CHAPTER seven

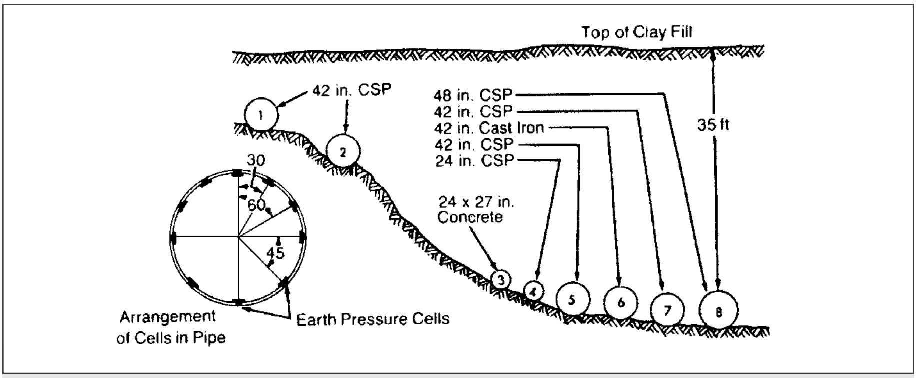
Structural Design

INTRODUCTION

Corrugated steel pipe has long been recognized for superior strength to withstand both high live loads and deep burial soil loads. Research over the last several decades has shown that this strength is the result of a complex composite behavior – the interaction of soil with the steel structure. In spite of this complex behavior, simple conservative design methods have been developed and are in widespread use. These are the methods generally adopted by specifying agencies such as the American Association of State Highway and Transportation Officials (AASHTO) and the American Society for Testing and Materials (ASTM), as discussed further in this chapter. However, CSP products can also be designed and evaluated by the newer evolving methods, such as Finite Element Analysis (FEA). The CANDE computer program and the SCI (Soil Culvert Interaction) design method represent applications of FEA to CSP design. A design method developed by the American Iron and Steel Institute (AISI), which is described in detail herein, has been used successfully for standard pipe, arches, and pipe arches for many years.

It has been well established that the main function of the soil is to provide lateral support to the steel pipe, maintaining its shape so the pipe wall acts as a compression ring. Design checks are made to ensure that the pipe wall has the required resistance to crushing and instability. Bending moments are generally disregarded except for certain types of structures such as box culverts, deep corrugated structures, and some long span structures.

When corrugated steel pipe was introduced over 100 years ago, early strength tests were quite crude and included circus elephants balanced on unburied pipe and threshing rigs placed over shallow buried pipe. However, it wasn't long before laboratory hydraulic and sand box tests were performed by Talbot, Fowler and others, as well as evaluations under deep fills by Iowa State University (Marston, Spangler et al, 1913) and the University of North Carolina (Braune, Cain, Janda). Large scale field tests under the Illinois Central



■ **Figure 7.2** American Railway Engineering Association tests on culvert pipe at Farina, Illinois. Readings were taken on earth pressure cells.

Railroad (1923) demonstrated early on that corrugated steel pipe carries only a portion of the expected load. These tests indicated that the pipe typically carried about 60 percent of the load and the backfill envelope carried the other 40 percent.

As mentioned above, finite element analysis has been used in more recent times to investigate the behavior of corrugated steel pipe. With this method the pipe and the surrounding backfill are broken into discrete structural elements with known properties and a computerized matrix analysis is used to solve for the forces in each element. Thus, detailed information is obtained on forces, bending moments, and soil pressures. This is the basis of the computer program CANDE (Culvert Analysis and Design), initially developed by M. G. Katona et al for the Federal Highway Administration (FHWA) in 1976. Continuing interest in this approach led to improved versions, culminating with the development of a new user friendly version of CANDE released in 2008.

The SCI (Soil Culvert Interaction) method developed by J. M. Duncan et al in 1978 is also based on the finite element approach. In this case, Prof. Duncan and colleagues ran numerous cases on the computer and synthesized the results into a set of equations and charts to determine maximum force and bending moment. Although lengthy, this method can be used to obtain a hand solution. It is particularly useful for investigating minimum cover situations with high live loads. This work is the basis of the method specified for design in the Canadian Highway Bridge Design Code (CHBDC).

In spite of the strength derived from the backfill envelope, much of the design emphasis today still concentrates on selecting a steel structure with adequate strength to carry the loads and an adequate stiffness to allow it to be installed while maintaining its shape. While the backfill envelope is a substantial portion of the final strength, it need only be adequate to support the corrugated steel pipe, allowing it to function in ring compression. The design procedures found in the specifications of AASHTO and ASTM are based on this concept.

Three design procedures are available in AASHTO. The traditional Service Load Design (SLD) procedure, also known as Allowable Stress Design (ASD) and Load Factor Design (LFD) are both found in the AASHTO Standard Specifications for Highway Bridges. Load and Resistance Factor Design (LRFD) is found in the AASHTO LRFD Bridge Design Specifications. AASHTO's goal is to use LRFD design for all new construction. ASTM Standard Practice A796/A796M includes both ASD and LRFD as alternatives. In many cases, the result obtained by each of these procedures is similar when similar loadings are used.

SALIENT RESEARCH

In addition to the development of design methods noted previously, there have been many additional studies made on the performance of corrugated steel pipe. Three of these salient research studies are noted on the following pages.

Utah State Test Program

Extensive research was conducted at Utah State University by Dr. R. K. Watkins and associates during 1967 – 1970 under the sponsorship of the American Iron and Steel Institute. This was the first time that numerous full-size CSP installed in a backfill were loaded to their ultimate performance limit in a field laboratory. Approximately 130 pipes, 20 feet long, in sizes from 24 inch to 60 inch diameter were loaded to their performance limit in low grade soil backfills compacted from 70% to 99% standard AASHTO density. Riveted, spot welded and helical pipe fabrications were included in both 2-2/3 x 1/2 inch and 3 x 1 inch corrugations. Confined compression tests were made on six different soils to correlate results to commonly used backfill materials.

The pipes were installed and loaded in a 24 foot long, 15 foot wide and 18 foot high test cell constructed of 5/8 inch steel plate of elliptic cross-section. (Figure 7.3). Steel trusses pinned to the top of the cell walls supported hydraulic cylinders, which applied a uniform pressure up to 20,000 psf on the upper surface of the soil. The backfill material was a silty sand installed in lifts and compacted with manually operated mechanical compactors. Compactive effort and moisture contents were varied to obtain densities from 70% to 99% standard AASHTO.

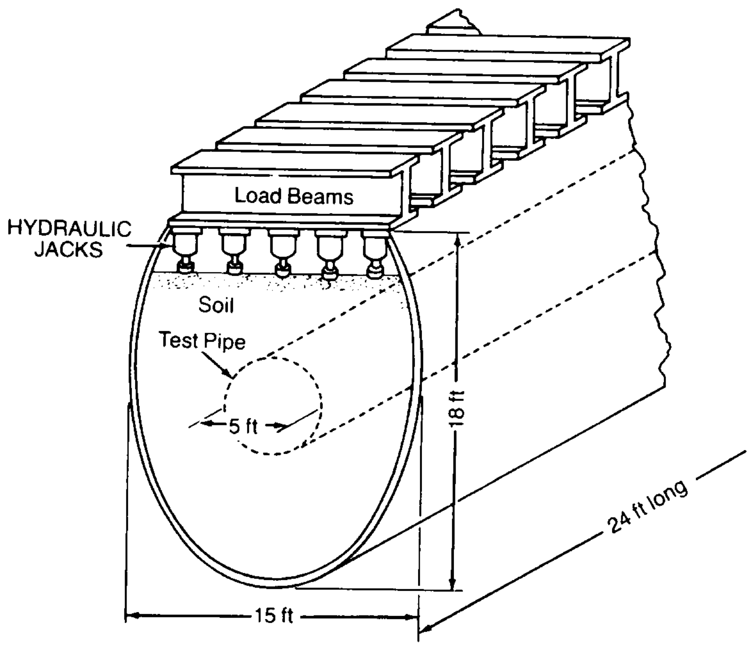


Figure 7.3 Diagramatic sketch of test cell showing method of applying load with hydraulic jacks. The cell was buttressed with reinforced concrete retaining walls and wing walls. Test were performed by Engineering Experiment Station of Utah State University for American Iron and Steel Institute.

After backfill, steel plates were placed on top of the soil to improve the bearing of the hydraulic rams. Load was applied in planned increments with the following readings taken: loading force, soil pressure on the pipe, vertical pipe deflection, and ring profile. Testing was terminated when the hydraulic ram pressure could no longer be increased. It is significant that, in this condition, the pipe could continue to deform in the test cell. Soil arching made the structure stable under applied loads much higher than those recorded in the test.

Results of the test plotted for five degrees of standard AASHTO density for the backfill are shown in Figure 7.4. Assuming the load applied by the hydraulic rams equals the pressure acting on the pipe, the ultimate steel stresses are plotted on a buckling chart. It is

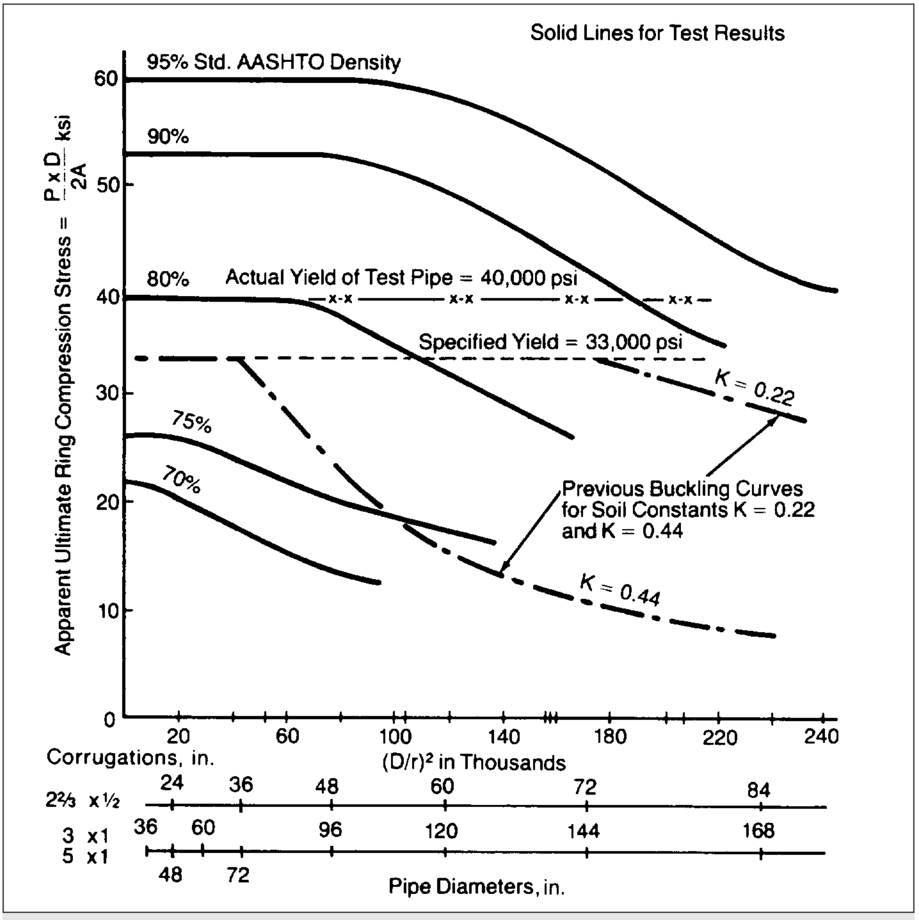
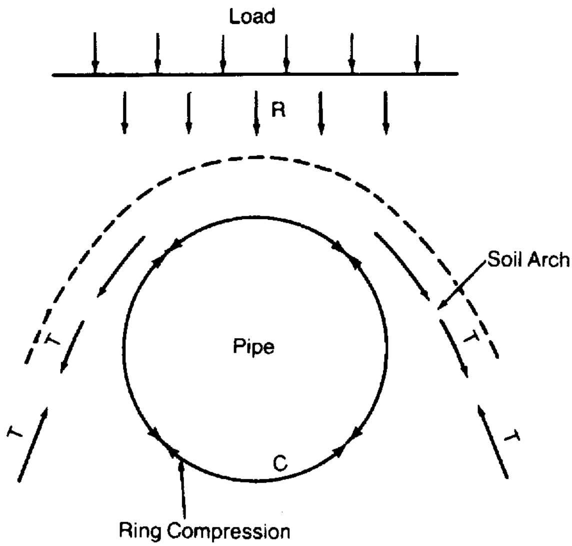


Figure 7.4 Results of Utah loading tests on corrugated steel pipe, showing apparent ultimate ring compression stress as a function of diameter and corrugations of various values of soil density determined by AASHTO standards.

immediately apparent that most of the steel stresses calculated by this criterion, are fictitious because they greatly exceed the yield point. This is explained by Figure 7.5, which illustrates how the applied load is actually carried in part by the soil arch formed in the compacted backfill as load is applied thereto and pipe and soil strains occur. Because the stresses on the ordinate in Figure 7.4 are calculated from the total load, with no reduction taken for the load carried by the soil in arching action, they are designated as apparent stresses.



■ **Figure 7.5** Diagram showing how load Pv is partly carried by means of a soil arch over the pipe.

A prime objective of the Utah program was to establish a practical correlation between backfill density and pipe behavior. The Utah program provided, for the first time, ultimate performance data on full scale soil-steel installations, utilizing a low-grade backfill soil and normal field methods and equipment. The Utah research confirmed what has been observed in field installations for decades. The quality and density of backfill required to permit the pipe to carry high stress levels, to or near the yield point, is of ordinary magnitude comparable to current common practices for most highway embankments. The test results (Figure 7.4) are plotted on an outdated buckling stress graph where dashed lines show buckling curves that were correlated to an unrealistically high level of soil compaction. The wide disparity between the K = 0.44 curve for 85% compaction and the actual performance results at 85% is readily apparent.

This research established a zone of "critical density" between 70% and 80% standard AASHTO density. The critical density represents a level of backfill compaction that will allow the pipe to carry ring compression stress at or near the yield point. At a conservative value of 80% standard AASHTO density, there is enough soil support to preclude deflection collapse and the pipe carries stress near the yield point.

The test soil used in the Utah research was considered a low grade material for pipe backfill. Specifically, it was a silty sand that bulked very easily and could be placed to a wide range of standard densities, something very necessary to a good test program. The tests confirmed that pipe backfill can be designed, specified, and evaluated on the basis of percent standard AASHTO density, regardless of soil type. The only exceptions are unstable soils, such as those which turn plastic with moisture, even though they have been well compacted to 85% or more standard AASHTO and confined in the fill. Such soils would, of course, not be suitable for a high embankment base, much less for pipe backfill.

Caltrans Tests

A significant research study led by A. E. Bacher of Caltrans in 1975 provided important data on a full scale installation under high fills. This project involved a 10 foot diameter structural plate pipe with a 0.109 inch wall, drastically under-designed to magnify the response and expected to fail. It was loaded with a fill of almost 200 feet, likely the record for this type of test. In addition to demonstrating the remarkable strength of the pipe, measurements of wall stresses and soil pressures contributed to the body of knowledge and gave confidence to design methods used by specifying agencies.

PRODUCT DESIGN PROPERTIES

This section provides properties for the design of all corrugated steel products. Mechanical properties are summarized in Table 7.1 and sectional properties are provided in Table 7.2. Ultimate longitudinal seam strengths are listed in Table 7.3 for riveted CSP, in Table 7.4A for bolted structural plate and in Table 7.4B for deep corrugated plate. Flexibility factors are provided in Table 7.5. The application of this information is discussed subsequently.

Table 7.1

Mechanical properties of products for design

Product	Minimum Yield Point, psi	Minimum Tensile Strength, psi	Minimum Elongation in 2 in.	Modulus of Elasticity, psi
6x2, Type 33	33,000	45,000	25	30,000,000
6x2, Type 38	38,000	48,000	25	30,000,000
15 x 5 1/2 and 16 x 6	44,000	55,000	25	30,000,000
All Other	33,000	45,000	20	30,000,000

Table 7.2

Sectional properties for corrugated steel pipe products

	Specified Thickness, in.											
Corrugation in.	0.052	0.064	0.079	0.109 0.111*	0.138 0.140*	0.168 0.170*	0.188	0.218	0.249	0.280	0.310 0.318*	0.389 0.380*
Moment of Inertia, I x 10^{-3} (in.^{4}/in.)												
1-1/2 x 1/4	0.343	0.439	0.566	0.857	1.205	1.635						
2 x 1/2	1.533	1.941	2.458	3.541	4.712	5.992						
2-2/3 x 1/2	1.500	1.892	2.392	3.425	4.533	5.725						
3 x 1	6.892	8.658	10.883	15.458	20.175	25.083						
5 x 1		8.850	11.092	15.650	20.317	25.092						
6 x 2				60.41	78.17	96.17	108.00	126.92	146.17	165.83	190.00	232.00
15 x 5 1/2					714.63	874.62	978.64	1143.59	1308.42	1472.17		
3/4 x 3/4x 7 1/2**		2.821	3.701	5.537	7.433							
3/4 x 1x 11 1/2**		4.580	6.080	9.260								
3/4 x 1x 8 1/2**		5.979	7.913	11.983								
Area of Wall Cross Section, A (in.^{2}/ft)												
1-1/2 x 1/4	0.608	0.761	0.950	1.331	1.712	2.093						
2 x 1/2	0.652	0.815	1.019	1.428	1.838	2.249						
2-2/3 x 1/2	0.619	0.775	0.968	1.356	1.744	2.133						
3 x 1	0.711	0.890	1.113	1.560	2.008	2.458						
5 x 1		0.794	0.992	1.390	1.788	2.186						
6 x 2				1.556	2.003	2.449	2.739	3.199	3.658	4.119	4.671	5.613
15 x 5 1/2					2.260	2.762	3.088	3.604	4.118	4.633		
3/4 x 3/4x 7 1/2**		0.509	0.712	1.184	1.717							
3/4 x 1x 11 1/2**		0.374	0.524	0.883								
3/4 x 1x 8 1/2**		0.499	0.694	1.149								
Radius of Gyration, r (in.)												
1-1/2 x 1/4	0.0824	0.0832	0.0846	0.0879	0.0919	0.0967						
2 x 1/2	0.1682	0.1690	0.1700	0.1725	0.1754	0.1788						
2-2/3 x 1/2	0.1707	0.1712	0.1721	0.1741	0.1766	0.1795						
3 x 1	0.3410	0.3417	0.3427	0.3448	0.3472	0.3499						
5 x 1		0.3657	0.3663	0.3677	0.3693	0.3711						
6 x 2				0.682	0.684	0.686	0.688	0.690	0.692	0.695	0.698	0.704
15 x 5 1/2					1.948	1.949	1.950	1.952	1.953	1.954	1.953	1.954
3/4 x 3/4x 7 1/2**		0.258	0.250	0.237	0.228							
3/4 x 1x 11 1/2**		0.383	0.373	0.355								
3/4 x 1x 8 1/2**		0.379	0.370	0.354								

* Where two thicknesses are shown, the top value is for corrugated steel pipe and the bottom value is for steel structural plate

** Ribbed pipe; properties are effective values.

For properties of the 16 x 6 in. corrugation, see Table 2.15.

Table 7.3

Ultimate longitudinal seam strength (lbs/ft) for CSP*

CSP Thickness, in.	3 x 1 in.	2-2/3 x 1/2 in. Riveted Seams			
		5/16 in. Single Rivet	3/8 in. Single Rivet	5/16 in. Double Rivet	3/8 in. Double Rivet
0.064	28,700	16,700		21,600	
0.079	35,700	18,200		29,800	
0.109	53,000 †		23,400		46,800 †
0.138	63,700		24,500		49,000
0.168	70,700		25,600		51,300

* See Chapter 2 for standard seam details.
† Seams develop full yield strength of pipe wall at 33,000 psi.

Table 7.4A

Ultimate longitudinal seam strength for 6 x 2 in. structural plate*

Structural Plate Thickness, in.	Bolt Diameter, in.	Bolts per ft	Seam Strength, lbs/ft**
0.111	3/4	4	43,000
0.140	3/4	4	62,000
0.170	3/4	4	81,000 †
0.188	3/4	4	93,000 †
0.218	3/4	4	112,000 † ‡
0.249	3/4	4	132,000 † ‡
0.280	3/4	4	144,000 † ‡
0.280	3/4	6	180,000 † ‡
0.280	3/4	8	194,000 † ‡
0.318	7/8	8	235,000 † ‡
0.380	7/8	8	285,000 † ‡

* See Chapter 2 for seam details.
** Industry recognized seam strengths for 6 x 2 in. are published in ASTM A796.
† Seams develop full yield strength of pipe wall at 33,000 psi.
‡ Seams develop full yield strength of pipe wall at 38,000 psi.

