order, rivets used in riveted pipe to be installed in severely corrosive environments shall be made of stainless steel conforming to any of the S3xxxx designations in ASTM A 493. Stainless steel rivets may be substituted for those described in Section 6.3 at the fabricator's option.

NOTE 2—Some polymer precoated pipe in a severe environment is reported to have failed due to corrosion of rivets conforming to Section 6.3, while the sheet was essentially unaffected. The use of stainless steel rivets is recommended to overcome such problems.

6.4 *Hardward for Coupling Bands*—Bolts and nuts for coupling bands shall conform to the following requirements. (See table entitled "Bolts and Nuts".) Bolts, nuts, and other threaded items used with coupling bands shall be zinc coated by one of the following processes: hot-dip process as provided in AASHTO M 232M/M 232; electroplating process as provided in ASTM B 633, Class Fe/Zn 8; or mechanical process as provided in M 298, Class 8. Other hardware items used with coupling bands shall be zinc coated by one of the following processes: hot-dip process as provided in M 232M/M 232; electroplating process as provided in ASTM B 633, Class Fe/Zn 25; or mechanical process as provided in AASHTO M 298, Class 25.

6.5 *Gaskets*—If gaskets are used in couplings, they shall be a band of expanded rubber meeting the requirements of ASTM D 1056 for the "RE" closed cell grades, or O-rings meeting the requirements of M 198.

7. FABRICATION

7.1 *General Requirements*—Pipe shall be fabricated in full circular cross section except for Type IIIA which is described in Section 8.4.

7.1.1 Type I pipe shall have annular corrugations with lap joints fastened with rivets or shall have helical corrugations with a continuous lock seam extending from end to end of each length of pipe. The type of fabrication used shall be the option of the fabricator unless otherwise specified.

7.1.2 Type IA pipe shall be fabricated with a smooth liner and helically corrugated shell integrally attached at helical lock seams extending from end to end of each length of pipe. The shell shall have corrugations of nominal 68 or 75 mm pitch.

7.1.3 Type IR pipe shall be fabricated with helical ribs projecting outward with a continuous lock seam extending from end to end of each length of pipe.

7.2 *Corrugations*—The corrugations shall be either annular or helical as provided in Section 7.1. The direction of the crests and valleys of helical corrugations shall not be less than 60 degrees from the axis of the pipe for pipe diameters larger than 500 mm and not less than 45 degrees from the axis for pipe diameters of 500 mm and smaller.

7.2.1 For Type I and IA pipe, corrugations shall form smooth continuous curves and tangents. The dimensions of the corrugations shall be in accordance with Table 1 for the size indicated in the order, except if the depth measurement of one or more corrugations is less than the minimum depth in Table 1, the depth of all corrugations between adjacent seams shall be measured and the values of Table 2 for minimum average depth and minimum corrugation depth shall apply.

NOTE 3—Inspection frequently consists of measurement of the depth of one or a few corrugations. If such measurement indicates insufficient depth, application of the requirements in Table 2 provides for acceptance where greater depth of some corrugations compensates for lack of depth of others. These measurements would normally be made at one location between seams on a length of pipe.

7.2.2 For Type IR pipe, the corrugations shall be essentially rectangular ribs projecting outward from the pipe wall. The dimensions and spacing of the ribs shall be in accordance with Table 3 for the size indicated on the order. For the 292 mm rib spacing, if the sheet between the ribs does not include a lock seam, a stiffener shall be included midway between the ribs. This stiffener shall have a nominal radius of 6.4 mm and a minimum height of 5.1 mm toward the outside of the pipe.

NOTE 4—The nominal dimensions and properties for smooth corrugations and for ribs are given in AASHTO *Standard Specifications for Highway Bridges*, Division I, Section 12, and in ASTM A 796/A 796M.

7.3 *Riveted Seams*—The longitudinal seams shall be staggered to the extent that no more than three thicknesses of sheet are fastened by any rivet. Pipe to be reformed into pipe-arch shape shall have seams meeting the longitudinal seam requirement of Section 8.2.2.

NOTE 5—Fabrication of pipe without longitudinal seams in 120 degrees of arc, so that the pipe may be installed without longitudinal seams in the invert, is subject to negotiation between the purchaser and fabricator.

7.3.1 The size of rivets, number per corrugation, and width of lap at the longitudinal seam shall be as stated in Table 4, depending on sheet thickness, corrugation size, and diameter of pipe. For pipe with 25 mm deep corrugations, M 12 diameter bolts and nuts may be used in lieu of rivets on a one-for-one replacement ratio. Circumferential seams shall be riveted using rivets of the same size as for longitudinal seams and shall have a maximum rivet spacing of 150 mm, measured on centers, except that six rivets will be sufficient in 300 mm diameter pipe.

7.3.2 All rivets shall be driven cold in such a manner that the sheets shall be drawn tightly together throughout the entire lap. The center of a rivet shall be

TABLE 1 Corrugation Requirements for Type I, IA, II, IIA, and III Pipe

Nominal Size	Maximum Pitch[A]	Minimum Depth[B]	Inside Radius[C] Nominal	Inside Radius[C] Minimum
		All values in millimeters		
38 by 6.5[D]	48	6.0	7	6.5
68 by 13	73	12	17	12
75 by 25	83	24	14	12
125 by 25	135	24	40	36

[A] Pitch is measured from crest to crest of corrugations at 90 degrees to the direction of the corrugations.
[B] Depth is measured as the vertical distance from a straightedge resting on the corrugation crests parallel to the axis of the pipe to the bottom of the intervening valley. If the depth measurement of one or more corrugations is less than the value indicated herein, the depth of all corrugations between seams shall be measured, and the requirements of Table 2 shall be applied. (See Section 7.2.1.)
[C] Minimum inside radius requirement does not apply to a corrugation containing a helical lock seam.
[D] The corrugation size of 38 by 6.5 mm is available only in helically corrugated pipe.

TABLE 2 Referee Requirements for Corrugation Depth[A]

Nominal Size	Diameter	Minimum Average Depth	Minimum Corrugation Depth
	All values in millimeters		
38 by 6.5	all	6.1	5.0
68 by 13	300 thru 525	12.1	10.0
68 by 13	over 525	12.4	11.0
75 by 25	all	24.9	23.0
125 by 25	all	24.9	23.0

[A] See Section 7.2.1 for application of Table 2.

no closer than twice its diameter from the edge of the sheet. All rivets shall have neat, workmanlike, and full hemispherical heads or heads of a form acceptable to the purchaser, shall be driven without bending, and shall completely fill the hole.

7.4 *Helical Lock Seams*—The lock seam for Type I pipe shall be formed in the tangent element of the corrugation profile with its center near the neutral axis of the corrugation profile. The lock seam for Type IA pipe shall be in the valley of the corrugation, shall be spaced not more than 760 mm apart, and shall be formed from both the liner and the shell in the same general manner as Type I helical lock seam pipe. The lock seam for Type IR pipe shall be formed in the flat zone of the pipe wall, midway between two ribs.

7.4.1 The edges of the sheets within the cross-section of the lock seam shall lap at least 4.0 mm for pipe 250 mm or less in diameter and at least 7.9 mm for pipe greater than 250 mm in diameter, with an occasional tolerance of minus 10 percent of lap width allowable. The lapped surfaces shall be in tight contact. The profile of the sheet shall include a retaining offset adjacent to the 180-degree fold (as described in T 249M) of one sheet thickness on one side of the lock seam, or one-half sheet thickness on both sides of the lock seam, at the fabricator's option. There shall be no visible cracks in the metal, loss of metal-to-metal contact, or excessive angularity on the interior of the 180-degree fold of metal at the completion of forming the lock seam.

7.4.2 Specimens cut from production pipe normal to and across the lock seam shall develop the tensile strength as provided in Table 5, when tested according to AASHTO T 249M. For Type IA pipe, the lock seam strength shall be as tabulated based on the thickness of the corrugated shell.

7.4.3 When the ends of helically corrugated lock seam pipe have been rerolled to form annular corrugations, either with or without a flanged end finish, the lock seam in the rerolled end shall not contain any visible cracks in the base metal and the tensile strength of the lock seam shall be not less than 60 percent of that required in Section 7.4.2.

7.5 *End Finish:*

7.5.1 To facilitate field jointing, the ends of the individual pipe sections with helical corrugations may be rerolled to form annular corrugations extending at least two corrugations from the pipe end, or to form an upturned flange meeting the requirements in Section 7.5.2, or both. The diameter of ends shall not exceed that of the pipe barrel by more than the depth of the corrugation. All types of pipe ends, whether rerolled or not, shall be matched in a joint such that the maximum difference in the diameter of abutting pipe ends is 13 mm.

7.5.1.1 When pipe with any size hel-

TABLE 3 Rib Requirements for Types IR and IIR Pipe

Nominal Size	Rib Width,[A] Minimum	Rib Depth,[B] Minimum	Rib Spacing,[C] Maximum	Bottom Outside Radius, Min.	Bottom[D] Outside Radius, Max. Avg.	Top Outside Radius, Min.	Top[D] Outside Radius, Max. Avg.
			Millimeters				
19 × 19 × 190	17	19	197	2.5	6.0	2.5+t	6.0+t
19 × 25 × 292	17	24	298	2.5	6.0	2.5+t	6.0+t

[A] Width is a dimension of the inside of the rib, but is measured on the outside of the pipe (outside of the rib) and shall meet or exceed the stated minimum width plus two times the wall thickness, that is, 2t + 17mm.

[B] Depth is an average of three ribs (one sheet width) measured from the inside by placing a straightedge across the open rib and measuring to the bottom of the rib.

[C] Spacing is an average of three ribs (one sheet width) measured center-to-center of the ribs at 90° to the direction of the ribs.

[D] The average of the four rib radii (Top and Bottom) shall be within the minimum and maximum tolerances. The outside radius refers to the surface outside of the pipe.

TABLE 4 Riveted Longitudinal Seams

Specified Sheet Thickness	Nominal Corrugation Size 68 × 13 mm[A,D]	75 × 25 mm[B,E]	125 × 25 mm[C,E]
	Rivet Diameters, Minimum		
mm	mm	mm	mm
1.32	8.0	—	—
1.63	8.0	9.5	9.5
2.01	8.0	9.5	9.5
2.77	9.5	11.0	11.0
3.51	9.5	11.0	11.0
4.27	9.5	11.0	11.0

[A] One rivet each valley for pipe diameters 900 mm and smaller. Two rivets each valley for pipe diameters 1000 mm and larger.

[B] Two rivets each valley for all pipe diameters.

[C] Two rivets each crest and valley for all pipe diameters.

[D] Minimum width of lap: 38 mm for pipe diameters 900 mm and smaller, and 75 mm for pipe diameters 1050 mm and larger.

[E] Minimum Width of lap: 75 mm for all pipe diameters.

TABLE 5 Lock Seam Tensile Strength

Specified Sheet Thickness[A] mm	Lock Seam Tensile Strength, per Unit Width, Minimum kN/m
1.02	30
1.32	42
1.63	60
2.01	91
2.77	122
3.50	154
4.27	210

[A] For Type IA pipe, the thickness shall be that of the corrugated shell.

ical corrugation or rib is rerolled to form annular corrugations in the ends, the usual size of the annular corrugations is 68 by 13 mm.

7.5.2 If a flanged finish is used on the ends of individual pipe sections to facilitate field jointing, the flange shall be uniform in width, be not less than 13 mm wide, and shall be square to the longitudinal axis of the pipe.

7.5.3 The ends of all pipe which will form the inlet and outlet of culverts, fabricated of sheets having nominal thicknesses of 2.01 mm and less, shall be reinforced in a manner approved by the purchaser, when specified.

8. PIPE REQUIREMENTS

8.1 *Type I, Type IA, and Type IR Pipe:*

8.1.1 *Pipe Dimensions*—The nominal diameter of the pipe shall be as stated in the order, selected from the sizes listed in Table 6. The size of corrugations which are standard for each size of pipe are also shown in Table 6. The average inside diameter of circular pipe and pipe to be reformed into pipe-arches shall not vary more than 1 percent or 13 mm, whichever is greater, from the nominal diameter when measured on the inside crest of the corrugations. Alternately, for pipe having annular corrugations, conformance with the inside diameter requirement may be determined by measuring the outside circumference, for which minimum values are given in Table 6.

NOTE 6—The outside circumference of helically corrugated pipe is influenced by the corrugation size and the angle of the corrugations, affecting the number of corrugations crossed; therefore, no minimum circumferential measurement can be specified.

8.1.2 *Sheet Thickness*—Sheet thickness shall be specified by the purchaser

TABLE 6 Pipe Sizes

Nominal Inside Diameter mm	Corrugation Sizes[A]					Minimum Outside Circumference[B] mm
	38 by 6.5 mm	68 by 13 mm	75 by 25 mm	125 by 25 mm	Ribbed Pipe[C]	
100	X					284
150	X					441
200	X					598
250	X					755
300	X	X				912
375	X	X				1148
450	X	X			X	1383
525		X			X	1620
600		X			X	1854
675		X			X	2091
750		X			X	2483
825		X			X	2561
900		X	X	X	X	2797
1050		X	X	X	X	3269
1200		X	X	X	X	3739
1350		X	X	X	X	4209
1500		X	X	X	X	4675
1650		X	X	X	X	5142
1800		X	X	X	X	5609
1950		X	X	X	X	6075
2100		X	X	X	X	6542
2250			X	X	X	7008
2400			X	X	X	7475
2550			X	X	X	7941
2700			X	X	X	8408
2850			X	X		8874
3000			X	X		9341
3150			X	X		9807
3300			X	X		10274
3450			X	X		10740
3600			X	X		11207

[A] An "X" indicates standard corrugation sizes for each nominal diameter of pipe.
[B] Measured in valley of annular corrugations. Not applicable to helically corrugated pipe.
[C] Rib sizes 19 × 19 × 190 mm and 19 × 25 × 292 mm.

TABLE 7 **Thicknesses of Metallic Coated Steel Sheet**[A]

Specified Thickness		Specification Designation	
mm	ASTM A 929M Zn-5A1 MM Alloy Coated	M 218M Zinc Coated	M 289M 55 Aluminum-Zinc Alloy Coated
1.02	X	X	X
1.32	X	X	X
1.63	X	X	X
2.01	X	X	X
2.77	X	X	X
3.51	X	X	X
4.27	X	X	

[A] An "X" indicates sheet thickness included in the applicable specifications which are referenced in M 246M. The specified thickness is the thickness of the metallic-coated steel sheet and does not include the thickness of the polymer coating.

from the specified sheet thicknesses listed in Table 7 (Notes 7 and 8). For Type IA pipe, the thickness of both the shell and the liner shall be given; the thickness of the corrugated shell shall not be less than 60 percent of the thickness of the equivalent Type I pipe; the liner shall have a nominal thickness of at least 1.02 mm and the sum of the specified thicknesses of shell and liner shall equal or exceed the specified thickness of an equivalent pipe of identical corrugations as the shell according to the design criteria in AASHTO *Standard Specifications for Highway Bridges.*

NOTE 7—The sheet thicknesses indicated in Table 7 are the thicknesses listed as available in M 246M. The specified thickness is based on the thickness of the metallic coated sheet, not including the thickness of polymer coating.

NOTE 8—The purchaser should determine the required thickness for each of the types of pipe described in Sections 4.1.1 through 4.1.6, according to the design criteria in AASHTO *Standard Specifications for Highway Bridges,* Division I, Section 12, or other appropriate guidelines.

8.1.3 When specified by the purchaser, the finished pipe shall be factory elongated to the extent specified. The elongation shall be accomplished by the use of a mechanical apparatus which will produce a uniform deformation throughout the length of the section.

8.2 *Type II, IIA, and IIR Pipe:*

8.2.1 *Pipe-Arch Dimensions*—Pipe furnished as Type II, IIA, or IIR shall be made from Type I, IA, or IR pipe respectively, and shall be reformed to provide a pipe-arch shape. All applicable requirements for Types I, IA, and IR pipe shall be met by finished Types II, IIA, and IIR pipe, respectively. Pipe-arches shall conform to the dimensional requirements of Tables 8, 9, or 10. All dimensions shall be measured from the inside crests of corrugations for Type II pipe or from the inside liner or surface for Types IIA or IIR pipe, respectively.

8.2.2 *Longitudinal Seams*—Longitudinal seams of riveted pipe arches shall not be placed in the corner radius.

8.2.3 Reforming Type IR into Type IIR pipe shall be done in such a manner as to avoid damage to the external ribs.

8.3 *Type III Pipe:*

8.3.1 Type III pipe shall have a full circular cross-section and shall conform to the requirements for Type I pipe, and in addition shall contain perforations conforming to one of the classes described in Section 8.3.2.

8.3.2 *Perforations*—The perforations shall conform to the requirements for Class I, unless otherwise specified in the order. Class I perforations are for pipe intended to be used for subsurface drainage. Class 2 perforations are for pipe intended to be used for subsurface disposal of water, but pipe containing Class 2 perforations may also be used for subsurface drainage.

8.3.2.1 *Class I Perforations*—The perforations shall be approximately circular and cleanly cut; shall have nominal diameters of not less than 4.8 mm nor greater than 9.5 mm and shall be arranged in rows parallel to the axis of the pipe. The perforations shall be located on the inside crests or along the neutral axis of the corrugations, with one perforation in each row for each corrugation. Pipe connected by couplings or bands may be unperforated within 100 mm of each end of each length of pipe. The rows of perforations shall be arranged in two equal groups placed symmetrically on either side of a lower unperforated segment corresponding to the flow line of the pipe. The spacing of the rows shall be uniform. The distance between the center lines of rows shall be not less than 25 mm. The minimum number of longitudinal rows of perforations, the maximum heights of the center lines of the uppermost rows above the bottom of the invert, and the inside

TABLE 8 **Pipe Arch Requirements 68 by 13 mm Corrugations**

Pipe-Arch Size, mm	Equivalent Diameter, mm	Span,[A] mm	Rise,[A] mm	Minimum Corner Radius, mm	Maximum B,[B] mm
430 × 330	375	430	330	75	135
530 × 380	450	530	380	75	155
610 × 460	525	610	460	75	185
710 × 510	600	710	510	75	205
780 × 560	675	780	560	75	225
885 × 610	750	870	630	75	240
970 × 690	825	970	690	75	255
1060 × 740	900	1060	740	90	265
1240 × 840	1050	1240	840	100	290
1440 × 970	1200	1440	970	130	345
1620 × 1100	1350	1620	1100	155	380
1800 × 1200	1500	1800	1200	180	420
1950 × 1320	1650	1950	1320	205	460
2100 × 1450	1800	2100	1450	230	510

[A] A tolerance of 25 mm or 2 percent of equivalent diameter, whichever is greater, will be permissible in span and rise.

[B] B is defined as the vertical dimension from a horizontal line across the widest portion of the arch to the lowest portion of the base.

TABLE 9 Pipe-Arch Requirements 75 by 25 mm or 125 by 25 mm Corrugations

Pipe-Arch Size, mm	Equivalent Diameter, mm	Span,[A] mm	Rise,[A] mm	Minimum Corner Radius, mm
1010 × 790	900	1010 − 45	790 + 45	130
1160 × 920	1050	1160 − 55	920 + 55	155
1340 × 1050	1200	1340 − 60	1050 + 60	180
1520 × 1170	1350	1520 − 70	1170 + 70	205
1670 × 1300	1500	1670 − 75	1300 + 75	230
1850 × 1400	1650	1850 − 85	1400 + 85	305
2050 × 1500	1800	2050 − 95	1500 + 95	355
2200 × 1620	1950	2200 − 110	1620 + 110	355
2400 × 1720	2100	2400 − 120	1720 + 120	410
2600 × 1820	2250	2600 − 130	1820 + 130	410
2840 × 1920	2400	2840 − 145	1920 + 145	460
2970 × 2020	2550	2970 − 150	2020 + 150	460
3240 × 2120	2700	3240 − 165	2120 + 165	460
3470 × 2220	2850	3470 − 175	2220 + 175	460
3600 × 2320	3000	3600 − 180	2320 + 180	460

[A] Negative and positive numbers listed with span and rise dimensions are negative and positive tolerances, no tolerance in opposite direction.

TABLE 10 Pipe-Arch Requirements—19 × 19 × 190 mm or 19 × 25 × 292 mm Rib Corrugations

Pipe-Arch Size, mm	Equivalent Diameter, mm	Span,[A]	Rise,[A]	Minimum Corner Radius, mm
500 × 400	450	500 − 25	410 + 25	130
580 × 490	525	580 − 25	490 + 25	130
680 × 540	600	680 − 40	540 + 40	130
750 × 620	675	750 − 40	620 + 40	130
830 × 670	750	830 − 40	670 + 40	130
900 × 750	825	900 − 45	750 + 45	130
1010 × 790	900	1010 − 45	790 + 45	130
1160 × 920	1050	1160 − 55	920 + 55	155
1340 × 1050	1200	1340 − 60	1050 + 60	180
1520 × 1170	1350	1520 − 70	1170 + 70	205
1670 × 1300	1500	1670 − 75	1300 + 75	230
1850 × 1400	1650	1850 − 85	1400 + 85	305
2050 × 1500	1800	2050 − 95	1500 + 95	355

[A] Negative and positive numbers listed with span and rise dimensions are negative and positive tolerances, no tolerance in opposite direction.

chord lengths of the unperforated segments illustrated in Figure 1 shall be as specified in Table 11.

NOTE 9—Pipe with Class 1 perforations is generally available in diameters from 100 to 525 mm inclusive, although perforated pipe in larger sizes may be obtained.

8.3.2.2 *Class 2 Perforations*—The perforations shall be circular holes with nominal diameters of 8.0 to 9.5 mm or slots with nominal width of 4.8 to 8.0 mm and not to exceed 13 mm in length. The perforations shall be uniformly spaced around the full periphery of the pipe. The perforations shall provide an opening area of not less than 230 square centimeters per square meter of pipe surface based on nominal diameter and length of pipe.

NOTE 10—323 perforations, 9.5-mm diameter, per square meter satisfies this requirement.

8.4 *Type IIIA Pipe:*

8.4.1 Type IIIA pipe shall be fabricated of an unperforated semicircular bottom section with a top shield of corrugated steel, both of nominal 1.32 mm thickness or greater. The smooth semicircular bottom section shall be approximately 120 mm in diameter and shall have a continuous lip extending outward along each side; the corrugated top shield shall be approximately 160 mm wide including a 19 mm sloping overhang on each side and shall be secured to the lip of the bottom section by integral tabs spaced at about 90 mm center to center. The top shield shall have corrugations approximately 22 mm center to center and approximately 8.0-mm depth.

9. COUPLING BANDS

9.1 *Types of Coupling Bands*—Field joints for each type of corrugated steel pipe shall maintain pipe alignment during construction and prevent infiltration of fill material during the life of the installation. Coupling bands may be of the following types:

Bands with annular corrugations,
Bands with helical corrugations,
Bands with projections (dimples),
Channel bands for upturned flanges, with or without annular corrugations,
Flat bands, and
Smooth sleeve-type couplers.

Except as provided in Sections 9.1.1 through 9.1.4, the type of coupling furnished shall be at the option of the fabricator unless the type is specified in the order.

NOTE 11—Bands are classified according to their ability to resist shear, moment, and tensile forces as described in AASHTO *Standard Specifications for Highway Bridges*, Divison II, Section 23, and identified as "standard joints" and "special joints." The first four types of bands listed in Section 9.1, and meeting the requirements of Section 9.2, are expected to meet the requirements for "standard joints." Some may also be able to meet the requirements for "special joints," but such capability should be determined by analysis or test.

