Chapter 2 MATERIALS AND STRUCTURAL DESIGN

2.1 INTRODUCTION

This chapter provides information regarding pipe service life, policy regarding material selection for pipe, and load tables for reinforced concrete and metal pipes.

2.2 FACTORS INFLUENCING SERVICE LIFE

Design service life is typically defined as the period of service without a need for major repairs. Highway drainage structures are usually designed with the goal of providing some pre-selected minimum number of years of service life. For corrugated metal pipes, this will normally be the period in years from installation until deterioration reaches the point of perforation of any point on the culvert. Reinforced concrete pipe service life is typically the period from installation until reinforcing steel is exposed , or a crack signifying severe distress develops. Plastic pipe service life may be considered at an end when excessive cracking, perforation or deflection has occurred. It is important to recognize that culverts are not assumed to be at or near the point of collapse at the end of their design service life. Rather, it is the period of little to no rehabilitative maintenance.

Some of the factors that affect service life are:

- Hydrogen-ion concentration (pH) of the surrounding soil and water;
- Soil resistivity, chloride and sulfate concentrations in the soil;
- Size, shape, hardness, and volume of bedload;
- Volume, velocity and frequency of streamflow in the culvert;
- Material characteristics of the culvert; and
- Anticipated changes in the watershed upstream of the culvert (such as development, industry, mining or logging).

2.2.1 Corrosion

Corrosion is the destruction of pipe material by chemical action. Most commonly, corrosion attacks metal culverts, or the reinforcement in concrete pipe, as the process of returning metals to their native state of oxides or salts. Similar processes can occur to the cement in concrete pipe if subjected to highly alkaline soils or to other pipe materials if subjected to extremely harsh environments. In order for corrosion to occur, an electrolytic corrosion cell must be formed. This requires the presence of water, or some other liquid to act as an electrolyte, as well as materials acting as an anode, cathode and conductor. As electrons move from the anode to the cathode, metal ions are released into solution, with characteristic pitting at the anode. The culvert will typically serve as both the anode and the cathode. Corrosion can affect either the inside or outside of a pipe, or both. The potential for corrosion to occur, and the rate at which it will progress, is variable and dependent upon a variety of factors.

<u>Hydrogen Ion Concentration (pH)</u>

The pH value is defined as the log of the reciprocal of the concentration of hydrogen ion in a solution. Values of pH in natural waters generally fall within the range of 4 to 10. A pH of less than 5.5 is usually considered to be strongly acidic, while values of 8.5 or greater are strongly alkaline.

<u>Soil Resistivity</u>

Resistivity of soil is a measure of the soils ability to conduct electrical current. It is affected primarily by the nature and concentration of dissolved salts, as well as the temperature, moisture content, compactness, and the presence of inert materials such as stones and gravel. The greater the resistivity of the soil, the less capable the soil is of conducting electricity and the lower the corrosive potential.

The unit of measurement for resistivity is ohm-centimeters, or more precisely, the electrical resistance between opposite faces of a one-centimeter cube. Resistivity values in excess of about 5000 ohm-cm are considered to present limited corrosion potential. Resistivities below the range of 1000 to 3000 ohm-cm will usually require some level of pipe protection, depending upon the corresponding pH level (e.g. if pH < 5.0, enhanced pipe protection may be needed for resistivities below 3000 ohm-cm; if pH > 6.5, enhanced pipe protection may not be needed unless resistivities are below 1500 ohm-cm). As a comparative measure, resistivity of seawater is in the range of 25 ohm-cm, clay soils range form approximately 750-2000 ohm-cm and loams from 3000-10,000 ohm-cm. Soils that are of a more granular nature exhibit even higher resistivities.

Chlorides

Dissolved salts containing chloride ions can be present in the soil or water surrounding a culvert. Dissolved salts can enhance culvert durability if their presence decreases oxygen solubility, but in most instances corrosive potential is increased as the negative chloride ion decreases the resistivity of the soil and/or water and destroys the protective film of anodic areas. Chlorides, as with most of the more common corrosive elements, primarily attack unprotected metal culverts and the reinforcing steel in concrete culverts if concrete cover is inadequate, cracked or highly permeable.