Table 7.4B

Ultimate longitudinal seam strength for 15 x 5 1/2 in. deep corrugated*

Structural Plate Thickness, in.	Bolt Diameter, in.	Seam Strength, lbs/ft**
0.140	3/4	66,000
0.170	3/4	87,000
0.188	3/4	102,000
0.218	3/4	127,000
0.249	3/4	144,000
0.280	3/4	144,000
0.249	7/8	159,000
0.280	7/8	177,000

* See Chapter 2 for seam details; 4.8 bolts per foot.
** Industry recognized seam strengths for 15 x 5 1/2 are published in ASTM A796.

Table 7.4C

Ultimate longitudinal seam strength for 16 x 6 in. deep corrugated*

Structural Plate Thickness, in.	Bolt Diameter, in.	Seam Strength, lbs/ft**
0.174	3/4	85,000
0.202	3/4	124,000
0.241	3/4	163,000
0.281	3/4	165,000
0.320	3/4	165,000
0.281	7/8	201,000
0.320	7/8	209,000

* See Chapter 2 for seam details; 6 bolts per corrugation.

Table 7.5

Recommended limits of Flexibility Factor (FF, in./lb) for round pipe*

2-2/3 x 1/2 Corrugation			
Embankment installations	FF = 0.0433		
Trench installations	FF = 0.0433 for diameters 42 in. or less		
	FF = 0.060 for diameters 48 – 72 in.		
	FF = 0.080 for diameters 78 in. or greater.		
3 x 1 and 5 x 1 Corrugations			
Embankment installations	FF = 0.0433		
Trench installations	FF = 0.060		
Spiral Rib Profiles			
Profile:	3/4 x 3/4 x 7-1/2	3/4 x 1 x 11-1/2	3/4 x 1 x 8-1/2
Type I (embankment) installations:	$0.217\ I^{1/3}$	$0.140\ I^{1/3}$	$0.140\ I^{1/3}$
Type II (trench) installations:	$0.263\ I^{1/3}$	$0.163\ I^{1/3}$	$0.163\ I^{1/3}$
Type III (special trench) installations:	$0.367\ I^{1/3}$	$0.220\ I^{1/3}$	$0.262\ I^{1/3}$
Structural Plate			
6 x 2 corrugation (either trench or embankment):	FF = 0.020		
15 x 5 1/2 corrugation (either trench or embankment):	FF = 0.010		

* Note: For pipe arch, arch, and underpass shapes where rise does not exceed 2/3 of span, the flexibility factor limit is increased: FF = 1.5 FF limit for round pipe.

SOIL CLASSIFICATION SYSTEMS

In selecting soils for backfill, reference is often made to the grouping of soils according to the ASTM United Classification System (UCS) or to the AASHTO M145 system. Table 7.6 provides soil descriptions and a comparison of these systems.

Table 7.6

Soil types by UCS and AASHTO classifications

UCS Soil Classification	AASHTO M 145 Soil Classification		Soil Description
	Group	Subgroup	
	A1		
GW GP SP		A1-a	Well graded gravel
GM SM SP SM		A1-b	Gravelly sand
	A2		
GM SM ML SP GP		A2-4	Sand and gravel with low plasticity silt
SC GC GM		A2-5	Sand and gravels with elastic silt
SC GC		A2-6	Sands with clay fines
SC GC		A2-7	Sands with highly plastic clay fines
SW SP SM	A3		Fine sands, such as beach sand
ML CL OL	A4		Low compressibility silts
MH OH ML OL	A5		High compressibility silts
CL ML CH	A6		Low to medium compressibility silts
OL OH CH CM CL	A7		High compressibility silts and clays
PT OH	A8		Peat and organics; Not suitable as backfill

DESIGN OF STANDARD STRUCTURES

This section presents procedures for the design of standard structures. In this context, standard structures generally refers to round pipe and arches with a maximum span of 26 feet as well as pipe arches and underpasses with a maximum span of 21 feet. Specifically excluded are long span structures, box culverts, and deep corrugated structures.

Backfill Design for Standard Structures

This section discusses backfill design for typical installations. Backfill requirements for long span structures, box culverts and deep corrugated structures are more demanding as treated later in this chapter.

Requirements for selecting and placing backfill material around and near a pipe are similar to those for selecting a roadway embankment fill. The main differences in requirements are due to the fact that the pipe generates more lateral pressure than the earth within the embankment would if no structure existed. Also, the backfill material must be placed and compacted around the pipe without distorting its shape. However, in the end, the quality of the backfill may be dictated by the need to support the pavement over the conduit.

The quality of the backfill is characterized by the soil stiffness, a property that results from the nature of the soil and the level of compaction. See Chapter 10, Installation, for further information on backfill materials and placement. The best backfill materials are non-plastic sands and gravel (GW, GP, GM, SW). Compaction to a minimum density of 90 percent of standard Proctor is generally sufficient.

Often, the backfill for standard structures may be selected from the materials available at the job site. Although highly plastic or organic soils are unsuitable, materials with some degree of plasticity (SM GM, etc.) can be used in most instances. The stiffness of corrugated steel pipe allows these materials to be placed and compacted to the density necessary to support the pipe. AASHTO requires that backfill materials meet AASHTO M 145 requirements for A1, A2 or A3 materials, compacted to 90 percent of standard Proctor density.

The height of final soil cover and the stiffness of the pipe influence the selection of materials. The soil load actually carried by the pipe is affected by the quality (stiffness) of the backfill. Obviously, higher covers dictate better backfill materials. They not only reduce the loads on the pipe, but also provide better support and improve structural strength.

Figure 7.6 By far the most economical choice, this 19 foot diameter, corrugated steel structural plate storm sewer, using crushed rock backfill, carries 90 feet of cover.

As pipes get larger and become more flexible, the choice of materials again becomes more important. The backfill must be compacted sufficiently to provide the necessary pipe support. Well-graded (densely graded), clean, non-plastic materials compact more easily. The reduced compaction forces they require have less effect on the pipe's shape during backfill. These materials also provide more support at a lower density, again reducing the compaction effort required. Because their jagged shape provides a degree of mechanical lock between soil particles, angular materials such as crushed rock typically offer excellent support with relatively minimum compaction effort.

Backfill typically extends to 12 inches above the pipe. A typical specification for pipe backfill under highway pavement may read as follows:

> *Backfill material to a distance of 12 inches above the pipe shall meet the requirements of AASHTO M 145 for A1, A2 or A3 materials. The backfill shall be placed and compacted in 8 to 12 inches loose lift thicknesses to 90% standard Proctor (90% AASHTO T 99) density.*

All state Departments of Transportation have backfill specifications for the installation of CSP under roadways. These specifications recognize local conditions and can provide valuable guidance for the engineer on various pipe projects.

Unlike rigid pipe such as concrete, steel pipe is typically designed to carry the full soil prism above the pipe. There is no concern that excessively wide trenches increase the load on the pipe. On the other hand, it is desirable to minimize trench width to reduce installation cost.

The required trench width, or the minimum backfill width in a normal highway embankment, depends on the backfill material and the compaction equipment used. In trench installations, the backfill must extend from trench wall to trench wall. In sound trench conditions or highway embankment applications, the trench only needs to be wide enough to allow the material to be placed under the haunch and compacted to the specified density. While backfill and trench widths often call for 2 feet on either side of the pipe, crushed stone, flowable gravel and similar soils can be placed in a narrower width.

ASTM A 798, *Standard Practice for Installing Factory-Made Corrugated Steel Pipe for Sewers and Other Installations*, permits the placement of cement slurries or controlled low strength materials with a trench width as little as 6 inches greater than the pipe span. An alternative material, cement stabilized sand, provides excellent support but must be used in a trench width adequate to allow placement and compaction.

With regard to installation demands, the required stiffness of the pipe decreases as the quality of the backfill increases. As subsequently discussed, the design of ribbed pipe takes advantage of this characteristic by defining three different soil conditions, referred to as Type I, Type II, and Type III installations.

Foundation Design for Standard Structures

The supporting soil beneath pipe is generally referred to as the pipe foundation. The foundation under the pipe is not of great concern in most cases. However, standard designs assume the foundation carries the full soil column above the pipe without appreciable settlement. If differential settlement between the pipe and the adjacent backfill does occur, it is desirable for the pipe to settle more than the backfill. This helps to defray any drag down loads that otherwise could occur.

The backfill load on the foundation typically is calculated as the height of the soil column above the pipe, H, times the density, γ, of the backfill and embankment or trench fill above it. Thus, the bearing strength of the foundation should equal or exceed γH. However, pipe arch and underpass shapes require additional considerations. Due to their small radius haunches, these shapes require higher foundation bearing strength levels. Means of determining foundation requirements for these structures are included later in this chapter.

Pipe in a full trench condition generally benefits from a foundation that has been naturally consolidated by the existing soil cover. Where soft foundations are encountered in a trench, they need to be improved by over-excavating and rebuilding the foundation with compacted granular material across the full trench width. Often this consists mostly of removing sloughed material and replacing it with compacted backfill.

Where soft foundations are encountered in embankment conditions, an improved foundation and backfill width equal to one pipe diameter on each side of the pipe is typically specified. This provides a sizeable block of backfill that settles with the pipe and helps ensure adequate pipe support.

Where rock foundations are encountered, it is typical to over-excavate to a maximum of 24 inches and then place 1/2 inch of compacted backfill for each foot of cover between the pipe and the rock.

On either native or improved foundations, a bed of loose material is placed to a minimum thickness of twice the corrugation depth to allow the corrugated pipe wall to nest and become fully supported.

Loads on Standard Structures

The first consideration in structural design is the evaluation of the loads on the pipe. Buried pipe is subject to two principal types of loads:

(1) Dead loads – developed by the embankment or trench fill materials, plus stationary, superimposed surface loads, either uniform or concentrated; and
(2) Live loads – moving loads, including impact, such as from highways, railways, or airplanes.

Dead Loads

The maximum dead load is considered to be the full soil prism over the pipe. The unit pressure of this prism acting on the horizontal plane at the top of pipe is equal to:

$$DL = \gamma H \qquad (1)$$

where

γ = Unit weight of soil, pcf
H = Height of fill over pipe, ft
DL = Dead load pressure, psf

Live Loads

In practice, live loads are typically due to highway, railway, aircraft or construction traffic. Live load pressures on pipe are usually determined from charts initially developed by the corrugated steel pipe industry and adopted by various specifying agencies. Figures 7.7 and 7.8 Show the variation of pressure with depth for a highway and a railway loading. These charts modify the theoretical distribution of live loads to values compatible with observed performance of structures under relatively low covers. Table 7.7 provides tabular values of live load pressure.

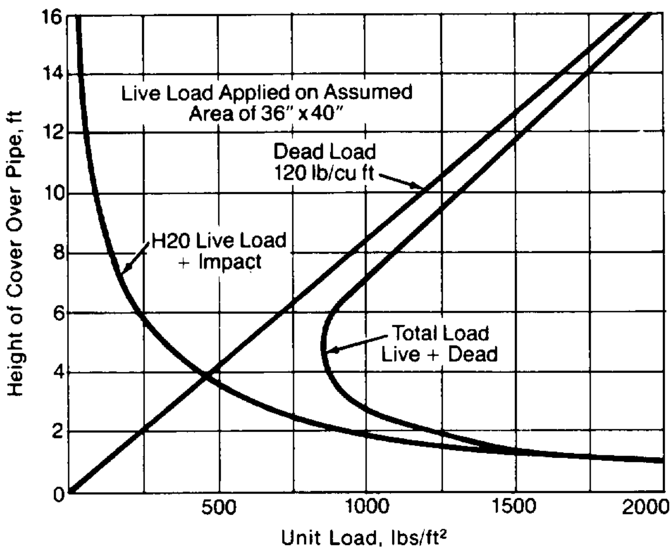
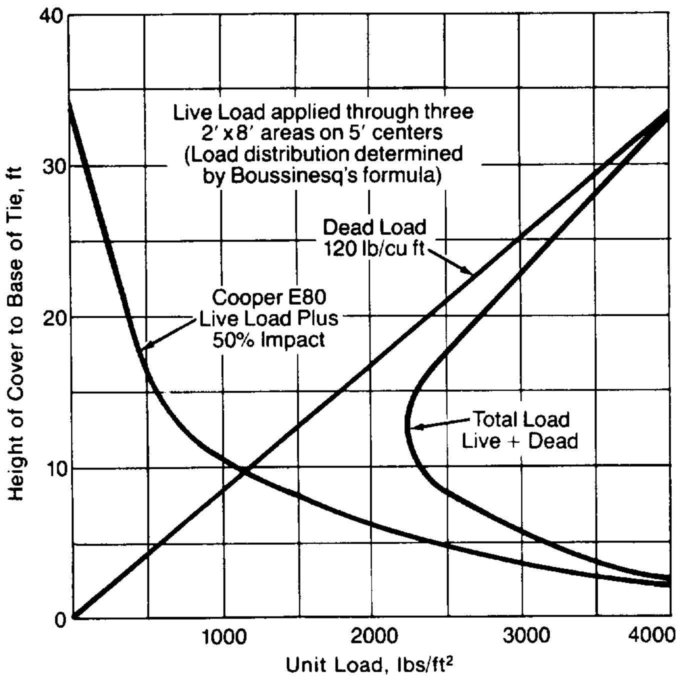


Figure 7.7 Combined H20 highway live load and dead load is a minimum at about 5 ft of cover. Live load is applied through a pavement of 1 ft thick.



■ **Figure 7.8** Railroad live load, Cooper E 80, combined with dead load is a minimum at about 12 ft. Live load is applied through three 2 ft x 8 ft areas on 5 ft centers.

Table 7.7

Highway and railway live loads (LL)*

Depth of Cover, ft	Highway Loading** Load, psf		Railway E 80 Loading**	
	H20	H25	Depthof Cover, ft	Load psf
1	1800	2280	2	3800
2	800	1150	5	2400
3	600	720	8	1600
4	400	470	10	1100
5	250	330	12	800
6	200	240	15	600
7	175	180	20	300
8	100	140	30	100
9	–	110	–	–

* See ASTM A 796.
** Neglect live load when less than 100 psf; use dead load only.

The live load pressure from other concentrated loads is often calculated on the basis of a load distribution slope of 1/2 to 1 (horizontal to vertical). A method is also provided in the AASHTO *LRFD Bridge Design Specifications*.

Minimum Covers

Minimum covers for H20 and H25 highway loads are taken as the greater of span/8 or 12 inches for all corrugated steel pipe except spiral rib pipe. For spiral rib pipe, this becomes span/4, but not less than 12 inches In all cases, the minimum cover is measured from the top (inside rise) of the pipe to the bottom of the asphalt pavement course and to the top of rigid pavements.

While asphalt does at least as good a job of distributing wheel loads as soil, it is not counted in the minimum cover. The asphalt layer is often very thick and must be placed and compacted in lifts with heavy equipment which would then be on the pipe with inadequate cover. Considering the asphalt thickness as part of the minimum cover could lead to construction problems.

Minimum covers for E 80 railroad loads are twice those for H20 and H25 highway loads, except for structural plate structures. Because of its deeper corrugations and greater bending strength, minimum cover is taken as span/5 or 24 inches, whichever is greater. E 80 minimum covers are measured from the top (inside rise) of the corrugated steel structure to the bottom of the tie.

Guidelines for minimum covers for construction loads are shown in Table 7.8. In some cases the minimum cover provided for design live loads may not be sufficient for the heavier loads from construction equipment. In such cases the construction contractor must provide any additional cover required to avoid damage to the pipe.

Table 7.8

General guidelines for minimum cover required
for heavy off-road construction equipment

Pipe Span, in.	Minimum Cover (ft) for Indicted Axle Loads (kips)*			
	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.

The significance of aircraft loads is principally in the area of required minimum cover. Airplanes weighing up to 1-1/4 million pounds and using tire pressures of 225 psi have been used to develop minimum cover tables for the Federal Aviation Administration. See Tables AISI-24 through AISI-27.

Structural Design of Standard Structures by the AISI Method

This section presents a design method for standard structures known as the AISI method. Considerations applicable to standard pipe arches and arches follow in the next section. AASHTO design methods are presented subsequently. As previously stated, standard structures include round pipe and arches with a maximum span of 26 feet as well as pipe arches and underpasses with a maximum span of 21 feet. Specifically excluded are long span structures, box culverts, and deep corrugated structures.

The structural design process consists of the following steps:

1. Select the backfill and other soil densities required or expected.
2. Calculate the design pressure.
3. Compute the compression in the pipe wall.
4. Select the allowable compressive stress.
5. Determine the corrugated steel pipe thickness required.
6. Check minimum handling stiffness.
7. For bolted or riveted pipe only: check seam strength.
8. Pipe arch only: check corner bearing pressure.
9. Arch only: check rise to span ratio (≥ 0.3) and calculate footing reactions.

1. Backfill Density

Select a percent compaction of pipe backfill for design. The value chosen should reflect the height of soil cover on the structure and the backfill quality that reasonably can be expected. The recommended minimum value for routine use in typical installations is 85%. It is good practice to specify a 90% compaction level for installation when 85% is used for design. However, for more important structures under higher cover situations, it is recommended the designer select a higher quality backfill and require the same in construction. This may increase the allowable fill height or save on thickness of the pipe wall.

2. Design Pressure

When the height of cover is equal to or greater than the span or diameter of the structure, enter the load reduction factor from the chart in Figure 7.9, to determine the percentage of the total load acting on the steel. For routine use, the 85% Proctor density value will provide a factor of 0.86. The load reduction factor, K, is applied to the total load to obtain the design pressure, P_v, acting on the steel. If the height of cover is less than one pipe diameter, the total load is assumed to act on the pipe (K = 1). Also, in reclaim (conveyor) tunnel applications, if the ore pile is drawn down and built back up repeatedly, use K = 1.

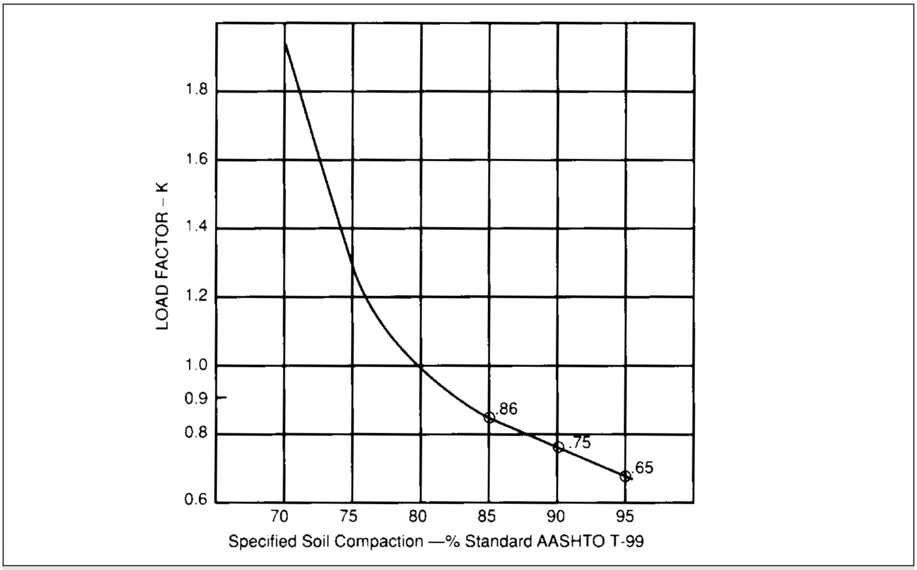


Figure 7.9 Load factors for corrugated steel pipe for backfill compacted to AASHTO T-99 density.