9.1.1 Coupling bands with annular corrugations shall be used only with pipe with annular corrugations, or helical pipe in which the ends have been rerolled to form annular corrugations. The corrugations in the band shall have the same

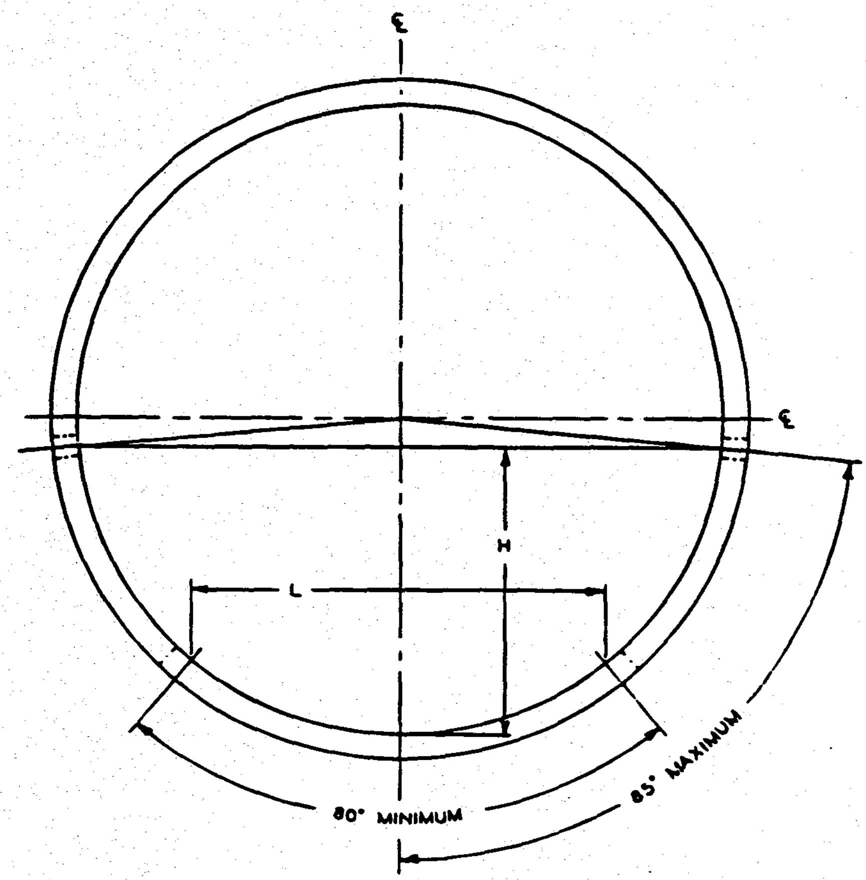


FIGURE 1 Requirements for Perforations

TABLE 11 Rows of Perforations, Height "H" of the Center Line of the Uppermost Rows Above the Invert, and Chord Length "L" of Unperforated Segment, for Class 1 Perforations

Internal Diameter of Pipe mm	Rows of Perforations[A]	H, Maximum[B] mm	L, Minimum[B] mm
100	2	46	64
150	4	69	96
200	4	92	128
250	4	115	160
300	6[C]	138	192
375	6[C]	172	240
450	6[C]	207	288
525	6	241	338
600 and larger	8	(D)	(D)

[A] Minimum number of rows. A greater number of rows for increased inlet area shall be subject to agreement between purchaser and fabricator. Note that the number of perforations per unit length in each row (and inlet area) is dependent on the corrugation pitch.
[B] See Figure 1 for location of dimensions "H" and "L."
[C] Minimum of 4 rows permitted in pipe with 38 by 6.5 mm corrugations.
[D] H (max) = 0.46D: L (min) = 0.64D, where D = internal diameter of pipe, millimeters or inches as appropriate.

TABLE 12 Coupling Band Thickness

Nominal Pipe Thickness mm	Nominal Coupling Band Thickness, Minimum mm
2.77 and thinner	1.32
3.51	1.63
4.27	2.01

dimensions as the corrugations in the pipe end, or may be of a special design to engage only the first or second corrugation from the end of each pipe. The band may also include a U-shaped channel to accommodate upturned flanges on the pipe.

9.1.2 Coupling bands with helical corrugations shall be used only with pipe with helically corrugated ends. The corrugations in the bands shall be designed to properly mesh with the corrugations in the pipe.

9.1.3 Coupling bands with projections (dimples) may be used with pipe with either annular or helical corrugations. The bands shall be formed with the projections in annular rows with one projection for each corrugation of helical pipe. Bands 265 or 300 mm wide shall have two annular rows of projections, and bands 415 or 560 mm wide shall have four annular rows of projections.

9.1.4 Channel bands may be used only with pipe having upturned flanges on the pipe ends.

9.1.5 Smooth sleeve-type couplers and flat bands may be used only with Type III and IIIA pipe of 300 mm diameter or smaller.

9.2 *Requirements*—Coupling bands shall be fabricated to lap on an equal portion of each of the pipe sections to be connected. The ends of the bands shall lap or be fabricated to form a tightly closed joint upon installation. Coupling band thickness shall conform to the requirements in Table 12, based on the sheet thickness of the pipe to be connected except as provided in Sections 9.2.1 and 9.2.2. The band width shall be not less than as shown in Table 13. The bands shall be connected in a manner approved by the purchaser with suitable galvanized devices such as: angles, or integrally or separately formed and attached flanges, bolted with zinc-coated bolts; bars and straps; wedge lock and straps; or lugs. Coupling bands shall be fastened with the following size of bolts:

Pipe diameters 450 mm and less—M10 diameter
Pipe diameters 525 mm and greater—M12 diameter
Type IIIA pipe—M8 diameter

9.2.1 If flanges are provided on the pipe ends, the coupling may also be made by interlocking the flanges with a preformed channel band or other band incorporating a locking channel not less than 19 mm in width. The depth of the channel shall be not less than 13 mm. The channel band shall have a minimum nominal thickness of 2.01 mm.

9.2.2 Smooth sleeve type couplings and flat bands shall be steel having a nominal thickness of not less than 1.02 mm or, as an option, may be a plastic sleeve to provide equivalent strength. The coupling shall be close-fitting to hold the pipe firmly in alignment without the use of sealing compounds or gaskets. The coupling or flat band shall contain a device so that the band or coupling will lap equally on the two pipes being joined. The overall length of the coupling shall be equal to or greater than the nominal diameter of the pipe.

9.3 *Gaskets*—Where infiltration or exfiltration is a concern, the couplings may be required to have gaskets. The closed-cell expanded rubber gaskets shall be a continuous band, approximately 180 mm wide and approximately 9.5 mm thick. Rubber O-ring gaskets shall be 20-mm diameter for pipe diameters of 900 mm or smaller, and 22-mm diameter for larger pipe diameters, having 13-mm deep end corrugations. Rubber O-ring gaskets shall be 35-mm diameter for pipe having 25-mm deep end corrugations.

NOTE 12—Riveted pipe is not water tight, having small openings at the intersection of longitudinal and circumferential seams. Therefore, this type of fabrication should not be used where water tightness is a concern unless the pipe is bituminous coated or lined prior to installation.

9.4 Other types of coupling bands or fastening devices which are as equally effective as those described, and which comply with the joint performance criteria of AASHTO *Standard Specifications for Highway Bridges,* Division II, Section 23 may be used when approved by the purchaser.

10. WORKMANSHIP

10.1 The completed pipe shall show careful, finished workmanship in all particulars. Pipe which has been damaged, either during fabrication or in shipping, may be rejected unless repairs are made which are satisfactory to the purchaser. Among others, the following defects shall be considered as constituting poor workmanship:

Variation from a straight center line;
Elliptical shape in pipe intended to be round;
Dents or bends in the metal;
Polymer coating or metallic coating which has been bruised, broken, disbonded, or otherwise damaged;
Lack of rigidity;
Illegible markings on the steel sheet;
Ragged or diagonal sheared edges;
Uneven laps in riveted pipe;
Loose, unevenly lined, or unevenly spaced rivets;
Loosely formed lockseams.

11. REPAIR OF DAMAGED COATINGS

11.1 Pipe on which either the polymer coating or the underlying metallic coating has been damaged in fabrication or handling shall be repaired. Damage to the metallic coating shall be repaired as described in Sections 11.2 through 11.4. Damage to the polymer coating shall be repaired as described in Section 11.5. The repair shall be done so that the completed pipe shall show careful finished workmanship in all particulars. Pipe which, in the opinion of the purchaser, has not been cleaned or coated satisfactorily may be rejected. If the purchaser so elects, the repair shall be done in his presence.

11.2 Damage to the metallic coating shall be repaired as provided in ASTM A 780 (Note 13) except as described herein. The damaged area shall be cleaned to bright metal by blast cleaning, power disk sanding, or wire brushing. The cleaned area shall extend at least 13 mm into the undamaged section of the coating. The cleaned area shall be coated within 24 hours and before any rusting or soiling.

NOTE 13—While ASTM A 780 specifically refers to repair of damaged zinc coatings, the same procedures are applicable to repair of aluminum-zinc alloy coatings except as described in this section.

11.3 *Zinc-Rich Paint Coating*—Zinc-rich paint shall be applied to a dry film thickness of at least 0.13 mm over the damaged section and surrounding cleaned area. Zinc-rich paint shall be used for repair of damage to both zinc and aluminum-zinc alloy coatings.

11.4 *Metallizing Coating*—The dam-

TABLE 13 Coupling Band Width Requirements

		Coupling Band Width, Minimum		
Nominal Corrugation Size[A]	Nominal Pipe Inside Diameter[B]	Annular Corrugated Bands	Helically Corrugated Bands	Bands With Projections
All values in millimeters				
38 by 6.5	100 to 450	285	180	285
68 by 13	300 to 900	180	300	285
	1050 to 1800	285	300	285
	1950 to 2100[C]	285	300	415
75 by 25	900 to 1800	300	350	285
	1950 to 3600	300	350	415
125 by 25	900 to 1800	500	560	300
	1950 to 3600	500	560	560

[A] For helically corrugated pipe with rerolled ends, the nominal corrugation size refers to the dimensions of the end corrugations in the pipe.
[B] Equivalent diameter for Type II, IIA, and IIR pipe.
[C] Diameters through 3600 mm for annular corrugated bands used on rerolled ends of helically corrugated pipe.

aged area shall be cleaned as described in Section 11.2, except it shall be cleaned to the near-white condition. The repair coating applied to the cleaned section shall have a thickness of not less than 0.13 mm over the damaged section and shall taper off to zero thickness at the edges of the cleaned undamaged section.

11.4.1 Where zinc coating is to be metallized, it shall be done with zinc wire containing not less than 99.98 percent zinc.

11.4.2 Where aluminum-zinc alloy coating is to be metallized, it shall be done using zinc wire containing not less than 99.98 percent zinc, aluminum wire containing not less than 99 percent aluminum, or an alloy wire of 55 percent aluminum and 45 percent zinc by mass.

11.5 Areas of damaged polymer coating shall be repaired with a polymer coating similar to and compatible with respect to durability, adhesion, and appearance of the original polymer coating.

11.5.1 Polymer coating damaged during shipping or installation may be repaired using materials as described in 11.5 or by the application of a protective coating material conforming to M 243M.

12. INSPECTION

12.1 The purchaser or his representative shall have free access to the fabricating plant for inspection, and every facility shall be extended to him for this purpose. This inspection shall include an examination of the pipe for the items in Section 10.1 and the specific requirements of this specification applicable to the type of pipe and method of fabrication.

12.2 On a random basis, samples may be taken for chemical analysis and metallic and polymer coating measurements for check purposes. These samples will be secured from fabricated pipe or from sheets or coils of the material used in fabrication of the pipe. The mass of metallic coating shall be determined in accordance with T 65M/T 65 for zinc and the dilute hydrochloric acid method of T 65M/T 65 for aluminum-zinc alloy. The thickness of polymer coating shall be measured according to ASTM D 1005.

13. REJECTION

13.1 Pipe that fails to conform to the specific requirements of this specification, or that shows poor workmanship, may be rejected. This requirement applies not only to the individual pipe, but to any shipment as a whole where a substantial number of pipe are defective. If the average deficiency in length of any shipment of pipe is greater than one percent, the shipment may be rejected.

14. CERTIFICATION

14.1 When specified in the purchase order or contract, a manufacturer's or fabricator's certification, or both, shall be furnished to the purchaser stating that samples representing each lot have been tested and inspected in accordance with this specification and have been found to meet the requirements for the material described in the order. When specified in the order, a report of the test results shall be furnished.

Standard Practice for Structural Design of Corrugated Steel Pipe, Pipe-Arches, and Arches for Storm and Sanitary Sewers and Other Buried Applications[1]

This standard is issued under the fixed designation A 796; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers the structural design of corrugated steel pipe and pipe-arches, and steel structural plate pipe, pipe-arches, arches, and underpasses for use as storm sewers and sanitary sewers, and other buried applications. This practice is for pipe installed in a trench or embankment and subjected to earth loads and live loads. It must be recognized that a buried corrugated steel pipe is a composite structure made up of the steel ring and the soil envelope, and both elements play a vital part in the structural design of this type of structure. This practice applies to structures installed in accordance with Practices A 798/A 798M or A 807/A 807M.

1.2 Corrugated steel pipe and pipe-arches shall be of annular fabrication using riveted or spot-welded seams, or of helical fabrication having a continuous lockseam or welded seam.

1.3 Structural plate pipe, pipe-arches, underpasses, and arches are fabricated in separate plates that, when assembled at the job site by bolting, form the required shape.

1.4 The values stated in inch-pound units are to be regarded as the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A 760/A 760M Specification for Corrugated Steel Pipe, Metallic-Coated for Sewers and Drains[2]

A 761/A 761M Specification for Corrugated Steel Structural Plate, Zinc-Coated, for Field-Bolted Pipe, Pipe-Arches, and Arches[2]

A 762/A 762M Specification for Corrugated Steel Pipe, Polymer Precoated for Sewers and Drains[2]

A 798/A 798M Practice for Installing Factory-Made Corrugated Steel Pipe for Sewers and Other Applications[2]

A 807/A 807M Practice for Installing Corrugated Steel Structural Plate Pipe for Sewers and Other Applications[2]

D 698 Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3) (600 kN-m/m^3)[3]

D 1556 Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method[3]

D 2167 Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method[3]

D 2487 Classification of Soils for Engineering Purposes (Unified Soil Classification System)[3]

D 2922 Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)[3]

D 2937 Test Method for Density of Soil in Place by the Drive-Cylinder Method[3]

2.2 *AASHTO Standard:*

Standard Specifications for Highway Bridges[4]

2.3 *FAA Standard:*

AC No. 150/5320-5B, Advisory Circular, "Airport Drainage," Department of Transportation, Federal Aviation Administration, 1970[5]

3. Terminology

3.1 *Symbols:*

- A = required wall area, in.^{2}/ft
- (AL) = maximum highway design axle load, lbf
- C_1 = longitudinal live load distribution factor for pipe arches
- d = depth of corrugation, in.
- E = modulus of elasticity, lbf/in.^{2} = 29×10^6 lbf/in.^{2}
- (EL) = earth load, lbf/ft^2
- (FF) = flexibility factor, in./lbf
- f_y = specified minimum yield strength, lbf/in.^{2} = 33 000 lbf/in.^{2}
- f_u = specified minimum tensile strength, lbf/in.^{2} = 45 000 lbf/in.^{2}
- f_c = critical buckling stress, lbf/in.^{2}
- h = height of cover, in., determined as follows: (*1*) highways—from top of pipe to top of rigid pavement, or to top of subgrade for flexible pavement; (*2*) railways—top of pipe to bottom of tie
- H = depth of fill above top of pipe, ft

---

[1] This practice is under the jurisdiction of ASTM Committee A-5 on Metallic-Coated Iron and Steel Products and is the direct responsibility of Subcommittee A05.17 on Corrugated Steel Pipe Specifications.

Current edition approved Oct. 10, 1995. Published December 1995. Originally published as A 796 – 82. Last previous edition A 796 – 94.

[2] *Annual Book of ASTM Standards*, Vol 01.06.

[3] *Annual Book of ASTM Standards*, Vol 04.08.

[4] Available from American Association of State Highway and Transportation Officials, 444 North Capitol St., N.W., Suite 225, Washington DC, 20001.

[5] Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. Publication No. SN-050-007-00149-5.

H_{min} = minimum depth of fill, ft
H_{max} = maximum depth of fill, ft
I = moment of inertia of corrugated shape, in.^{4}/in. (see Tables 1 through 9)
(IL) = impact load, lbf/ft^2
k = soil stiffness factor = 0.22 for good side-fill material compacted to 90 % of standard density based on Test Method D 698
L_1, L_2, L_3 = loaded lengths, in., defined in 11.3
(LL) = live load, lbf/ft^2
P = total design load or pressure, lbf/ft^2
P_c = corner pressure, lbf/ft^2
r = radius of gyration of corrugation, in. (see Tables 1 through 9)
r_c = corner radius of pipe-arch, ft
r_t = radius at crown, ft
S = pipe diameter or span, ft
s = pipe diameter or span, in.
(SF) = safety factor
(SS) = required seam strength, lbf/ft
T = thrust in pipe wall, lbf/ft
w = density of fill material, lbf/ft^3 (when actual weight is not known use 120 lbf/ft^3)

4. Basis of Design

4.1 The safety factors and other specific quantitative recommendations herein represent generally accepted design practice. The design engineer should, however, satisfy himself that these recommendations meet his particular needs.

4.2 This practice is not applicable for long-span structural plate pipe or other multi-radius shapes not described herein. Such structures require additional design considerations for both the pipe and the soil envelope. In addition to meeting all other design requirements given herein, the maximum diameters or spans for structures designed by this practice are as follows:

Shape	Maximum Diameter or Span, ft
pipe, arch	26
pipe-arch, underpass	21

5. Loads

5.1 The total design load or pressure on a pipe is the sum of several separate and individual loads. This total design load is applied as a fluid pressure acting on the pipe periphery and is given as:

$$P = (EL) + (LL) + (IL)$$

5.2 For steel pipe buried in a trench or in an embankment on a yielding foundation, loads are defined as follows:

5.2.1 The earth load (EL) is the weight of the column of soil directly above the pipe:

$$(EL) = Hw$$

5.2.2 *Live Loads*—The live load (LL) is that portion of the weight of vehicle, train, or aircraft moving over the pipe that is distributed through the soil to the pipe.

5.2.2.1 *Live Loads Under Highways*—Live load pressures for H20 highway loadings, including impact effects, are:

Height of Cover, ft	Live Load, lbf/ft^2
1	1800
2	800
3	600
4	400
5	250
6	200
7	175
8	100
over 8	neglect

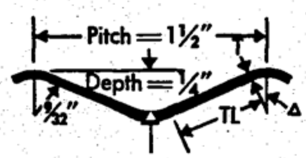
5.2.2.2 *Live Loads Under Railways*—Live load pressures for E80 railway loadings, including impact effects, are as follows:

Height of Cover, ft	Live Load, lbf/ft^2
2	3800
5	2400
8	1600
10	1100
12	800
15	600
20	300
30	100
over 30	neglect

5.2.2.3 Values for intermediate covers may be interpolated.

5.2.2.4 *Live Loads Under Aircraft Runways*—Because of the many different wheel configurations and weights, live load pressures for aircraft vary. Such pressures must be determined for the specific aircrafts for which the installation

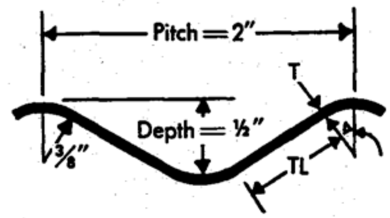
TABLE 1 Sectional Properties of Corrugated Steel Sheets for Corrugation: 1½ by ¼ in. (Helical)



Specified Thickness, in.	Area of Section, A, in.^{2}/ft	Tangent Length, TL, in.	Tangent Angle, Δ, °	Moment of Inertia, I × 10^{-3} in.^{4}/in.	Radius of Gyration, r, in.
0.040[A]	0.456	0.571	21.44	0.253	0.0816
0.052	0.608	0.566	21.52	0.343	0.0824
0.064	0.761	0.560	21.61	0.439	0.0832
0.079	0.950	0.554	21.71	0.566	0.0846

[A] This thickness should only be used for the inner liner of double-wall type IA pipe, or for temporary pipe. When used for other than temporary pipe, it should be polymer coated.

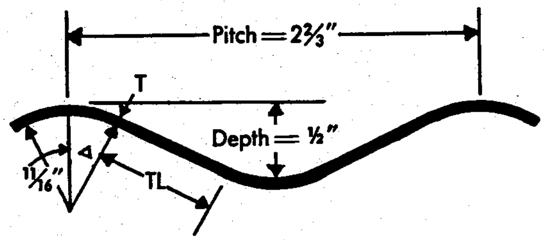
TABLE 2 Sectional Properties of Corrugated Steel Sheets for Corrugation: 2 by ½ in. (Helical)



Specified Thickness, in.	Area of Section, A, in.^{2}/ft	Tangent Length, TL, in.	Tangent Angle, Δ, °	Moment of Inertia, I × 10^{-3} in.^{4}/in.	Radius of Gyration, r, in.
0.040[A]	0.489	0.681	33.12	1.142	0.1676
0.052	0.652	0.672	33.29	1.533	0.1682
0.064	0.815	0.663	33.46	1.942	0.1690
0.079	1.019	0.625	33.68	2.458	0.1700
0.109	1.428	0.629	34.13	3.542	0.1725

[A] This thickness should only be used for temporary pipe.

TABLE 3 Sectional Properties of Corrugated Steel Sheets for Corrugation: 2⅔ by ½ in. (Annular or Helical)



Specified Thickness, in.	Area of Section, A, in.²/ft	Tangent Length, TL, in.	Tangent Angle, Δ, °	Moment of Inertia, I × 10⁻³ in.⁴/in.	Radius of Gyration, r, in.	Ultimate Longitudinal Seam Strength of Riveted or Spot Welded Corrugated Steel Pipe in Pounds per Foot of Seam			
						5/16 Rivets		3/8 Rivets	
						Single	Double	Single	Double
0.040[A]	0.465	0.785	26.56	1.122	0.1702	...	...	...	...
0.052	0.619	0.778	26.65	1.500	0.1707	...	...	...	...
0.064	0.775	0.770	26.74	1.892	0.1712	16 700	21 600	...	...
0.079	0.968	0.760	26.86	2.392	0.1721	18 200	29 800	...	...
0.109	1.356	0.740	27.11	3.425	0.1741	...	...	23 400	46 800
0.138	1.744	0.720	27.37	4.533	0.1766	...	...	24 500	49 000
0.168	2.133	0.699	27.65	5.725	0.1795	...	...	25 600	51 300

[A] This thickness should only be used for the inner liner of double-wall type IA pipe, or for temporary pipe. When used for other than temporary pipe, it should be polymer oated.

s designed; see the Federal Aviation Administration's publi- ation "Airport Drainage."

5.2.3 *Impact Loads*—Loads caused by the impact of noving traffic are important only at low heights of cover. Their effects have been included in the live load pressures in 5.2.2.

6. Design

6.1 The thrust in the pipe wall shall be checked by three criteria. Each considers the joint function of the steel pipe and the surrounding soil envelope.

6.1.1 *Required Wall Area:*

6.1.1.1 Determine the ring compression or thrust in the steel pipe wall as follows:

$$T = \frac{PS}{2}$$

6.1.1.2 Determine the required wall cross-sectional area. The safety factor (SF) on wall area is 2.

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

Select from Tables 1, 2, 3, 4, 5, 6, 7, 8, or 9 a wall thickness equal to or greater than the required wall area (A).

6.1.2 *Critical Buckling Stress*—Check corrugations with the required wall area for possible wall buckling. If the critical buckling stress f_c is less than the minimum yield stress f_y, recalculate the required wall area using f_c instead of f_y.