Sulfates

Sulfates can be naturally occurring or may be a result of man's activities, most notably mine wastes. Sulfates, in the form of hydrogen sulfide can also be created from biological activity, which is more common in wastewater or sanitary sewers and can combine with oxygen and water to form sulfuric acid. Although high concentrations can lower pH and be of concern to metal culverts, sulfates are typically more damaging to concrete. Typically, the sulfate in one or more various forms combines with the lime in cement to form calcium sulfate, which is structurally weak. Concrete pipe is normally sufficient to withstand sulfate concentrations of 1000 parts per million (ppm) or less. For higher concentrations of sulfates, higher strength concrete, concrete with lower amounts of calcium aluminate (under 5%) or special coatings may be necessary.

2.2.2 Abrasion

Abrasion is the gradual wearing away of the culvert wall due to the impingement of bedload and suspended material. Abrasion will almost always manifest itself first in the invert of the culvert. As with corrosion, abrasion potential is a function of several items, including culvert material, frequency and velocity of flow in the culvert and composition of bedload.

Bedload

By far, bedload is the leading cause of culvert abrasion. Critical factors in evaluation of the abrasive potential of bedload material are the size, shape and hardness of the bedload material, and the velocity and frequency of flow in the culvert. Generally, flow velocities less than 5 ft/sec are not considered to be abrasive, even if bedload material is present. Velocities in excess of 15 ft/sec which carry bedload, are considered to be very abrasive and some modifications to protect the culvert should be considered.

Tests performed on concrete pipe have generally shown excellent wear characteristics. Although high velocity flow will induce abrasion regardless of the size of bedload particles, tests performed on concrete pipe have shown that cobble and larger sizes will induce higher wear rates that sands and gravels.

Steel culverts are susceptible to the dual action of abrasion and corrosion. Once the thin protective coating on a steel pipe is worn away whether if is zinc or other substance, exposure to low resistivity and/or low pH environments can dramatically shorten the life of a steel culvert.

Plastic culvert materials (both polyvinyl chloride and high density polyethylene) exhibit good abrasion resistance. Since plastic is not subject to corrosion it will not experience the dual action of corrosion and abrasion.

2.3 PIPE DURABILITY

The Department is presently doing a statewide condition survey of centerline culverts. It is planned to correlate the results of the survey with information regarding soil and water properties including pH and resistivity measurements to develop a revised policy regarding the use of metal culverts. Until that study is completed the usage criteria for prefabricated corrugated galvanized steel culverts that was previously in the Drainage Manual will remain in effect and are given in Table 2.1 and Figure 2.1. Structural plate culverts although normally having heavier galvanizing and a greater metal thickness than prefabricated culverts are still vulnerable to corrosive attack in an aggressive environment. Therefore, usage criteria for structural plate culverts is included in Table 2.1.