The total load on the pipe becomes:

$$P_v = K\,(DL + LL),\ \text{when } H \geq S \qquad (2a)$$

$$P_v = (DL + LL),\ \text{when } H < S \qquad (2b)$$

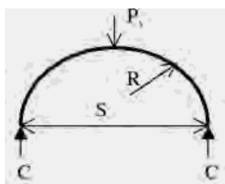
where

P_v = Design pressure, psf
K = Load reduction factor
DL = Dead load, psf
LL = Live load, psf
H = Height of cover, ft
S = Diameter or span, ft

3. Ring Compression

From fundamental mechanics, the compressive thrust in the conduit wall, *C*, is equal to the radial pressure, *P*, acting on the wall multiplied by the wall radius, *R*, or: $C = PR$. This ring compression thrust, which is the force carried by the steel, acts tangentially to the pipe wall. For conventional structures in which the top arc approaches a semicircle, it is convenient to substitute half the span for the wall radius. Then,

$$C = P_v(S/2) \qquad (3)$$



where

C = Ring compression, lbs/ft
P_v = Vertical design pressure, psf
S = Span, ft

4. Allowable Wall Stress
The ultimate compressive stress (f_b) for corrugated steel structures with a minimum yield point of 33,000 psi and backfill compacted to 85% standard AASHTO density is shown in Figure 7.10. The following gives f_b in equation form:

when $D/r \leq 294$

$$f_b = f_y = 33{,}000\text{psi} \tag{4}$$

when $294 < D/r \leq 500$

$$f_b = 40{,}000 - 0.081(D/r)^2 \tag{5}$$

when $D/r > 500$

$$f_b = \frac{4.93 \times 10^9}{(D/r)^2} \tag{6}$$

where
D = Diameter or span, inches
r = radius of gyration of corrugation (see Table 7.2)

A safety factor of 2 is applied to the ultimate wall stress to obtain the design stress, f_c:

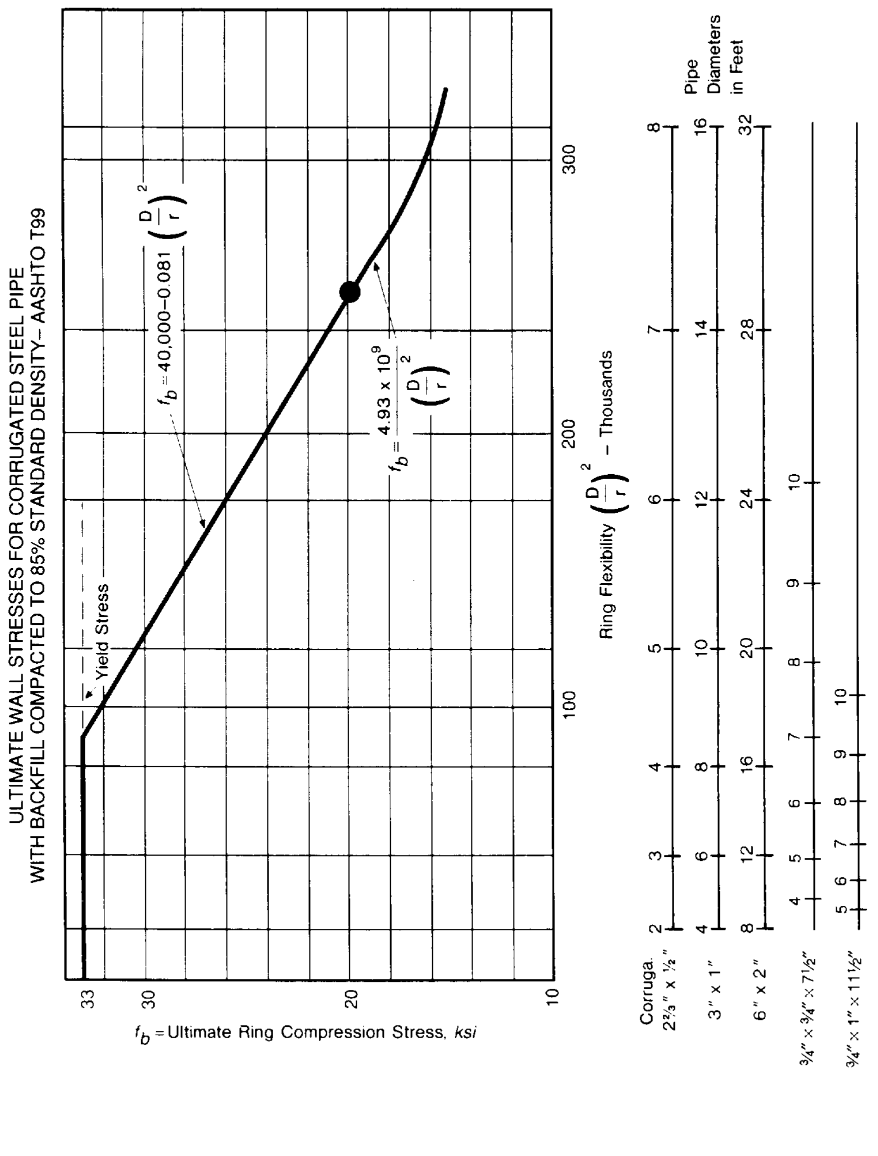
$$f_c = f_b/2 \tag{7}$$

5. Wall Cross-Sectional Area
The required wall area, A, is computed from calculated compressive thrust in the pipe wall, C, and the allowable stress, f_c.

$$A = C/f_c \tag{8}$$

From Table 7.2 select the wall thickness that provides the required wall area for the same corrugation used to select the allowable stress.

6. Handling Stiffness
Minimum stiffness requirements to assure practical handling and installation without undue care have been established through experience. The resultant flexibility factor, *FF*, limits the size of each combination of corrugation and pipe wall thickness. However, the *FF* limit depends on the type of installation. Embankment installations, which often involve the use of heavier compaction equipment, require a lower *FF* limit (a stiffer pipe) to handle the resulting compaction pressures. Trench installations on the other hand may be designed with a higher *FF* limit (a more flexible pipe) because of the smaller, lighter



■ **Figure 7.10** Ultimate wall or buckling stresses for corrugated steel pipe of various diameters and corrugations. The allowable stress is taken as one-half the ultimate.

compaction equipment employed. The typical, narrow trench does not allow for the use of larger, heavier compaction equipment.

The flexibility factor is expressed as:

$$FF = S^2/EI \text{ in./lb} \qquad (9)$$

where

E = Modulus of elasticity of steel = 30,000,000 psi
S = Diameter or span, in.
I = Moment of inertia of corrugation (wall), in.^{4}/in. (see Table 7.2)

Limits for *FF* for round pipe are given in Table 7.5. The note in the table indicates that a 50% increase in flexibility factor limit is allowed for pipe arch, arch, and underpass shapes where the rise does not exceed 2/3 of the span. For these structure shapes, the rise is less than the span. Thus, compared to a round pipe with the same span, there are fewer lifts of backfill that must be placed to get over the structure, and less distortion while the backfill is placed and compacted.

For some pipe arches, fabrication requirements dictate a wall thickness greater than that corresponding to the *FF* limit. Except with plate structures, pipe arches are formed from round pipe and, especially with a 1 inch deep corrugation, a thicker wall may be required for forming. In these instances, the height of cover tables subsequently presented in this chapter show the minimum gage required for fabrication rather than those dictated by the *FF* limit.

For spiral rib pipe, a somewhat different approach is used. To obtain better control, the flexibility factors are varied with corrugation profile, sheet thickness, and type of installation, as shown in Table 7.5. There are three installation types (Type I, II, and III) established for better control. Type I and Type II installations are the traditional embankment and trench installations for all corrugated steel pipe. However, the Type III spiral rib installation goes one step farther, creating a trench installation with special, high quality backfill. These materials – such as crushed rock, pea gravel, cement stabilized sand, etc. – can be compacted to a high strength and stiffness with minimal effort, allowing for proper installation of the more flexible pipe used in Type III installations. The details of the installation requirements are given with the allowable fill heights in Table HC-2.

In the same manner, for pipe of all wall profiles, where special backfill materials or special controls are used, more flexible pipe works well. The use of cementitious grout backfill or controlled low strength materials (CLSM) allows for more flexible pipe than indicated by the trench *FF* limits. They also allow a much narrower trench. In this case, trench widths are limited to the width necessary to place and assemble the pipe. Grout and CLSM flows easily into the pipe haunch area and does not require compaction. Typically a space of only a few inches on each side of the pipe is necessary to place such backfills.

7. Longitudinal Seam Strength
Ultimate longitudinal seam strengths are listed in Table 7.3 for riveted CSP, in Table 7.4A for bolted structural plate, and in Table 7.4B and 7.4C for deep corrugated plate. Seams that develop the full yield strength of the pipe wall are noted. Except for these cases, to maintain a consistent factor of safety of 2.0, it is necessary to limit the maximum ring compression to one half the indicated seam strength.

Expressed in equation form, the required wall seam strength, SS, is calculated from the compressive thrust in the pipe wall, C, using a safety factor of 2.0 as:

$$SS = Cx2 \tag{10}$$

where both C and S have units of lb/ft.

From Table 7.3, 7.4A, or 7.4B, select the wall thickness that provides the required longitudinal seam strength.

Since helical lock seam and continuously welded seam pipe have no longitudinal seams, there is no seam strength check necessary for these types of pipe.

Additional Considerations for Standard Pipe Arch Structures
An additional important design consideration for pipe arches is the corner bearing pressure. Pipe arches generate radial corner pressures as illustrated in Figure 7.11. These haunch pressures, which are greater than the pressure applied at the top of the structure, must be limited to the allowable bearing capacity of the soil adjacent to the haunch. This often becomes the limiting design factor rather than structural strength.

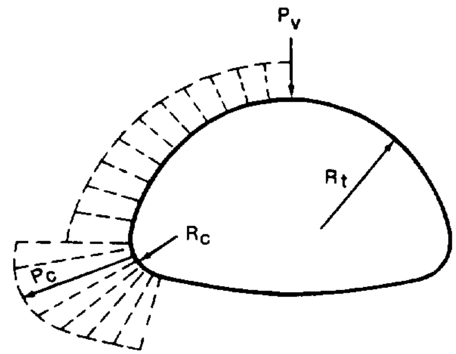


Figure 7.11 The pressure on a pipe arch varies with location and radius, being greatest at the corners.

Dead Load Corner Bearing Pressure. The dead corner pressure can be calculated as follows. Ignoring the bending strength of the pipe wall and the longitudinal distribution of pressure, the ring compression force, *C*, is the same at any point around the structure.

From the familiar relationship $C = P_v R$, the pressure normal to the wall is inversely proportional to the radius. With these assumptions, the corner pressure, P_{CDL}, due to dead (soil) loads would be:

$$P_{CDL} = (R_T/R_C)\, P_{DL} \tag{11}$$

where
- R_T = Top radius, in.
- R_C = Corner (haunch) radius, in.
- P_{DL} = Vertical pressure at top from dead load

This approach calculates the corner pressure at the surface of the pipe. If this bearing pressure is excessive, an extra width of compacted backfill, both beside and below the haunch can be placed to reduce the bearing pressure from that of the pipe arch acting on the trench wall or embankment material. As a simple rule of thumb, extending the backfill a distance of one haunch radius beyond the surface of the haunch reduces pressure on the trench wall or embankment by 50%. A more in-depth evaluation of corner bearing pressures follows.

Live Load Corner Bearing Pressure. The above calculation for P_{CDL} is overly conservative for live loads, such as wheel loads that are not uniformly distributed over the full pipe length. As the ring compression force generated by live loads above the pipe arch is transmitted circumferentially down toward the haunch region, it is also being distributed along the length of the pipe. Thus, the length of the haunch region that transmits the live load pressures into the soil is much greater than the length of pipe arch over which they were initially applied. The corner pressure can be more realistically calculated as:

$$P_{CLL} = R_T C_1 (P_{VLL}/R_C) \tag{12}$$

where
- P_{CLL} = Live load pressure acting on soil at the haunches, psf
- R_T = Radius at crown, in. (≈ 1/2 span; or see tables in Chapter 2)
- C_1 = Longitudinal live load distribution factor
- P_{VLL} = Design live load pressure at crown (psf)
- R_C = Radius at haunch, in. (see tables in Chapter 2)

The total corner bearing pressure then becomes:

$$P_C = P_{CDL} + P_{CLL} \tag{13}$$

This is the procedure that was used to calculate the height-of-cover limits for pipe arches in this design manual. Furthermore, the live load was used without impact because (1) the distance from the point of pressure application to the corner region is greater than the distance from that point to the crown of the structure, and (2) bearing failures are progressive failures occurring over a significant time period as opposed to the brief time of an impact loading. However, the full live load pressure (including impact and unmodified by the C_1 factor) must continue to be used to design the pipe wall.

Equations for C_1, which have been derived from accepted methods, are given below for standard highway and railway loadings. Their derivation is discussed at the end of this section.

C_1 for H20 or H25 highway live loads:
L_1 is the length (inches) over which the live load pressure is applied at the top of the pipe. The length (inches) along the corner which transmits the live load pressure is L_2, when there is no overlap from the wheels at either end of the axle, or L_3, when overlap occurs. Therefore:

$$C_1 = L_1/L_2 \quad \text{when } L_2 < 72 \text{ in.} \qquad (14)$$

$$C_1 = 2\,L_1/L_3 \quad \text{when } L_2 > 72 \text{ in.} \qquad (15)$$

where

$$L_1 = 40 + (h-12)1.75 \qquad (16)$$

$$L_2 = L_1 + 1.37s \qquad (17)$$

$$L_3 = L_2 + 72 \qquad (18)$$

h = Height of cover (in.)
s = Span (in)

The live loads for highway loads are as given in Table 7.7 except that the following values (psf) should be used for 1 foot depth of cover:

H20	H25
1600	2000

C_1 for E80 railway live loads:
Because of the function of the tie, there is no pressure overlap for single track arrangements. However, it may be appropriate to consider overlap for some multiple track arrangements. Therefore, for single track arrangements:

$$C_1 = L_1/L_2 \qquad (19)$$

where

$$L_1 = 96 + 1.75h \qquad (20)$$

$$L_2 = L_1 + 1.37s \qquad (21)$$

h = Height of cover (in.)
s = Span (in.)

The live load pressures for railway loads given in Table 7.7 should be divided by 1.5 to remove the impact factor.

Derivation of C_1 for H20 or H25 highway live loads:
The live load pressures for highway live loads have traditionally been based on load application through an assumed 12 inch thick pavement area of 36 by 40 inches Figure 7.12 shows how the load is distributed from an axle load over a pipe arch. The pressure at any height-of-cover h (inches) below the 40 inch wide area is spread over a length L_1 (inches) = 40 + (h – 12)x1.75 at the top of the structure. The stress in the pipe wall from this pressure also spreads longitudinally as it flows toward the corner. Its length at the corner increases by 1.75 times the arc length from the top of the structure to the corner. If this arc length is approximated as (π x span/4 = 1.37s) where s is span (inches), it may be seen that the length along the corner which transmits the live load pressure is L_2 (inches) = L_2 + 1.37s where s is the span (inches). No overlap of corner pressure zones occurs until L_2 exceeds 72 inches Thereafter, the reaction length L_3 (inches) = L_2 + 72. Thus, the live load pressure can be multiplied by a coefficient C_1 expressed simply as Equations 14 and 15 above.

Derivation of C_1 for E80 railway live loads:
The live load pressures for each railway axle have traditionally been based on load application through a 24 by 96 inch bearing area. Figure 7.13 shows how the load is distributed from a tie over a pipe arch. The pressure at any height-of-cover h (inches) below the 96 inch tie is spread over a length L_1 (inches) = 96 + 1.75h at the top of the structure. The stress in the pipe wall from this pressure also spreads longitudinally as it flows toward the corner. Its length at the corner increases by 1.75 times the arc length from the top of the structure to the corner. With the same approximations as above, it may be seen that the length along the corner which transmits the live load pressure is L_2 (inches) = L_1 + 1.37s where s is the span (inches). Thus, the live load pressure for a single track railway load can be multiplied by a coefficient C_1 expressed simply as Equation 19 above.

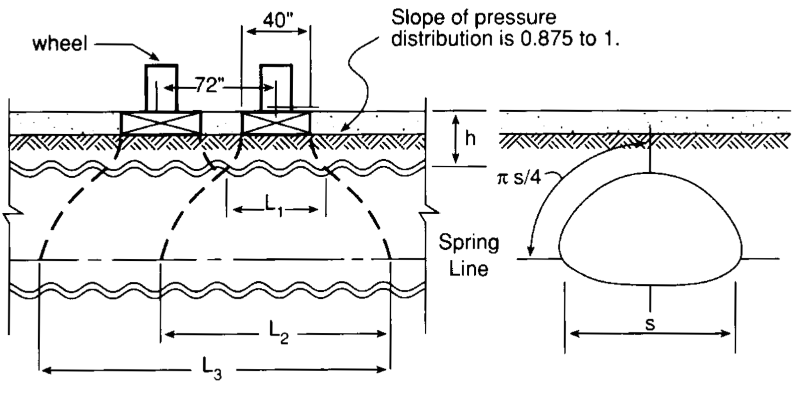
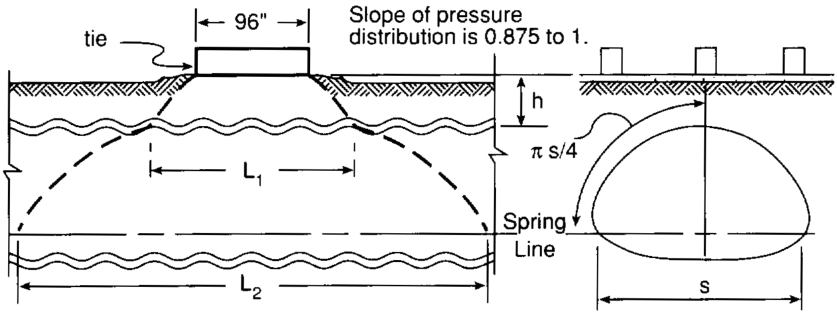


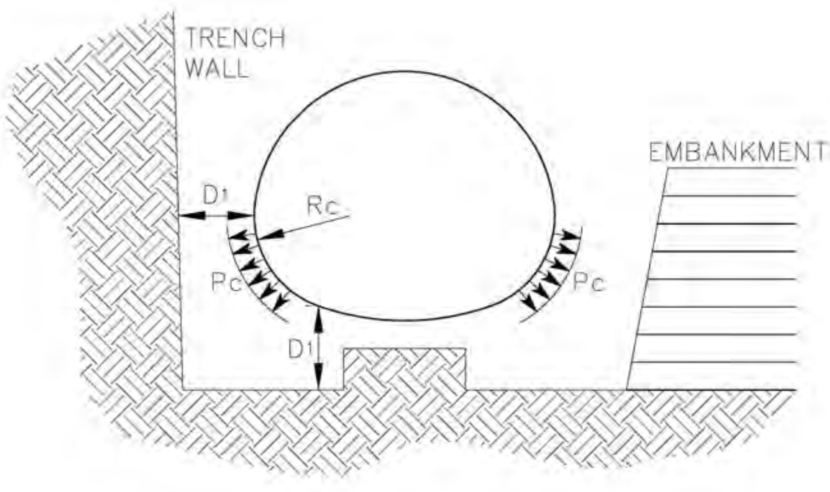
Figure 7.12 Longitudinal distribution of live load corner bearing pressure in pipe-arches under highway loading.



■ **Figure 7.13** Longitudinal distribution of live load corner bearing pressure in pipe-arches under railway loading.

Corner Bearing Pressure at a Distance From the Structure

Where insitu bearing strength conditions dictate, select backfill material can be placed adjacent to the haunch of a pipe arch or other structure. A select granular material is placed and compacted below and beside the haunch in a thickness that allows the bearing pressure at the haunch to spread and dissipate to a level that the insitu material can support (see Figure 7.14).



■ **Figure 7.14** Corner bearing pressure distributed through select, granular fill.

The resulting pressure a distance from the haunch can be calculated as:

$$P_1 = P_c R_c/(R_c + D_1) \qquad (22)$$

where
- P_1 = Pressure at the desired distance (D_1) from the haunch surface (psf)
- P_c = Total dead and live load pressure at the surface of the haunch (psf) (Eq. 13)
- R_c = Radius of the haunch (ft)
- D_1 = Distance from the haunch (point of interest – ft)

Similarly, the necessary thickness of this select material can be determined from the allowable bearing pressure of the insitu soil as:

$$D_1 = [(R_c P_c)/P_{brg}] - R_c \qquad (23)$$

where
- D_1 = Distance from the haunch surface necessary to reduce pressure (ft)
- R_c = Radius of the haunch (ft)
- P_c = Corner pressure (psf)
- P_{brg} = Allowable bearing pressure of the insitu soil (psf)

Additional Considerations for Standard Arch Structures

The design of structural plate arches is based on a minimum ratio of rise to span of 0.3; otherwise, the structural design of the barrel is the same as for structural plate pipe. However, there are two important additional considerations.