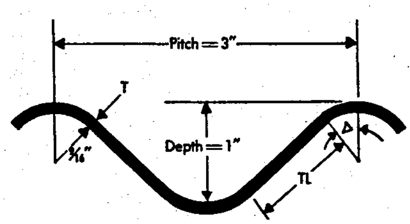
$$\text{If } s < \frac{r}{k}\sqrt{\frac{24E}{f_u}} \text{ then } f_c = f_u - \frac{f_u^2}{48E}\left(\frac{ks}{r}\right)^2$$

$$\text{If } s > \frac{r}{k}\sqrt{\frac{24E}{f_u}} \text{ then } f_c = \frac{12E}{\left(\frac{ks}{r}\right)^2}$$

6.1.3 *Required Seam Strength:*

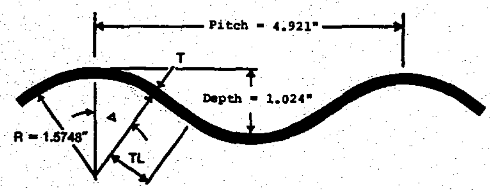
6.1.3.1 Since helical lockseam and welded-seam pipe have

TABLE 4 Sectional Properties of Corrugated Steel Sheets for Corrugation: 3 by 1 in. (Annular or Helical)



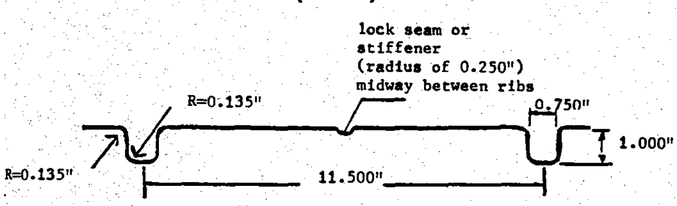
Specified Thick- ness, in.	Area of Section, A, in.²/ft	Tangent Length, TL, in.	Tangent Angle, Δ, °	Moment of Inertia, I × 10⁻³ in.⁴/in.	Radius of Gyration, r, in.	Ultimate Longitudinal Seam Strength of Riveted or Spot Welded Corrugated Steel Pipe in Pounds per Foot of Seam	
						3/8 Rivets	7/16 Rivets
						Double	Double
0.052	0.711	0.951	44.39	6.892	0.3410	...	...
0.064	0.890	0.938	44.60	8.658	0.3417	28 700	...
0.079	1.113	0.922	44.87	10.883	0.3427	35 700	...
0.109	1.560	0.889	45.42	15.458	0.3448	...	53 000
0.138	2.008	0.855	46.02	20.175	0.3472	...	63 700
0.168	2.458	0.819	46.65	25.083	0.3499	...	70 700

TABLE 5 Sectional Properties of Corrugated Steel Plates for Corrugation: 5 by 1 in. (Helical)



Specified Thickness, in.	Area of Section, A, in.^{2}/ft	Tangent Length, TL, in.	Tangent Angle, Δ, °	Moment of Inertia, $I \times 10^{-3}$ in.^{4}/in.	Radius of Gyration, r, in.
0.064	0.794	0.730	35.58	8.850	0.3657
0.079	0.992	0.708	35.80	11.092	0.3663
0.109	1.390	0.664	36.30	15.650	0.3677
0.138	1.788	0.616	36.81	20.317	0.3693
0.168	2.186	0.564	37.39	25.092	0.3711

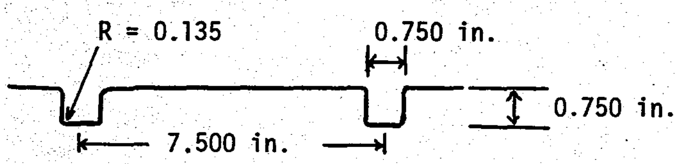
TABLE 6 Sectional Properties of Spiral Rib Pipe for Rib: ¾ in. wide by 1 in. deep with a Spacing of 11½ in. Center to Center (Helical)



Specified Thickness, in.	Effective Properties[A] Area of Section, A, in.^{2}/ft.	Moment of Inertia, $I \times 10^{-3}$ in.^{4}/in.	Radius of Gyration, r, in.
0.064	0.374	4.580	0.383
0.079	0.524	6.080	0.373
0.109	0.883	9.260	0.355

[A] Net effective properties at full yield stress.

TABLE 7 Sectional Properties for Spiral Rib for Rib ¾ in. wide by ¾ in. deep with a Spacing of 7½ in. Center to Center (Helical)



Specified Thickness, in.	Effective Properties[A] Area of Section, A, in.^{2}/ft.	Moment of Inertia, $I \times 10^{-3}$ in.^{4}/in.	Radius of Gyration, r, in.
0.064	0.511	3.590	0.290
0.079	0.715	4.740	0.282
0.109	1.192	7.150	0.268
0.138	1.729	9.640	0.259

[A] Net effective properties at full yield stress.

no longitudinal seams, this criterion is not valid for these types of pipe.

6.1.3.2 For pipe fabricated with longitudinal seams (riveted, spot-welded, or bolted) the seam strength shall be sufficient to develop the thrust in the pipe wall. The safety factor on seam strength (SS) is 3.

$$(SS) = T(SF)$$

6.1.3.3 Check ultimate seam strengths shown in Tables 3, 4, 8, or 9. If the required seam strength exceeds that shown for the steel thickness already chosen, use a heavier pipe whose seam strength exceeds the required seam strength.

6.2 *Handling and Installation Strength*—The pipe shall have enough rigidity to withstand the forces that are normally applied during shipment, handling, and installation. Both shop- and field-assembled pipe shall have strength adequate to withstand compaction of the sidefill without interior bracing to maintain pipe shape. Handling and installation rigidity is measured by the following flexibility requirement:

$$(FF) = \frac{s^2}{EI}$$

6.2.1 For curve and tangent corrugated pipe installed in a trench cut in undisturbed soil, the flexibility factor shall not exceed the following:

Depth of Corrugation, in.	(FF) in./lbf
¼	0.043
½	0.060
1	0.060
2	0.020
5½	0.020

6.2.2 For curve and tangent corrugated pipe installed in an embankment or fill section and for all multiple lines of pipe, the flexibility factor shall not exceed the following:

Depth of Corrugation, in.	(FF) in./lbf
¼	0.043
½	0.043
1	0.033
2 (round pipe)	0.020
2 (pipe-arch, arch, underpass)	0.030
5½ (round pipe)	0.020
5½ (pipe-arch, arch, underpass)	0.030

6.2.3 For ribbed pipes installed in a trench cut in undisturbed soil and provided with a soil envelope meeting the requirements of 11.2.3 to minimize compactive effort, the flexibility factor shall not exceed the following:

Depth of rib, in.	(FF) in./lbf
¾	$0.265\ I^{1/3}$
1	$0.220\ I^{1/3}$

6.2.4 For ribbed pipes installed in a trench cut in undisturbed soil and where the soil envelope does not meet the requirements of 11.2.3, the flexibility factor shall not exceed the following:

Depth of rib, in.	(FF) in./lbf
¾	$0.200\ I^{1/3}$
1	$0.163\ I^{1/3}$

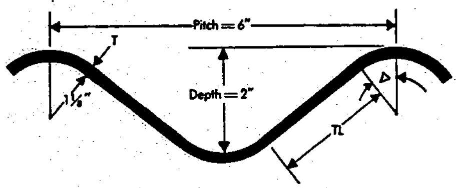
6.2.5 For ribbed pipes installed in an embankment or fill section, the flexibility factor shall not exceed the following:

Depth of rib, in.	(FF) in./lbf
¾	$0.173\ I^{1/3}$
1	$0.140\ I^{1/3}$

6.3 *Minimum Cover Requirements:*

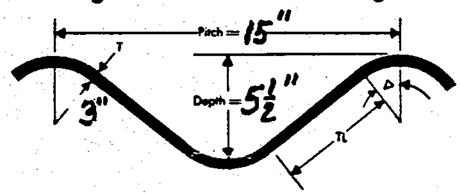
6.3.1 *Minimum Cover Design*—Where pipe is to be placed under roads, streets, or freeways, the minimum cover requirement shall be determined. Minimum cover (H_{min}) is

TABLE 8 Sectional Properties of Corrugated Steel Sheets for Corrugation: 6 by 2 in. (Annular)



Specified Thickness, in.	Area of Section, A, in.^{2}/ft.	Tangent Length, TL, in.	Tangent Angle, Δ, °	Moment of Inertia, $I \times 10^{-3}$ in.^{4}/in.	Radius of Gyration, r, in.	Ultimate Strength of Bolted Structural Plate Longitudinal Seams in Pounds per Foot of Seam		
						4 Bolts Per Foot	6 Bolts Per Foot	8 Bolts Per Foot
0.109	1.556	1.893	44.47	60.417	0.682	42 000	...	...
0.138	2.003	1.861	44.73	78.167	0.684	62 000	...	...
0.168	2.449	1.828	45.00	96.167	0.686	81 000	...	...
0.188	2.739	1.807	45.18	108.000	0.688	93 000	...	...
0.218	3.199	1.773	45.47	126.917	0.690	112 000	...	...
0.249	3.658	1.738	45.77	146.167	0.692	132 000	...	...
0.280	4.119	1.702	46.09	165.834	0.695	144 000	180 000	194 000

TABLE 9 Sectional Properties of Corrugated Steel Plates for Corrugation: 15 by 5½ in. (Annular)



Specified Thickness, in.	Area of Section, A, in.^{2}/ft	Tangent Length, TL, in.	Tangent Angle, Δ,°	Moment of Inertia, $I \times 10^{-3}$ in.^{4}/in.	Radius of Gyration, r, in.	Ultimate Strength of Bolted Structural Plate Longitudinal Seams in Pounds per Foot of Seam	Diameter, Bolt in.
						4.8 Bolts per Foot	
0.138	2.260	4.361	49.75	714.63	1.948	62 000	¾
0.168	2.762	4.323	49.89	874.62	1.949	81 000	¾
0.188	3.088	4.299	49.99	978.64	1.950	93 000	¾
0.218	3.604	4.259	50.13	1143.59	1.952	112 000	⅞
0.249	4.118	4.220	50.28	1308.42	1.953	132 000	⅞
0.280	4.633	4.179	50.43	1472.17	1.954	144 000	⅞

defined as the distance from the top of the pipe to the top of rigid pavement or to the top of subgrade for flexible pavement. Maximum axle loads in accordance with AASHTO "Standard Specification for Highway Bridges" are as follows:

Class of Loading	Maximum Axle Load, lbf
H20	32 000
HS 20	32 000
H15	24 000
HS 15	24 000

When

$$\sqrt{\frac{(AL)d}{EI}} > 0.23 \text{ or} < 0.45,$$

the minimum cover requirement is:

$$H_{min} = 0.55S \sqrt{\frac{(AL)d}{EI}}$$

When

$$\sqrt{\frac{(AL)d}{EI}} < 0.23 \text{ then } H_{min} = \frac{S}{8}$$

When

$$\sqrt{\frac{(AL)d}{EI}} > 0.45 \text{ then } H_{min} = \frac{S}{4}$$

In all cases, H_{min} is never less than 1 ft.

6.3.2 *Minimum Cover Under Railways*—Where pipe is to be placed under railways, the minimum cover (measured from the top of the pipe to the bottom of the crossties) shall not be less than ¼ of the span for factory-made pipe, or ⅕ of the span for field-bolted pipe. In all cases, the minimum cover is never less than 1 ft for round pipe, or 2 ft for arches and pipe-arches.

6.3.3 *Minimum Cover Under Aircraft Runways*—Where pipe is to be placed under rigid-pavement runways, the minimum cover is 1.5 ft from the top of the pipe to the bottom of the slab, regardless of the type of pipe or the loading. For pipe under flexible-pavement runways, the minimum cover must be determined for the specific pipe and loadings that are to be considered; see the Federal Aviation Administration's publication, "Airport Drainage."

6.3.4 *Construction Loads*—It is important to protect drainage structures during construction. Heavy construction equipment shall not be allowed close to or on buried pipe unless provisions are made to accommodate the loads imposed by such equipment. A minimum cover of 4 ft is suggested; however, this may be modified depending on field conditions and by experience.

6.4 *Deflection*—The application of a deflection design criteria is optional. Long-term field experience and test results have demonstrated that corrugated steel pipe, properly installed using suitable fill material, will experience no significant deflection. Some designers, however, continue to apply a deflection limit.

7. Smooth-Lined Pipe

7.1 Corrugated steel pipe composed of a smooth interior steel liner and a corrugated steel exterior shell that are attached integrally at the continuous helical lockseam, shall be designed in accordance with this practice on the same basis as a standard corrugated steel pipe having the same corrugation as the shell and a weight per foot equal to the sum of the weights of liner and shell. The corrugated shell shall be limited to corrugations having a maximum pitch of 3 in. and a thickness of not less than 60 % of the total thickness of the equivalent standard pipe. The distance between parallel helical seams, when measured along the longitudinal axis of the pipe, shall be no greater than 30 in.

8. Smooth Pipe with Rectangular Ribs

8.1 Pipe composed of a single thickness of smooth sheet with helical rectangular ribs projecting outwardly shall be designed on the same basis as a standard corrugated steel pipe.

9. Pipe-Arch Design

9.1 Pipe-arch and underpass design shall be similar to round pipe using twice the top radius as the span (S).

10. Materials

10.1 Acceptable pipe materials, methods of manufacture, and quality of finished pipe are given in Specifications A 760/A 760M, A 761/A 761M, and A 762/A 762M.

11. Soil Design

11.1 The performance of a flexible corrugated steel pipe is dependent on soil-structure interaction and soil stiffness.

11.2 *Soil Parameters to be Considered:*

11.2.1 The type and anticipated behavior of the foundation soil under the design load must be considered.

11.2.2 The type, compacted density, and strength properties of the soil envelope immediately adjacent to the pipe shall be established. Good side-fill material is considered to be a granular material with little or no plasticity and free of organic material. Soils meeting the requirements of Groups GW, GP, GM, GC, SW, and SP as described in Classification D 2487 are generally acceptable, when compacted to 90 % of maximum density as determined by Test Method D 698. Test Methods D 1556, D 2167, D 2922, and D 2937 may be used to determine the in-place density of the soil. Soil types SM and SC are acceptable but may require closer control to obtain the specified density; the recommendation of a qualified geotechnical or soils engineer is advisable, particularly on large structures.

11.2.3 Ribbed pipes covered by 6.2.3 shall have soil envelopes of clean, nonplastic materials meeting the requirements of Groups GP and SP in accordance with Classification D 2487, or well-graded granular materials meeting the requirements of Groups GW, SW, GM, SM, GC, or SC in accordance with Classification D 2487, with a maximim plasticity index (PI) of 10. All envelope materials shall be compacted to a minimum 90 % standard density in accordance with Test Method D 698. Maximim loose lift thickness shall be 8 in.

NOTE 1—Soil cement or cement slurries may be used in lieu of the select granular materials.

11.2.4 The size of the structural soil envelope shall be 2 ft minimum each side for trench installations and one diameter minimum each side for embankment installations. This structural soil envelope shall extend at least 1 ft above the top of the pipe.

11.3 *Pipe-Arch Soil Bearing Design*—The pipe-arch shape causes the soil pressure at the corner to be much higher than the soil pressure across the top of the pipe-arch. The bearing capacity of the soil in the region of the pipe-arch corner often limits the maximum fill over a pipe-arch, and may also increase the minimum cover requirement. Accordingly, bedding and backfill material in the region of the pipe-arch corners shall be selected and placed such that the allowable soil bearing pressure is no less than the anticipated corner pressure calculated from the following equation:

$$P_c = (C_1\text{LL} + \text{EL})r_t/r_c$$

LL shall be calculated as described in Section 5 for the design depths of fill (maximum and minimum), except that the following modifications shall be made to remove impact effects: (*1*) for H20 live loads (see 5.2.2.1), use 1600 psf instead of 1800 psf; and (*2*) for E80 live loads, divide the live load pressures listed in 5.2.2.2 by 1.5. The factor C_1 may be conservatively taken as 1.0 or may be calculated as follows:

11.3.1 For H20 highway live loads:

$$C_1 = L_1/L_2 \text{ when } L_2 \leq 72 \text{ in.}$$
$$C_1 = 2L_1/L_3 \text{ when } L_2 > 72 \text{ in.}$$

where:

$$L_1 = 40 + (h - 12)1.75$$
$$L_2 = L_1 + 1.37s$$
$$L_3 = L_2 + 72$$

11.3.2 For E80 railway live loads:

$$C_1 = L_1/L_2$$

where:

$$L_1 = 96 + 1.75h$$
$$L_2 = \text{L}_1 + 1.37s$$

12. Minimum Spacing

12.1 When multiple lines of pipes or pipe-arches greater than 48 in. in diameter or span are used, they shall be spaced so that the sides of the pipe shall be no closer than one half a diameter or 3 ft, whichever is less, so that sufficient space for adequate compaction of the fill material is available. For diameters up to 48 in., the minimum distance between the sides of the pipes shall be no less than 2 ft.

12.2 Materials such as cement slurry, soil cement, concrete, and various foamed mixes, that set-up without mechanical compaction, may be placed between structures with as little as 6 in. of clearance.

13. End Treatment

13.1 Protection of end slopes shall require special consideration where backwater conditions may occur or where erosion and uplift could be a problem.

13.2 End walls designed on a skewed alignment requirement special design.

14. Abrasive or Corrosive Conditions

14.1 Extra steel thickness or coatings may be required for resistance to corrosion. Extra steel thickness or paving may be required for resistance to abrasion.

15. Construction and Installation

15.1 The construction and installation of corrugated steel pipe and pipe-arches and steel structural plate pipe, pipe-arches, arches, and underpasses shall conform to Practices A 798 or A 807.

16. Structural Plate Arches

16.1 The design of structural plate arches shall be based on a minimum ratio of rise to span of 0.3; otherwise, the structural design is the same as for structural plate pipe.

16.2 *Footing Design:*

16.2.1 The load transmitted to the footing is considered to act tangential to the steel plate at its point of connection to the footing. The load is equal to the thrust in the arch plate.

16.2.2 The footing shall be designed to provide settlement of an acceptable magnitude uniformly along the longitudinal axis. Providing for the arch to settle will protect it from possible overload forces induced by the settling adjacent embankment fill.

16.2.3 Where poor materials are encountered that might settle excessively, some of this poor material shall be removed and replaced with acceptable material.

16.2.4 It is undesirable to make the arch relatively unyielding or fixed compared to the adjacent sidefill. The use of massive footings or piles to prevent settlement of the arch is generally not required.

16.2.5 Invert slabs or other appropriate methods should be provided when scour is anticipated.

17. Keywords

17.1 abrasive conditions; buried applications; composite structure; corrosive conditions; corrugated steel pipe; dead loads; embankment installation; handling and installation; live loads; minimum cover; sectional properties; sewers; steel pipe structural design; trench installation

Designation: A 798/A 798M – 95

Standard Practice for Installing Factory-Made Corrugated Steel Pipe for Sewers and Other Applications[1]

This standard is issued under the fixed designation A 798/A 798M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This practice covers procedures, soils, and soil placement for the proper installation of corrugated steel pipe and pipe-arches produced to Specification A 760/A 760M or A 762/A 762M, for proper installation of corrugated steel in either trench or embankment conditions. The pipes described in this practice are manufactured in a factory and furnished to the job in lengths ordinarily from 10 to 30 ft [3 to 9 m] with 20-ft (6-m) common practice for field joining. This practice applies to structures designed in accordance with Practice A 796/A 796M.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.3 The values stated in either inch-pound units or SI units shall be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system must be used independently of the other, without combining values in any way. SI units are shown in brackets in the text for clarity, but they are the applicable values when the installation is to be performed using SI units.

2. Referenced Documents

2.1 *ASTM Standards:*

A 760/A 760M Specification for Corrugated Steel Pipe, Metallic-Coated for Sewers and Drains[2]

A 762/A 762M Specification for Corrugated Steel Pipe, Polymer Precoated for Sewers and Drains[2]

A 796/A 796M Practice for Structural Design of Corrugated Steel Pipe, Pipe-Arches, and Arches for Storm and Sanitary Sewers and Other Buried Applications[2]

A 902 Terminology Relating to Metallic Coated Steel Products[2]

D 698 Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3))[3]

D 1556 Test Method for Density of Soil in Place by the Sand-Cone Method[3]

D 2167 Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method[3]

D 2487 Classification of Soils for Engineering Purposes (Unified Soil Classification System)[3]

D 2922 Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)[3]

D 2937 Test Method for Density of Soil in Place by the Drive-Cylinder Method[3]

3. Terminology

3.1 *Definitions*—For definitions of general terms used in this practice, see Terminology A 902.

3.2 *Descriptions of Terms Specific to This Standard:*

3.2.1 *bedding*—the earth or other material on which a pipe is supported.

3.2.2 *haunch*—the portion of the pipe cross section between the maximum horizontal dimension and the top of the bedding.

3.2.3 *invert*—the lowest point on the pipe cross section; also, the bottom portion of a pipe.

3.2.4 *pipe*—a conduit having full circular shape; also, in a general context, all structure shapes covered by this practice.

3.2.5 *pipe-arch*—an arch shape with an approximate semicircular crown, small-radius corners, and large-radius invert.

4. Significant Factors

4.1 Corrugated steel pipe functions structurally as a flexible ring which is supported by and interacts with the compacted surrounding soil. The soil constructed around the pipe is thus an integral part of the structural "system." It is therefore important to ensure that the soil structure or backfill is made up of acceptable material and well-constructed. Field verification of soil structure acceptability using Test Methods D 1556, D 2167, D 2922, or D 2937, as applicable, and comparing the results with Test Methods D 698 in accordance with the specifications for each project is the most reliable basis for installation of an acceptable structure. The required density and method of measurement are not specified by this practice but must be established in the specifications for each project.

5. Trench Excavation

5.1 To obtain anticipated structural performance of corrugated steel pipe it is not necessary to control trench width

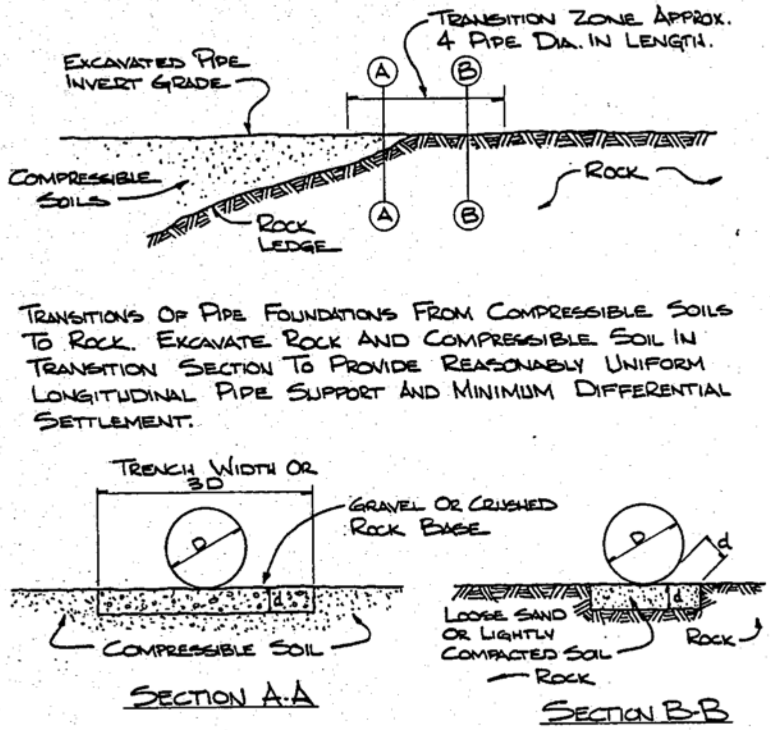
---

[1] This practice is under the jurisdiction of ASTM Committee A-5 on Metallic Coated Iron and Steel Products and is the direct responsibility of Subcommittee A05.17 on Corrugated Steel Pipe Specifications.

Current edition approved Oct. 10, 1995. Published December 1995. Originally published as A 798 – 82. Last previous edition A 798 – 94.

[2] *Annual Book of ASTM Standards*, Vol 01.06.