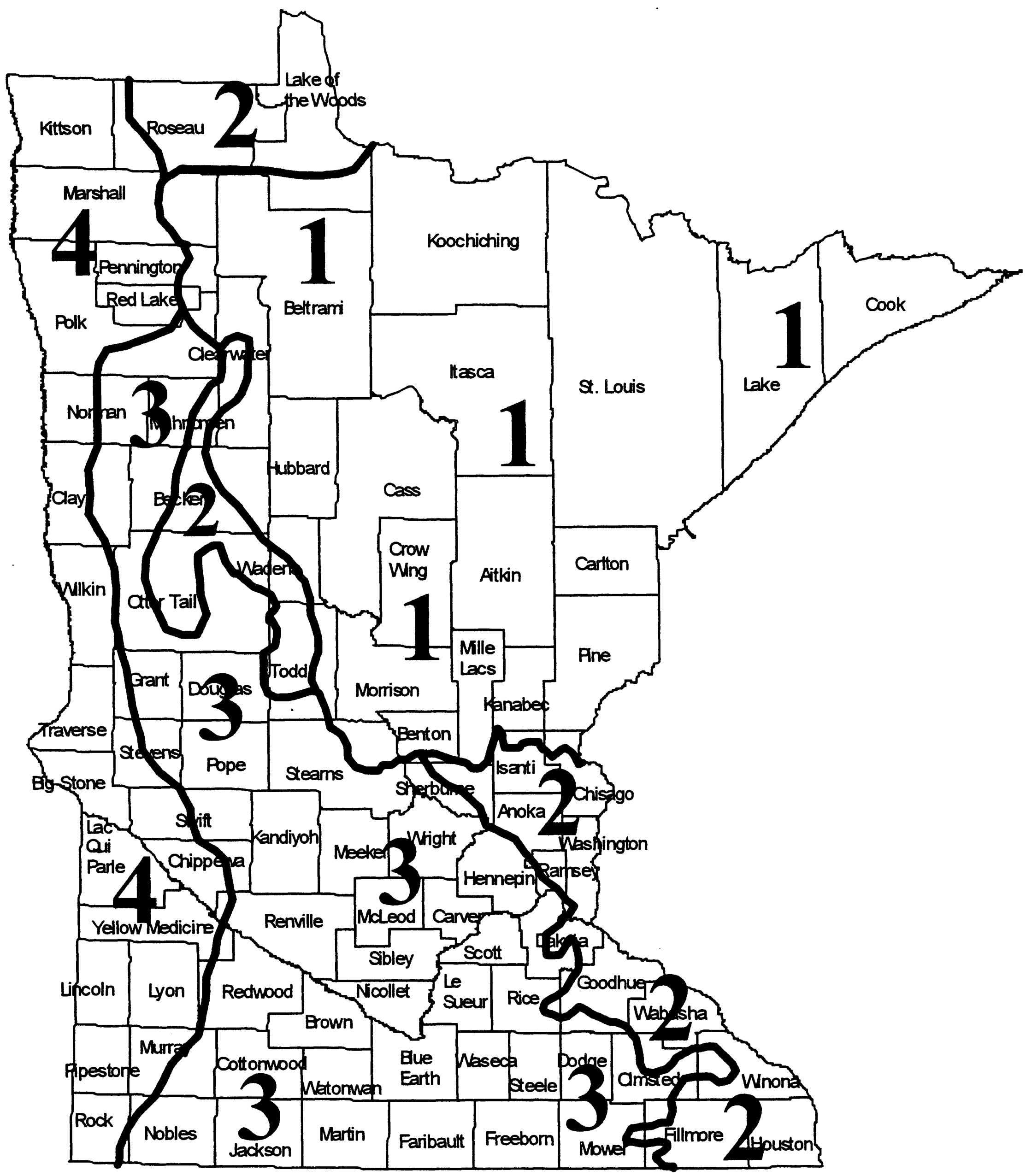


Figure 2.1 Four Soil Zones of Minnesota

Table 2.1 Drainage Condition at Culvert Location

Zone [4]	Water [1]	Prefabricated Corrugated Galvanized Steel Culvert	Structural Plate Culvert
1	Dry	Yes	Yes
	Wet	No	Yes [3]
2	Dry	Yes	Yes
	Wet	Yes , if not acid [2]	Yes [3]
3	Dry	Yes	Yes
	Wet	No	Yes [3]
4	Dry	Yes	Yes
	Wet	Yes	Yes

[1] Dry refers to structures that drain out after rainfall or snow melt and Wet is when there is standing or flowing water practically the entire year.

[2] District Soils Engineers should make pH determinations of samples from drainage area of the proposed culvert.

[3] Provided the location is not in a swamp or that the soil or water does not have a pH of 6.5 or less. The District Soil Engineer should take samples from the drainage area for pH determination.

[4] The Zones referred to in the Table 2.1 criteria for selecting prefabricated and structural plate culverts are shown in Figure 2.1.

For locations where corrugated steel (galvanized) pipe is not recommended or where its service life is limited by pH and/or resistivity, the following information is provided for guidance regarding service life and use of increased steel thickness or protective coatings.

Two nationally recognized methods for estimating corrugated steel pipe (AASHTO M36/M36M) service life are the empirical charts developed by the California Department of Transportation (Caltrans Test Method 642-C) and the American Iron and Steel Institute (AISI). Both of these charts require, as a minimum, site specific pH and resistivity data in order to estimate the pipe's service life.

These two methods are essentially identical in their form, but make different assumptions in the definition of service life. The California chart assumes that the end of the maintenance free service life occurs when the culvert first experiences perforation. This corresponds to approximately a 13% loss of metal thickness over the entire invert area. The AISI chart, which is based on the same data as the California chart, allows total loss to reach approximately 25% before indicating that the service life has been reached. Depending upon service conditions, such as continually submerged pipe, either test method can underestimate or overestimate the usable life that a culvert can be expected to provide. Because the Department has not yet completed its condition survey of centerline culverts, the California chart is provided as guidance in determining average life of galvanized pipe and the use of increased steel thickness or protective coatings.