The first is foundation rigidity. It is undesirable to make the steel arch relatively unyielding or fixed compared with the adjacent side fill. 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 it and replacing with acceptable material. The footing should be designed to provide uniform, longitudinal settlement of acceptable magnitude from a functional aspect. Allowing the arch to settle will protect it from possible drag-down forces caused by the settlement of the adjacent side fill.

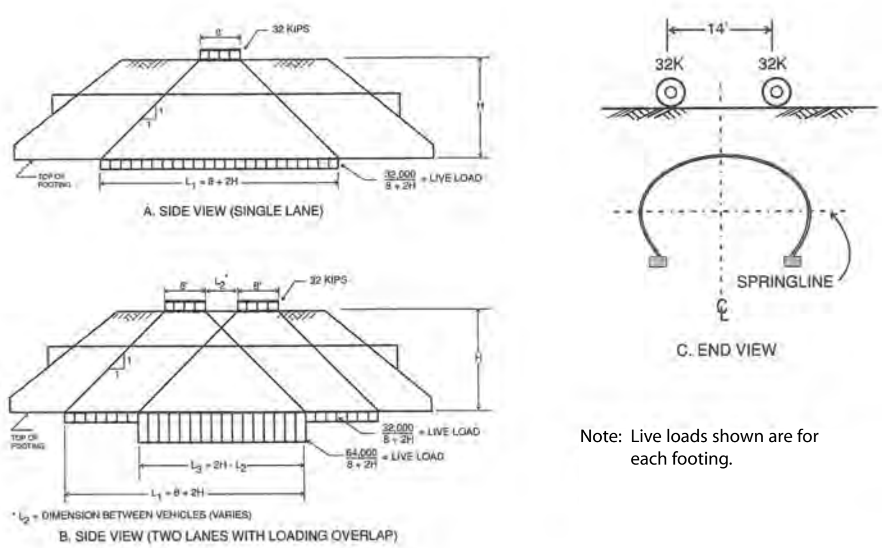
The second consideration is the direction of the forces on the footing. The footing reaction acts tangential to the plate where it connects to the footing. Arches that are not half a circle exert both a vertical and a horizontal reaction on the footing. The value of the tangential footing reaction, which is calculated in a later example, is approximately equal to the thrust in the arch plate at the footing.

However, the vertical footing reaction due to dead (soil) loads can be calculated as follows. Take the vertical dimension from the spring line of the arch to the top of the fill, multiply it by the maximum span of the structure, and then subtract the structure area above the spring line. Multiplied by the density of the soil (usually 120 pcf) to obtain the total soil load on the structure, then divide by two to obtain the vertical soil load on each footing.

Live load footing reactions are calculated as shown in Figures 7.15 and 7.16. The live loads act on the surface and are spread down, through the fill and arch, a distance shown as H, to the elevation of the footing at a 1:1 slope. An H20 wheel load is handled as 64,000 lbs. (80,000 lbs. for H25) applied as two 32,000 lbs. (40,000 lbs. for H25) loads spread over 8 feet on each side of the top centerline of the arch as shown in the figure.

For an H20 live load, the reaction at each footing becomes:

- 32,000/(8+2H) lb/ft, for a single lane crossing.
- 64,000/(8+2H) lb/ft for multiple lanes or meeting vehicles. The length of the overlapping zone, where 64,000/(8+2H) applies, depends on the variable distance between the lanes on the surface and the height H.



■ **Figure 7.15** Details for calculating footing reactions with H20 wheel loads.

Similarly, as shown in Figure 7.16, footing reactions for E80 loads are determined by applying 320,000 lbs. to the fill surface as four 80,000 lbs. concentrated loads on a 5 foot spacing across the span. Each 80,000 lb load is spread over 8 feet longitudinally along the structure by the ties. Thus, the E80 live load reaction at each footing is:

- 160,000 /(8+2H) lb/ft for a single track.
- 320,000/(8+2H) lb/ft for twin tracks. The overlapping zone, where 32,000/(8+2H) depends on the distance between the tacks and the height H.

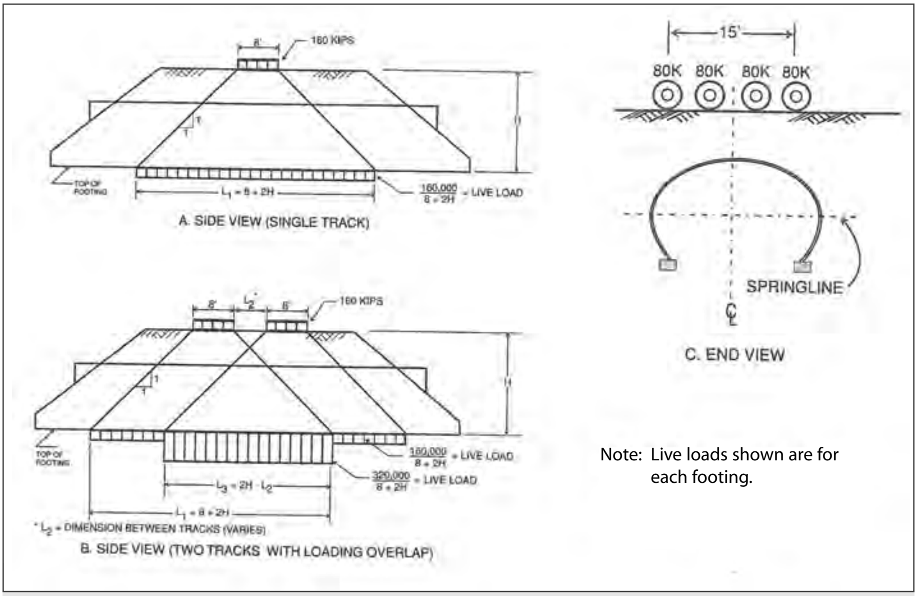


Figure 7.16 Details for calculating footing reactions with E80 railroad loads.

Deflection Limits for Standard Structures

Early on, designers were concerned about possible excessive pipe deflection levels. Simply stated, corrugated steel pipe is not rigid compared to the clay and concrete pipe of that time. Today it is recognized that excessive deflections are due to inadequate backfill. When backfill materials or their compaction levels are insufficient for the loads, flexible steel pipe will show an unacceptable shape change. It is not feasible to try to control deflection by adjusting the pipe wall stiffness. Instead, deflection is controlled by providing an adequate backfill envelope to support the pipe and its design loads. Strutting CSP is not advised. It is generally ineffective and can result in damaged pipe.

Significant deflection levels in themselves are only an indication that the backfill is consolidating due to the side pressures from the pipe as it seeks support. As the pipe deflects, it moves out and compacts the backfill beside it. In many cases – depending upon the soil type, initial compaction and other factors – this shape change, combined with the overburden pressure, is sufficient to provide the necessary backfill compaction. The structure becomes stable and exhibits the necessary design strength.

CSP is not stress crack sensitive. When the movement stops, if the shape is smooth and exhibits suitable curvature with smooth radius changes, the pipe is usually structurally sound. Bending strains induced by the shape change typically are not detrimental to the performance of the structure or the steel it is made from. After all, corrugated steel pipe is formed by corrugating and curving into the desired shape.

Generally, deflections of 10% of the rise are not considered excessive, provided the shape change has stopped, the shape is suitable for the intended function, and the backfill has become suitably consolidated.

Design Examples for Standard Structures

The following examples illustrate the application of design procedures developed in the preceding pages and referred to as the AISI method. They include: (1) 54 inch diameter pipe under a 60 foot embankment fill, (2) 144 inch diameter pipe in a trench condition, (3) a 20 foot 5 inch pipe arch under 6 feet of cover, and (4) a 23 foot span arch under 19 feet of cover.

Example 1

Given: Pipe diameter, D = S = 54 in.
Seam type: Lock seam – no seam strength check required
Height of cover, H = 60 ft
Live load, LL = H 20 Highway
Weight of soil, γ = 120 pcf
Installation type: Embankment

Find: Wall thickness and type of corrugation.

Solution:

1. Backfill Density:
90% standard Proctor density is specified for construction. Assume a minimum of 85% for design. The height of cover is greater than the span. Therefore, K = 0.86.

2. Design Pressure:
$DL = H\gamma = 60(120) = 7200$ psf
LL = negligible for cover greater than 8 ft (from Table 7.7)
$P_v = K(DL + LL)$
$= 0.86(7200 + 0) = 6190$ psf

3. Ring Compression:
   $C = P_v(S/2)$
   $= 6190(4.5/2) = 13{,}900$ lbs/ft

4. Allowable Wall Stress:
   Try the 2-2/3 x 1/2 in. corrugation with 0.079 in. wall.
   $D/r = 54/0.1721 = 314$
   when $294 < D/r \leq 500$, $f_b = 40{,}000 - 0.081(D/r)^2 = 32{,}000$ psi
   $f_c = f_b/2 = 16{,}000$ psi

5. Wall Cross-Sectional Area:
   $A = C/f_c = 13{,}900/16000 = 0.869$ in.^{2}/ft required
   From Table 7.2 a specified wall thickness of 0.079 in. provides an uncoated wall area of 0.968 in.^{2}/ft.
   $0.869 < 0.968$ in.^{2}/ft, **OK**

6. Handling Stiffness:
   $FF = S^2/EI$
   $= (54)^2/(30{,}000{,}000 \times 0.002392)$
   $= 0.0406$ in./lb < 0.0433 limit, **OK**

Alternative Solution—Using 3 x 1 in. CSP

4A. Allowable Wall Stress:
   Try the 3 x 1 in. corrugation with 0.064 in. wall.
   $D/r = 54/0.3417 = 158$
   when $D/r < 294$, $f_b = 33{,}000$ psi
   $f_c = f_b/2 = 16{,}500$ psi

5A. Wall Cross-Sectional Area:
   $A = C/f_c = 13{,}900/16{,}500 = 0.842$ in.^{2}/ft required
   From Table 7.2 a specified thickness of 0.064 in. provides an uncoated wall area of 0.890 in.^{2}/ft.
   $0.842 < 0.890$ in.^{2}/ft, **OK**

6A. Handling Stiffness:
   $FF = S^2/EI$
   $= (54)^2/(30{,}000{,}000 \times 0.008658)$
   $= 0.0406$ in./lb < 0.0433 limit, **OK.**

Results: Acceptable designs include (1.) 2-2/3 x 1/2 inch corrugation with specified wall minimum thickness of 0.079 inch and (2.) 3x1 inch corrugation with specified wall min. thickness of 0.064 inch.

Example 2

Given: Pipe diameter, D = S = 144 in.
Seam type: Lock seam – no seam strength check required
Height of cover, H = 30 ft
Live load, LL = E80 Railway
Weight of soil, γ = 120 pcf
Installation type: Trench

Find: Wall thickness and type of corrugation.

Solution:

1. Backfill Density:
   90% standard Proctor density is specified for construction. Assume a minimum of 85% for design. The height of cover is greater than the span. Therefore, K = 0.86.

2. Design Pressure:
   DL = H γ = 30(120) = 3600 psf
   LL = negligible for cover greater than 8 ft (from Table 7.7)
   P_v = K(DL + LL)
   = 0.86(3600 + 0) = 3100 psf

3. Ring Compression:
   C = P_v(S/2)
   = 3100(12/2) = 18,600 lbs/ft

4. Allowable Wall Stress:
   Try the 5 x 1 in. corrugation with 0.109 in. wall.
   D/r = 144/0.3677 = 392
   when $294 < D/r \leq 500$, $f_b = 40{,}000 - 0.081(D/r)^2 = 27{,}580$ psi
   $f_c = f_b/2 = 13{,}790$ psi

5. Wall Cross-Sectional Area:
   $A = C/f_c = 18{,}600/13{,}790 = 1.349$ in.^{2}/ft required
   From Table 7.2 a specified thickness of 0.109 in. provides an uncoated wall area of 1.390 in.^{2}/ft.
   1.349 < 1.390 in.^{2}/ft, **OK**

6. Handling Stiffness:
   FF = S^2/EI
   = $(144)^2$/(30,000,000 x 0.0156)
   = 0.0443 in./lb < 0.060 limit, **OK.**

Results: The 5x1 inch corrugation with specified wall minimum thickness of 0.109 inches is an acceptable design.

Example 3

Given: Structural plate pipe arch with span, S = 20 ft - 5 in. and rise = 13 ft - 0 in.
Corrugation: 6 x 2 in., 31 in corner radius
Height of cover, H = 6 ft
Live load, LL = H20 Highway
Weight of Soil, γ = 120 pcf
Installation type: Trench or embankment

Find: Wall thickness, bolting requirements for longitudinal seams, and corner bearing pressure requirement.

Solution:

1. Backfill Density:
90% standard Proctor density is specified for construction. Assume a minimum of 85% for design. The height of cover is less than the span. Therefore, K = 1.0.

2. Design Pressure:
$DL = H\gamma = 6(120) = 720$ psf
$LL = 200$ psf (from Table 7.7)
$P_v = K(DL + LL)$
$= 1.0(720 + 200) = 920$ psf

3. Ring Compression:
$C = P_v(S/2)$
$= 920(20.42/2) = 9390$ lbs/ft

4. Allowable Wall Stress:
Try the 6 x 2 in. corrugation with 0.140 in. wall.
$D/r = 144/0.684 = 211$
when $D/r < 249$, $f_b = 40{,}000$ psi
$f_c = f_b/2 = 20{,}000$ psi

5. Wall Cross-Sectional Area:
$A = C/f_c = 9390/20{,}000 = 0.4695$ in.^{2}/ft required
From Table 7.2 a specified thickness of 0.140 in. provides an uncoated wall area of 2.003 in.^{2}/ft.
$0.4695 < 2.003$ in.^{2}/ft, **OK**

Note: A thinner wall would meet this requirement but design is controlled by the flexibility factor limit, step 6.

6. Handling Stiffness:
   FF limit for 6 x 2 in. pipe arch is 0.020 x 1.5 = 0.030 in./lb
   FF = D^2/EI
   = $(245)^2/(30{,}000{,}000 \times 0.07817)$
   = 0.0256 in./lb < 0.030 limit, **OK.**

   Note: A thinner wall would not meet this check.

7. Longitudinal Seam Strength:
   SS = Cx2 = 9390x2 = 18,780 lb/ft required
   From Table 7.4A, the seam strength for 0.140 thickness = 62,000 lbs/ft
   18,780 < 62,000 **OK**

   Note: A thinner wall would meet this requirement but design is controlled by the flexibility factor limit, step 6.

8. Corner Bearing Pressure:
   Calculate C_1:
   $L_1 = 40 + (h-12)1.75 = 40 + (72 - 12)1.75 = 145$ in.
   $L_2 = L_1 + 1.37s = 145 + 1.37(245) = 481$ in. > 72 in.
   $L_3 = L_2 + 72 = 481 + 72 = 553$ in.
   when $L_2 > 72$ in., $C1 = 2L_1/L_3 = 2x145/553 = 0.524$

   Calculate corner bearing pressure using span/2 for R_T:
   $P_{CLL} = R_T C_1 (P_{VLL}/R_C) = (245/2)(0.524)(200/31) = 414$ psf
   $P_{CDL} = (R_T/R_C)P_{DL} = (122.5/31)720 = 2845$ psf
   $P_C = P_{CDL} + P_{CLL} = 414 + 2845 = 3259$ psf required

   It is imperative that the allowable bearing pressure of the material below and outside the haunch be at least 4000 psf (2 tons/ft^2), which is generally the minimum value used for design.

Results: For the 6 x 2 inch corrugation, a specified wall minimum thickness of 0.140 inch with standard seams (2 bolts/corrugation or 4 bolts/ft) is an acceptable design. Soil in the haunch area must have an allowable bearing pressure of 4000 psf.

Example 4

Given: Structural plate arch with span, S = 23 ft - 0 in. and Rise = 9 ft -10 in
Corrugations: 6 x 2 in.
Height of cover, H = 19 ft
Live load, LL = H20 Highway
Weight of Soil, γ = 120 pcf
Arch return angle (α) is 14.09°
Flow area = 171 ft^2
Installation type: Trench or embankment

Find: Wall thickness, bolting requirements for longitudinal seams, and footing reactions.

Solution:

First check the rise/span ratio: 10.83/23.0 = 0.428 > 0.30. Therefore, structural design is similar to that for round pipe.

1. Backfill Density:
   90% standard Proctor density is specified for construction. Assume a minimum of 85% for design. The height of cover is less than the span. Therefore, K = 1.0.

2. Design Pressure:
   DL = H γ = 19(120) = 2280 psf
   LL = negligible for cover greater than 8 ft (from Table 7.7)
   P_v = K(DL + LL)
   = 1.0(2280 + 0) = 2280 psf

3. Ring Compression:
   C = P_v(S/2)
   = 2280(23/2) = 26,220 lbs/ft

4. Allowable Wall Stress:
   Try the 6 x 2 in. corrugation with 0.170 in. wall.
   D/r = 276/0.686 = 402
   when 294 < D/r ≤ 500, $f_b = 40{,}000 - 0.081(D/r)^2 = 26{,}900$ psi
   $f_c = f_b/2 = 13{,}450$ psi

5. Wall Cross-Sectional Area:
   A = C/f_c = 26,220/13,450 = 1.949 in.^{2}/ft required
   From Table 7.2 a specified thickness of 0.170 in. provides an uncoated wall area of 2.449 in.^{2}/ft.
   1.949 < 2.449 in.^{2}/ft, **OK**

   Note: A thinner wall would meet this requirement but design is controlled by the flexibility factor limit, step 6.

6. Handling Stiffness:
   FF limit for 6 x 2 in. pipe arch is 0.020 x 1.5 = 0.030 in./lb
   FF = D^2/EI
   = $(276)^2$/(30,000,000 x 0.09617)
   = 0.0264 in./lb < 0.030 limit, **OK.**

   Note: A thinner wall would not meet this check.

7. Longitudinal Seam Strength:
   SS = Cx2 = 26,220x2 = 52,440 lb/ft required
   From Table 7.4A, the seam strength for 0.170 thickness = 81,000 lbs/ft
   52,400 < 81,000 **OK**

   Note: A thinner wall would meet this requirement but design is controlled by the flexibility factor limit, step 6.

8. Footing Reaction
   Weight of soil on arch = [(rise + H) span – flow area]
   = [(9.83 + 19.0) 23 - 171]120 = 59,050 lb/ft.
   R_{dl} = Vertical reaction @ spring line due to soil load
   = Weight of soil/2 = 29,525 lbs/ft
   R_{ll} = Vertical reaction @ spring line due to live load
   Assume two trucks meeting.
   R_{ll} = 64,000/(8 + 2H) = 64,000/{8+[2(19 + 9.83)} = 975 lbs/ft
   $R_{total} = R_{dl} + R_{ll}$ = 29,525 + 975 = 30,500 lbs/ft
   R_v = vertical footing reaction = R cos(α)
   = 30,500 cos(14.09) = 29,580 lbs/ft
   R_h = Horizontal footing reaction = R sin(α)
   = 30,500 sin(14.09) = 7,425 lbs/ft.

Results: For the 6 x 2 inch corrugation, a specified wall min. thickness of 0.170 inchwith standard seams (2 bolts/corrugation or 4 bolts/ft) is an acceptable design. The footings must be designed for R_v = 29,583 lbs/ft and R_h = 7,425 lbs/ft.

HEIGHT OF COVER TABLES FOR STANDARD CORRUGATED STEEL PIPE

The following height-of-cover tables are presented for the designer's convenience to use in routine applications. They are based on the design procedures presented in this chapter for the AISI method. The following values were adopted:

Unit weight of soil = 120 pcf
Density of compacted backfill = 90% AASHTO T-99
AISI load reduction factor K = 0.86

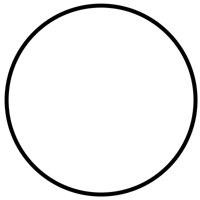
Fill heights for factory made pipe are based on helical seam fabrication. Joint strength must be checked for factory made pipe with other types of seams.

Except as noted, embankment or trench construction is permitted.