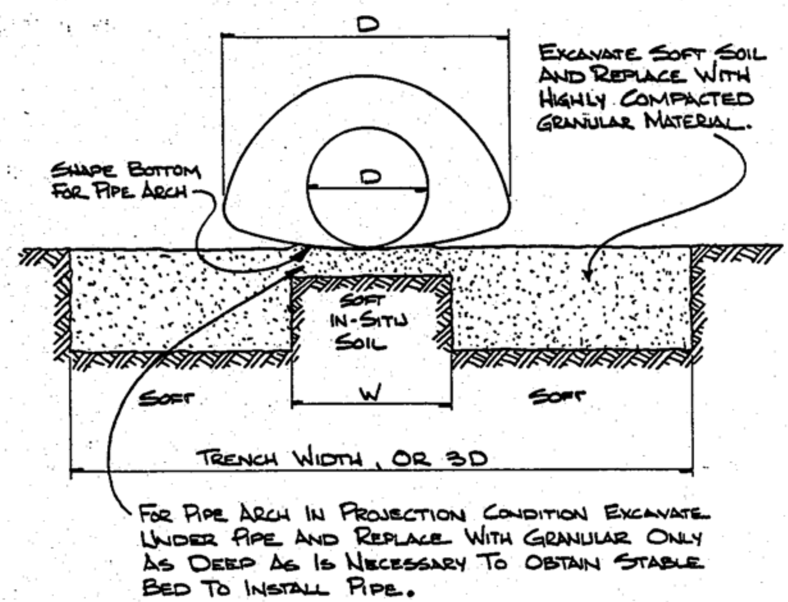
[3] *Annual Book of ASTM Standards*, Vol 04.08.



d = ½ in./ft [40 mm/m] of fill over pipe, with a 24-in. [600-mm] maximum.

NOTE—Section B-B is applicable to all continuous rock foundations.

FIG. 1 Foundation Transition Zones and Rock Foundations



W = *D* for round pipe
W = width of flat bottom arc of pipe-arch

FIG. 2 Soft Foundation Treatment for Larger Pipe and Pipe-Arch

beyond the minimum required for proper installation of pipe and backfill. However, the soil on each side beyond the excavated trench must be of the same or higher density as that of the compacted trench material. When a construction situation calls for a relatively wide trench, it may be made as wide as required, for its full depth if so desired. However, trench excavation must be in compliance with any local, state, and federal codes and safety regulations.

6. Foundation

6.1 The supporting soil beneath the pipe must provide a reasonably uniform resistance to the imposed load, both longitudinally and laterally. Sharp variations in the foundation must be avoided. When rock is encountered, it must be

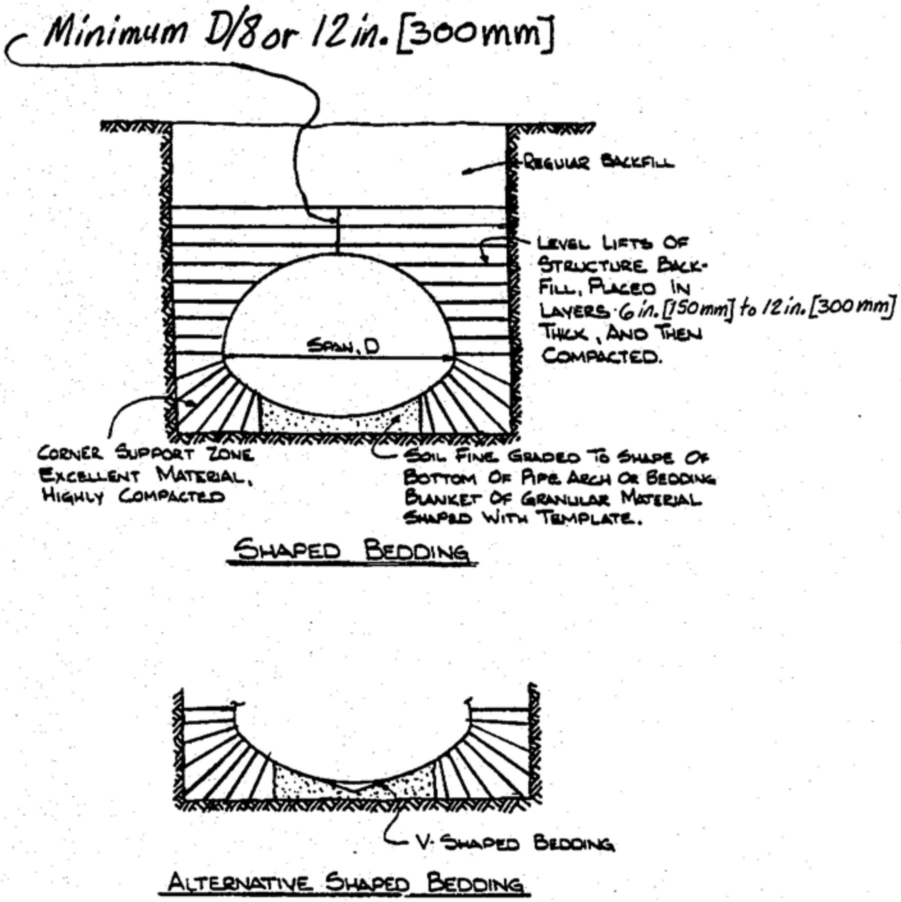


FIG. 3 Pipe Arch Bedding and Corner Zone Treatment—Ordinary Conditions

excavated and replaced with soil. If the pipe runs along a continuous rock foundation, it is necessary to provide a suitable soil bedding under the pipe. See Fig. 1.

6.2 Lateral changes in foundation should never be such that the pipe is firmly supported while the backfill alongside is not. When soft material is encountered and must be removed in order to maintain the pipe on grade during construction, it must be removed for at least three pipe widths. See Fig. 2. A smaller width of removal can sometimes be used if established by the engineer.

6.3 Performance of buried pipe is enhanced by allowing the pipe to settle slightly under load compared to the columns of soil alongside. Thus, for larger pipes it can be beneficial to purposely create a foundation under the pipe itself which will yield under load more than will the foundation under the columns of soil to each side. It can usually be obtained by placing beneath the structure a suitable-thickness layer of compressible soil, less densely compacted than the soil alongside. This creates "favorable" relative movement between pipe and the soil on each side. It is of particular importance on pipe arches.

6.4 *Pipe-Arches*—All pipe-arch structures under significant backfill load (depth of backfill > 10 ft [3 m]) must have excellent soil support at the corners. Conversely, little support is required under the large-radius bottom. A foundation for a pipe arch under significant load must provide for this as shown in Fig. 3.

6.5 The engineer is encouraged to develop details specific to the site based on the general principles for foundation conditions given in 6.1 through 6.4.

7. Bedding

7.1 Corrugated steel pipe may be placed directly on the fine-graded foundation for the pipe line. Material in contact with the pipe shall not contain rock retained on a 3-in. [76-mm] ring, frozen lumps, chunks of highly plastic clay, organic matter, corrosive material, or other deleterious material. It is not required to shape the bedding to the pipe geometry. However, for pipe-arches, it is recommended to either shape the bedding to the relatively flat bottom arc or fine-grade the foundation to a slightly v-shape. This avoids the problem of trying to backfill back in under the difficult area beneath the invert of pipe arches.

8. Pipe Installation

8.1 All pipe shall be unloaded and handled with reasonable care. Pipe shall not be rolled or dragged over gravel or rock and shall be prevented from striking rock or other hard objects during placement on bedding. Pipe with protective coatings shall be handled with special care to avoid damage. Paved inverts shall be placed and centered in the invert. Riveted pipe should be installed so that outside circumferential joints point upgrade.

8.2 *Field Joints:*

8.2.1 Transverse field joints shall be of such design that the successive connection of pipe sections will form a

TABLE 1 Categories of Pipe Joints

Joint Properties	Soil Condition			
	Nonerodible Joint Type		Erodible Joint Type	
	Standard	Special	Standard	Special
Shear strength, %	2	5	2	5
Moment strength,[A] %	5	15	5	15
Tensile strength, min, lbf (kN):				
0–42-in. [1050 mm] diameter	0	5 000 [22]	·	5 000 [22]
48–84-in. [1200–2100 mm] diameter		10 000 [45]		10 000 [45]
Joint overlap, min, in. (mm)[B]	10½ [265]	NA	10½ [265]	NA
Soiltightness[C]	NA	NA	0.3 or 0.2	0.3 or 0.2

[A] See 8.2.4.2.
[B] Alternative requirement. See 8.2.4.4.
[C] Minimum ratio of D_{85} soil size to size of opening 0.3 for medium to fine sand and 0.2 for uniform sand.

continuous line free of appreciable irregularities in the flow line. Each successive length of pipe in a field joint should be adjusted longitudinally or circumferentially when necessary so that coupling bands with projections, helical corrugations, or annular corrugations will properly engage the corrugations in both lengths of pipe. In addition, the joints shall meet the general performance requirements described herein. Suitable transverse field joints, which satisfy the requirements for one or more of the subsequently defined joint performance categories, can be obtained with the following types of connecting bands furnished with the suitable band-end fastening devices.

8.2.1.1 Corrugated bands.

8.2.1.2 Bands with projections.

8.2.1.3 Flat bands.

8.2.1.4 Bands of special design that engage factory reformed ends of corrugated pipe.

8.2.1.5 Other equally effective types of field joints may be used with the approval of the engineer.

8.2.2 *Joint Types*—Applications may require either standard or special joints. Standard joints are for pipe not subject to large soil movements or disjointing forces. These joints are satisfactory for ordinary installations, where simple slip-type joints are typically used. Special joints are for more adverse requirements such as the need to withstand soil movements or resist disjointing forces. Special designs must be considered for unusual conditions as in poor foundation conditions.

8.2.3 *Soil Conditions:*

8.2.3.1 The requirements of the joints are dependent upon the soil conditions at the construction site. Pipe backfill that is not subject to piping action is classified as "nonerodible." Such backfill typically includes granular soil (with grain sizes equivalent to coarse sand, small gravel, or larger) and cohesive clays.

8.2.3.2 Backfill that is subject to piping action, and would tend either to infiltrate the pipe or to be easily washed by exfiltration of water from the pipe, is classified as "erodible." Such backfill typically includes fine sands and silts.

8.2.3.3 Special joints are required when poor soil conditions are encountered such as when the backfill or foundation material is characterized by large soft spots or voids. If construction in such soil is unavoidable, this condition can only be tolerated for relatively low fill heights, since the pipe must span the soft spots and support imposed loads. Backfills of organic silt, which are typically semifluid during installation, are included in this classification.

8.2.4 *Joint Properties*—The requirements for joint properties are divided into the six categories. The properties are defined in 8.2.4.1 through 8.2.4.6, and requirements (except for watertightness) are shown in Table 1. The values for various types of pipe can be determined by a rational analysis or a suitable test.

8.2.4.1 *Shear Strength*—The shear strength required of the joint is expressed as a percent of the calculated shear strength of the pipe on a transverse cross section remote from the joint.

8.2.4.2 *Moment Strength*—The moment strength required of the joint is expressed as a percent of the calculated moment capacity of the pipe on a transverse cross section remote from the joint.

8.2.4.3 *Tensile Strength*—Tensile strength is required in a joint when the possibility exists that a longitudinal load could develop that would tend to separate adjacent pipe sections.

8.2.4.4 *Joint Overlap*—Standard joints that do not meet the moment strength alternatively shall have a minimum sleeve width overlapping the abutting pipes. The minimum total sleeve width shall be as shown in Table 1. Any joint meeting the requirements for a special joint may be used instead of a standard joint.

8.2.4.5 *Soiltightness*—Soiltightness refers to openings in the joint through which soil may infiltrate. Soiltightness is influenced by the size of the opening (maximum dimension

TABLE 2 Structural Backfill Width Requirements[A,B]

Adjacent Material	Required Structural Backfill Width
Normal highway embankment compacted to minimum of 90 % Test Method D 698 density or equivalent trench wall.	As needed to establish pipe bedding and to fill and compact the backfill in the haunch area and beside the pipe. Where backfill materials that do not require compaction are used, such as cement slurry or controlled low-strength material (CLSM), a minimum of 3 in. [75 mm] on each side of the pipe is required.
Embankment or trench wall of lesser quality.	Increase backfill width as necessary to reduce horizontal pressure from pipe to a level compatible with bearing capacity of adjacent materials.

[A] For pipe-arches and other multiple-radius structures, as well as for all structures carrying off-road construction equipment, the structural backfill width including any necessary foundation improvement materials, must be sufficient to reduce the horizontal pressure from the structure so that it does not exceed the bearing capacity of the adjacent material.

[B] In embankment construction, the structural backfill width must be adequate to resist forces caused by the embankment construction equipment. Generally, the width of each side of the pipe should be no less than 1 diameter or 2 ft [600 mm], whichever is less.

normal to the direction that the soil may infiltrate) and the length of the channel (length of the path along which the soil may infiltrate). No opening may exceed 1 in. [25 mm]. In addition, for all categories, if the size of the opening exceeds 1/8 in. [3 mm], the length of the channel must be at least four times the size of the opening. Furthermore, for nonerodible or erodible soils, the ratio of D_{85} soil size to size of opening must be greater than 0.3 for medium to fine sand or 0.2 for uniform sand; these ratios need not be met for cohesive backfills where the plasticity index exceeds 12. (D_{85} is the soil diameter at which 85 % of the soil weight is finer.) As a general guideline, a backfill material containing a high percentage of fine-grained soils requires investigation for the specific type of joint to be used to guard against soil infiltration. Alternatively, if a joint demonstrates its ability to pass a 2-psi [14-kPa] hydrostatic test without leakage, it will be considered soil tight.

8.2.4.6 *Watertightness*—Watertightness may be specified for joints of any category where needed to satisfy other criteria. The leakage rate shall be measured with the pipe in place or at an approved test facility.

9. Structure Backfill Material

9.1 Structural backfill is that material which surrounds the pipe, extending laterally to the walls of the trench, or to the fill material for embankment construction, and extending vertically from the invert to an elevation of 1 ft [300 mm], or 1/8 the span, whichever is greater, over the pipe. The necessary width of structural backfill depends on the quality of the trench wall or embankment material, the type of material and compaction equipment used for the structural backfill, and in embankment construction, the type of construction equipment used to compact the embankment fill. The width of structural backfill shall meet the requirements given in Table 2.

9.2 Structure backfill material shall be fine, readily compacted soil or granular fill material. Structure backfill material may be excavated native material, when suitable, or select material. Select materials such as bank run gravels or other processed granular materials less than 3 in. [75-mm] maximum with excellent structural characteristics are preferred. Desired end results can be obtained with this type of material with a minimum of effort over a wide range of moisture content, lift depth, and compaction equipment characteristics. Excavated native soils used as structure backfill shall not contain stones retained on a 3-in. [75-mm] ring, frozen lumps, highly plastic clay, organic material, corrosive material, or other deleterious foreign materials. Soils meeting the requirements of Groups GW, GP, GM, GC, SW, and SP as described in Test Method D 2487 are generally acceptable, when compacted to the specified percent of maximum density as determined by Test Methods D 698. Test Methods D 1556, D 2167, D 2922, and D 2937 may be used to determine the in-place density of the soil. Soil Types SM and SC are acceptable, but may require closer control to obtain the specified density. Soil Types ML and CL are not preferred materials, while Soil Types OL, MH, CH, OH, and PT are not acceptable.

9.3 Special materials other than soil may be used as described in 10.1.

10. Structure Backfill Placement

10.1 Structure backfill shall be placed in layers from 6 to 12 in. [150 to 300 mm] in depth depending on the type of material and compaction equipment or method. Each layer or "lift" shall be compacted before adding the next lift. On flat bedding, care must be taken to place material under the pipe haunches and compact it firmly. Backfill on each side of the pipe shall be kept in balance. Generally, no more than one lift difference should be permitted. Construction equipment shall not be used over or alongside the pipe without sufficient compacted soil between it and the pipe to prevent distortion, damage, or overstressing. Mechanical soil compaction of layers is preferred. However, when acceptable end results can be achieved with water consolidation, it may be used. When water methods are used, care must be taken to prevent flotation. It shall be used only on free-draining structure backfill material. If cohesive soils are used as structure backfill, good compaction can only be obtained at proper moisture content. Shallower lifts are generally required for acceptable end results with cohesive soils than with granular or mixed soils. In general, much closer inspection and testing must be exercised to ensure good results with cohesive structure backfill material. Water compaction is not acceptable with cohesive material. Unusual field conditions may make relatively costly special backfill material practical. Materials that set up without compaction, such as cement slurry, controlled low-strength material (CLSM), and various foamed mixtures, provide excellent structure backfill provided they are designed to yield the compressive strength required. As with water compaction, care must be taken to avoid flotation.

10.2 The compaction of structure backfill shall provide a soil structure around the pipe to uniformly apply overburden pressures on the crown of the pipe and provide uniform bearing for the pipe side walls and lower haunches. The required degree of compaction will vary with the job. The structure backfill is an integral part of the design process. Therefore, required end results regarding in-place density of structure backfill shall be in accordance with job specifications. Most structural design tables for corrugated steel pipe establish maximum overfill depths based on a specified field density of 90 % in accordance with Test Methods D 698 with good structure backfill material. However, the majority of sewer pipe installations do not require deep overfills. For relatively shallow buried pipes not subject to live load, acceptable structure backfill material and its degree of compaction may be determined by the character of the adjacent ground. A "balanced design" making the conduit homogeneous with the ground on either side is often desirable. For this reason, it is not practical to establish arbitrary minimums for soil characteristics of structure backfill for all installations. In general, when the soil adjacent to the structure backfill is relatively soft, structure backfill must be at least equal in density to the adjacent soil. "Adjacent soil" applies to either constructed embankment in projection conditions or to in-situ soil in trench walls.

10.3 *Pipe-Arches*—Special attention must be given to the material used and compaction obtained around the corners of pipe arches. Vertical load over the pipe is transmitted into the soil principally at the corners. Therefore, just as with the foundation, structure backfill against the corner must be "good" for all pipe-arches and must be "excellent" for pipe-arches under significant fills. In the case of higher fills or deep trenches, special designs may be required for corner backfill zones.

10.4 Generally, construction experience and a site appraisal will establish the most economical combination of material, method, and equipment to yield acceptable end results. Test Methods D 698 is the preferred means of determining maximum (standard) density and optimum moisture content. A construction procedure must then be established that will result in the specified percent of maximum density. Once that is established, primary inspection effort should be directed at ensuring that the established procedure is followed. Such a procedure may involve material, depth of lift, moisture content, and compactive effort. Only occasional checks may then be required, as long as the material and procedures are unchanged. In situ density may be determined by Test Methods D 1556, D 2167, D 2922, or D 2937 as applicable, for field verification. Testing should be conducted on both sides of the structure. Any construction methods and equipment that achieve required end results in completed structure backfill without damage to or distortion of the pipe shall be acceptable.

10.5 *Shape Control*—Excessive compaction, unbalanced loadings, loads from construction equipment, as well as inadequate compaction or poor backfill materials, can cause excessive pipe distortion. For larger pipe, the construction contractor may set up a shape monitoring system, prior to placement of structural backfill, to aid in establishing and maintaining proper installation procedures. Direct measurement of span and rise, offset measurements from plumb bobs hanging over reference points, and similar types of measurements are effective means for monitoring shape change during backfill placement and compaction. In general, it is desirable for the crown of the pipe to rise slightly, in a balanced concentric manner, during placement and compaction of soil beside the pipe. Under the load of the completed fill and the service load, vertical deflections will be a small percentage of the pipe rise dimension if backfill compaction is adequate.

11. Regular Backfill

11.1 Regular backfill in trench installation is that material replaced in the trench above the structure backfill. In projection conditions, it is also the embankment fill adjacent to the structure backfill.

11.2 Regular backfill shall consist of native materials and shall be placed and compacted as required by job specifications. Large rocks or boulders shall not be placed within 4 ft [1.2 m] of the pipe. Large boulders should not be permitted in regular backfill in trenches that are under surface structures, including pavements. Construction equipment shall not be used over or alongside the pipe without sufficient compacted soil in between it and the pipe to prevent distortion, damage, or overstressing.

12. Multiple Structures

12.1 When two or more structures are installed in adjacent lines, the minimum spacing requirements given in Practice A 796/A 796M must be provided.

13. Keywords

13.1 corrugated steel pipe; installation; sewers; steel pipe

Designation: A 807/A 807M – 96

Standard Practice for Installing Corrugated Steel Structural Plate Pipe for Sewers and Other Applications[1]

This standard is issued under the fixed designation A 807/A 807M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

. Scope

1.1 This practice covers procedures, soils, and soil place-
ıent for the proper installation of corrugated steel structural
late pipe, pipe arches, arches, and underpasses produced to
pecification A 761/A 761M, in either trench or embank-
ıent conditions. Structural plate structures as described
erein are those structures factory fabricated in plate form
ıd bolted together on site to provide the required shape,
ze, and length of structure. This practice applies to struc-
ıres designed in accordance with Practice A 796/A 796M.

1.2 *This standard does not purport to address all of the fety concerns, if any, associated with its use. It is the sponsibility of the user of this standard to establish appro- iate safety and health practices and determine the applica- lity of regulatory limitations prior to use.*

1.3 The values stated in either inch-pound units or SI ıits shall be regarded separately as standard. The values ıted in each system may not be exact equivalents; there- re, each system must be used independently of the other, ithout combining values in any way. SI units are shown in ackets in the text for clarity, but they are the applicable lues when the installation is to be performed using SI ıits.

Referenced Documents

2.1 *ASTM Standards:*

A 761/A 761M Specification for Corrugated Steel Structural Plates, Zinc Coated, for Field-Bolted Pipe, Pipe Arches, and Arches[2]

A 796/A 796M Practice for the Structural Design of Corrugated Steel Pipe, Pipe-Arches, and Arches for Storm and Sanitary Sewers and Other Buried Applications[2]

A 902 Terminology Relating to Metallic Coated Steel Products[2]

D 698 Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3))[3]

D 1556 Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method[3]

D 1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (56 000 ft-lbf/ft^3 (2700 kN-m/m^3))[3]

D 2167 Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method[3]

D 2487 Classification of Soils for Engineering Purposes (Unified Soil Classification System)[3]

D 2922 Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)[3]

D 2937 Test Method for Density of Soil in Place by the Drive-Cylinder Method[3]

3. Terminology

3.1 *Definitions*—For definitions of general terms used in this practice, refer to Terminology A 902.

3.2 *Descriptions of Terms Specific to This Standard:*

3.2.1 *arch*—a part circle shape spanning an open invert between the footings on which it rests.

3.2.2 *bedding*—the earth or other material on which a pipe is supported.

3.2.3 *haunch*—the portion of the pipe cross section between the maximum horizontal dimension and the top of the bedding.

3.2.4 *invert*—the lowest point on the pipe cross section; also, the bottom portion of a pipe.

3.2.5 *pipe*—a conduit having full circular shape; also, in a general context, all structure shapes covered by this specification.

3.2.6 *pipe-arch*—an arch shape with an approximate semicircular crown, small-radius corners, and large-radius invert.

3.2.7 *underpass*—a high arch shape with an approximate semicircular crown, large-radius sides, small-radius corners between sides and invert, and large-radius invert.

4. Significance and Use

4.1 Structural plate structures function structurally as a flexible ring that is supported by and interacts with the compacted surrounding soil. The soil placed around the structure is thus an integral part of the structural system. It is therefore important to ensure that the soil structure is made up of acceptable material and is well constructed. Field verification of soil structure acceptability using Test Methods D 1556, D 2167, D 2922, or D 2937, as applicable, and comparing the results with either Test Methods D 698 or D 1557, in accordance with the specifications for each project, is the most reliable basis for installation of an acceptable structure. The required density and method of measurement are not specified by this practice, but must be established in the specifications for each project. Figure 1 shows a typical trench installation, and Fig. 2 shows a typical embankment (projection) installation.

---

[1] This practice is under the jurisdiction of ASTM Committee A-5 on Metallic ıted Iron and Steel Products and is the direct responsibility of Subcommittee ı.17 on Corrugated Steel Pipe Specifications.

Current edition approved April 10, 1996. Published September 1996. Originally lished as A 807 – 82. Last previous edition A 807 – 95.

[2] *Annual Book of ASTM Standards*, Vol 01.06.

[3] *Annual Book of ASTM Standards*, Vol 04.08.