There is little data available regarding abrasion. It is recommended that a paved invert be considered for metal pipes if abrasion is considered to be a concern. For structural plate pipe consideration should be given to increasing the thickness of the steel if abrasion is considered to be a concern. For further information on protecting metal pipe against corrosion and/or abrasion designers may seek additional information from the State Hydraulics Engineer.

Table 2.2 Average Life Adjustment for Gage and Material

Gage	18	16	14	12	10	8
Thickness (inches)	0.052	0.064	0.079	0.109	0.138	0.168
Thickness (mm)	1.32	1.63	2.01	2.77	3.51	4.27
GALV.	1	1.3	1.6	2.2	2.8	3.4
ALT2.	2.3	2.6	2.9	3.5	4.1	4.7

Base gage for Figure 2.2 is 18 gage. Adjustment factors are given in Table 2.2. To get the service life for 16 gage pipe (Mn/DOT minimum gage) multiple service life for 18 gage by 1.3.

Polymeric coated pipe may be considered as an equal to Aluminized Type 2 (ALT2.) Pipe.

Figure 2.2 is based on Equations 2.1 and 2.2.
For pH of environment normally greater than 7.3

$$YEARS = 1.47R^{0.41} \qquad (2.1)$$

For pH of environment normally less than 7.3

$$YEARS = 13.79\left[Log_{10}R - Log_{10}\left(2160 - 2490Log_{10}pH\right)\right] \qquad (2.2)$$