List of Height of Cover Tables

	Structure Shape					Live Load		Corrugation Profile				
Table No.	Pipe	Pipe Arch	Horizontal Ellipse	Arch	Under-pass	H20/ H25	E80	2-2/3 x 1/2 in.	5x1 or 3x1 in.	Spiral Rib	6x2 in.	Corner Radius, in.
AISI-1	x					x		x				
AISI-2	x					x				x		
AISI-3	x					x				x		
AISI-4	x					x			x			
AISI-5	x						x	x				
AISI-6	x						x		x			
AISI-7	x					x					x	
AISI-8	x						x				x	
AISI-9		x				x		x				
AISI-10		x				x				x		
AISI-11		x				x			x			
AISI-12		x					x	x				
AISI-13		x					x		x			
AISI-14		x				x					x	18
AISI-15		x				x					x	31
AISI-16		x					x				x	18
AISI-17		x					x				x	31
AISI-18			x			x					x	
AISI-19			x				x				x	
AISI-20					x	x					x	
AISI-21					x		x				x	
AISI-22				x		x					x	
AISI-23				x			x				x	
AISI-24	x					Airport		x				
AISI-25	x					Airport			x			
AISI-26	x					Airport		x	x			x
AISI-27	x					Airport						x

Structural plate pipe used for stockpile tunnels at a copper mine in Utah.



AISI-1

Height of Cover Limits for Steel Pipe
H20 or H25 Live Load • 2-2/3 x 1/2 Corrugation

Diameter or Span, in.	Min.* Cover, in.	Maximum Cover (ft) for Specified Thickness (in.)					
		0.052	0.064	0.079	0.109	0.138	0.168
12	12	197	248	310			
15	12	158	198	248			
18	12	131	165	206			
21	12	113	141	177	248		
24	12	98	124	155	217		
30	12	76	99	124	173		
36	12	64	83	103	145	186	
42	12	54	71	88	124	159	195
48	12		62	77	108	139	171
54	12		(53)	67	94	122	150
60	12			(57)	80	104	128
66	12				68	88	109
72	12				(57)	75	93
78	12				(48)	63	79
84	12				(40)	52	66
90	12				(32)	43	54
96	12					35	45

Notes:
1. Fill heights in parentheses require standard trench installation; all others may be embankment or trench.
2. In 12 in. through 36 in. diameter, heavier gages may be available – check with the manufacturer.
* Minimum covers are measured from top of pipe to bottom of flexible pavement or top of pipe to top of rigid pavement. Minimum covers must be maintained in unpaved traffic areas.

INSTALLATION AND BACKFILL OF SPIRAL RIB PIPE

Satisfactory backfill material, proper placement, and compaction are key factors in obtaining satisfactory performance.

Minimum pipe metal thickness (gage) is dependent upon minimum & maximum cover and installation TYPE I, II, or III, as noted in the fill height table. Backfill in the pipe envelope shall be granular materials with little or no plasticity; free from rocks, frozen lumps, and foreign matter that could cause hard spots or that could decompose and create voids; compacted to a minimum 90% standard density per ASTM D698 (AASHTO T99).

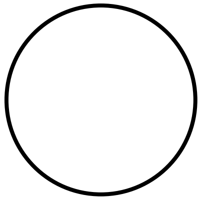
Installation types are:

Type I Installations can be in an embankment or fill condition. Installations shall meet ASTM A798 requirements. ML and CL materials are typically not recommended. Compaction equipment or methods that cause excessive deflection, distortion, or damage shall not be used.

Type II Installations require trench-like conditions where compaction is obtained by hand, or walk behind equipment, or by saturation and vibration. Backfill materials are the same as for TYPE I installations. Special attention should be paid to proper lift thicknesses. Controlled moisture content and uniform gradation of the backfill may be required to limit the compaction effort while maintaining pipe shape.

Type III Installations have the same requirements as TYPE II installations except that backfill materials are limited to clean, non-plastic materials that require little or no compaction effort (GP, SP), or to well graded granular materials classified as GW, SW, GM, SM, GC, or SC with a maximum plasticity index (PI) of 10. Maximum loose lift thickness shall be 8 inches Special attention to moisture content to limit compaction effort may be required. Soil cement or cement slurries may be used in lieu of the selected granular materials.

Note: Simple shape monitoring—measuring the rise and span at several points in the run—is recommended as good practice with all types of installation. It provides a good check on proper backfill placement and compaction methods. Use soil placement and compaction methods which will insure that the vertical pipe dimension (rise) does not increase in excess of 5% of the nominal diameter. Use methods which will insure that the horizontal pipe dimension (span) does not increase in excess of 3% of the nominal diameter. These guidelines will help insure that the final deflections are within normal limits.

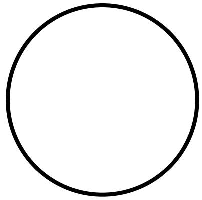


AISI-2

Height of Cover Limits for Spiral Rib Steel Pipe
H20 or H25 Live Load • 3/4 x 3/4 x 7-1/2 in.

Diameter or Span, in.	Min.* Cover, in.	Maximum Cover (ft) for Specified Thickness (in.)			
		0.064	0.079	0.109	0.138
24	12	81	113	189	
30	12	65	91	151	
36	12	54	75	126	
42	12	46	65	108	
48	12	40	56	94	
54	18	(36)	50	84	
60	18	[32]	45	75	109
66	18	[29]	(41)	68	99
72	18		[37]	(63)	(93)
78	24		[34]	(58)	(84)
84	24			(54)	(78)
90	24			(50)	(73)
96	24			(47)	(68)
102	30			[33]	(60)
108	30				(54)
114	30				(49)
120	30				(43)

Notes:
1. Except as noted, installations may be embankment or trench.
( ) Fill heights in parentheses require Type II trench installation.
[ ] Fill heights in brackets require Type III trench installation.
* Minimum covers are measured from top of pipe to bottom of flexible pavement or top of pipe to top of rigid pavement. Minimum covers must be maintained in unpaved traffic areas.

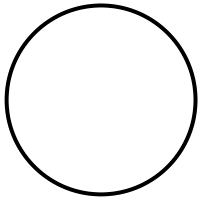


AISI-3

Height of Cover Limits for Spiral Rib Steel Pipe
H20 or H25 Live Load • 3/4 x 1 x 11-1/2 in.

Diameter or Span, in.	Min.* Cover, in.	Maximum Cover (ft) for Specified Thickness (in.)		
		0.064	0.079	0.109
24	12	60	84	141
30	12	48	67	113
36	12	40	56	94
42	12	34	48	81
48	12	30	42	71
54	18	27	37	63
60	18	(24)	34	56
66	18	[22]	30	51
72	18		(28)	47
78	24		[26]	43
84	24		[24]	40
90	24			38
96	24			(35)
102	30			[33]
108	30			[31]

Notes:
1. Except as noted, installations may be embankment or trench.
( ) Fill heights in parentheses require Type II trench installation.
[ ] Fill heights in brackets require Type III trench installation.
* Minimum covers are measured from top of pipe to bottom of flexible pavement or top of pipe to top of rigid pavement. Minimum covers must be maintained in unpaved traffic areas.

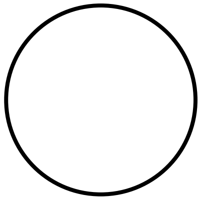


AISI-4

Height of Cover Limits for Steel Pipe
H20 or H25 Live Load • 5 x 1 or 3 x 1 in. Corrugation

Diameter or Span, in.	Min.* Cover, in.	Maximum Cover (ft) for Specified Thickness (in.)				
		0.064	0.079	0.109	0.138	0.168
54	12	56	70	99	127	155
60	12	51	63	89	114	140
66	12	46	58	81	104	127
72	12	42	53	74	95	117
78	12	39	49	68	88	108
84	12	36	45	63	82	100
90	12	34	42	59	76	93
96	12	32	40	56	71	87
102	18	30	37	52	67	82
108	18	(28)	35	49	64	78
114	18	(26)	33	46	59	72
120	18	(24)	30	42	54	67
126	18	(22)	(28)	39	50	62
132	18		(26)	36	47	57
138	18		(24)	33	43	53
144	18			(31)	40	49

Notes:
1. Fill heights in parentheses require standard trench installation; all others may be embankment or trench.
2. Maximum covers shown are for 5 x 1 in.; increase them by 12% for 3 x 1 in.
* Minimum covers are measured from top of pipe to bottom of flexible pavement or top of pipe to top of rigid pavement. Minimum covers must be maintained in unpaved traffic areas.

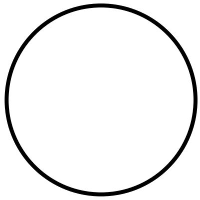


AISI-5

Height of Cover Limits for Steel Pipe
E80 Live Load • 2-2/3 x 1/2 Corrugation

Diameter or Span, in.	Min.* Cover, in.	Maximum Cover (ft) for Specified Thickness (in.)				
		0.064	**0.079**	**0.109**	**0.138**	**0.168**
12	12	248	310	434		
15	12	198	248	347	446	546
18	12	165	206	289	372	455
21	12	141	177	248	319	390
24	12	124	155	217	279	341
30	12	99	124	173	223	273
36	12	83	103	145	186	227
42	12	71	88	124	159	195
48	12	62	77	108	139	171
54	18		67	94	122	150
60	18			80	104	128
66	18			68	88	109
72	18				75	93
78	24					79
84	24					66

Note:
* From top of pipe to bottom of tie.

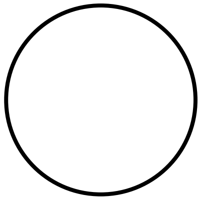


AISI-6

Height of Cover Limits for Steel Pipe
E80 Live Load • 5 x 1 or 3 x 1 in. Corrugation

Diameter or Span, in.	Min.* Cover, in.	Maximum Cover (ft) for Specified Thickness (in.)				
		0.064	0.079	0.109	0.138	0.168
54	18	56	70	99	127	155
60	18	51	63	89	114	140
66	18	46	58	81	104	127
72	18	42	53	74	95	117
78	24	39	49	68	88	108
84	24	36	45	63	82	100
90	24	33**	42	59	76	93
96	24	31**	40	56	71	87
102	30	29**	37	52	67	82
108	30		35	49	64	78
114	30		32**	46	59	72
120	30		30**	42	54	67
126	36			39	50	62
132	36			36	47	57
138	36			33**	43	53
144	36				40	49

Notes:
1. Maximum covers shown are for 5 x 1 in.; increase them by 12% for 3 x 1 in.
* From top of pipe to bottom of tie.
** These pipe require additional minimum cover.



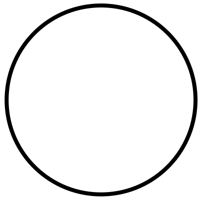
AISI-7

Height of Cover Limits for Steel Pipe
H20 or H25 Live Load • 6 x 2 Corrugation

Diameter or Span,		Min.* Cover,	Maximum Cover (ft) for Specified Thickness (in.)						
ft	in.	in.	0.111	0.140	0.170	0.188	0.218	0.249	0.280
5.0	60	12	81	120	157	175	205	234	263
5.5	66	12	74	109	142	159	186	213	239
6.0	72	12	68	100	131	146	170	195	220
6.5	78	12	63	92	120	135	157	180	203
7.0	84	12	58	86	112	125	146	167	188
7.5	90	12	54	80	104	117	136	156	176
8.0	96	12	51	75	98	109	128	146	165
8.5	102	18	48	71	92	103	120	138	155
9.0	108	18	45	67	87	97	114	130	146
9.5	114	18	43	63	82	92	108	123	139
10.0	120	18	41	60	78	88	102	117	132
10.5	126	18	39	57	75	83	97	111	125
11.0	132	18	37	55	71	80	93	106	120
11.5	138	18	35	52	68	76	89	102	115
12.0	144	18	34	50	65	73	85	97	110
12.5	150	24	33	48	63	70	82	94	105
13.0	156	24	31	46	60	67	79	90	101
13.5	162	24	30	45	58	65	76	87	98
14.0	168	24	29	43	56	63	73	84	94
14.5	174	24	28	41	54	60	71	81	91
15.0	180	24	27	40	52	58	68	78	88
15.5	186	24	26	39	51	57	66	75	85
16.0	192	24		38	49	55	64	73	82
16.5	198	30		36	47	53	62	71	80
17.0	204	30		35	46	51	60	69	77
17.5	210	30		34	44	49	58	66	74
18.0	216	30		33	42	47	55	63	71
18.5	222	30			40	45	53	61	68
19.0	228	30			39	43	51	58	66
19.5	234	30			37	42	49	56	63
20.0	240	30			36	40	47	54	61
20.5	246	36				38	45	51	58
21.0	252	36				37	43	49	56
21.5	258	36					41	47	54
22.0	264	36					40	45	51
22.5	270	36					38	44	49
23.0	276	36						42	47
23.5	282	36						40	45
24.0	288	42						38	43
24.5	294	42						37	42
25.0	300	42							40
25.5	306	42							38
26.0	312	42							36

Notes:

* Minimum covers are measured from the top of pipe to bottom of flexible pavement and top of pipe to top of rigid pavement. Minimum covers must be maintained in unpaved traffic areas.

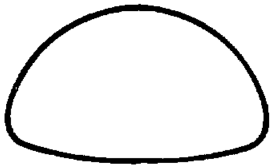


AISI-8

Height of Cover Limits for Steel Pipe
E80 Live Load • 6 x 2 Corrugation

Diameter or Span,		Min.* Cover,	Maximum Cover (ft) for Specified Thickness (in.)						
ft	**in.**	**in.**	**0.111**	**0.140**	**0.170**	**0.188**	**0.218**	**0.249**	**0.280**
5.0	60	24	81	120	157	175	205	234	263
5.5	66	24	74	109	142	159	186	213	239
6.0	72	24	68	100	131	146	170	195	220
6.5	78	24	63	92	120	135	157	180	203
7.0	84	24	58	86	112	125	146	167	188
7.5	90	24	54	80	104	117	136	156	176
8.0	96	24	51	75	98	109	128	146	165
8.5	102	24	48	71	92	103	120	138	155
9.0	108	24	45	67	87	97	114	130	146
9.5	114	24	43	63	82	92	108	123	139
10.0	120	24	41	60	78	88	102	117	132
10.5	126	30	39	57	75	83	97	111	125
11.0	132	30	37	55	71	80	93	106	120
11.5	138	30	35**	52	68	76	89	102	115
12.0	144	30	34**	50	65	73	85	97	110
12.5	150	30	32**	48	63	70	82	94	105
13.0	156	36	31**	46	60	67	79	90	101
13.5	162	36	29**	45	58	65	76	87	98
14.0	168	36	28**	43	56	63	73	84	94
14.5	174	36	26**	41	54	60	71	81	91
15.0	180	36	25**	40	52	58	68	78	88
15.5	186	42	24**	39	51	57	66	75	85
16.0	192	42	23**	38	49	55	64	73	82
16.5	198	42		36	47	53	62	71	80
17.0	204	42		35	46	51	60	69	77
17.5	210	42		34	44	49	58	66	74
18.0	216	48		33	42	47	55	63	71
18.5	222	48			40	45	53	61	68
19.0	228	48			39	43	51	58	66
19.5	234	48			37	42	49	56	63
20.0	240	48			36	40	47	54	61
20.5	246	54				38	45	51	58
21.0	252	54				37	43	49	56
21.5	258	54					41	47	54
22.0	264	54					40	45	51
22.5	270	60					38	44	49
23.0	276	60						42	47
23.5	282	60						40	45
24.0	288	60						38	43
24.5	294	60						37	42
25.0	300	60							40
25.5	306	60							38
26.0	312	60							36

Notes:
* From top of pipe to bottom of tie.
** These pipe require additional minimum cover.



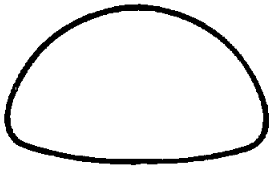
AISI-9

Height-of-Cover Limits for Corrugated Steel Pipe Arch
H20 or H25 Live Load • 2-2/3 x 1/2 in. Corrugation

Span & Rise in.	Minimum Specified Thickness Required in.	Maximum Cover (ft) Over Pipe Arch for Soil Corner Bearing Capacity of 2 tons/ft^2	Minimum Cover (in)
17 x 13	0.064	16	12
21 x 15	0.064	15	12
24 x l 8	0.064	15	12
28 x 20	0.064	15	12
35 x 24	0.064	15	12
42 x 29	0.064	15	12
49 x 33	0.079	15	12
57 x 38	0.109	15	12
64 x 43	0.1 09	15	12
71 x 47	0.138	15	12
77 x 52	0.168	15	12
83 x 57	0.168	15	12

Notes:
1. Soil bearing capacity refers to the soil in the region of the pipe corners. See Chapter 10 for design of pipe envelope at pipe corners. The remaining backfill around the pipe arch must be compacted to a specified AASHTO T-99 density of 90%.
2. Use reasonable care in handling and installation.

* Minimum covers are for H20 and H25 loads. See Table 10.1 for construction load requirements. Minimum covers are measured from top of pipe to bottom of flexible pave-ment or top of pipe to top of rigid pavement. Minimum cover must be maintained in unpaved traffic areas.

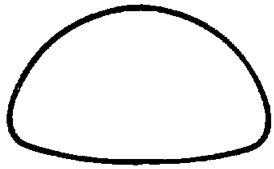


AISI-10

Height-of-Cover Limits for Steel Spiral Rib Pipe Arch
H20 or H25 Live Load • 3/4 x 3/4 x 71/2 in. and 3/4 x 1 x 111/2 in. Configurations

Span & Rise in.	Minimum Specified Thickness Required in.	Minimum Cover in.	Maximum Cover (ft) Over Pipe Arch for Soil Corner Bearing Capacity of 2 tons/ft^2
20 x 16	0.064	12	13
23 x 19	0.064	12	14
27 x 21	0.064	12	13
33 x 26	0.064	12	13
40 x 31	0.064	12	13
46 x 36	0.064	12	14
53 x 41	0.064	18	(13)
60 x 46	0.079	18	20
66 x 51	0.079	18	(21)
73 x 55	0.109	18	21
81 x 59	0.109	18	(17)
87 x 63	0.109	18	(17)
95 x 67	0.109	18	[17]

Notes:
l . Soil bearing capacity refers to the soil in the region of the pipe corners. See Chapter 10.
2. Minimum covers are for H20 and H25 loads. See Table 10.1 for heavy construction load requirements. Minimum covers are measured from top of pipe to bottom of flexible pavement or top of pipe to top of rigid pavement. Minimum cover must be maintained in unpaved traffic areas.
3. TYPE I installations are allowed unless otherwise shown.
4. ( ) Requires TYPE II installation
5. [ ] Requires TYPE III installation
6. For more details on TYPE I, II, and III installations, refer to the section on Installation and Backfill of Spiral Rib Pipe found earlier in this chapter.



AISI-11

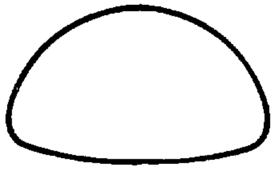
Height-of-Cover Limits for Corrugated Steel Pipe Arch
H20 or H25 Live Load • 5 x 1 in. and 3 x 1 in. Corrugations

Span & Rise in.	Minimum Specified Thickness Required 3 x 1 in.	Minimum Specified Thickness Required 5 x 1** in.	Minimum* Cover in.	Maximum Cover (ft) Over Pipe Arch for Soil Corner Bearing Capacity of 2 tons/ft^2
53 x 41	0.079	0.109	12	25
60 x 46	0.079	0.109	15	25
66 x 51	0.079	0.109	15	25
73 x 55	0.079	0.109	18	24
81 x59	0.079	0.109	18	21
87 x 63	0.079	0.109	18	20
95 x 67	0.079	0.109	18	20
103 x 71	0.079	0.109	18	20
112 x 75	0.079	0.109	21	20
117 x 79	0.109	0.109	21	19
128 x 83	0.109	0.109	24	19
137 x 87	0.109	0.109	24	19
142 x 91	0.138	0.138	24	19
150 x 96	0.138	0.138	30	19
157 x 101	0.138	0.138	30	19
164 x 105	0.138	0.138	30	19
171 x 110	0.138	0.138	30	19

Notes:
1. Soil bearing capacity refers to the soil in the region of the pipe corners. See Chapter 10 for design of pipe envelope at pipe corners. The remaining backfill around the pipe arch must be compacted to a specified AASHTO T-99 density of 90%
2. Use reasonable care in handling and installation.
3. Pipe arches are typically used where the cover does not exceed 15 feet.

* Minimum covers are for H20 and H25 loads. See Table 10.1 for construction load requirements. Minimum covers are measured from top of pipe to bottom of flexible pave-ment or top of pipe to top of rigid pavement. Minimum cover must be maintained in unpaved traffic areas.