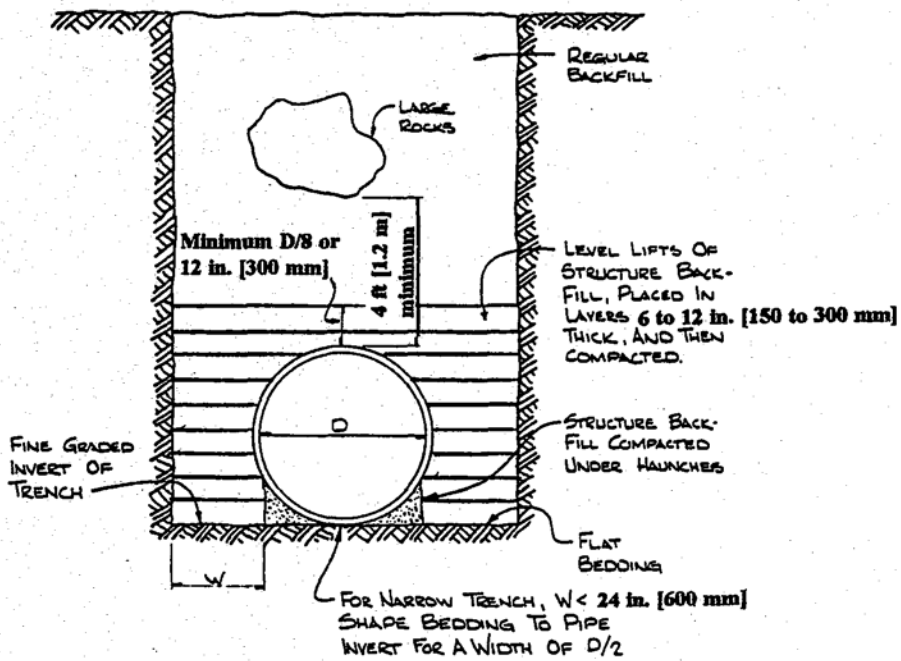


FIG. 1 Ordinary Trench Condition

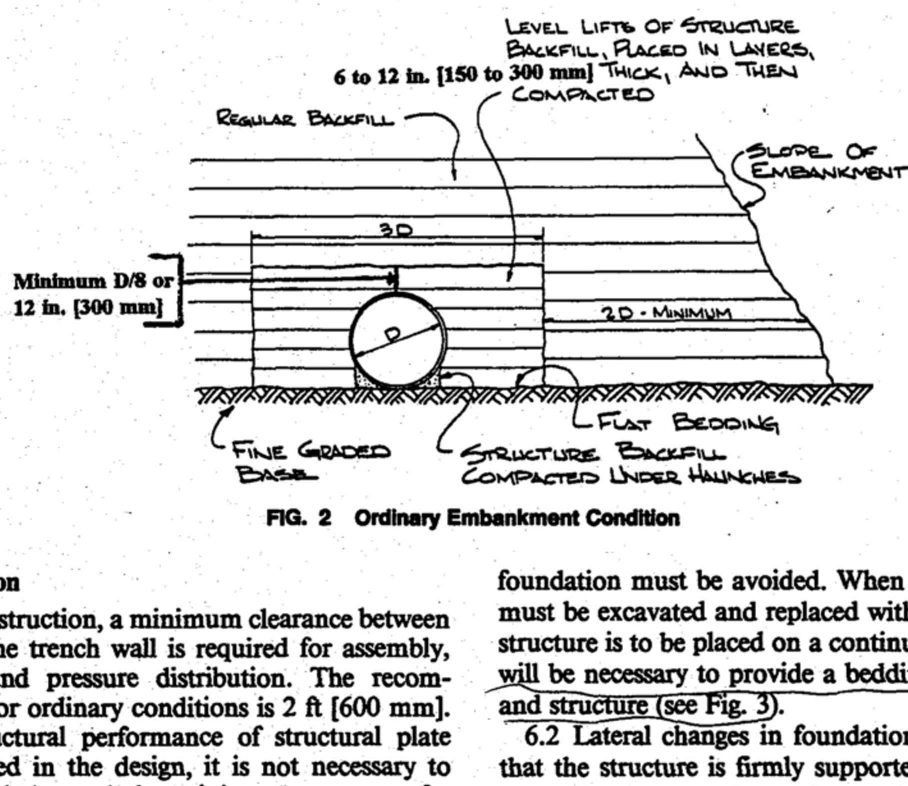


FIG. 2 Ordinary Embankment Condition

5. Trench Excavation

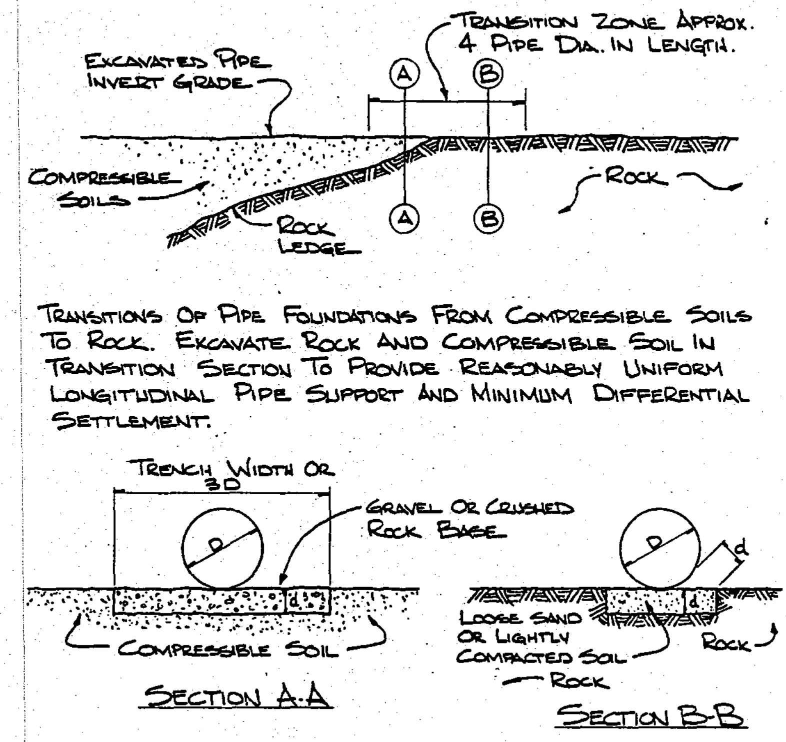
5.1 In trench construction, a minimum clearance between the structure and the trench wall is required for assembly, soil compaction, and pressure distribution. The recommended clearance for ordinary conditions is 2 ft [600 mm]. To obtain the structural performance of structural plate structures anticipated in the design, it is not necessary to control trench width beyond the minimum necessary for proper assembly of the structure and placement of the backfill. However, the soil on each side beyond the excavated trench must be of the same or higher density as that of the compacted trench material.

6. Foundation

6.1 The supporting soil beneath the structure must provide a reasonably uniform resistance to the imposed load, both longitudinally and laterally. Sharp variations in the foundation must be avoided. When rock is encountered, it must be excavated and replaced with soil (see Fig. 3). If the structure is to be placed on a continuous rock foundation, it will be necessary to provide a bedding of soil between rock and structure (see Fig. 3).

6.2 Lateral changes in foundation should never be such that the structure is firmly supported while the backfill on either side is not. When soft material is encountered in the structure excavation and must be removed to maintain grade on the structure, then it must be removed, usually for a minimum of three structure widths (see Fig. 4). A smaller width of removal can sometimes be used if established by the engineer.

6.3 Performance of buried structures is enhanced by allowing the structure to settle slightly relative to the columns of earth alongside. Therefore, when significant settlement of the overall foundation is expected, it is beneficial to



d = ½ in./ft [40 mm/m] of fill over pipe, with a 24-in. [600-mm] maximum.

NOTE—Section *B-B* is applicable to all continuous rock foundations.

FIG. 3 Foundation Transition Zones and Rock Foundations

provide a yielding foundation under structural plate structures. A yielding foundation is one that allows the structure to settle vertically by a greater amount than the vertical settlement of the columns of earth alongside. It can usually be obtained by placing a layer of compressible soil of suitable thickness beneath the structure that is less densely compacted than the soil alongside. This is particularly important on structures with relatively large-radius invert plates.

6.4 For all structures with relatively small-radius plates adjacent to large-radius invert plates (such as pipe-arches or underpass structures), excellent soil support must be provided under the small-radius plates. A yielding foundation must be provided beneath the invert plates for such structures when soft foundation conditions are encountered.

6.5 The engineer is encouraged to develop details specific to the site based on the general principles for foundation conditions given in 6.1 through 6.4.

7. Bedding

7.1 In most cases, structural plate structures may be assembled directly on in-situ material fine-graded to proper alignment and grade. On flat beddings, take care to compact the material beneath the haunches prior to placing structure backfill. Material in contact with the pipe must not contain rock retained on a 3-in. [75-mm] diameter ring, frozen lumps, chunks of highly plastic clay, organic matter, corrosive material, or other deleterious material. Figure 4 illustrates the shaped bedding for a pipe-arch. The soil adjacent to the corners of a pipe-arch much be of an excellent quality and highly compacted to accommodate the high reaction pressures that can develop at that location.

7.2 Structures having a span greater than 15 ft [5 m] or a depth of cover greater than 20 ft [6 m] should be provided with a shaped bedding on a yielding foundation. The bedding should be shaped to facilitate the required compaction of the structure backfill adjacent to the bedding beneath the lowest extremes of the invert plates. A shaped bedding on a yielding foundation is always required under structures with small-radius plates attached to invert plates.

8. Assembly

8.1 Structural plate structures are furnished in components of plates and fasteners for field assembly. These components are furnished in accordance with Specification A 761. Plates are furnished in various widths and multiple lengths, preformed and punched for assembling into the required structure shape, size, and length. The plate widths form the periphery of the structure. The various widths and the multiple lengths can be arranged to allow for staggered seams (longitudinal or transverse, or both) to avoid four-plate laps. The fabricator of the structural plate should furnish an assembly drawing showing the location of each plate by width, length, thickness, and curvature. The plates must be assembled in accordance with the fabricator's drawing.

8.2 For structures with inverts, assembly should preferably begin with the invert plates at the downstream end. As assembly proceeds upstream, plates that fall fully or partly below the maximum width of the structure should be lapped over the preceding plates to construct the transverse seams.

8.3 Arches have no integral invert and usually rest in special channels cast into, or connected to, abutments.

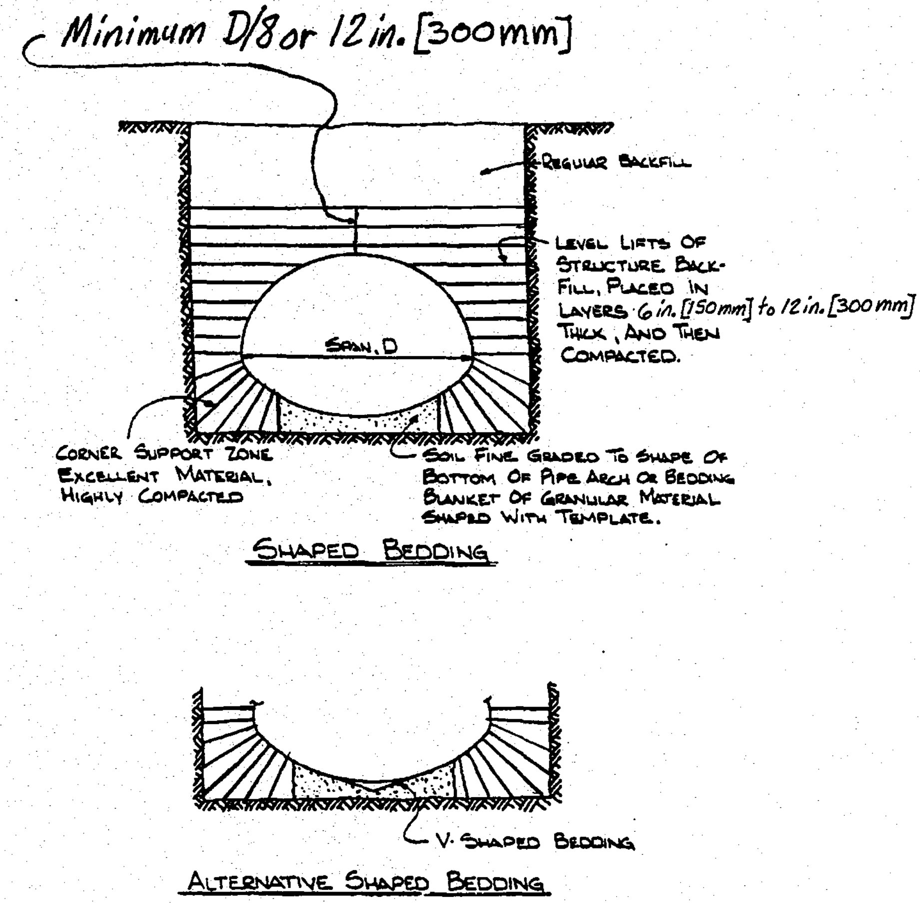


FIG. 4 Pipe-Arch Bedding and Corner Zone Treatment—Ordinary Conditions

Channels must be accurately set to span, line, and grade as shown on the fabricator's drawing. When the arch is other than a half circle, the channel must be rotated in the abutment to allow for entrance of the plate arch. For arches with ends cut on a skew, the opposing abutment channel must be offset. All pertinent dimensions must be shown on the fabricator's drawing. For arch structures, assembly should usually begin at the upstream end and proceed downstream, with each succeeding plate lapping on the outside of the previous plate. Plates attached to the abutment channel are usually not self-supporting and may require temporary support. Assemble as few plates as practical pyramid style and complete the periphery to maintain the structure shape.

8.4 Generally, structural plate should be assembled with as few bolts as practical. These bolts should be placed loose and remain loose until the periphery has been completed for several plate lengths. However, on large structures, it is practical to align bolt holes during assembly and tighten the bolts to maintain structure shape. After the periphery of the structure is completed for several plate lengths, all bolts may be placed and tightened. Correct any significant deviation in structure shape before tightening bolts (see Section 10). It is advisable not to encroach on the loose assembly closer than 30 ft [9 m] when installing and tightening bolts. All bolts shall be tightened using an applied torque of between 100 and 300 ft-lbf [136 and 407 N·m]. It is important not to over-torque the bolts.

8.5 Standard structural plate structures, because of the bolted construction, are not intended to be watertight. On occasions where a degree of watertightness is required, it is practical to introduce a seam sealant tape within the bolted seams. The tape shall be wide enough to effectively cover all rows of holes in plate laps, and of the proper thickness and consistency to effectively fill all voids in plate laps. General procedures for installing sealant tape are as follows: On longitudinal seams, prior to placing the lapping plate, roll the tape over the seam and work into the corrugations. Do not stretch the tape. Remove any paper backing prior to making up the joint. Seal transverse seams in a like manner with tape. At all points where three plates intersect, place an additional thickness of tape for a short distance to fill the void caused by the transverse seam overlap. It is most practical to punch the tape for bolts with a hot spud wrench or sharp tool. At least two tightenings of the bolts will usually be necessary to accomplish the required torque.

9. Structural Backfill Material

9.1 Structural backfill is that material which surrounds the pipe, extending laterally to the walls of the trench, or to the fill material for embankment construction, and extending vertically from the invert to an elevation of 1 ft [300 mm], or ⅛ the span, whichever is greater, over the pipe. The necessary width of structural backfill depends on the quality of the trench wall or embankment material, the type of material and compaction equipment used for the structural ackfill, and in embankment construction, the type of onstruction equipment used to compact the embankment ill. The width of structural backfill shall meet the requirenents given in Table 1.

9.2 Structural backfill material shall be readily compacted oil or granular fill material. Structural backfill may be xcavated native material, when suitable, or select material. elect material such as bank-run gravel, or other processed ranular materials (not retained on a 3-in. [75-mm] diameter ing) with excellent structural characteristics, is preferred. Desired end results can be obtained with such material with minimum of effort over a wide range of moisture content, ft depths, and compaction equipment. Soil used as strucıral backfill must not contain rock retained on a 3-in. 75-mm] diameter ring, frozen lumps, highly plastic clays, rganic matter, corrosive material, or other deleterious oreign matter. Soils meeting the requirements of Groups W, GP, GM, GC, SW, and SP as described in Classification 2487, are generally acceptable, when compacted to the pecified percent of maximum density as determined by Test Method D 698. Test Methods D 1556, D 2167, D 2922, and 2937 may be used to determine the in-place density of the il. Soil Types SM and SC are acceptable but may require oser control to obtain the specified density. Soil Types ML nd CL are not preferred materials, while soil Types OL, H, CH, OH, and PT are not acceptable.

). Shape Control

10.1 Excessive compaction, unbalanced loadings, loads om construction equipment, as well as inadequate compacon or poor backfill materials, can cause excessive pipe stortion. For larger pipe, the construction contractor may t up a shape monitoring system, prior to placement of uctural backfill, to aid in establishing and maintaining oper installation procedures. Such a system is particularly sirable for structures having a span greater than 20 ft [6]. Direct measurement of span and rise, offset measurents from plumb bobs hanging over reference points, and e of surveying instruments are effective means for moniing shape change during backfill placement and compacn. The final installed shape must be within the design teria, exhibit smooth uniform radii, and provide acceptable clearances for its intended use. In general, it is desirable for the crown of the pipe to rise slightly, in a balanced concentric manner, during placement and compaction of soil beside the pipe. Under the load of the completed fill and the service load, vertical deflections will be a small percentage of the pipe rise dimension if backfill compaction is adequate. Structures having a span greater than 20 ft [6 m] should be within 2 % of the calculated dimensions as given in Specification A 761/A 761M prior to backfill placement.

TABLE 1 Structural Backfill Width Requirements[A,B]

Adjacent Material	Required Structural Backfill Width
mal highway embankment compacted to ninimum of 90 % Test Method D 698 density, r equivalent trench all.	As needed to establish pipe bedding and to place and compact the backfill in the haunch area and beside the pipe. Where backfill materials that do not require compaction are used, such as cement slurry or controlled low-strength material (CLSM), a minimum of 3 in. [75 mm] on each side of the pipe is required.
ankment or trench all of lesser quality.	Increase backfill width as necessary to reduce horizontal pressure from pipe to a level compatible with bearing capacity of adjacent materials.

For pipe-arches and other multiple-radius structures, as well as for all ctures carrying off-road construction equipment, the structural backfill width, ding any necessary foundation improvement materials, must be sufficient to ce the horizontal pressure from the structure so that it does not exceed the ing capacity of the adjacent material.

In embankment construction, the structural backfill width must be adequate sist forces caused by the embankment construction equipment. Generally, the each side of the pipe should be no less than 2 ft [600 mm] for spans that do xceed 12 ft [4 m], or 3 ft [900 mm] for greater spans.

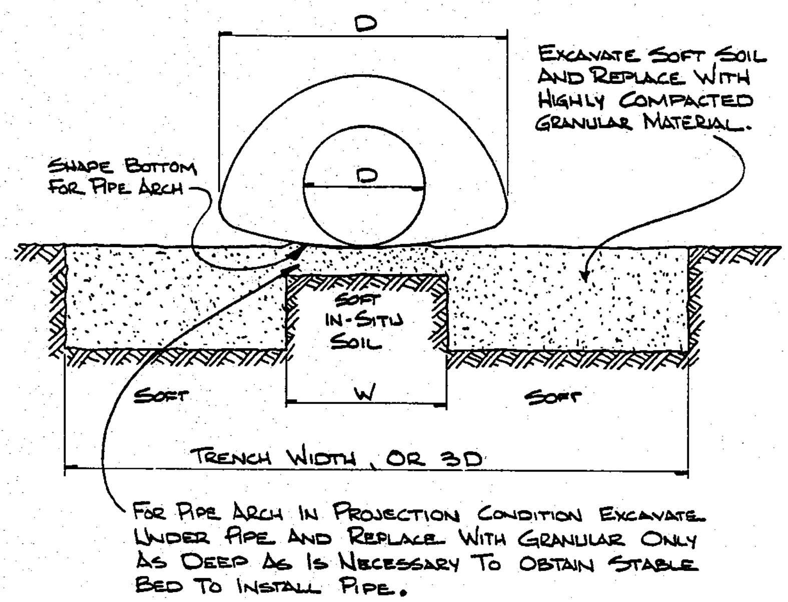
11. General Placement of Structural Backfill

11.1 Structural backfill should be placed by moving equipment longitudinally, parallel to the structure centerline, rather than at right angles to the structure. Material must not be dumped directly on or against the structure. In embankment installations, heavy compaction equipment should stay at least 4 ft [1.2 m] away from the structure. In trench installations, the width of trench will dictate the type of compaction equipment. Heavy construction equipment must not be operated over the structure without adequate protective cover. Adequate cover depends on structure size and structural backfill placement, and must be determined by the engineer. *Depending on the type of material and compaction equipment or method used*, the structural backfill should be placed in 6 to 12-in. [150 to 300-mm] "lifts" or layers before compaction. Each lift must be compacted before the next lift is placed. The difference in the depth of backfill on opposite sides of the structure should not be greater than 2 ft [600 mm]. The compacted backfill should usually be placed to 0.75 the height of structure before covering the crown. However, soil may be placed over the crown whenever required to control the structure shape. A layer of structural backfill (depth of 1 ft [300 mm] or 1/8 the span, whichever is greater) should be placed over the crown before introduction of regular backfill.

11.2 The compaction of structural backfill shall provide a soil structure around the pipe to uniformly apply overburden on the crown of the structure and provide adequate uniform bearing for the structure side walls and haunches. For relatively shallow buried structures, under no live loads, acceptable structural backfill and the degree of compaction may be determined by the character of the total installation. The structural backfill is, however, an integral part of the structural system. Therefore, required end results regarding material type and in-place density of the structural backfill must be in accordance with project specifications.

11.3 When cohesive soils are used for structural backfill, good compaction can be obtained only at proper moisture content. Shallower lifts are usually necessary with cohesive soils than with granular materials to arrive at acceptable in-place density. Mechanical compaction effort should be used with all cohesive soils. Mechanical soil compaction in layers is generally preferred. However, when acceptable end results can be achieved with water consolidation, it may be used. When water methods are used, care must be taken to prevent flotation. Water methods can be used only on free-draining structure backfill material. The structure backfill and adjacent soil must be sufficiently permeable to dispose of the excess water. Water consolidation is not acceptable with cohesive soils.

11.4 *Pipe-Arches*—Special attention must be given to



W = *D* for round pipe
W = width of flat bottom arc of pipe-arch

FIG. 5 Soft Foundation Treatment for Larger Pipe and Pipe-Arch

materials used and compaction obtained around the corners of pipe-arches (Fig. 5). At the corners of all structures with short-radius haunch plates, the structural backfill must be well compacted, particularly for those structures under significant loads. For structures with large spans or heavy loads, special design of the structural backfill may be required for the corner plate zone.

11.5 *Arches*—Placement procedures for structural backfill for arches deviates from that for other structures. The desired procedure is to place fill material in lifts evenly on both sides of the structure to construct a narrow envelope over the crown. Lightly compact each lift as the envelope is constructed. Take care not to distort the arch. Continue to build structural backfill away from the original envelope maintaining sufficient load on the crown to limit "peaking" as the side fill is compacted.

11.6 Generally, construction experience and a site appraisal will establish the most economical combination of material, method, and equipment to yield acceptable end results. Test Methods D 698 or D 1557 are usually the preferred means of determining maximum (standard) density and optimum moisture content. A construction procedure must then be established that will result in the specified percent of maximum density. Once a procedure is established, the primary inspection effort should be directed at ensuring that the established procedure is followed. Such a procedure may involve material, depth of lift, moisture content, and compaction effort. Only occasional checks of soil density may then be required, as long as the material and procedures are unchanged. In situ density may be determined by Test Methods D 1556, D 2167, D 2922, or D 2937, as applicable, for field verification. Testing should be conducted on both sides of the structure. Any construction methods and materials that achieve required end results in the completed structural backfill, without damage to or distortion of the structure, are acceptable. Unless project specifications provide other limits, the soil should be compacted to a minimum of 90 % density in accordance with Test Methods D 698.

12. Regular Backfill

12.1 Regular backfill in trench installations is that material placed in the trench above the structural backfill. In embankment installations, regular backfill is that material, outside the limits of the structural backfill. Regular backfill usually consists of native materials placed in accordance with project specifications. Large boulders must not be permitted in regular backfill in trenches that are under surface loads and never within 4 ft [1.2 m] of the structure (Fig. 1).

13. Multiple Structures

13.1 When two or more structures are installed in adjacent lines, the minimum spacing requirements given in Practice A 796/A 796M must be provided.