Where: R = minimum resistivity

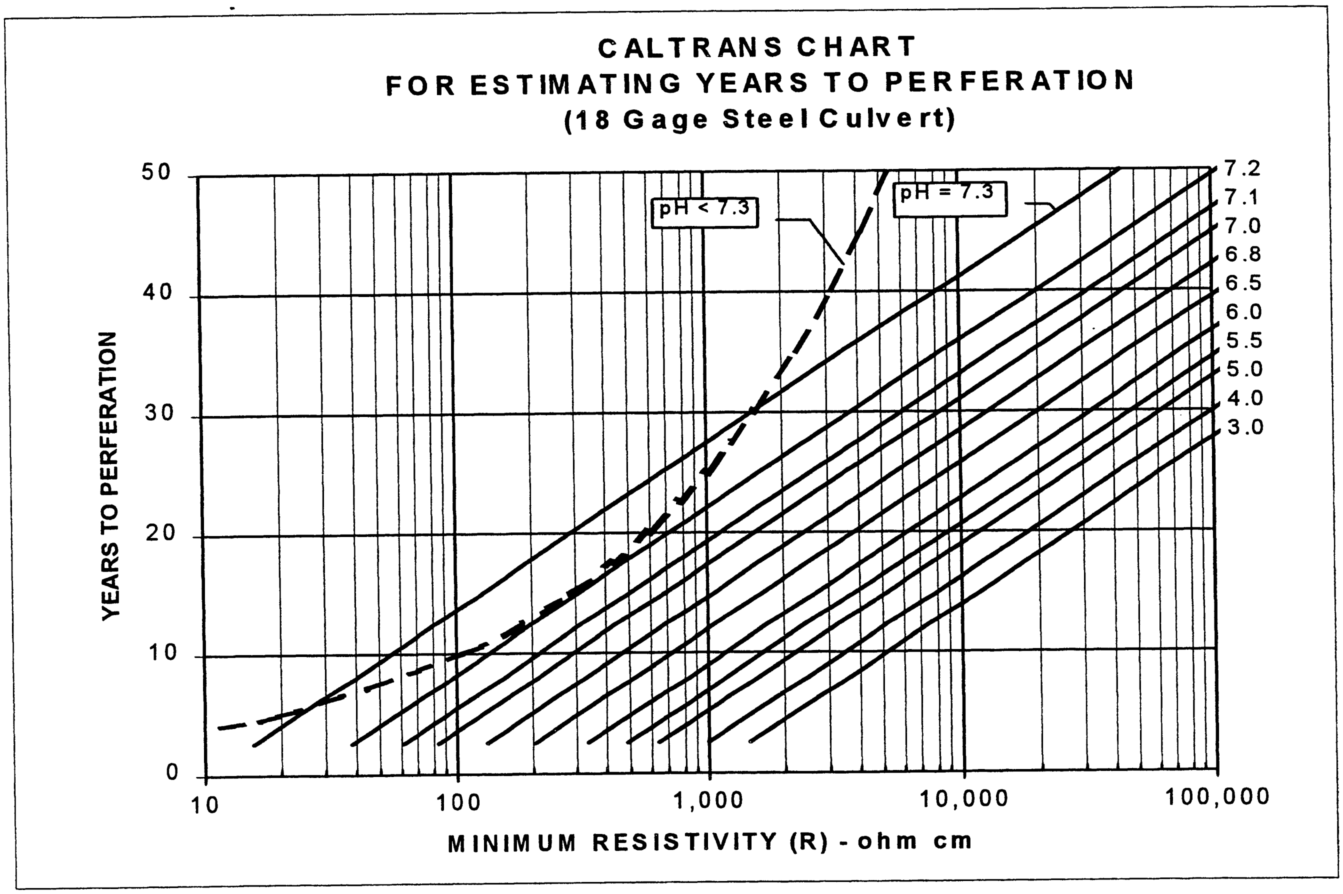


Figure 2.2 CALTRANS Service Life Chart
Source: Highway Drainage Guidelines (AASHTO, 1999)

2.4 MATERIAL TYPES FOR DRAINAGE FACILITIES

Following is the policy for selecting material types for culverts, storm drains and tile.

2.4.1 Culvert Materials

Pipe for culverts shall be selected on the basis of the type which best fulfills all of the engineering requirements for a specific installation. Factors to be considered in fulfilling the engineering requirements should be hydraulic performance, structural stability, serviceability, and economy. The culvert design sheet shall provide documentation for each pipe installation indicating the engineering considerations which dictate the selection of the specific type of pipe.

If, for engineering reasons, the use of corrugated metal pipe is necessary in areas that have been detrimental to this type of pipe, the designer must take proper precautions such as increasing the thickness of the base metal or providing a protective coating to assure required serviceability.

Pipes for centerline culverts shall be selected on the basis of engineering analysis which result in the most favorable combination of hydraulic performance, structural stability, serviceability, and economy.

Reinforced concrete pipe, plain galvanized corrugated steel pipe or corrugated polyethylene pipe will normally be considered acceptable for culverts installed under minor side road approaches and private entrances except where engineering considerations dictate otherwise. If site considerations dictate, corrugated metal pipe with a protective coating could be used. The designer may choose to allow alternate material types in bidding proposals.

2.4.2 Storm Drain Material

Reinforced concrete pipe will normally be required for all storm drains. Corrugated polyethylene pipe may be allowed as an alternate to reinforced concrete pipe for 12" - 36" diameter pipes.

2.4.3 Tile Materials

For agricultural tile line crossings, 12-inch reinforced concrete pipe will generally be required between points five feet outside the toe of embankment slopes for tile lines 12 inches or less in diameter. Equivalent size reinforced concrete pipe will be required for tile lines larger than 12 inches in diameter.

2.5 PIPE INSTALLATION

2.5.1 Pipe Bedding

Since bedding is an important element in determining the ability of pipe to carry load, the various types of bedding in general use are explained below. An additional consideration in bedding conditions occurs when bell end pipe is used. The bedding must be excavated to accept the bell end so that the pipe is supported along its full length and not just at the bell.

Class A Bedding (Concrete Cradle)
Class A bedding consists of a continuous monolithic, concrete cradle having a minimum thickness under the pipe of 1/4 of the nominal inside diameter or span and extending up the sides of the pipe for a height equal to 1/4 the outside diameter or rise. The width of the cradle must equal or exceed the outside diameter or span of the pipe plus eight inches.

Class B Bedding (First Class Bedding)
Class B bedding consists of bedding the pipe on a minimum six-inch thickness of granular bedding accurately shaped by means of a template to fit the lower part of the pipe exterior for a width of at least 60 percent of the diameter for round pipe and at least 80 percent of the span for pipe arches. The existing ground at the culvert site is first excavated to an elevation which is approximately 15 percent of the outside diameter or rise of the pipe above the established grade for the bottom of the pipe. Then the foundation for the bedding is prepared by carefully excavating to the required depth and shape of the bedding.