** Same thicknesses as specified for 3 x 1 may be provided when the corner radius meets the requirements of ASTM A760.

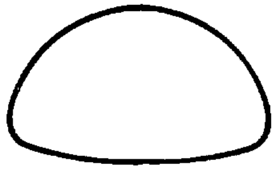


AISI-12

Height-of-Cover for Corrugated Steel Pipe Arch
E80 Live Load •2 2/3 x 1/2 in. Corrugation

Span & Rise in.	Minimum Specified Thickness Required in.	Minimum* Cover in.	Maximum Cover (ft) Over Pipe Arch for Soil Corner Bearing Capacity of 3 tons/ft^2
17 x 13	0.079	24	22
21 x 15	0.079	24	22
24 x 18	0.109	24	22
28 x 20	0.109	24	22
35 x 24	0.138	24	22
42 x 29	0.138	24	22
49 x 33	0.168	24	22
57 x 38	0.168	24	22
64 x 43	0.168	24	22
71 x47	0.168	24	22

Notes:
1. Soil bearing capacity refers to the soil in the region of the pipe corners. See Chapter 10 for design of pipe envelope at pipe corners. The remaining backfill around the pipe arch must be compacted to a specified AASHTO T-99 density of 90%
2. Use reasonable care in handling and installation.
3. Pipe arches are typically used where the cover does not exceed 15 feet.
* Minimum cover is from top of pipe to bottom of tie.



AISI-13

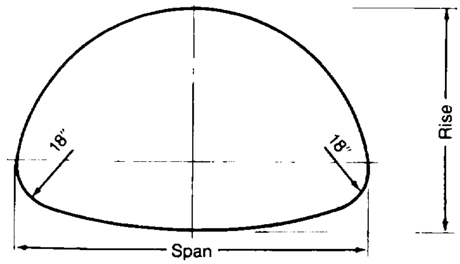
Height-of-Cover for Corrugated Steel Pipe Arch
E80 Live Load • 5 x 1 in. and 3 x 1 in. Corrugations

Span & Rise in.	Minimum Specified Thickness Required 3 x 1 in.	Minimum Specified Thickness Required 5 x 1** in.	Minimum* Cover in.	Maximum Cover (ft) Over Pipe Arch for Soil Corner Bearing Capacity of 2 tons/ft^2
53 x 41	0.079	0.109	24	25
60 x 46	0.079	0.109	24	25
66 x 51	0.079	0.109	24	25
73 x 55	0.079	0.109	30	24
81 x 59	0.079	0.109	30	21
87 x 63	0.079	0.109	30	18
95 x 67	0.079	0.109	30	18
103 x 71	0.079	0.109	36	18
112 x 75	0.079	0.109	36	18
117 x 79	0.109	0.109	36	17
128 x 83	0.109	0.109	42	17
137 x 87	0.109	0.109	42	17
142 x 91	0.138	0.138	42	17
150 x 96	0.138	0.138	48	17
157 x 101	0.138	0.138	48	17
164 x 105	0.138	0.138	48	17
171 x 110	0.138	0.138	48	17

Notes:
1. Soil bearing capacity refers to the soil in the region of the pipe corners. See Chapter 10 for design of pipe envelope at pipe corners. The remaining backfill around the pipe arch must be compacted to a specified AASHTO T-99 density of 90%.
2. Use reasonable care in handling and installation.
3. Pipe arches are typically used where the cover does not exceed 15 feet.

* From top of pipe to bottom of tie.

** Lesser thicknesses may be provided if justified by calculations.

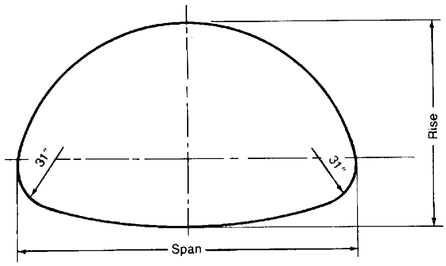


AISI-14

Height-of-Cover Limits for Structural Plate Pipe Arch • 18 in. R_C Corner Radius
H20 or H25 Live Load • 6 x 2 in. Corrugation

Size		Minimum Specified Thickness Required in.	Minimum* Cover in.	Maximum Cover (ft) Over Pipe Arch for the Following Soil Corner Bearing Capacities	
Span ft-in.	Rise ft-in.			2 tons/ft^2	3 tons/ft^2
6-1	4-7	0.111	12	19	
6-4	4 9	0.111	12	18	
6-9	4-11	0.111	12	17	
7-0	5-1	0.111	12	16	
7-3	5-3	0.111	12	16	
7-8	5-5	0.111	12	15	
7-11	5-7	0.111	12	14	
8-2	5-9	0.111	18	14	
8-7	5-11	0.111	18	13	
8-10	6-1	0.111	18	13	
9-4	6-3	0.111	18	12	
9-6	6-5	0.111	18	12	
9-9	6-7	0.111	18	12	
10-3	6-9	0.111	18	10	
10-8	6-11	0.111	18	8	
10-11	7-1	0.111	18	8	
11-5	7-3	0.111	18	8	15
11-7	7-5	0.111	18	8	15
11-10	7-7	0.111	18	7	14
12-4	7-9	0.111	24	6	12
12-6	7-11	0.111	24	6	12
12-8	8-1	0.111	24	6	11
12-10	8-4	0.111	24	6	11
13-5	8-5	0.111	24	5	11
13-11	8-7	0.111	24	5	10
14-1	8-9	0.111	24	5	10
14-3	8-11	0.111	24	5	10
14-10	9-1	0.111	24	5	10
15-4	9-3	0.111	24		9
15-6	9-5	0.111	24		9
15-8	9-7	0.111	24		9
15-10	9-10	0.111	24		9
16-5	9-11	0.111	30		9
16-7	10-1	0.111	30		9

Notes:
1. Soil bearing capacity refers to the soil in the region of the pipe corners. See Chapter 10 for design of pipe envelope at pipe corners. The remaining backfill around the pipe arch must be compacted to a specified AASHTO T-99 density of 90%.
2. Use reasonable care in handling and installation.
3. Pipe arches are typically used where the cover does not exceed 15 feet.
* Minimum covers are for H20 and H25 loads. See Table 7.8 for construction load requirements. Minimum covers are measured from top of pipe to bottom of flexible pave-ment or top of pipe to top of rigid pavement. Minimum cover must be maintained in unpaved traffic areas.



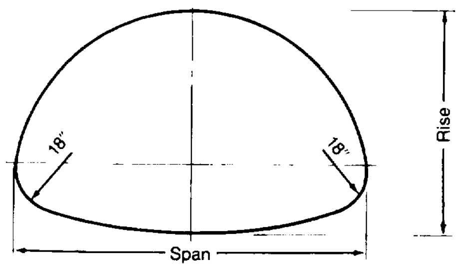
AISI-15

Height-of-Cover Limits for Structural Plate Pipe Arch • 31 in. R_C Corner Radius
H20 or H25 Live Load • 6 x 2 in. Corrugation

Size		Minimum Specified Thickness Required in.	Minimum* Cover in.	Maximum Cover (ft) Over Pipe Arch for the Following Soil Corner Bearing Capacities	
Span ft-in.	Rise ft-in.			2 tons/ft²	3 tons/ft²
13-3	9-4	0.111	24	13	
13-6	9-6	0.111	24	13	
14-0	9-8	0.111	24	12	
14-2	9-10	0.111	24	12	
14-5	10-0	0.111	24	12	
14-11	10-2	0.111	24	12	
15-4	10-4	0.111	24	11	
15-7	10-6	0.111	24	11	
15-10	10-8	0.111	24	10	
16-3	10-10	0.111	30	10	
16-6	11-0	0.111	30	10	
17-0	11-2	0.111	30	10	15
17-2	11-4	0.111	30	10	15
17-5	11-6	0.111	30	10	15
17-11	11-8	0.111	30	10	14
18-1	11-10	0.111	30	9	14
18-7	12-0	0.111	30	9	14
18-9	12-2	0.111	30	9	14
19-3	12-4	0.111	30	9	13
19-6	12-6	0.140	30	9	13
19-8	12-8	0.140	30	9	13
19-11	12-10	0.140	30	9	13
20-5	13-0	0.140	36	8	13
20-7	13-2	0.140	36	8	13

Notes:
1. Soil bearing capacity refers to the soil in the region of the pipe corners. See Chapter 10 for design of pipe envelope at pipe corners. The remaining backfill around the pipe arch must be compacted to a specified AASHTO T-99 density of 90%.
2. Use reasonable care in handling and installation.

* Minimum covers are for H20 and H25 loads. See Table 7.8 for construction load requirements. Minimum covers are measured from top of pipe to bottom of flexible pave-ment or top of pipe to top of rigid pavement. Minimum cover must be maintained in unpaved traffic areas.

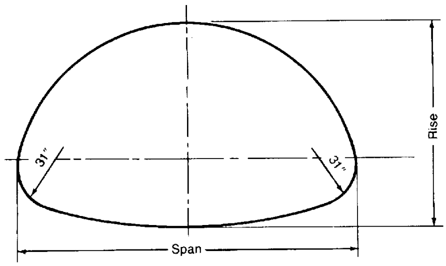


AISI-16

Height-of-Cover Limits for Structural Plate Pipe Arch • 18 in. R_C Corner Radius
E80 Live Load • 6 x 2 in. Corrugation

Size		Minimum Specified Thickness Required in.	Minimum* Cover in.	Maximum Cover (ft) Over Pipe Arch for the Following Soil Corner Bearing Capacities		
Span ft-in.	Rise ft-in.			2 tons/ft^2	3 tons/ft^2	4 tons/ft^2
6-1	4-7	0.111	24	19		
6-4	4-9	0.111	24	15		
6-9	4-11	0.111	24	15		
7-0	5-1	0.111	24	13		
7-3	5-3	0.111	24	12		
7-8	5-5	0.111	24	12		
7-11	5-7	0.111	24	11		
8-2	5-9	0.111	24	10		
8-7	5-11	0.111	24	6		
8-10	6-1	0.111	24	5		
9-4	6-3	0.111	24		17	
9-6	6-5	0.111	24		16	
9-9	6-7	0.111	24		16	
10-3	6-9	0.111	30		15	
10-8	6-11	0.111	30		13	
10-11	7-1	0.111	30		13	
11-5	7-3	0.111	30		12	
11-7	7-5	0.140	30		12	
11-10	7-7	0.140	30		12	
12-4	7-9	0.140	30		6	
12-6	7-11	0.140	30		6	16
12-8	8-1	0.140	36		6	16
12-10	8-4	0.140	36		6	16
13-5	8-5	0.140	36			15
13-11	8-7	0.140	36			15
14-1	8-9	0.140	36			14
14-3	8-11	0.140	36			11
14-10	9-1	0.140	36			9
15-4	9-3	0.140	42			9
15-6	9-5	0.140	42			9
15-8	9-7	0.140	42			9
15-10	9-10	0.140	42			9
16-5	9-11	0.140	42			7
16-7	10-1	0.140	42			7

Notes:
1. Soil bearing capacity refers to the soil in the region of the pipe corners. See Chapter 10 for design of pipe envelope at pipe corners. The remaining backfill around the pipe arch must be compacted to a specified AASHTO T-99 density of 90%.
2. Use reasonable care in handling and installation.
3. Pipe arches are typically used where the cover does not exceed 15 feet.
* From top of pipe to bottom of tie.



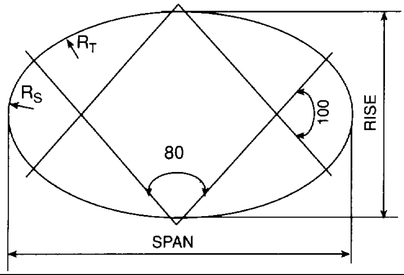
AISI-17

Height-of-Cover Limits for Structural Plate Pipe Arch • 31 in. R_C Corner Radius
E80 Live Load • 6 x 2 in. Corrugation

Size		Minimum Specified Thickness Required in.	Minimum* Cover in.	Maximum Cover (ft) Over Pipe Arch for the Following Soil Corner Bearing Capacities	
Span ft-in.	Rise ft-in.			2 tons/ft^2	3 tons/ft^2
13-3	9-4	0.140	36	9	22
13-6	9-6	0.140	36	8	22
14-0	9-8	0.140	36	6	21
14-2	9-10	0.140	36	6	21
14-5	10-0	0.140	36	6	21
14-11	10-2	0.140	36	6	20
15-4	10-4	0.140	42	6	19
15-7	10-6	0.140	42	6	19
15-10	10-8	0.140	42	6	19
16-3	10-10	0.140	42		14
16-6	11-0	0.140	42		14
17-0	11-2	0.140	42		13
17-2	11-4	0.140	42		13
17-5	11-6	0.140	42		
17-11	11-8	0.140	48		11
18-1	11-10	0.140	48		11
18-7	12-0	0.140	48		11
18-9	12-2	0.140	48		11
19-3	12-4	0.140	48		10
19-6	12-6	0.170	48		10
19-8	12-8	0.170	48		10
19-11	12-10	0.170	48		10
20-5	13-0	0.170	48		10
20-7	13-2	0.170	48		10

Notes:
1. Soil bearing capacity refers to the soil in the region of the pipe corners. See Chapter 10 for design of pipe envelope at pipe corners. The remaining backfill around the pipe arch must be compacted to a specified AASHTO T-99 density of 90%.
2. Use reasonable care in handling and installation.
3. Pipe arches are typically used where the cover does not exceed 15 feet.

*From top of pipe to bottom of tie.



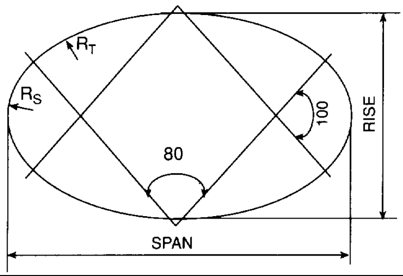
AISI-18

Height-of-Cover Limits for Structural Plate Horizontal Elliptical Pipe
H20 or H25 Live Load • 6 x 2 in. Corrugation

Pipe Size	Span ft-in.	Rise ft-in.	R_T in.	R_s in.	Minimum* Cover in.	Minimum Specified Thickness Required in.	Maximum Cover (ft) Over Pipe for Side and Haunch Soil Bearing Capacity of 2 tons/ft^2
24 E 15	7-4	5-6	54.00	26.50	12	0.111	16
27 E 15	8-1	5-9	60.88	26.50	18	0.111	14
30 E 15	8-10	6-0	67.75	26.50	18	0.111	13
30 E 18	9-2	6-9	67.75	32.00	18	0.111	15
33 E 15	9-7	6-4	74.63	26.50	18	0.111	11
33 E 18	9-11	7-0	74.63	32.00	18	0.111	14
36 E 15	10-4	6-7	81.51	26.50	18	0.111	10
36 E 18	10-8	7-3	81.51	32.00	18	0.111	13
36 E 21	11-0	8-0	81.51	37.50	18	0.111	15
39 E 15	11-1	6-10	88.38	26.50	18	0.111	10
39 E 18	11-4	7-6	88.38	32.00	18	0.111	12
39 E 21	11-8	8-3	88.38	37.50	18	0.111	14
39 E 24	12-0	8-11	88.38	43.00	24	0.111	16
42 E 15	11-9	7-1	95.26	26.50	18	0.111	9
42 E 18	12-1	7-10	95.26	32.00	24	0.111	11
42 E 21	12-5	8-6	95.26	37.50	24	0.111	13
42 E 24	12-9	9-2	95.26	43.00	24	0.111	15
45 E 15	12-6	7-4	102.13	26.50	24	0.111	8
45 E 18	12-10	8-1	102.13	32.00	24	0.111	10
45 E 21	13-2	8-9	102.13	37.50	24	0.111	12
45 E 24	13-6	9-6	102.13	43.00	24	0.111	14
48 E 18	13-7	8-4	109.01	32.00	24	0.111	9
48 E 21	13-11	9-0	109.01	37.50	24	0.111	11
48 E 24	14-3	9-9	109.01	43.00	24	0.111	13
48 E 27	14-7	10-5	109.01	48.50	24	0.111	14
48 E 30	14-11	11-2	109.01	54.00	24	0.111	16

Notes:
1. Soil bearing capacity refers to the soil in the region of the pipe haunches. See Chapter 10 for design of pipe envelope at pipe haunches. The remaining backfill around the ellipse must be compacted to a specified AASHTO T-99 density of 90%.
2. Use reasonable care in handling and installation.

* Minimum covers are for H20 and H25 loads. See Table 10.1 for construction load requirements. Minimum covers are measured from top of pipe to bottom of flexible pavement or top of pipe to top of rigid pavement. Minimum cover must be maintained in unpaved traffic areas.

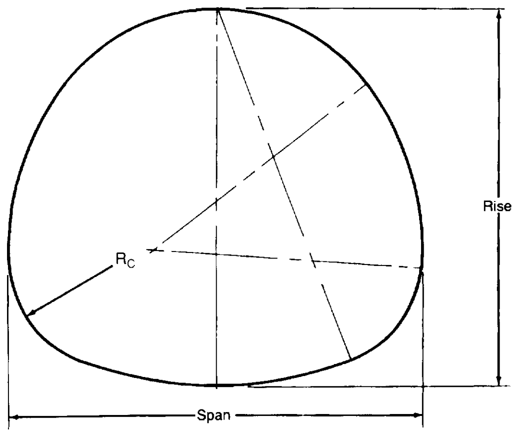


AISI-19

Height-of-Cover Limits for Structural Plate Horizontal Elliptical Pipe
E80 Live Load • 6 x 2 in. Corrugation

Pipe Size	Span ft-in.	Rise ft-in.	R_T in.	R_s in.	Minimum* Cover in.	Minimum Specified Thickness Required in.	Maximum Cover (ft) Over Pipe for Side and Haunch Soil Bearing Capacity of 3 tons/ft²
24 E 15	7-4	5-6	54.00	26.50	24	0.111	24
27 E 15	8-1	5-9	60.88	26.50	24	0.111	21
30 E 15	8-10	6-0	67.75	26.50	24	0.140	19
30 E 18	9-2	6-9	67.75	32.00	24	0.140	24
33 E 15	9-7	6-4	74.63	26.50	24	0.140	17
33 E 18	9-11	7-0	74.63	32.00	30	0.140	21
36 E 15	10-4	6-7	81.51	26.50	30	0.140	15
36 E 18	10-8	7-3	81.51	32.00	30	0.140	20
36 E 21	11-0	8-0	81.51	37.50	30	0.140	23
39 E 18	11-4	7-6	88.38	32.00	30	0.140	18
39 E 21	11-8	8-3	88.38	37.50	30	0.140	22
39 E 24	12-0	8-11	88.38	43.00	30	0.140	25
42 E 18	12-1	7-10	95.26	32.00	30	0.140	16
42 E 21	12-5	8-6	95.26	37.50	30	0.140	20
42 E 24	12-9	9-2	95.26	43.00	36	0.140	23
45 E 18	12-10	8-1	102.13	32.00	36	0.170	15
45 E 21	13-2	8-9	102.13	37.50	36	0.170	19
45 E 24	13-6	9-6	102.13	43.00	36	0.170	22
48 E 18	13-7	8-4	109.01	32.00	36	0.170	13
48 E 21	13-11	9-0	109.01	37.50	36	0.170	17
48 E 24	14-3	9-9	109.01	43.00	36	0.170	20
48 E 27	14-7	10-5	109.01	48.50	36	0.170	23
48 E 30	14-11	11-2	109.01	54.00	42	0.170	26

Notes:
1. Soil bearing capacity refers to the soil in the region of the pipe haunches. See Chapter 10 for design of pipe envelope at pipe haunches. The remaining backtill around the ellipse must be compacted to a specified AASHTO T-99 density of 90%.
2. Use reasonable care in handlgng and installation.
* From top of pipe to bottom of tie.