14. Keywords

14.1 installation; sewers; steel pipe; structural plate pipe

Designation: D 2412 – 96

Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading[1]

This standard is issued under the fixed designation D 2412; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of load-deflection characteristics of plastic pipe under parallel-plate loading.

1.2 This test method covers thermoplastic resin pipe, reinforced thermosetting resin (RTRP) pipe, and reinforced plastic mortar (RPMP) pipe.

1.3 The characteristics determined by this test method are pipe stiffness, stiffness factor, and load at specific deflections.

1.4 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

NOTE 1—While this test method can be used in measuring the pipe stiffness of corrugated plastic pipe or tubing, special conditions and procedures are used. These details are included in the product standards, for example, Specification F 405.

1.5 The text of this test method references notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the test method.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 695 Test Method for Compressive Properties of Rigid Plastics[2]

D 1600 Terminology for Abbreviated Terms Relating to Plastics[2]

D 2122 Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings[3]

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[4]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[4]

F 405 Specification for Corrugated Polyethylene (PE) Tubing and Fittings[3]

F 412 Terminology Relating to Plastic Piping Systems[3]

3. Terminology

3.1 *Definitions:* Definitions are in accordance with Terminology F 412, and abbreviations are in accordance with Terminology D 1600, unless otherwise specified.

3.2 *Descriptions of Terms Specific to This Standard:*

3.2.1 Δy—measured change of the inside diameter in the direction of load application expressed in inches (millimetres).

3.2.2 *initial inside diameter (d)*—the average of the inside diameters as determined for the several test specimens and expressed in inches (millimetres).

3.2.3 *load (F)*—the load applied to the pipe to produce a given percentage deflection. Expressed as newtons per metre or pounds-force per linear inch.

3.2.4 *mean radius (r)*—the mid-wall radius determined by subtracting the average wall thickness from the average outside diameter and dividing the difference by two. Expressed as inches (millimetres).

3.2.5 *pipe deflection (P)*—the ratio of the reduction in pipe inside diameter to the initial inside diameter expressed as the percentage of the initial inside diameter.

3.2.6 *pipe significant events:*

3.2.6.1 *liner cracking or crazing*—the occurrence of a break or network of fine breaks in the liner visible to the unaided eye.

3.2.6.2 *rupture*—a crack or break extending entirely or partly through the pipe wall.

NOTE 2—The significant events listed may or may not occur in a specific pipe material.

3.2.6.3 *wall cracking*—the occurrence of a break in the pipe wall visible to the unaided eye.

3.2.6.4 *wall delamination*—the occurrence of any separation in the components of the pipe wall visible to the unaided eye.

3.2.7 *pipe stiffness (PS)*—the value obtained by dividing the force per unit length of specimen by the resulting deflection in the same units at the prescribed percentage deflection.

3.2.8 *stiffness factor (SF)*—the product of pipe stiffness and the quantity $0.149\ r^3$.

3.2.8.1 *Discussion*—The "pipe stiffness" and "stiffness factor" are related as follows:

$$PS = F/\Delta y$$
$$SF = EI = 0.149\ F\ r^3/\Delta y = 0.149\ r^3\ (PS) \quad (1)$$

NOTE 3—See Appendix X2 for information relating PS, E, and Δy.

4. Summary of Test Method

4.1 A short length of pipe is loaded between two rigid parallel flat plates at a controlled rate of approach to one

[1] This test method is under the jurisdiction of ASTM Committee F-17 on Plastic Piping Systems and is the direct responsibility of Subcommittee F17.40 on Test Methods.

Current edition approved March 10, 1996. Published May 1996. Originally published as D 2412 – 65 T. Last previous edition D 2412 – 93.

[2] *Annual Book of ASTM Standards*, Vol 08.01.

[3] *Annual Book of ASTM Standards*, Vol 08.04.

[4] *Annual Book of ASTM Standards*, Vol 14.02.

another. Load-deflection (of the pipe diameter) data are obtained. If cracking, crazing, delamination, or rupture occurs, the corresponding load and deflection are recorded.

5. Significance and Use

5.1 The external loading properties of plastic pipe obtained by this test method are used for the following:

5.1.1 To determine the stiffness of the pipe. This is a function of the pipe dimensions and the physical properties of the material of which the pipe is made.

5.1.2 To determine the load-deflection characteristics and pipe stiffness which are used for engineering design (see Appendix X1).

5.1.3 To compare the characteristics of various plastics in pipe form.

5.1.4 To study the interrelations of dimensions and deflection properties of plastic pipe and conduit.

5.1.5 To measure the deflection and load-resistance at any of several significant events which may occur during the test.

6. Apparatus

6.1 *Testing Machine*—A properly calibrated compression testing machine of the constant-rate-of-crosshead movement type meeting the requirements of Test Method D 695 shall be used to make the tests. The rate of head approach shall be 0.50 ± 0.02 in. (12.5 ± 0.5 mm)/min.

NOTE 4—Hydraulic testing machines that may vary slightly from these rate limits are commonly used and are satisfactory for testing RTRP and RPMP pipe 24-in. (610-mm) size and larger.

6.2 *Loading Plates*—The load shall be applied to the specimen through two parallel steel bearing plates. The plates shall be flat, smooth, and clean. The thickness of the plates shall be sufficient so that no bending or deformation occurs during the test, but it shall not be less than 0.25 in. (6.0 mm). The plate length shall equal or exceed the specimen length and the plate width shall not be less than the pipe contact width at maximum pipe deflection plus 6.0 in. (150 mm).

NOTE 5—For some types of testing machines a greater plate thickness may be required to limit plate bending.

6.3 *Deformation (Deflection) Indicator*—The change in inside diameter, or deformation parallel to the direction of loading, shall be measured with a suitable instrument meeting the requirements of Test Method D 695, except that the instrument shall be accurate to the nearest 0.010 in. (0.25 mm). The instrument shall not support the pipe test specimen or the plate or affect in any way the load deflection measurements. Changes in diameter may be measured during loading by continuously recording plate travel or by periodically computing it.

7. Test Specimens

7.1 For thermoplastic pipe, the test specimen shall be a piece of pipe 6 ± ⅛ in. (150 ± 3 mm) long.

7.2 For reinforced thermosetting resin pipe, the minimum test specimen length shall be three times the nominal pipe diameter or 12.0 in. (300 mm), whichever is smaller. For pipe larger than 60 in. (1524 mm) in diameter, the minimum specimen length shall be 20 % of the nominal diameter adjusted to the nearest 1 in. (25.4 mm).

7.3 The ends of specimens shall be cut square and shall be free of burrs and jagged edges.

7.4 No less than three specimens shall be tested for each sample of pipe.

NOTE 6—For quality control testing a single specimen may be used with the thinnest wall at the top.

7.5 Certain RTRP pipes may exhibit surface irregularity because the production process is inside diameter controlled. To assure accurate test results by parallel-plate loading, the test specimen must be uniformly loaded along its entire bearing surface. If surface irregularities (resin-rich areas) along the outside diameter prevent the bearing load from being uniformly distributed along the length of the specimen, the outside surface along the loading line shall be sanded smooth by hand. This sanding is permitted only if the reinforcement is not damaged. Note that sanding shall be done only along the plate contact lines.

8. Conditioning

8.1 Condition pipe for at least 4 h in air, at a temperature of 73.4 ± 3.6°F (23 ± 2°C), and conduct the test in a room maintained at the same temperature.

8.2 When a referee test is required, condition specimens for at least 40 h at 73.4 ± 3.6°F (23 ± 2°C) and 50 ± 5 % relative humidity and conduct the test under the same conditions.

9. Procedure

9.1 Make the following measurements on each specimen:

9.1.1 Determine the length of each specimen to the nearest 1/32 in. (1 mm) or better, by making and averaging at least four equally spaced measurements around the perimeter.

9.1.2 Measure the wall thickness of each specimen in accordance with Test Method D 2122. Make at least eight measurements equally spaced around one end and calculate the average wall thickness.

9.1.3 Determine whether a line of minimum wall thickness exists along the length of the specimen and if so mark it for use in 9.2.1.

NOTE 7—On RTRP and RPMP pipe measurements may be made at both ends.

9.1.4 Determine the average outside diameter to the nearest 0.01 in. (0.2 mm) using a circumferential wrap tape or by averaging the maximum and minimum outside diameters as measured with a micrometer or caliper.

9.1.5 For OD-controlled pipe calculate the average pipe inside diameter (ID) by subtracting two times the average of all wall thicknesses (9.1.2) from the average of all outside diameters (9.1.4). For ID-controlled pipe determine the average ID by measuring the maximum and minimum inside diameters. Use this average ID as the basis for computing the percentage of deflection for all specimens in that lot of pipe.

9.2 Locate the pipe section with its longitudinal axis parallel to the bearing plates and center it laterally in the testing machine.

9.2.1 If an orientation of minimum wall thickness has been found, place the first specimen so the thinnest wall is at the top and rotate successive specimens 35 and 70°. If no minimum wall thickness was identified, use any base line.

TABLE 1 Pipe Stiffness—Precision Statistics[A]

Material	Deflection Level, %	Average	S_{mean}	S_r[B]	S_R[B]	r	R	Standard Deviation of Cell Averages[C]	Repeatability Standard Deviation[C]	Reproduceability Standard Deviation[C]	Repeatability Limit (95 %)[C]	Reproduceability Limit (95 %)[C]
A	2.5	772.3	54.95	84.69	101.0	237.1	282.7	7.11	11.0	13.1	30.7	36.6
B	2.5	380.2	20.52	18.12	27.37	50.72	76.64	5.40	4.77	7.20	13.3	20.2
C	2.5	463.9	79.07	57.82	97.96	161.9	274.3	17.0	12.5	21.1	34.9	59.1
A	5.0	755.7	33.30	80.30	86.93	224.8	243.4	4.41	10.6	11.5	29.7	32.2
B	5.0	356.1	19.13	15.32	24.51	42.89	68.62	5.37	4.30	6.88	12.0	19.3
C	5.0	419.4	37.80	27.74	46.89	77.68	131.3	9.01	6.61	11.2	18.5	31.3
A	7.5	724.8	27.85	76.14	81.07	213.2	227.0	3.84	10.5	11.2	29.4	31.3
B	7.5	332.6	16.87	13.94	21.88	39.02	61.27	5.07	4.19	6.58	11.7	18.4
C	7.5	371.7	26.70	18.82	32.66	52.69	91.45	7.18	5.06	8.79	14.2	24.6

[A] Terms are used as specified in Practice E 177.
[B] S_r = standard deviation of repeatability (variation of replicate samples by same laboratory).
S_R = standard deviation of reproducibility (variability between laboratory).
[C] Precision statistics as percent of average.

9.3 With the deflection indicator in place, bring the upper plate into contact with the specimen with no more load than is necessary to hold it in place. This establishes the beginning point for subsequent deflection measurements.

9.4 Compress the specimen at a constant rate of 0.50 ± 0.02 in. (12.5 ± 0.5 mm)/min.

NOTE 8—For larger sizes of pipe made from relatively low-modulus materials, creep may affect the results of this test because of the loading rate specified.

9.5 Record load-deflection measurements continuously or intermittently with reference to the relative movement of the bearing plates. If measurements are made intermittently, make and record such measurements at increments of not more than 5 % of the average inside diameter of the specimen. Refer to Annex A1.

9.6 Observe and note the load and deflection at the first evidence of each of the following significant events when and if they occur:

9.6.1 Liner cracking or crazing.

9.6.2 Wall cracking.

9.6.3 Wall delamination.

9.6.4 Rupture.

9.7 Record type and position of each event with respect to the corresponding load and deflection. Discontinue the test when either of the following occur:

9.7.1 The load on the specimen fails to increase with increasing deflection (maximum point on load-deflection plot has been reached).

9.7.2 The specimen deflection reaches 30 % of the average inside diameter or the required maximum deflection.

10. Calculation

10.1 Calculate the pipe stiffness, PS, for any given deflection as follows:

$$PS = F/\Delta y \quad \text{lbf/in./in. (kPa)} \qquad (2)$$

NOTE 9—Refer to Appendix X3 for additional information on units.

10.2 When required, calculate the stiffness factor, SF, for any given deflection as follows:

$$SF = 0.149\, r^3 \cdot PS \quad \text{in.}^3 \cdot \text{lbf/in.}^2\ (\text{Pa} \cdot \text{m}^3) \qquad (3)$$

10.3 When required, calculate the percentage pipe deflection, P, as follows:

$$P = \Delta y/d \times 100 \qquad (4)$$

11. Report

11.1 Report the following information:

11.1.1 Complete identification of the material tested, including type, source, manufacturer's code, previous history (if any), and product identification by standard number.

11.1.2 Dimensions of each specimen, including average outside diameter, average wall thickness, average inside diameter, liner thickness and reinforcement thickness where applicable, and average length.

11.1.3 Whether or not the outside diameter of the specimen was sanded.

11.1.4 Conditioning temperature, time, and environment.

11.1.5 The load and deflection at which any of the following events occurred:

11.1.5.1 Liner cracking or crazing,

11.1.5.2 Wall cracking,

11.1.5.3 Wall delamination, and

11.1.5.4 Rupture.

11.1.6 The reason for terminating the test.

11.1.7 If required, a plot on cartesian coordinates of the load in pounds-force per inch (or newtons per metre) versus deflection in inches (or millimetres) for each specimen tested. Each of the following occurrences shall be noted on the plots where applicable:

11.1.7.1 Liner cracking or crazing,

11.1.7.2 Wall cracking, and

11.1.7.3 Wall delamination.

11.1.8 Pipe stiffness, $F/\Delta y$, at 5 and 10 % deflection, for each specimen. If any cracking, crazing, or delamination occurred below 5 % deflection, calculate pipe stiffness at that percent deflection where cracking or delamination occurred and note this in the report.

11.1.9 When specifically requested determine the stiffness factor, SF, at 5 and 10 % deflection, for each specimen. If any cracking, crazing, or delamination occurred below 5 % deflection, calculate apparent stiffness factor at the percent deflection where cracking or delamination occurred and note this in the report.

11.1.10 Date of test.

12. Precision and Bias

12.1 *Precision*[5]—An interlaboratory study of pipe stiff-

[5] Supporting data are available from ASTM Headquarters. Request RR: F17-104.

ness was conducted in accordance with Practice E 691 with seven laboratories participating, each obtaining nine results at three deflection levels on three pipe samples. The pipe samples were C = 4 in. corrugated PE pipe, A = 6 in. SDR 26 ABS dwv pipe, and B = 12 in. SDR 35 PVC sewer pipe. The user of this test method may determine information regarding the precision from Table 1.

12.2 *Bias*—Data obtained using this test method are believed to be reliable since accepted techniques of analysis are used. However, because no reference method is available no bias statement can be made.

ANNEX

(Mandatory Information)

A1. PLOTTING LOAD VERSUS DEFLECTION

A1.1 The load versus deflection plot is typically a smooth curve. In some cases, for example, when the curve is generated automatically, the zero point may be in error: see Fig. A1.1. In such cases, the initial straight line portion of the curve shall be extrapolated back, and this intercept be used as the (0,0) point.

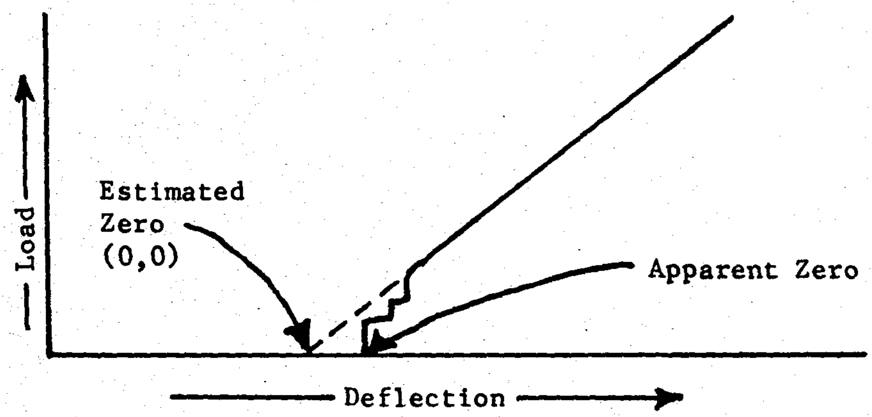


FIG. A1.1 Method of Estimating the Origin

APPENDIXES

(Nonmandatory Information)

X1. METHOD OF APPLYING PIPE STIFFNESS FOR ENGINEERING DESIGN

X1.1 The PS determined by this test method can be used to calculate approximate deflections under earth load. Accordingly, the following modified Spangler equation is one available expression that can be used to give approximations of deflections occurring in plastic pipe under earth load:

$$x = \frac{D_e K W_c}{0.149\, PS + 0.061\, E'}$$

where:

x = horizontal deflection of pipe, in. (or mm), (may be taken also as the vertical deflection),
K = bedding constant, dependent upon the support the pipe received from the bottom of the trench,
W_c = vertical load per unit of pipe length, lbf/in. (or N/m) of pipe,
PS = $F/\Delta y$ = pipe stiffness (as determined by test), lbf/in./in. or (kPa),
D_e = deflection lag factor, and
E' = modulus of soil reaction, psi (or kPa).

X1.2 Pipe stiffness also relates to handling and installation characteristics of a pipe during the very early stages of soil consolidation around the pipe. There can be a minimum pipe stiffness below which pipe becomes difficult to install. Local conditions and installation practice must be considered in selecting this minimum for a particular project and in assigning specific values to be used in the above equations for pipe deflection. Beyond these statements no representation in regard to limiting maximum or minimum pipe stiffness values determined in accordance with the provision of this test method is made or implied.

X2. PS AND SF VERSUS DEFLECTION

X2.1 The *EI* of a pipe is a function of the material's flexural modulus (E) and the wall thickness (t) of the pipe, since $I = t^3/12$. As such it is a fixed value for any given set of material and dimensional parameters. However, the quantities pipe stiffness (PS) and stiffness factor (SF) are computed values determined from the test resistance at a particular deflection. These values are highly dependent on the degree of deflection, for as the pipe deflects the radius of curvature changes. The greater the deflection at which PS or SF are determined, the greater the magnitude of the deviation from the true *EI* value. By application of the correction factor $C = [1 + (\Delta y/2d]^3$ the measured PS or SF values can be related to the true *EI* of the pipe as long as the pipe remains elliptical. Therefore:

$$PS = \frac{F}{\Delta y} C = \frac{F}{\Delta y}\left(1 + \frac{\Delta y}{2d}\right)^3$$

$$EI = (SF) = 0.149r^3\ (PS)$$

X2.2 Use of the load deflection values from this test method to calculate a material flexural modulus should incorporate this correction. Also, it should be recognized that in the study of the behavior of deflected pipe it is the term *EI* which was used in developing much of the theory of flexible pipe.

X3. UNITS FOR PS AND SF

X3.1 The pipe stiffness value is calculated by dividing the force per unit length by the deflection. In the inch-pound system of units, this is pounds-force per inch of length per inch of deflection, lbf/(in.·in.): this is commonly expressed as lbf/in.^{2} or psi. In SI, with the force expressed in newtons per metre of length and the deflection in millimetres, the PS is expressed in kilopascals (kPa). Although PS units are dimensionally the same as those for pressure and stress, they are different quantities and should not be confused one with the other.

X3.2 The stiffness factor is calculated from PS and the mean radius of the tube, in inches or millimetres. These units are in.^{3}·lbf/in.^{2} or mm^3·kPa which can be expressed dimensionally as lbf·in. or μN·m.

APPENDIX E

FDOT Topic No. 625-040-001b

(Chapter 6)

CHAPTER 6
OPTIONAL CULVERT MATERIALS

6.1 INTRODUCTION

Optional culvert materials shall be considered for all culvert applications including, but not limited to, storm drains, cross drains, side drains, gutter drains, and french drains. All culvert materials shown in Table 6-1 for the application being designed shall be evaluated. The evaluation shall consider functionally equivalent performance in three areas: durability, structural capacity, hydraulic capacity.

6.2 DURABILITY

Culverts shall be designed for a design service Life (DSL) appropriate for the culvert function and highway type. Department requirements: for DSL are provided in Table 6-1. The projected service life of pipe material options called for in the plans shall provide, as a minimum, the Design Service Life. Pipe material standards shall not be reduced when projected service life exceeds design service life.

In estimating the projected service life of a material, consideration shall be given to actual performance of the material in nearby similar environmental conditions, its theoretical corrosion rate, the potential for abrasion, and other appropriate site factors. Theoretical corrosion rates shall be based on the environmental conditions of both the soil and water. As a minimum the following corrosion indicators shall be considered:

1. pH
2. Resistivity
3. Sulfates
4. Chlorides

Tests for the above characteristics shall be based on FDOT approved test procedures. To avoid unnecessary site specific testing, generalized soil maps may be used to delete unsuitable materials from consideration. The potential for future land use changes which may change soil and water corrosion indicators shall also be, considered to the extent practical.

6.2.1 Culvert Service Life Estimation

The Tables and Figures, or criteria stated below should be used in evaluating the estimates service life for the following culvert materials:

- Galvanized Steel: Figure 6.1 and Table 6.2
- Aluminized Steel: Figure 6.2 and Table 6.3
- Aluminum: Figure 6.3 and Table 6.4
- Reinforced Concrete: Figure 6.4 and Table 6.5
- Polyethylene: 50 Years
- Polyvinyl Chloride: 50 Years

6.3 STRUCTURAL EVALUATION

Standard Index Drawing 205 provides minimum and maximum cover requirements. The `minimum thickness established to meet Durability requirements shall be evaluated to assure structural adequacy and increased if necessary. Materials and sizes not listed in Index 205 shall be evaluated using: AASHTO design guidelines and industry recommendations, and modified as necessary to be consistent. with Index 205 and: any applicable specifications and installation procedures.

6.4 HYDRAULIC EVALUATION

The hydraulic evaluation shall establish the hydraulic size in accordance with the design standards provided in the Drainage Manual for the particular culvert application. :For storm drains and cross drains, only one hydraulic design is required. This design shall use the Manning's roughness coefficient associated with concrete pipe, spiral rib pipe, polyethylene pipe and polyvinyl chloride pipe

For side drains, two hydraulic designs shall be considered; one using the Manning's roughness coefficient (n=0.012) associated with concrete, spiral rib, polyethylene and polyvinyl chloride (PVC) pipe, and one using the Manning's roughness coefficients associated with conventionally corrugated helical pipe. If a material type is considered to be inappropriate, it will need to be eliminated as an option in the plans.

In addition, the hydraulic evaluation shall verify that the standard joint performance as required by the Standard Specifications will be sufficient. Minimum joint performance requirements established in the Standard Specifications are as follows:

Application	Minimum Joint Performance
Storm Drain	Soiltight
Cross Drain	Soiltight
Side Drain	Soiltight
Gutter Drain	Watertight
French Drain	Alignment .
Underdrain	Alignment

For situations where the minimum joint performance as required by the Standard Specifications is not sufficient, special provisions to specify the proper joint shall be provided in the plans. For example, a pump station with a small diameter pressurized storm drain should use a High Pressure joint. (Note: Joints are tested and rated by the Office of Materials and Research.)

6.5 CULVERT MATERIAL TYPES

The types of culvert materials to be considered for the various culvert applications are as follows. Other materials may be considered, but are not required to be.

Application	Materials to be Considered
Cross Drain French Drain Side Drain Storm Drain	Aluminized Steel Aluminum Concrete Corrugated Polyethylene (1200 mm maximum) Polyvinyl Chloride (1200 mm maximum) Steel
Gutter Drain	Corrugated Aluminized Steel (n > 0.020) Corrugated Aluminum (n > 0.020) Corrugated Steel (n > 0.020)
Vertical Drain	Ductile Iron (In saline environments, consider aluminum and fiberglass)

The Plans Preparation Manual illustrates a method of presenting the acceptable pipe materials in the plans.

6.6 DOCUMENTATION

The documentation shall be sufficient to justify eliminating material types from being acceptable and shall include at a minimum the following:

1. Design Service Life required.
2. Soil and water corrosion indicators used in estimating service life,
3. Estimates of service life at cross drains and at various locations of storm drain systems.
4. Structural Evaluation (comparison of maximum and minimum cover heights to actual cover, height).