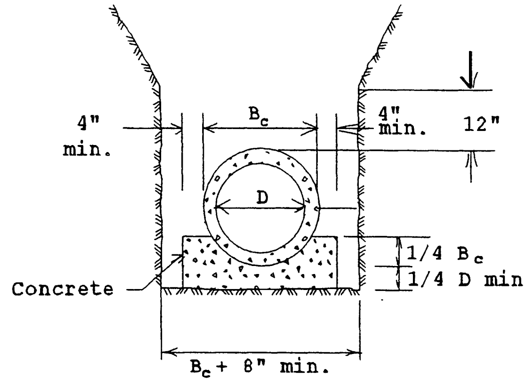
Class C Bedding (Ordinary Bedding)
Class C bedding consists of carefully shaping the foundation soil to fit the lower part of the pipe exterior to a depth of at least 15 percent of the outside diameter for circular pipes, and at least equal to one-half of the height of pipe-arch structures.

Class D Bedding (Impermissible Bedding)
As the name implies, Class D bedding is not ordinarily permitted for pipe installations, particularly if the pipe is to be subjected to even moderate dead or live loads. Under current specifications, no special shaping of the foundation is required for entrance culverts unless they are to be laid in a trench. This is the only condition under which Class D bedding is permitted in highway construction. When an entrance culvert is to be laid in a trench, Class C bedding is required unless a higher class of bedding is specified in the plan or special provisions.

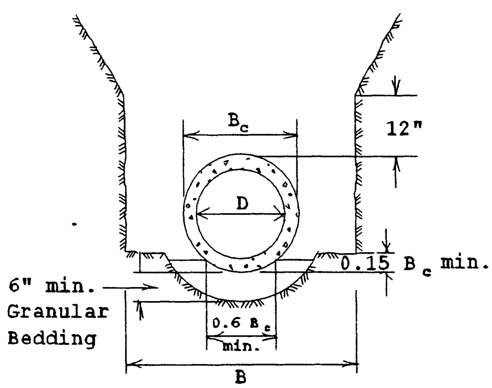
Rock or Unyielding Foundations
When rigid or flexible pipe is laid on rock or other unyielding material, a trench must be excavated in the underlying unyielding material or rock. The trench is excavated to a depth of one foot below the bottom of the structure for its full length, and to a width two feet wider than the outside extremities of the pipe. The excavated trench is backfilled with selected, compressible, mineral soil placed in layers not exceeding six inches in uncompacted thickness and each layer is lightly compacted to form a uniform but yielding foundation. This backfill is constructed to such elevation that the proper bedding can be constructed.

For further information regarding pipe installation see Chapter 8 of the Road Design Manual and/or the District Soils Engineer. Figures 2.3 and 2.4 show classes of bedding for trench and embankment conditions.

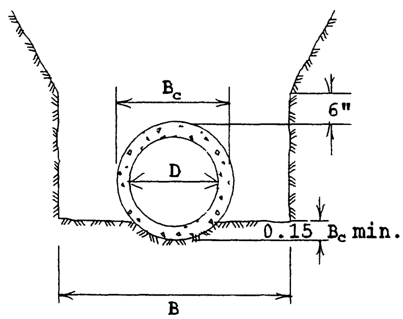
Where: B_c = outside diameter of the pipe
D = inside diameter of the pipe
B = trench width



CLASS A



Pipe Dia.	B
36" or less	B_c+ 24"
42" to 54"	1.5 x B_c
60" or over	B_c+ 36"



Pipe Dia.	B
36" or less	B_c+ 24"
42" to 54"	1.5 x B_c
60" or over	B_c+ 36"