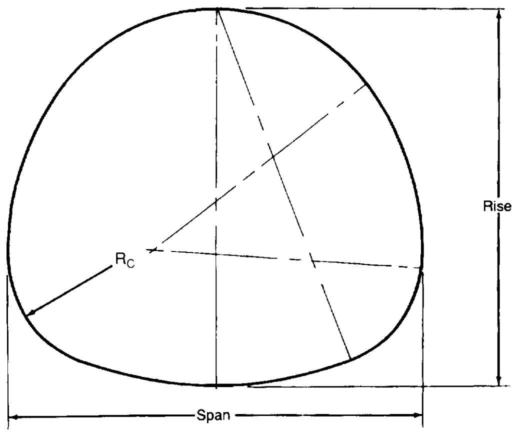
AISI-20

Height-of-Cover Limits for Structural Plate Underpass
H20 or H25 Live Load • 6 x 2 in. Corrugation

Size		R_c Corner Radius in.	Minimum Specified Thickness Required in.	Minimum* Cover in.	Maximum Cover (ft) Over Underpass for Soil Corner Bearing Capacity of 2 tons/ft²
Span ft-in.	Rise ft-in.				
5-8	5-9	18	0.111	12	26
5-8	6-6	18	0.111	12	24
5-9	7-4	18	0.111	12	24
5-10	7-8	18	0.111	12	24
5-10	8-2	18	0.111	12	24
12-2	11-0	38	0.111	24	22
12-11	11-2	38	0.111	24	20
13-2	11-10	38	0.111	24	20
13-10	12-2	38	0.111	24	19
14-1	12-10	38	0.111	24	l9
14-6	13-5	38	0.111	24	19
14-10	14-0	38	0.111	24	19
15-6	14-4	38	0.111	24	15
15-8	15-0	38	0.111	24	15
16-4	15-5	38	0.140	36	15
16-5	16-0	38	0.140	36	14
16-9	16-3	38	0.140	36	14
17-3	17-0	47	0.140	36	17
18-4	16-11	47	0.170	36	16
19-1	17-2	47	0.170	36	15
19-6	17-7	47	0.170	36	15
20-4	17-9	47	0.188	36	14

Notes:
1. Soil bearing capacity refers to the soil in the region of the pipe corners. See Chapter 10 for design of pipe envelope at pipe corners. The remaining backfill around the underpass must be compacted to a specified AASHTO T-99 density of 90%.
2. Use reasonable care in handling and installation.

* Minimum covers are for H20 and H25 loads. See Table 10.1 for heavy construction load requirements. Minimum covers are measured from top of pipe to bottom of flexible pavement or top of pipe to top of rigid pavement. Minimum cover must be maintained in unpaved traffic areas.

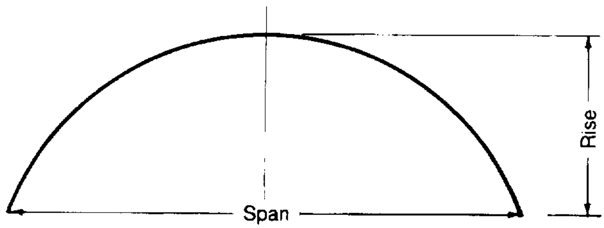


AISI-21

Height-of-Cover Limits for Structural Plate Underpass
E80 Live Load • 6 x 2 in. Corrugation

Size		R_C Corner Radius in.	Minimum Specified Thickness Required in.	Minimum* Cover in.	Maximum Cover (ft) Over Underpass for Soil Corner Bearing Capacity of 2 tons/ft^2
Span ft-in.	Rise ft-in.				
5-8	5-9	18	0.111	24	26
5-8	6-6	18	0.111	24	24
5-9	7-4	18	0.111	24	24
5-10	7-8	18	0.111	24	24
5-10	8-2	18	0.111	24	24
12-2	11-0	38	0.140	36	22
12-11	11-2	38	0.140	36	20
13-2	11-10	38	0.140	36	20
13-10	12-2	38	0.140	36	17
14-1	12-10	38	0.140	36	17
14-6	13-5	38	0.140	36	19
14-10	14-0	38	0.140	36	19
15-6	14-4	38	0.140	48	12
15-8	15-0	38	0.140	48	13
16-4	15-5	38	0.140	48	13
16-5	16-0	38	0.140	48	11
16-9	16-3	38	0.140	48	11
17-3	17-0	47	0.140	48	15
18-4	16-11	47	0.170	48	14
19-1	17-2	47	0.170	48	13
19-6	17-7	47	0.170	48	13
20-4	17-9	47	0.188	48	12

Notes:
1. Soil bearing capacity refers to the soil in the region of the pipe corners. See Chapter 10 for design of pipe envelope at pipe corners. The remaining backfill around the underpass must be compacted to a specified AASHTO T-99 density of 90%.
2. Use reasonable care in handling and installation.
* From top of pipe to bottom of tie.



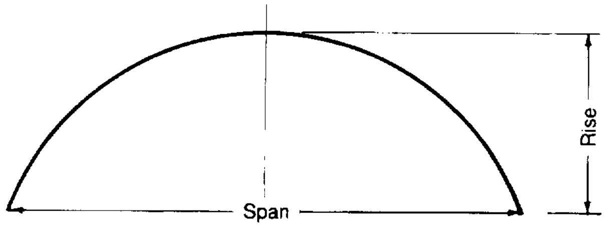
AISI-22

Height-of-Cover Limits for Structural Plate Arches
H20 or H25 Live Load • 6 x 2 in. Corrugation

$\frac{Rise}{Span} \geq 0.30$

Span, ft	Min.* Cover, in.	Maximum Cover (ft) for Specified Thickness (in.) 0.111	0.140	0.170	0.188	0.218	0.249	0.280
5	12	81	120	157	176	205	234	264
6	12	68	101	131	146	171	195	220
7	12	58	86	112	125	146	168	188
8	12	51	75	98	111	128	146	165
9	24	45	67	87	97	114	130	146
10	24	40	60	78	87	102	117	132
11	24	37	54	71	79	93	106	120
12	24	34	50	65	73	85	97	110
13	24	31	46	60	67	79	90	101
14	24	29	43	56	62	73	83	94
15	24	27	40	52	58	68	78	88
16	24	25	37	49	54	64	73	82
17	36	24	35	45	51	60	68	77
18	36	23	33	42	47	55	63	71
19	36	18	31	38	43	50	58	65
20	36		28	35	40	47	53	60
21	36		27	32	36	43	49	56
22	36		21	31	33	39	45	51
23	36			27	31	36	41	46
24	36			21	28	33	38	43
25	48				22	31	35	39
26	48					24	32	35

Notes:
1. Arches with R/S less than 0.30 require special design.
* Minimum covers are for H20 and H25 loads. See Table 10.1 for heavy construction load requirements. Minimum covers are measured from top of pipe to bottom of flexible pavement or top of pipe to top of rigid pavement. Minimum cover must be maintained in unpaved traffic areas.



AISI-23

Height-of-Cover Limits for Structural Plate Arches
E80 Live Load • 6 x 2 in. Corrugation

$\frac{\text{Rise}}{\text{Span}} \geq 0.30$

Span, ft	Min.* Cover, in.	Maximum Cover (ft) for Specified Thickness (in.)						
		0.111	0.140	0.170	0.188	0.218	0.249	0.280
5	24	81	120	157	176	205	234	264
6	24	68	101	131	146	171	195	220
7	24	58	86	112	125	146	168	188
8	24	51	75	98	111	128	146	165
9	24	45	67	87	97	114	130	146
10	24	40	60	78	87	102	117	132
11	30	37	54	71	79	93	106	120
12	30	34**	50	65	73	85	97	110
13	36	31 **	46	60	67	79	90	101
14	36	29**	43	56	62	73	83	94
15	36	24**	40	52	58	68	78	88
16	48	23**	37	49	54	64	73	82
17	48	16**	35	45	51	60	68	77
18	48	14**	35	42	47	55	63	71
19	48	13**	31	37	43	50	58	65
20	48		28	33	40	47	53	60
21	60		20	31	35	43	49	56
22	60		16	27	31	39	45	51
23	60			21	28	35	41	46
24	60			17	22	31	37	43
25	60				19	24	33	39
26	60					21	24	35

Notes:
1. Arches with R/S less than 0.30 require special design.
* From top of pipe to bottom of tie.
** These structural plate arches require additional minimum cover.

AISI-24

Minimum Cover In Feet for Airplane
Wheel Loads on Flexible Pavements* - 2-2/3 x 1/2 in. Corrugation

Specified Thickness in.	Pipe Diameter, in.								
	12	18	24	36	48	60	72	84	96
Case 1. Loads to 40,000 Lb. - Dual Wheels									
.064	1.0	1.0	1.0	1.5	2.0				
.079	1.0	1.0	1.0	1.5	2.0				
.109			1.0	1.0	1.5	2.0			
.138				1.0	1.5	1.5	2.0		
.168				1.0	1.0	1.5	1.5	2.0	2.0
Case 2. Loads to 110,000 Lb—Dual Wheels									
.064	1.5	1.5	1.5	2.0	2.5				
.079	1.5	1.5	1.5	2.0	2.5				
.109			1.5	1.5	2.0	2.5			
.138				1.5	2.0	2.0	2.5		
.168				1.5	1.5	2.0	2.5	2.5	2.5
Case 3. Loads to 750 000 Lb—Dual-Dual									
.064	2.0	2.0	2.0	2.5	3.0				
.079	2.0	2.0	2.0	2.0	2.5				
.109			2.0	2.0	2.5	2.5			
.138				2.0	2.0	2.5	3.0		
.168				2.0	2.0	2.0	2.5	3.0	3.0
Case 4. Loads to 1.5 Million Lb									
.064	2.5	2.5	2.5	2.5	3.0				
.079	2.5	2.5	2.5	2.5	2.5				
.109			2.5	12.5	2.5	2.5			
.168				2.5	2.5	2.5	2.5	3.0	3.0
Diam.	12	18	24	36	48	60	72	84	96

Notes:
1. See Table AISI-5 (E 80 requirements) for maximum cover.
2. Backfill around pipe must be compacted to a specified AASHTO T-99 densitiy of 90%.
3. Use reasonable care in handling and installation.
4. Minimum cover is from top surface of flexible pavement to top of CSP.
5. Loads are total load of airplane.
6. Seam strength must be checked for riveted pipe.
* From "Airport Drainage," U.S. Dept. of Transportation, F.A.A., 1994.

AISI-25

Minimum Cover In Feet for Airplane
Wheel Loads on Flexible Pavements* - 5 x 1 in. and 3 x 1 in. Corrugations

Specified Thickness in.	Pipe Diameter, in.							
	36	48	60	72	84	96	108	120
Case 1. Loads to 40,000 Lb.—Dual Wheels								
.064	1.0	1.5	1.5	2.0	2.0	2.5		
.079	1.5	1.5	1.5	2.0	2.0	2.5		
.109	1.0	1.0	1.5	1.5	1.5	2.0	2.0	2.0
.138	1.0	1.0	1.0	1.5	1.5	1.5	2.0	2.0
.168	1.0	1.0	1.0	1.5	1.5	1.5	1.5	2.0
Case 2. Loads to 110,000 Lb—Dual Wheels								
.064	1.5	2.0	2.0	2.5	2.5	3.0		
.079	1.5	1.5	2.0	2.5	2.5	2.5	3.0	
.109	1.5	1.5	2.0	2.0	2.5	2.5	2.5	3.0
.138	1.5	1.5	1.5	2.0	2.0	2.5	2.5	2.5
.168	1.5	1.5	1.5	1.5	2.0	2.0	2.5	2.5
Case 3. Loads to 750,000 Lb—Dual-Dual								
.064	2.0	2.0	2.5	2.5	3.0	3.5		
.079	2.0	2.0	2.5	2.5	3.0	3.0	3.5	
.109	2.0	2.0	2.0	2.5	2.5	3.0	3.0	3.0
.138	2.0	2.0	2.0	2.0	2.5	2.5	2.5	3.0
.168	2.0	2.0	2.0	2.0	2.0	2.5	2.5	2.5
Case 4. Loads to 1.5 Million Lb								
.064	2.5	2.5	2.5	3.0	3.0	3.5		
.079	2.5	2.5	2.5	2.5	3.0	3.0	3 5	
.109	2.5	2.5	2.5	2.5	2.5	3.0	3.0	3.5
.138	2.5	2.5	2.5	2.5	2.5	2.5	3.0	3.0
.168	2.5	2.5	2.5	2.5	2 5	2 5	2 5	3 0
Diam.	36	48	60	72	84	96	108	120

Notes:
1. See Table AISI-5 (E80 requirements) for maximum cover.
2. Backfill around pipe must be compacted to a specified AASHTO T-99 densitiy of 90%.
3. Use reasonable care in handling and installation.
4. Minimum cover is from top surface of flexible pavement to top of CSP.
5. Loads are total load of airplane.
6. Seam strength must be checked for riveted pipe.
* From "Airport Drainage," U.S. Dept. of Transportation, F.A.A., 1994.

AISI-26

Minimum Cover in Feet for Airplane Wheel Loads on Rigid Pavements—* (All Corrugations)

Pipe Diameter, in.	15,000 lb. Single Wheel	25,000 lb. Single Wheel	100,000 lb. Twin Assembly	265,000 lb. Twin-Twin Assembly
6-60	0.5	0.5	1.0	1.0
66-108	1.0	1.0	1.5	1.5

Notes:
1. See Table AISI-5,-6,-8 for maximum cover.
2. Backfill around pipe must be compacted to a specified AASHTO T-99 density of 90%.
3. Use reasonable care in handling and installation.
4. Minimum cover is from bottom of slab to top of pipe.
5. Loads are not total loads but loads per wheel or assembly.
6. Minimum cover for C5A airplane is same as 100,000 lb. assembly.

* From "Development of Minimum Pipe-Cover Requirements for C-5A and Other Aircraft Loadings," C.C. Calhoun, Jr. and H.H. Ulery, Jr., U.S. Army WES, Vicksburg, MS, Paper S-73-65, November 1973.

AISI-27

Minimum Cover in Feet for Airplane Wheel Loads on Flexible Pavements*— 6 x 2 in. Corrugation

DualWheels With Loads To	40,000 lb.	110,000 lb.	750,000 lb.	1.5 Million lb.
Minimum Cover	D/8 but not less than 1.0 feet	D/6 but not less than 1.5 feet	D/5 but not less than 2.0 feet	D/4 but not less than 2.5 feet

Notes:
1. See Table AISI-8 for maximum depth of cover.
2. Backfill around pipe must be compacted to a specified AASHTO T-99 density of 90%.
3. Use reasonable care in handling and installation.
4. Minimum cover is from top surface of flexible pavement to top of CSP.
5. Loads are total load of airplane.

* From "Airport Drainage," U.S. Dept. of Transortation, F.A.A., 1994.

STRUCTURAL DESIGN OF STANDARD STRUCTURES BY THE LRFD METHOD

Load and Resistance Factor Design (LRFD) is a method of proportioning structural elements (the pipe) by applying factors to both the loads (load factors) and the nominal strength levels (resistance factors). The specified factors are based on the mathematical theory of reliability and a statistical knowledge of load and material characteristics. The load factors are multipliers (typically greater than 1.0) that take account of the variability of different types of loads, such as earth loads and live loads. Thus, the pipe must be designed to resist a combination of factored earth loads and factored live loads plus impact.

Resistance factors are tytpically 1.0 or lower. They account for the possible reduction in the strength of the structural materials involved. While LRFD designs don't openly display the degree of safety (the factor of safety) as such, it is essentially the ratio of the factored load divided by the factored resistance.

LRFD methods may be found in both the AASHTO *LRFD Bridge Design Specifications* and in ASTM Standard Practice A796/A796M. AASHTO has set a goal to use the LRFD method for all new construction. ASTM A976/A796M includes both Allowable Stress Design (ASD) and LRFD as alternative procedures. ASTM LRFD is a simplified version of AASHTO LRFD, which involves additional factors and alternative live loads. The referenced documents should be referred to for complete details.

DESIGN OF OTHER STRUCTURES

The design methods discussed previously in this chapter address standard corrugated steel pipe and plate structures. They are based on the American Iron and Steel Institute (AISI) working stress design method, or similar AASHTO methods, which have been used successfully for traditional products for over 60 years. This includes round pipe and arches with a maximum span of 26 feet as well as pipe arches and underpasses with a maximum span of 21 feet. However such methods are not applicable to structures with long spans or high bending moments, such as box culverts and long span shapes and deep corrugated structures.

Because of their size or shape, the design of those structures is based on simplified methods derived from finite element evaluations, or direct finite element designs using software such as CANDE. The most recent design methods are included in the AASHTO *LRFD Bridge Design Specifications* and in the *Canadian Highway Bridge Design Code* (CHBDC).

A limited discussion of product background and design aspects for these larger or special shape structures follows. However, reference should be made to the above references for further design information for those structures.

Long Span Structures

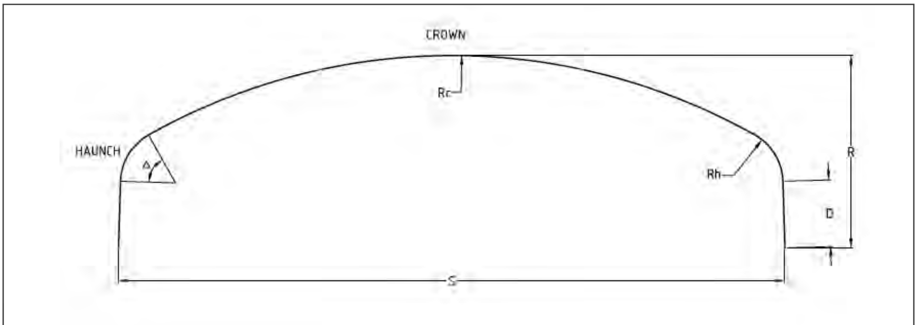
Structural design of long span structures with the 6 inch x 2 inch corrugation follows the traditional ring compression method with additional checks to account for size and flexibility. Designs can be made with both the AASHTO *LRFD Bridge Design Specifications* and the AASHTO *Standard Specifications for Highway Bridges*. An empirical table of minimum thickness is specified based on a top radius from 15 to 25 feet. Long span structures, like box culverts, are limited to backfill materials that meet AASHTO M 145 requirements for A1, A2-4, A2-5, and A3 materials. These materials must be compacted to a minimum 90% modified Proctor density (90% AASHTO T-180). Long span structures are installed in accordance with the AASHTO *LRFD Bridge Construction Specifications*, Section 26.

Corrugated Steel Box Culvert Development

As illustrated in Figure 7.17, corrugated steel box culverts have a low, wide rectangular profile that necessitates the use of special design methods. Because of their nearly flat crowns and large span/rise ratios, box culverts behave differently than traditional soil-metal structures and must be designed in a different way. The first corrugated metal box culverts were built in 1975 using an empirical design method. Within a few years, a considerable number had been constructed and the demand for larger sizes increased to a point where completely empirical design procedures were no longer appropriate.

A study was initiated at the University of California - Berkeley (Duncan et al) to develop a rational design method for aluminum box culverts. The first phase of the study was a series of finite element analyses to evaluate the bending moments and the axial forces in box structures under loads imposed by backfill and live loads. In the next phase, full scale tests were conducted on instrumented box structures to provide a basis for calibrating the finite element analysis with measured behavior. This was augmented by several state DOTs that conducted field live load tests on each box culvert installed.

In 1987, AASHTO adopted a simplified design method for corrugated steel and aluminum box culverts based on the box culvert geometry limits represented in the various studies. This method is limited to box structures with spans through 25 feet 5 inches and rises through 10 feet 6 inches. Cover limits range from a minimum of 1.4 feet to a maximum of 5 feet.



■ **Figure 7.17** The Standard Corrugated Steel Box Culvert shape

Structural Plate Box Culverts

Many corrugated steel box culverts are made with 6 inch x 2 inch corrugated steel structural plate, strengthened with longitudinally spaced steel ribs to provide the necessary moment resistance. Design became standardized with the advent of the AASHTO box culvert design method and ASTM specification A 964/A 964M.

Steel box culverts are not ring compression structures. Rather, they act as soil supported, semi-rigid frames and are designed on the basis of bending moments and plastic moment strength. A design method is available in Section 12 of both the AASHTO *LRFD Bridge Design Specifications* and the AASHTO *Standard Specifications for Highway Bridges*. The following table lists the geometry limits that are applicable to the AASHTO LRFD method. Box structures outside the geometry limits in Table 7.9 must be designed using more rigorous, finite element methods.

Table 7.9

Standard Corrugated Steel Box Culvert Geometry Limits

Dimension	Minimum	Maximum
Span	8 ft - 0 in.	25 ft - 5 in.
Rise	2 ft - 6 in.	10 ft - 6 in.
Crown Radius	–	24 ft - 9 1/2 in.
Haunch Radius	2 ft - 6 in.	–
Included Angle of Haunch	50°∞	70°∞
Leg Length (to bottom of plate)	0 ft - 4 3/4 in.	5 ft - 11 in.

Standard corrugated steel box culverts are installed in accordance with the AASHTO *LRFD Bridge Construction Specifications*, Section 26. They require backfill materials classified by AASHTO M 145 as A1, A2-4, A2-5, and A3, compacted to a minimum 95% standard Proctor density (AASHTO T-99).