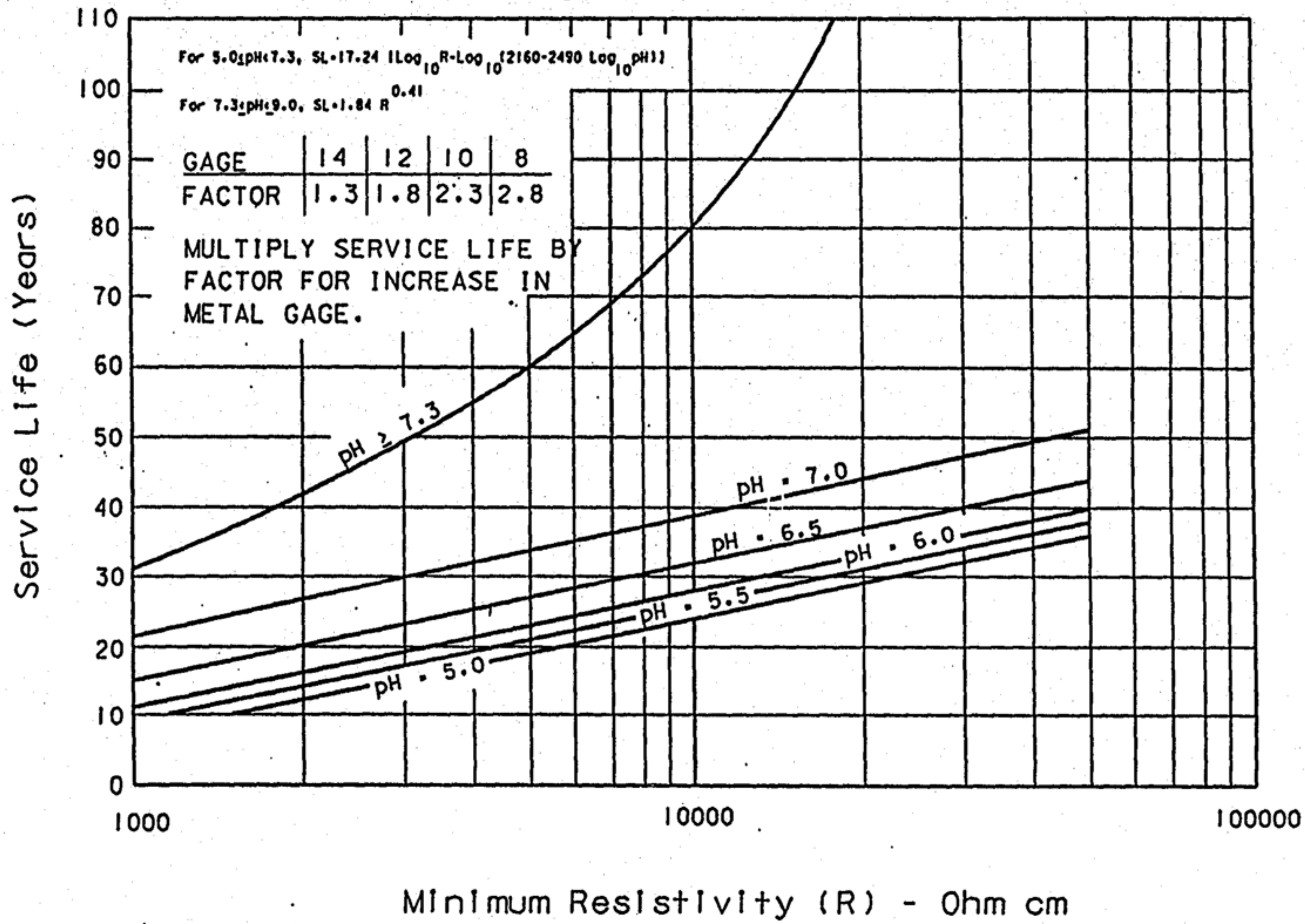
TABLE 6-1 CULVERT MATERIAL APPLICATIONS AND DESIGN SERVICE LIFE

	Application ➤	Storm Drain		Cross Drain			Side Drain [5]	Gutter Drain	French Drain			
									Replacement will Impact the Roadway [6]			Other
	Highway Facility ➤ (see notes below)	Major & Minor	Urban	Minor	Major & Urban	Urban > 6 Lanes	All	All	Minor	Major	Urban	All
	Design Service Life ➤	50	100	25	50	100	25	25	25	50	100	25
	Culvert Material	"◆" indicates suitable for further evaluation.										
PIPE	Corrugated Aluminum Pipe CAP	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
PIPE	Corrugated Steel Pipe CSP	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
PIPE	Corrugated Aluminized Steel Pipe CASP	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
PIPE	Spiral Rib Aluminum Pipe SRAP	◆	◆	◆	◆	◆	◆		◆	◆	◆	◆
PIPE	Spiral Rib Steel Pipe SRSP	◆	◆	◆	◆	◆	◆		◆	◆	◆	◆
PIPE	Spiral Rib Aluminized Steel Pipe SRASP	◆	◆	◆	◆	◆	◆		◆	◆	◆	◆
PIPE	Concrete Pipe CP	◆	◆	◆	◆	◆	◆		◆	◆	◆	◆
PIPE	Corregated Polyethylene Pipe and Tubing CPE	◆		◆	◆		◆		◆	◆		◆
PIPE	Polyvinyl-Chloride Pipe PVC	◆		◆	◆		◆		◆	◆		◆
STR PLATE	Structural Plate Aluminum Pipe SPAP	◆	◆	◆	◆	◆	◆					
STR PLATE	Structural Plate Alum. Pipe-Arc SPAPA	◆	◆	◆	◆	◆	◆					
STR PLATE	Structural Plate Steel Pipe SPSP	◆	◆	◆	◆	◆	◆					
STR PLATE	Structural Plate Steel Pipe-Arch SPSPA	◆	◆	◆	◆	◆	◆					
BOX	Aluminum Box Culvert	◆	◆	◆	◆	◆	◆					
BOX	Concrete Box Culvert	◆	◆	◆	◆	◆	◆					
BOX	Steel Box Culvert	◆	◆	◆	◆	◆	◆					

1. A <u>minor</u> facility is permanent construction where design traffic volume is less than 1600 vpd (ADT), such as minor collectors, local streets and highways, and driveways, provided culvert cover is less than 10 feet.
2. A <u>major</u> facility is permanent construction where design traffic volume is greater than 1600 vpd (ADT), such as freeways, arterials, and major collectors. It also includes minor facilities where culvert cover is greater than 10 feet.
3. An <u>urban</u> facility is any permanent construction that functions as an "urban principle arterial road", i.e., routes which generally serve the major centers of activity in an urban area, the highest traffic corridors, and the longest trip purpose, and carry a high proportion of the total urban traffic on a minimum of mileage.
4. Temporary construction normally requires a shorter design service life than permanent does. However, temporary measures may be suitable to be incorporated as permanent facilities and this should be considered.
5. Although culverts under intersecting streets (crossroads) function as sidedrains for the project under consideration, these culverts are cross drains and shall be designed using appropriate cross drain criteria.
6. Replacing this pipe would require removal and replacement of the project's pavement, curb, or sidewalk.

FIGURE 6.1

Estimated Service Life vs. pH and Resistivity for 16 ga. Galvanized Steel



For $5.0 \le pH < 7.3$, $SL = 17.24\,(\log_{10} R - \log_{10}(2160 - 2490 \log_{10} pH))$

For $7.3 \le pH \le 9.0$, $SL = 1.84\,R^{0.41}$

GAGE	14	12	10	8
FACTOR	1.3	1.8	2.3	2.8

MULTIPLY SERVICE LIFE BY FACTOR FOR INCREASE IN METAL GAGE.

TABLE 6.2

Design Service Life vs. pH and Resistivity for 16 ga. GALVANIZED STEEL Culvert Pipe

pH	Resistivity 1000	1500	2000	3000	4000	5000	7000	10000	15000	20000	30000	40000	≥50000
5.0	7	10	12	15	17	19	21	24	27	29	32	34	36
5.1	7	10	12	15	17	19	21	24	27	29	32	34	36
5.2	8	10	13	16	18	19	22	25	28	30	33	35	37
5.3	8	11	13	16	18	20	22	25	28	30	33	35	37
5.4	8	11	13	16	19	20	23	25	28	31	34	36	37
5.5	9	12	14	17	19	21	23	26	29	31	34	36	38
5.6	9	12	14	17	19	21	24	26	29	32	35	37	38
5.7	10	13	15	18	20	22	24	27	30	32	35	37	39
5.8	10	13	15	18	21	22	25	27	30	32	36	38	39
5.9	11	14	16	19	21	23	25	28	31	33	36	38	40
6.0	11	14	16	20	22	23	26	28	32	34	37	39	41
6.1	12	15	17	20	22	24	26	29	32	34	37	40	41
6.2	13	16	18	21	23	25	27	30	33	35	38	40	42
6.3	13	16	19	22	24	25	28	31	34	36	39	41	43
6.4	14	17	19	22	24	26	29	31	34	36	40	42	43
6.5	15	18	20	23	25	27	30	32	35	37	40	43	44
6.6	16	19	21	24	26	28	31	33	36	38	41	44	45
6.7	17	20	22	25	27	29	32	34	37	39	42	45	46
6.8	18	21	23	26	29	30	33	36	39	41	44	46	48
6.9	20	23	25	28	30	32	34	37	40	42	45	47	49
7.0	22	25	27	30	32	34	36	39	42	44	47	49	51
7.1	24	27	29	32	34	36	39	41	44	46	50	52	53
7.2	28	31	33	36	38	40	42	45	48	50	53	55	57
7.3	34	37	39	42	45	46	49	52	54	57	60	61	64
7.4 to 9.0	34	37	42	49	55	60	69	80	95	107	126	142	155

Estimated Service Life: $(SL) = 17.24\{Log_{10}R - Log_{10}[2160 - 2490(Log_{10}pH)]\}$ for $5 \leq pH \leq 7.3$

$(SL) = 1.84\ R^{0.41}$ for $7.3 < pH \leq 9$

FIGURE 6.2

Estimated Service Life vs. pH and Resistivity for 16 ga. Aluminized Steel Type II

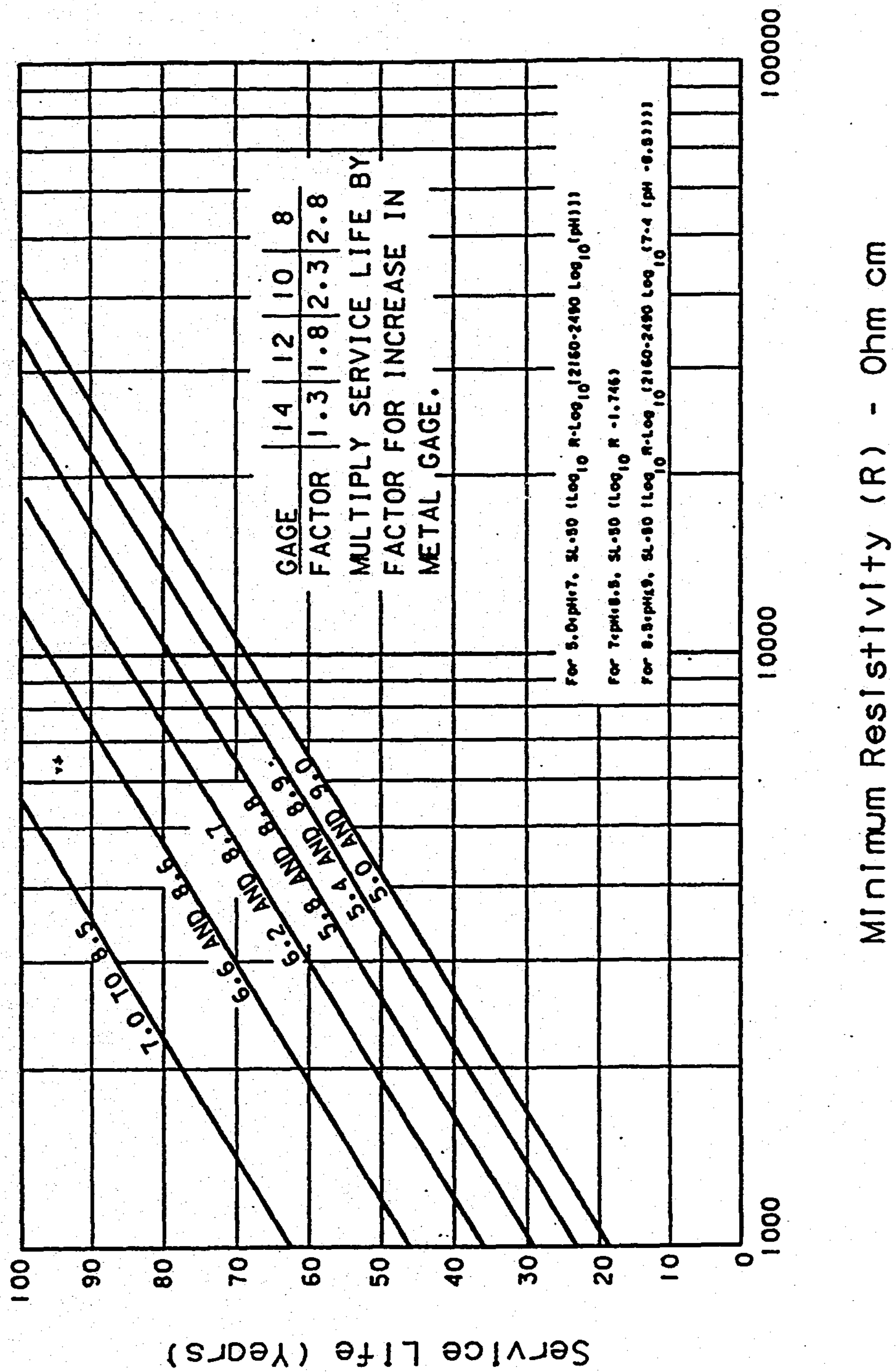


TABLE 6.3

Estimated Service Life vs. pH and Resistivity for 16 ga. ALUMINIZED STEEL Culvert Pipe

pH	Resistivity 1000	1500	2000	3000	4000	5000	7000	10000	15000	20000	30000	40000	≥50000
5.0	19	28	34	43	49	54	61	69	78	84	93	99	104
5.1	20	29	35	44	50	55	62	70	79	85	94	100	105
5.2	21	30	36	45	51	56	63	71	80	86	95	101	106
5.3	22	31	37	46	52	57	65	72	81	87	96	102	107
5.4	24	32	39	48	54	59	66	74	82	89	98	104	109
5.5	25	34	40	49	55	60	67	75	84	90	99	105	110
5.6	26	35	41	50	56	61	69	76	85	91	100	106	111
5.7	28	37	43	52	58	63	70	78	87	93	102	108	113
5.8	29	38	44	53	59	64	72	79	88	94	103	109	114
5.9	31	40	46	55	61	66	73	81	90	96	105	111	116
6.0	33	41	48	56	63	68	75	83	91	98	106	113	118
6.1	34	43	50	58	65	69	77	84	93	100	108	115	119
6.2	36	45	51	60	67	71	79	86	95	101	110	116	121
6.3	38	47	54	62	69	73	81	88	97	104	112	119	123
6.4	41	50	56	65	71	76	83	91	100	106	115	121	126
6.5	43	52	58	67	73	78	86	93	102	108	117	123	128
6.6	46	55	61	70	76	81	88	96	105	111	120	126	131
6.7	49	58	64	73	79	84	92	99	108	114	123	129	134
6.8	53	62	68	77	83	88	95	103	112	118	127	133	138
6.9	57	66	72	81	87	92	100	107	116	122	131	137	142
7.0 to 8.5	63	72	78	87	93	98	105	113	122	128	137	143	148
8.6	46	55	61	70	76	81	88	96	105	111	120	126	131
8.7	36	45	51	60	67	71	79	86	95	101	110	116	121
8.8	29	38	44	53	59	64	72	79	88	94	103	109	114
8.9	24	32	39	48	54	59	66	74	82	89	98	104	109
9.0	19	28	34	43	49	54	61	69	78	84	93	99	104

Estimated Service Life:

$(SL) = 50\{Log_{10}R - Log_{10}[2160 - 2490(Log_{10}pH)]\}$ for $5.0 \leq pH < 7.0$

$(SL) = 50(Log_{10}R - 1.746)$ for $7.0 \leq pH \leq 8.5$

$(SL) = 50\{Log_{10}R - Log_{10}\{2160 - 2490\ Log_{10}[7 - 4(pH - 8.5)]\}\}$ for $8.5 < pH \leq 9.0$

FIGURE 6.3

Estimated Service Life vs. pH and Resistivity for Aluminum

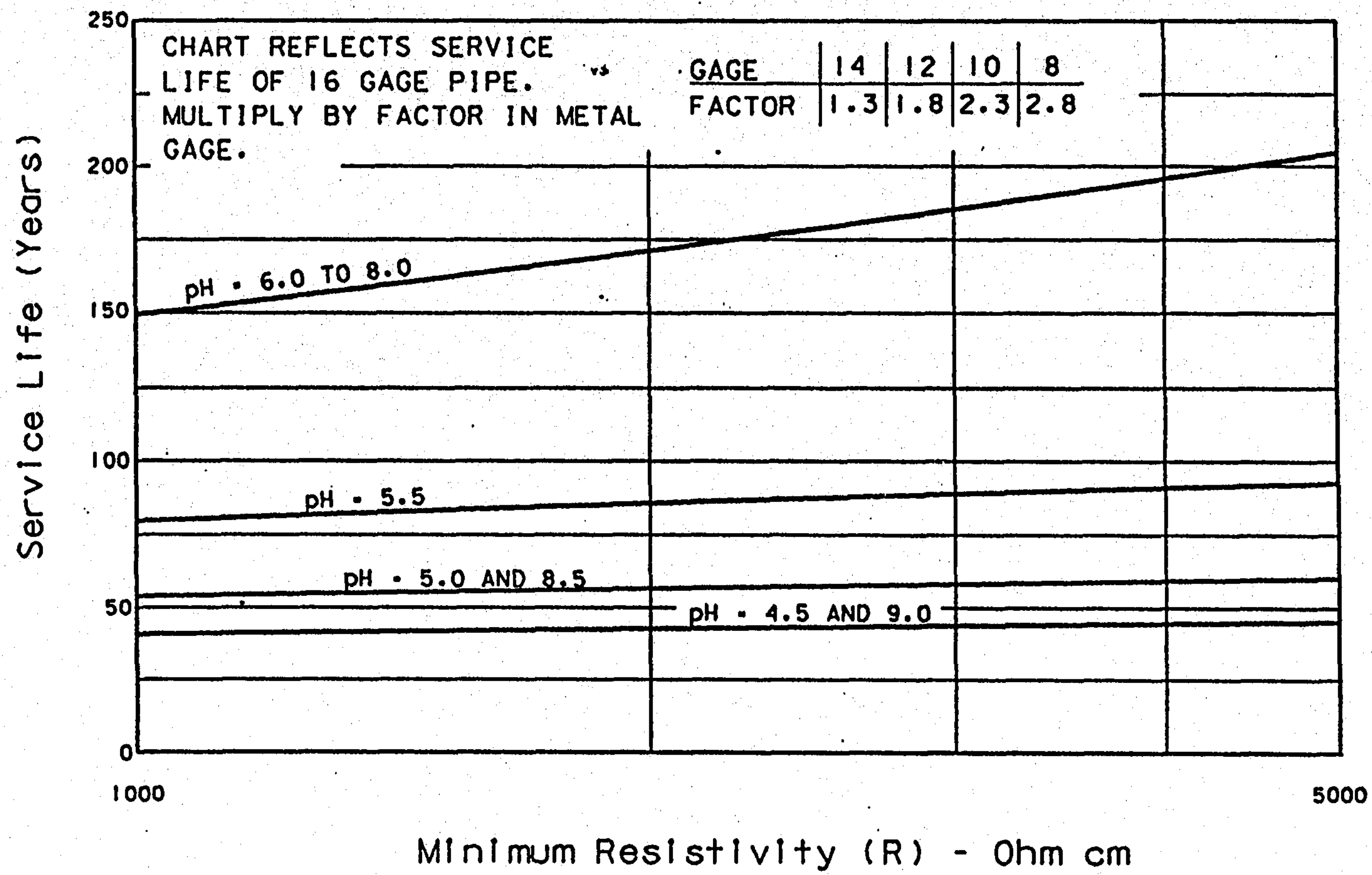


TABLE 6.4

Estimated Service Life vs pH and Resistivity for 16 Ga. ALUMINUM Culvert Pipe

pH	Resistivity ≤200	400	600	800	1000	1200	1400	1600	1800	2000	2300	2700	3200	3800	4500	≥5000
4.5 and 9.0	36	39	40	41	41	42	42	42	43	43	43	43	44	44	44	45
4.6 and 8.9	38	41	42	43	43	44	44	45	45	45	45	46	46	47	47	48
4.7 and 8.8	40	43	44	45	46	46	47	47	47	48	48	48	49	49	50	51
4.8 and 8.7	42	45	46	48	48	49	49	50	50	50	51	51	52	52	53	54
4.9 and 8.6	44	48	49	50	51	52	52	53	53	54	54	55	55	56	56	57
5.0 and 8.5	46	50	52	53	54	55	56	56	57	57	58	58	59	59	60	61
5.1	49	53	56	57	58	59	60	60	61	61	62	62	63	64	65	66
5.2 and 8.4	52	57	59	61	62	63	64	65	65	66	67	67	68	69	70	71
5.3	55	61	64	66	67	68	69	70	71	71	72	73	74	75	76	77
5.4 and 8.3	59	66	69	71	73	74	75	76	77	78	79	80	81	82	83	84
5.5	63	71	75	78	80	81	83	84	85	86	87	88	90	91	92	93
5.6 and 8.2	68	78	82	85	88	90	91	93	94	95	97	98	100	102	104	105
5.7	74	85	91	95	98	100	102	104	106	107	109	111	113	116	118	119
5.8 and 8.1	81	95	102	107	110	114	116	119	121	122	125	128	131	134	137	138
5.9	89	107	115	122	127	131	134	138	140	143	146	150	154	158	163	165
≥6.0 and ≤8.0	100	122	133	142	149	154	159	164	168	171	176	182	188	194	200	204

Service Life (SL): $\frac{T_p}{R_{pH} + R_r}$

Where:

- SL - Years to first perforation
- T_p - Thickness of pipe - Inches
- R_{ph} - Corrosion Rate for pH - Inches/yr.
- R_r - Corrosion Rate for Resistivity - Inches/yr.

FIGURE 6.4

Estimated Service Life vs. pH and Resistivity for 60" DIA Concrete Culverts, S = 1500 ppm

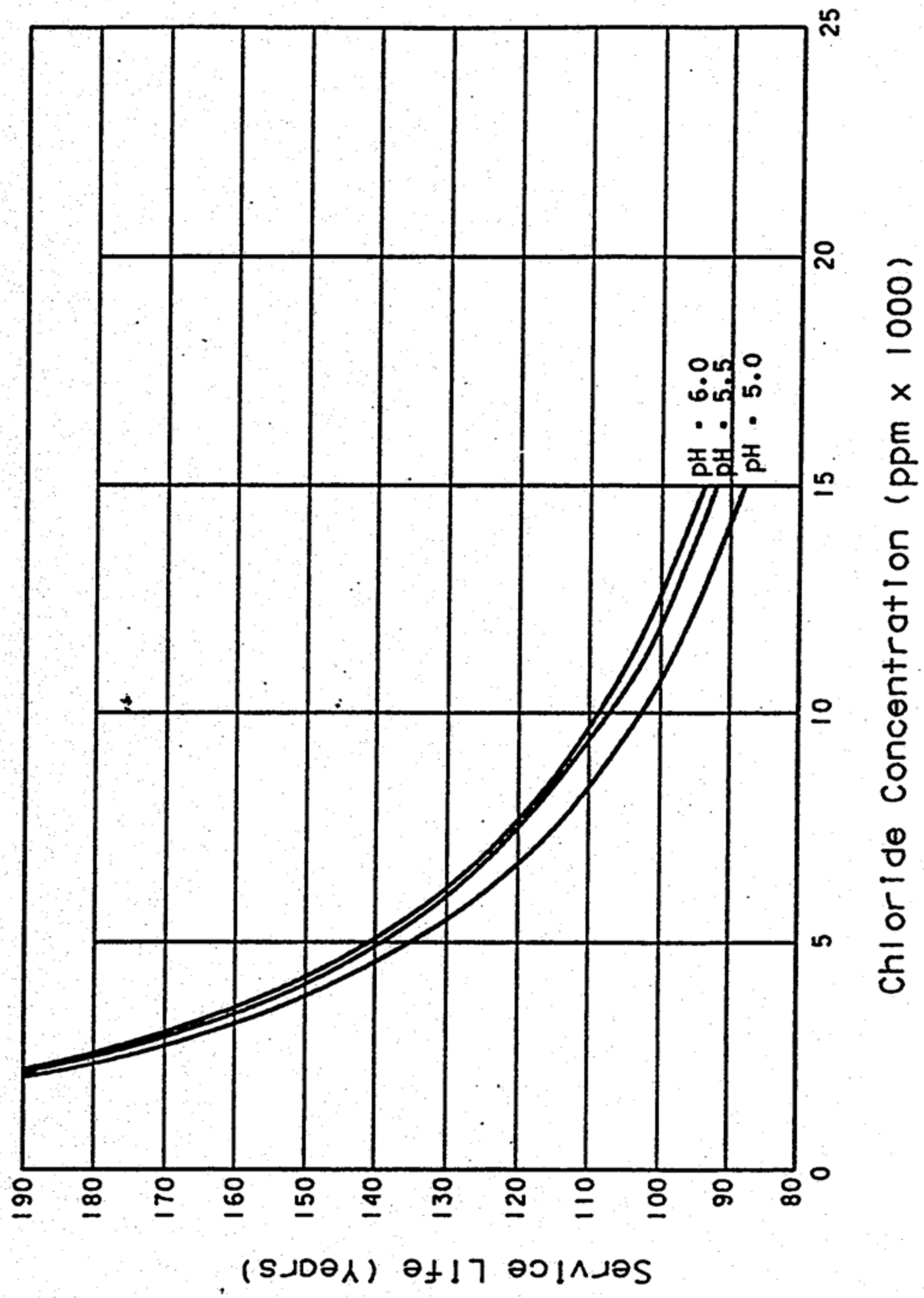


Table 6.5

Estimated Service Life vs. pH and Chlorides for 60" Dia. REINFORCED CONCRETE Culverts at 1500 ppm Sulfate Concentration

	Chlorides											
pH	15000	13000	11000	9000	7000	5000	3000	2000	1000	750	500	250
5.0	88	93	99	107	118	135	164	192	250	278	324	360
5.1	89	94	101	109	119	136	165	193	251	279	325	360
5.2	90	95	102	110	121	137	167	194	252	281	327	360
5.3	91	96	102	111	122	138	167	195	253	282	327	360
5.4	92	97	103	111	122	139	168	196	253	282	328	360
5.5	92	97	103	112	123	139	168	196	254	282	328	360
5.6	93	98	104	112	123	140	169	196	254	283	329	360
5.7	93	98	104	112	123	140	169	197	254	283	329	360
5.8	93	98	104	113	124	140	169	197	255	283	329	360
5.9	93	98	105	113	124	140	170	197	255	284	330	360
≥6.0	94	99	105	113	124	141	170	197	255	284	330	360

Conversion Factors for Different Size Culverts

Pipe Dia.	Mult. By
12"	.36
18"	.36
24"	.41
30"	.48
36"	.54
42"	.65
48"	.76
60"	1
72"	1.25
84"	1.51
96"	1.77
108"	2.04

SL Reduction Factors for Sulfates

Sulfate Content	Subtract from SL
1500	0
3200	5
4900	10
6600	15
8300	20
10000	25

Note: Sulfate derating not applicable when Type V cement is used.

Service Life (SL) = $1000(1.107^{C} C^{0.717} D^{1.22} K^{-0.37} W^{-0.631}) - 4.22\times10^{10}(pH^{-14.1}) - 2.94\times10^{-3}(S) + 4.41$

Where:
- C = Sacks of cement per cubic yard
- D = Steel depth in the concrete
- K = Environmental Chloride concentration in ppm
- W = Total percentage of water in the mix
- S = Environmental Sulfate Content in ppm

APPENDIX F

M E M O R A N D U M

Telephone: 513/425-2161
Fax: 513/425-5993
E-mail: jschluter@contech-cpi.com

MEMORANDUM

CC Matt Dorser, Uni-Bell

Paul Harkins 5 pages faxed
From: Jim Schluter
Date: 12/21/99
Re: Stain in deflected pipe calculations

The calculations I used to support my recommend pipe deflection limits were roughed out in scratch paper, so I took a minute to put them into a form you can read and check. The values, with the exception of one minor correction are the same as in my written summary. The attached calculations support those recommendations.

None of the AASHTO or ASTM specifications require detailed wall profiles for plastic pipes like they do for steel. Corrugated steel pipe with a 2-2/3x1/2 corrugation is spelled out specifically. Plastic pipes, by specification are only referred to as corrugated, ribbed, etc. The profile dimensions can be anything the manufacturer desires.

To overcome this "dimensional" problem AASHTO has put limiting (worst case) dimensions into the bridge specification to use for design. These are the dimensions (tables A12-11 and A12-13 of the LRrl7 Bridge Spec.) I used in my original calculations to evaluate strain, levels: Pipes can be and are made to these dimensions. In the attached, however, I also show the bending strains for Contech's M304 pipe and one M294 product that I have specific dimensions for.

While there is a range between some of the different manufacturer's products:

- M294 pipes consistently produces about twice the bending strain level of PVC pipes at the same amount of deflection.
- The grades of HDPL allowed in M294 are much more strain sensitive than M304 PVC materials.
- The strain levels reached at 5% deflection in M294 pipes are enough to be of concern (tensile cracking and local buckling) while the PVC pipes aren't a concern even at 7-1/2% deflection.

Part of this entire issue is local buckling instability do to compression, bending strain caused by deflection. NCHMP 20-7, Task 89, the local buckling study for

December 21, 1999

plastic pipe design, openly restricts deflections for M294 pipes to levels well below 5% in higher cover cases, to control local buckling. It also indicates that today's PVC products are fully stable.

Paul, I hope to get my formal comments together from our last niccting over the holidays. Let me also see if NCBIZP will let me copy my 20-7, task 89 report for your use.

PIPE WALL BENDING STRAIN DUE TOP PIPE DEFLECTION STRAIN EQUATION

$\varepsilon = Df(C/R)\,\Delta$

where: ε = pipe wall strain due to deflection bending (%)
Δ = pipe deflection {%)
C =pipe wall extreme fiber distance (in.)
R = mean radius of the pipe (in.)
Df = a factor that relates to pipe shape after deflection. Low stiffness pipes tend to deflect in more of a "square" shape than do stiffer pipes.
= 4.27 for stiffer (100 psi) pipes
= 6.0 for lower stiffness (M204f M304) pipes

24" diameter, AASHTO M36, 2-2/3 x 1/2 corrugated steel pipe.

d = Corrugation depth, out-to-out = 0.5+t = 0.56 in.
C = d/2 = 0.28 in.
R = (ID/2) + C =12.28 in.

@ 5% deflection (i.e. Δ = 5%)

ε = 4.27 (0.28/12.28) 5 = 0.49%

Note: if the Df of 6.0 was applied to this stiffer pipe (pipe stiffness > 100 psi.) the pipe, strain would still be only 0.68%

24"diameter, AASHTO M294 pipe
AASHTO dimensions ref: AASHTO LRFD Bridge Spec. Division 1, table A12-11

OD = 28.7 Cmin = 0.65
ID = 23.6
Thus:
d = depth of wall = (OD-ID)/2 = 2.55 in.
C = Cmax = 2.55 - .65 = 1.90 in
R = (23.6/2) + .65 = 12.45 in.

@ 5% deflection
ε = 6 (1.9/12.45) 5 = 4.58%

Since the plastic pipe product specifications do not provide limits or controls an the ID OD etc. of theses pipe AASHTO has adopted the use of tables such as Al2-11 that give the worst case dimensions of what is known to be manufactured Any one manufacturer's product my produce less strain.

Example: Hancor 24", M294 pipe

OD = 28.4 in.
ID = 24.07 in.

Cmin = 0.863 in
d = (28.4-24.07)/2 =2.17 in.
C = Cmax = 217 - .863 = 1.307
R = (ID/2) + Cmin =12.898

@ 5% deflection

ε = 6 (1:307/ 12.898) 5 = 3.04%

24" diameter AASHTO M304 PVC pipe
AASHTO dimensions ref: AASHTO LRFD BridgerSpec. Division 1, table A12-13

OD = 26.0 in.
ID = 23.4 in
Cmin = 0.23 in.
d = (26.0 - 23.4)/2 =1.3 in
C = Cmax = 1.3 - .23 = 1.07 in
R = 23.4/2+0.23 = 11.93 in

@ 5% deflection

ε = 6(1.07/11.93)5 = 2.69%

As above, this_ is AASHTO's worst case assumption. Some manufacturers pipes could exhibit less strain.

Example: Contech 24" M304 pipe

OD = 25.58
ID = 23.47
Cmin = 0.401
D = (25.58 - 23.47)/2 =1.055
C = Cmax = 1.065 - .401 = 0.654 in
R= (23.47)/2 + 0.401 = 12.136 in.

@ 5% deflection

ε = 6(0.654/12.136)5 = 1.61%

A-2000 PVC PIPE FOR STORM SEWERS AND DRAINAGE

CONTECH A-2000 PVC pipe represents the high quality, thorough background engineering, and performance characteristics needed for durable and dependable storm sewer applications.

When installed in accordance with established procedures (ASTM D2321), A-2000 provides years of trouble-free service, even under high fills or low-cover H-20 wheel loads. A-2000 is a unique blend of corrugated outer wall profile for extra structural capacity and smooth inner wall for more efficient hydraulic performance. Meeting all of the performance and material requirements of ASTM F949, with a minimum ring stiffness of 50 psi, CONTECH A-2000 provides the deflection control needed to withstand installation stresses and in-service loads.

Its additional resistance to corrosive and bacterial attack, tight infiltration-resistant joints, and lower installation costs make A-2000 the ideal storm sewer material for most applications.

TABLE 1: A-2000 PVC PIPE SECTION PROPERTIES

SIZE	INSIDE DIAMETER (Inches)	OUTSIDE DIAMETER (Inches)	AREA (in.²/foot)	C(1) (Inches)	I (in.⁴/in.)
4	3.95	4.29	0.658	0.105	0.00021
6	5.88	6.41	0.842	0.163	0.00070
8	7.87	8.59	1.142	0.222	0.00175
10	9.84	10.78	1.176	0.277	0.00334
12	11.72	12.80	1.591	0.330	0.00568
15	14.34	15.66	1.884	0.405	0.01040
18	17.55	19.15	2.503	0.493	0.01860
21	20.47	22.59	2.868	0.586	0.02880
24	23.47	25.58	3.360	0.654	0.04190
30	29.47	32.15	4.104	0.824	0.08360

TABLE 2: MECHANICAL PROPERTIES(2) (CELL CLASS 12454B PVC RESIN)

MINIMUM TENSILE STRENGTH	MINIMUM MODULUS OF ELASTICITY
Initial 7,000 psi	Initial 400,000 psi
50 Years 3,700 psi	50 Years 140,000 psi

Notes for Pipe Section and Resin Properties (Tables 1 & 2)

(1) Extreme fiber distance from neutral axis.
(2) Allowable long term strain = 5%.

CONTECH CONSTRUCTION PRODUCTS INC. • P. O. Box 800 • Middletown, Ohio 45042

CONTECH CONSTRUCTION PRODUCTS INC.

Regional Offices and Plastic Pipe Specialists are in the following cities:

Atlanta, GA 30359	P.O. Box 29649	404/325-0814
Bloomfield Hills, MI 48034	2655 S. Woodward Ave., Suite 350	810/332-6030
Bridgeton, MO 63044	12739 Carrolton Industrial Park	314/344-8170
Casselberry, FL 32707	950 S. Winter park Drive, Suite 300	407/331-0770
Charlotte, NC 28209	5821 Fairview Road, Suite 216	704/554-0010
Columbus, OH 43221	3360 Tremont Rd.	614/457-7450
Des Moines, IA 50313	1704 E. Euclid	515/265-2517
Greenville, NC 27858	523 Clifton Street, Suite 3	919/355-8114
Houston, TX 77014	14505 Torrey Chase Blvd., Suite 108	713/893-6012
Indianapolis, IN 46250	7164 Graham Rd., Suite 120	317/842-7766
Irving, TX 75038	4234 N. Belt Line Rd., Suite C110	214/659-0828
Madison, WI 53719	6441 Enterprise Lane, Suite 109	608/277-8580
Memphis, TN 38157	5050 Poplar Avenue, Suite 1028	901/761-3446
Oak Brook, IL 60521	1200 Harger Road, Suite 707	708/573-1110
Palmer, MA 01069	Fenton Street	413/283-7611
Raleigh, NC 27609	4700 Homewood Court, Suite 108	919/781-8540
San Bernardino, CA 92408	1845 S. Business Center Dr., Suite 130	909/885-8800
Topeka, KS 66614	5883 S.W. 29th Street	913/273-5950
Wheat Ridge, CO 80033	4891 Independence Street, Suite 195	303/431-8999

Other Sales Offices are in Principal Cities.

CP-1060-2 (Replaces CP-1060-1) 11/95 5M AP

Date: 09/15/99 08:19
From: jschluter@contech-cpi.com JSCHLUTE- MAIL
To: MCLEMORE, Shawn RD960SM - DOT1
Copylist: HARKINS, Paul RD960PH - DOT1
Subject: Culvert Advisory Group- comments on issues

<<...>>

Mr. Shawn McLemore, PE September 14, 1999
State Drainage Engineer
Roadway Design Office
Haydon Burns Building
605 Suwannee St.
Mail Station 32
Tallahassee, FL. 32399-0450a

Re. Pipe Culvert Advisory Group

Dear Shawn:

Enclosed are my comments on issues #2 (a deflection limit is not appropriate for metal pipes), #3 (why is that limit 5%) and # 7 (metals and plastics pipes must be separated). I elected to make these comments as a unit because the three issues can't be separated. Issue #7, is the root of all three issues.

We are discussing three quite different pipes when we talk about M304 PVC, M294 and metal pipes. Because of the differences in stiffness (young's modulus - "E") of the materials, the wall profiles are very different. Lower modulus materials use much deeper profiles to get the desired pipe stiffness. This causes the problems that require deflection limits and deflection testing. When NCHRP 20 - 7, task 89 publishes later this year, this will be very evident.

With deep wall profiles, relatively low deflection levels produce comparatively high bending stresses and strains. These lead to cracking problems with strain sensitive resins and local instability (local buckling) problems with thin cross sections. As the NCHRP 4 -24 study demonstrates, both can be problems for some plastic pipes.

While Plastic pipes use different depth profiles for every diameter, metal pipes use a single corrugation and gage over a wide range of sizes. Thus, 12 inch through 48 or 60 inch diameter pipes use the same corrugation, in16 gage. This makes the smaller pipes very stiff. Deflections are usually low.

High modulus metal pipes have shallow wall profiles and develop relatively little strain from deflection bending. That's why a deflection limit isn't necessary.

Sincerely;
Jim Schluter

Florida DOT, Culvert Pipe Advisory Group
Response to Issues:

#2-Deflection testing is not appropriate for metal pipes
#3- Why a 5% limit
#7- Separate metals and plastic pipes

A round pipe, even squashed into a pipe arch retains over 90% of the original (round) flow area while experiencing more than an 20% reduction in rise. A reduction in flow area is not a significant deflection control consideration. However, there are considerable differences in the structural characteristics of the flexible; pipe materials as well as dimensional differences in their wall profiles. These are important considerations. Both support the need for different deflection limits for the various pipe materials.

While metal pipes have been around for over 100 years, deflection (mandrel) testing started with PVC pipes in the early 1970's and has since been limited exclusively to plastic pipes. Deflection controls for plastic pipes are necessary because they:

- Are less stiff than metal pipes. and thus exhibit greater deflections.
- Have material strain capacity and wail profile design considerations that make limiting deflection levels important.

There are significant differences between PVC and HDPE materials as well as in the pipes made from them. M294 wall profiles are deeper, structurally unstable and made from low strain capacity grades of: HDPE. A 5% deflection limit is necessary to eliminate cracking (from bending tension strains) and local pipe wall buckling from excessive compression strain (see NCHRP 4 - 24, table 13, page 39).

Alternatively, PVC pipes have a higher tensile strain capacity as well as structurally stable (compact) wall profiles. Metals are not tensile strain sensitive and their profiles are also compact. Metal pipes don't require specific deflection control limits while deflections are much less a concern with PVC (M304) than with M294 pipes.

When the deflection in any pipe exceeds 10%, the suitability of the backfill and installation process need to be investigated. Beyond. this, each pipe material and pipe wall configuration has its own limit. For equal, long term performance, recommended deflection limits are tabulated below.

Recommended Deflection Limits

- Installation integrity limit (all flexible pipes): 10% max.
- Metals: No specific limit other than the 10% installation integrity limit.
- PVC (M304): 7-112% max. deflection
- HDPE (M294): 5% max. deflection (once the NCHRP 4-24 material cracking requirements are met)

There is no reason for all types of flexible pipes to have a deflection limit, much less for them to have the same deflection limit!

Discussion:

Stress based design methods fall by the wayside where, plastic pipes are concerned. Because of stress relaxation, stresses in the pipe are hard to evaluate. Stress relaxation erroneously appears to make long term considerations moot. However, in service, plastic pipes experience relatively fixed levels of both tensile and compression strain from ring bending (deflection), ring compression and beam bending from any loss of line and grade. When excessive, these strains cause cracking, profile buckling, etc. overtime.

Stiffness

A pipe's stiffness dictates the magnitude of deflections that can be expected from both installation and service loads. Metal pipes are, significantly stiffer than plastic pipes in the sizes that can be deflection tested. Because of this high stiffness, "excessive" deflections are uncommon in metal pipes. Deflection testing is unnecessary.

Profile Design

The differences between these pipe materials significantly effects their profile designs. Each flexible pipe material has its own set of structural properties and tensile strain limits. The materials Young's modulus (E) dictates the profiles used. Generally speaking, pipe walls are designed to give an "adequate" level of pipe stiffness while using a minimum amount of plastic. M294, HDPE pipe materials exhibit an initial modulus in the range of 110,000 to 160,000 psi., while PVC pipe materials have a modulus exceeding 400,000 psi. To economically obtain the necessary pipe stiffness, HDPE wall profiles are much deeper (to maximize the moment of inertia) than those for PVC pipes. Steel and aluminum, with moduli a couple of magnitudes larger than these values, have relatively shallow, compact profiles. The dimensional differences in the wall profiles become significant strain considerations.

Tensile Strain

Each metal and each type and grade of thermoplastic materials have different tensile strain capacities. Metals arecorrugated and then wrapped into a pipe. Often they are then bent into ellipse and pipe-arch shapes, all without damage. Steel and aluminum are unaffected by tensile strains at least those generated in piping applications. With plastics, on the other hand, tensile strains must be limited to control, cracking and rapture.

AASHTO correctly limits PVC pipe materials to those that exhibit minimum 3-1/2 to 5% long-term strain capacities

.
Unfortunately, AASHTO (Bridge Specification) strain limits for designing M294 pipes are based on the original AASHTO material that had a Hydrostatic design basis (HDB). This material has never been a M294 product requirement. AASHTO

did not change the M294 Bridge Specification material design properties when they changed the cell class to match M294.
HDPE materials with strain capacities of even 3 - 4% or more can meet HDB requirements. Current M294 materials are much more strain sensitive. The need to control strain cracking in M294 pipes is made obvious in the NCHRP 4-24, "Drexel study," results (see table 13, page 39).

Tensile strains in pipes acting in ring compression come from loss of line and grade, stone impingements pipe deflection, etc. Ring bending strain from pipe deflection is relatively easy to evaluate. It can be expressed as:

$$\varepsilon = Df\,(C/r)\,\Delta \qquad \text{equation 1}$$

Where:

ε = Bending strain due to deflection (%)
Df = a factor that relates the deflected shape pipe's shape
= 4.27 for relatively stiff (100 psi) pipes
= 6.0 for less stiff, M294 and M304 pipes
Δ = pipe deflection (%)
C = extreme fiber distance of the wall profile
R =mean radius of the pipe

To evaluate tensile strains from deflection bending to control cracking, assume the pipe is under low cover (ring compression is minimal) with a 5%, construction induced, pipe deflection. Using AASHTO pipe wall properties (LRFD Bridge Spec. section 12, tables Al2-4, Al2-12 and A12-13) the bending strains can be calculated directly from equation 1. Five percent deflection produces tensile bending strains of 0.5%,2.7% and 6.1% in 24 inch steel (2-2/3x 1/2), M304 PVC and M294 HDPE pipes, respectively. While tensile strain levels are within the strain capacity of the metal and PVC materials, tensile strain from 5% deflection indicate cracking problems in M294 pipes.

Compression Strain and Buckling
AASHTO has long required all metal pipe profiles to be fully stable (i.e. compact) in, compression. This has not been the case for plastic pipes. NCHRP 4-24(see table 13, page 39 and site reports E, F, K, O, U and W), the Penn. Deep Burial study and many other field evaluations provide examples of local buckles in M294 pipe walls.

NCHRP 20-7, Task 89, to publish later this year, will provide a means to calculate the compression strain level required to induce local buckling in each specific profile. However, AASHTO has long handled metal pipes appropriately. Shallow profiles and extrusion limitations have avoided producing too thin, unstable PVC profiles.

While a specific wall profile will buckle at about the same level of total compression strain, regardless of the pipe material, the material is important. Assuming identical wall profiles in ring compression, high modulus materials strain less and thus are more stable in buckling, than lower modulus materials. PVC with about 5 times the

50 year modulus as HDPE, would see 20% of the ring compression strain experienced by the HDPE profile. Ring compression strains in this same profile made from steel or aluminum is insignificant (negligible) because of the high moduli.

From a local buckling standpoint, the least serviceable pipe:
- Has a thin wall profile with high slenderness ratios (is not compact).
- Develops high ring bending strains when deflected (i.e. a deep profile).
- Is made from a material with low resistance to ring compressive strain (low modulus and wall area combination).

Using design properties from the above AASHTO tables, and material properties from table. 12.12.3.3-1, 24 inch M304 PVC and M294 HDPE pipes, under 10 feet of cover will experience ring compression strains of 0.4% and 1.8% respectively. The combined ring and bending compression strains become 0.5, 3.1 % and 7.9% for the respective steel, PVC and HDPE pipes.

Unlike the other "flexible pipes", deflected 5% under 10 feet of cover, compression strains developed from either ring compression or pipe deflection in M294 pipes are more than twice those experienced in other flexible pipes!

Conclusions

There are easily evaluated differences between "flexible pipes". Their materials are not the same. Their wall profiles are different. In the same service conditions, their strain levels are very different.

- Metal pipes, which are not tensile strain sensitive (cracking), and have structurally stable profiles, experience less strain than the other "flexible pipes". Even if they are deflected, they do not experience significant bending strains and <u>do not need a specific deflection limit:</u>
- AASHTO M294 pipes require stringent deflection controls. They have deep profiles, generating the largest deflection bending strains, yet they:
  *Are made from the least crack resistant material.
  *Are the most susceptible to local buckling with the highest combined ring compression and bending strains and the highest slenderness ratios.
  *<u>Are not serviceable at 5% deflection</u> unless the NCHRP 4-24 materials are required.
- AASHTO PVC pipes are limited to high. strain capacity materials. They use relatively shallow profiles and do not develop excessive deflection bending strains. The 7-1/2% deflection limit originally developed for PVC pipes is totally serviceable and is recommended as the PVC pipe deflection limit for Florida DOT use. Even at 7-1/2% deflection, PVC pipes provide a substantially greater factor of safety than do M294 pipes at 5% deflection.

James C Schluter
For the Uni-Bell PVC pipe Association