Deep Corrugated Steel Box Culverts

The Canadian Highway Bridge Design Code (CHBDC) box culvert design method was developed from the 1993 AASHTO design method. With the introduction of deep corrugated plate it became practical to increase the span of box culverts beyond the limits of the original 1984 Duncan study. Deep corrugated steel box culverts manufactured with 15 x 5.5 inch and 16 x 6 inch corrugation profiles have reached spans of over 50 feet. The design of structures with such long spans is complex. Performance is related to the interaction of the structure and the surrounding soil and, thus, the properties of the surrounding soil have a major effect on performance. For spans greater than 26 feet and/or rises greater than 10 feet 5 inches, the forces in the structure are calculated by rigorous methods of analysis, taking into account the beneficial effects of soil-structure interaction. All deep corrugated box structures can be analyzed with finite element programs.

Other Deep Corrugated Structures (Arches, Ellipses, and Round)

A limit states design method that reflects the variability in both loads and resistance of structural elements is used for deep corrugated structures. It is calibrated to provide a more uniform and quantifiable level of reliability than can be achieved with working stress design (WSD). The *Canadian Highway Bridge Design Code* (CHBDC) introduced this design method for deep corrugated structures in 2001 and updated it in 2006. The

CHBDC design code has been adopted by many countries around the world as the design method of choice for deep corrugated structures. The CHBDC method is based on limit states design philosophy (ultimate strength principles) rather than traditional working stress or service load design methods.

Deep corrugated steel structures using 15 x 5.5 inch and 16 x 6 inch corrugation profiles have reached spans of 80 feet. The design of structures with such long spans is complex. Performance is related to the interaction of the structure and the surrounding soil and, thus, the properties of the surrounding soil have a major effect on performance. The CHBDC design method quantifies the strength of both the soil and the structure.

The AASHTO design method was developed for 6 x 2 inch structural plate. It considers axial thrust effects only because the flexural rigidity of these plates is relatively small and bending moment can be ignored in most practical cases (when minimum cover levels are adequate). In contrast, deep corrugated plate has three times the bending strength and ten times the elastic stiffness of 6 x 2 inch plate. As a result, bending moments cannot be ignored in deep corrugated structures. A design procedure that includes the effects of bending moments, such as the CHBDC method, is necessary to account for the increased stiffness of deep corrugated plate. In addition to the CHBDC method, deep corrugated soil-metal structures can be analyzed by rigorous design methods, such as with finite element programs, taking into account the beneficial effects of soil-structure interaction.

The CHBDC design method involves the following steps:

1. Check minimum allowable cover
2. Calculate dead load thrust
3. Calculate live load thrust
4. Calculate earthquake thrust
5. Calculate the total factored thrust
6. Calculate the compressive stress
7. Calculate the wall strength in compression
8. Check combined bending and axial strength during construction
9. Check combined bending and axial strength in the ultimate limit state
10. Check seam strength
11. Check difference in plate thickness of adjacent plates
12. Calculate footing loads
13. Check plate radius of curvature

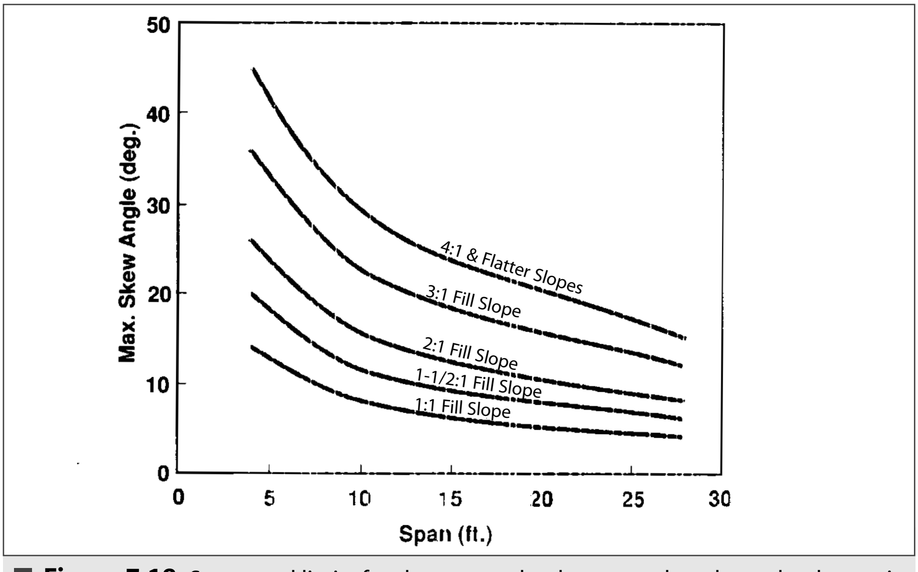
OTHER DESIGN REQUIREMENTS

End Treatment

Designing the ends of a flexible culvert requires additional considerations beyond those addressed in the ring compression design of the culvert barrel. End treatment design must also consider any unbalanced soil loadings due to skews or excessive cross slopes, the residual strength of any skew cut or bevel cut ends employed, as well as possible hydraulic action due to flow forces, uplift, and scour.

Pipe skewed to an embankment (pipe that cross through at an angle) are subjected to unbalanced soil loads through and beyond the area of the fill slope. The unbalance is easily seen by cutting a section across the pipe perpendicular to its longitudinal axis. The amount of unbalance depends on the degree of skew (angle), the diameter (span) of the pipe, and the slope of the embankment. Unbalanced soil loads typically are not a serious consideration when skews are maintained within the limits of Figure 7.18. Where multiple runs of pipe are used, the total span of the entire run, including the space between the pipes, must be considered in lieu of the span or diameter of a single pipe.

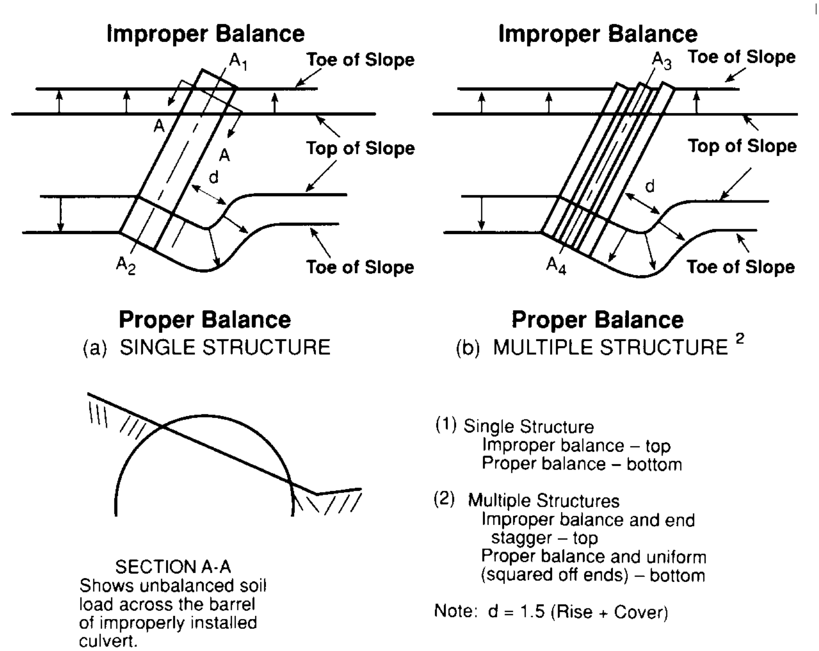
Where skews must exceed these limits, the embankment may be shaped or warped to balance the loads and ensure side support. Figure 7.20 provides typical examples of both properly and improperly balanced end treatments. Alternatively, full headwalls can be used. A rigid headwall, designed to carry the thrust forces of the cut end of the pipe can provide for nearly any degree of skew required.



■ **Figure 7.18** Suggested limits for skews to embankments unless the embankment is warped for support or full head walls are provided.

For most applications square end pipe is recommended. In multiple runs, the ends must be extended so they are aligned perpendicularly as shown for "Proper Balance" in Figure 7.20 (b). Adequate side support at the ends of multiple runs cannot be achieved if they are staggered as shown for "Improper Balance" in Figure 7.20 (b).

■ **Figure 7.19** Long span grade separation.



■ **Figure 7.20** Properly and improperly balanced (warped) embankment fills for single and multiple culvert installations.

Skew cut, bevel cut or skewed/bevel cut ends are sometimes used for hydraulic or aesthetic reasons. When the pipe ends are cut in any fashion, the compression ring is interrupted and pipe strength in the cut area is limited to the bending strength of the corrugation. Simple skew cut ends can generally handle soil and installation loads if they are limited to the skew angle limits of Figure 7.18. However, hydraulic flow forces must be considered separately. Headwalls, concrete collars, and other reinforcements can be provided as necessary.

Bevel cuts, as shown in Figure 7.21, can be done in several fashions. Step bevels are recommended for all pipe sizes. Step bevels are typically limited to 3:1, 2:1 or steeper slopes on long span and larger structural plate pipe, depending on their rise (height). Full and partial bevels are typically applicable only to smaller pipe as suggested by Table 7.10.

Full bevels are not recommended for multiple radius shapes such as pipe arch and underpass or with bevel slopes flatter than 3:1. Even then, pipe with full inverts must have the invert trimmed, as shown for a partial bevel.

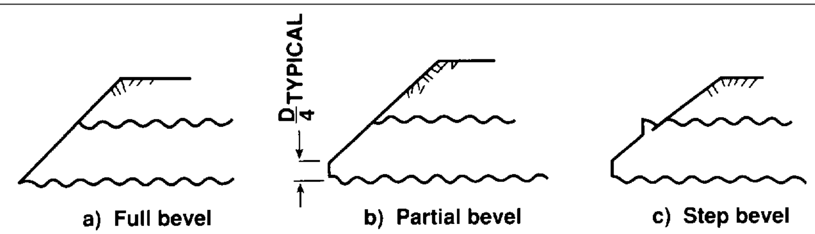


Figure 7.21 Types of beveled ends.

Table 7.10

Recommended Diameter (or Span) Limits (in.) for Full and Partial Bevel Cut Ends (Slope Collars, Toe Anchorage, etc. are required)

	Corrugation Type		
Specified Thickness in.	**2-2/3 x 1/2 in. 3/4 X 3/4 X 7-1/2 in. 3/4 X 1 X 11-1/2 in.**	**3 x 1 in. 5 x 1 in.**	**6 x 2 in.**
.064	48	78	
.079	54	84	
.109/.111	60	96	156
.138/.140	66	108	168
.168 /.170 /.188	72	114	180
.218			198
.249			210
.280			216

All types of bevel cut ends typically require protection, especially when hydraulic flow forces are anticipated. The cut portion should be anchored to slope pavement, slope collars or headwalls at approximately 18 inch intervals. Cutoff walls or other types of toe anchorage are recommended to avoid scour or hydraulic uplift problems.

Skew bevel cut ends may be used where they meet the criteria for both skew and bevel cut ends.

Hydraulic forces on inlet or outlet ends are difficult to quantify. When structures are designed to flow full under pressure, where flow velocities are high or where flows are expected to increase abruptly, significant hydraulic forces should be anticipated. Alternatively, equalizer pipe, slow flowing canal crossings, etc., generally do not provide the same level of concern.

Where significant hydraulic action is anticipated, support and protection of the pipe end (especially the inlet), erosion of the embankment fill, undercutting or piping of the backfill or bedding, and hydraulic uplift, become important design considerations. Slope collars, or slope pavements with proper pipe end anchorage can provide support for the pipe end and reduce erosion concerns. A compacted 1 foot thick clay cap over the fill slope, with proper erosion protection such as riprap, helps keep water from the backfill. Toe or cutoff walls, placed to an adequate depth, keep flow from undermining the invert and provides anchorage for the pipe end.

Half headwalls with cutoff walls (especially on the inlet end), as well as more elaborate full headwalls, not only stiffen the pipe end against damage from water energy, but also improve the efficiency of the inlet. Figures 7.22 – 7.25 show typical headwall treatments.

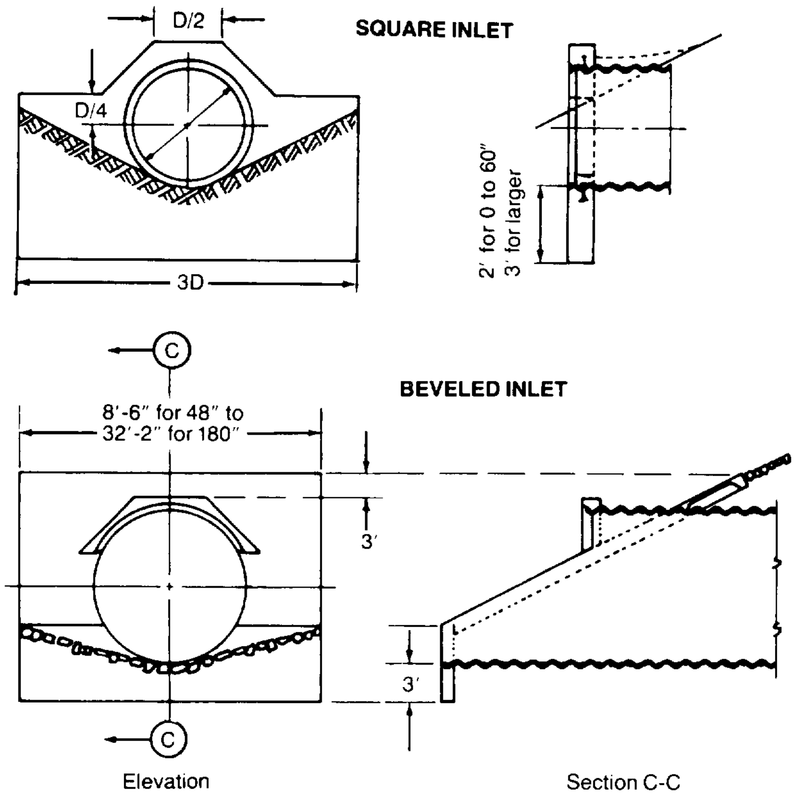
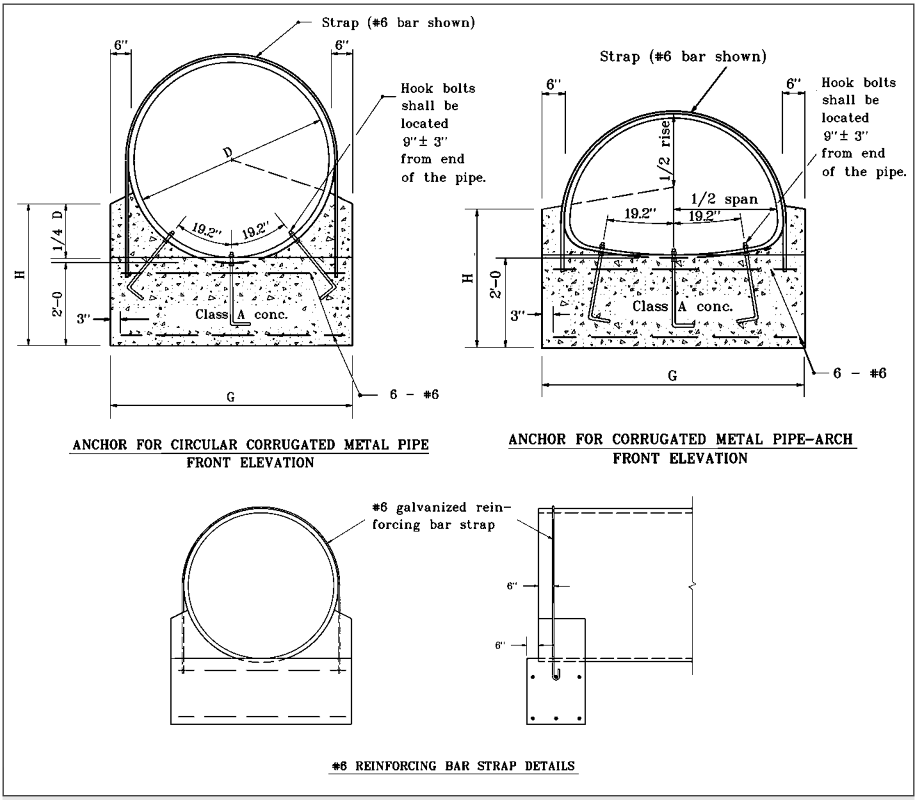


Figure 7.22 Treatment of inlet end of large corrugated steel structures as recommended by the Federal Highway Administration.



■ **Figure 7.23** Treatment of inlet end of corrugated steel pipes or structural plate pipes as recommended by the State of Indiana, Department of Transportation.

■ **Figure 7.24** Pipe arch can be installed in limited headroom situations with shallow cover.

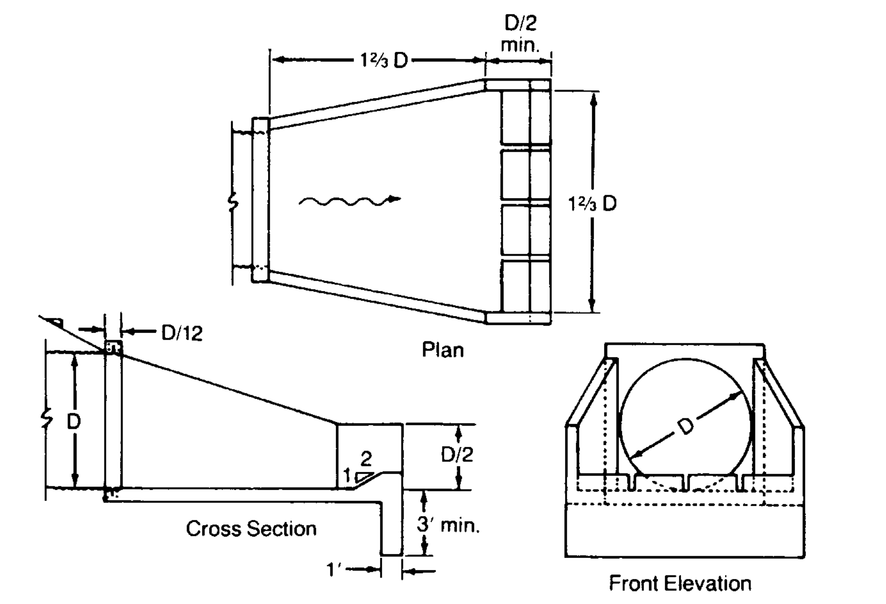


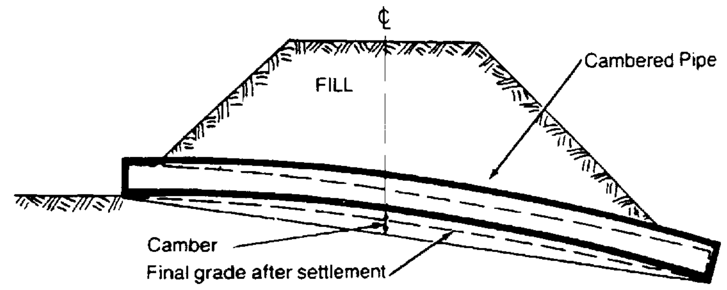
Figure 7.25 Treatment of outlet end of large corrugated steel structures.

Besides improving hydraulic flow and supporting any skew or bevel cut ends, these treatments provide cutoff walls below and beside the pipe to protect the backfill and embankment slope from piping and erosion. By decreasing the quantity of seepage from the upstream water course into the granular backfill, they reduce the hydraulic uplift (pore pressure) forces on the pipe.

Most highway and railway design offices have adequate design standards suitable to their terrain. Reference to these is valuable for design of headwalls, riprap protection and slope pavements.

Camber

An embankment exerts more load on the foundation at the center of the embankment than at the toe of the slope, so more settlement will occur in the center area. A corresponding settlement of the conduit will occur. Hence, the foundation profile should be cambered longitudinally as illustrated in Figure 7.26. The upstream half of the pipe may be laid on almost a flat grade and the downstream half on a steeper grade. The mid-ordinate of the curve should be determined by the soils engineer. For further details on foundation preparation, see Chapter 10 Installation.



■ **Figure 7.26** Camber allows settlement of a culvert under a high fill. Most of the fall is in the outlet half. Diameters 10ft and smaller are easier to camber, as are the lighter wall thickness.

Temporary Bracing

During the construction of headwalls, the ends of structures may require temporary bracing to prevent distortion. The end of a conduit cut on an extreme skew and bevel typically requires support from shoring or bracing until the slope pavement is completed. However, it is not normal, necessary or recommended to brace steel pipe on a routine basis in an attempt to control shape change or deflection during construction. The desired results are best obtained by proper compaction of a suitable backfill material.

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