CLASS B CLASS C

Figure 2.3 Classes of Bedding for Trench Conditions

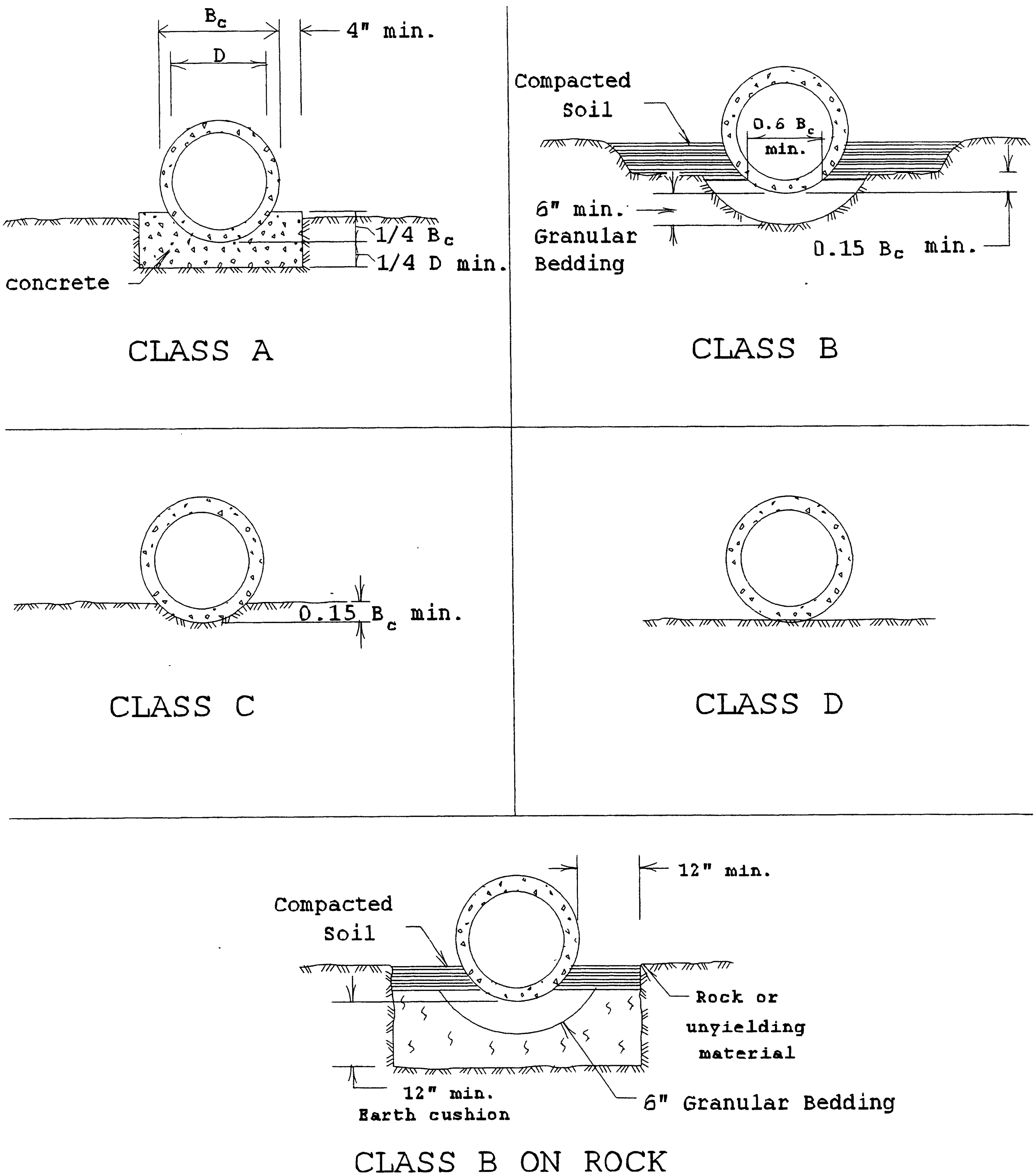


Figure 2.4 Classes of Bedding for Embankment Conditions

2.5.2 Concrete Pipe Load Tables

Trench width, backfill height and embankment fill are provided for circular concrete pipe in Tables 2.3, 2..4 2.5, 2.6 and 2.7. Loading and installation specifications for concrete arch pipe is included in the Standard Plate 3014.

Table 2.3 Trench Width for Concrete Pipe with Class B Bedding

Circular Concrete Pipe
Narrow and Wide Trench Widths in Feet
for Class B Bedding, Measured at Top of Pipe in Feet

Pipe Class	Class II		Class III		Class IV		Class V	
Pipe Diameter \ Trench Type	N	W	N	W	N	W	N	W
12	3.5	3.5	3.5	3.5	3.5	3.5	3.5	4.0
15	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.5
18	4.0	4.0	4.0	4.0	4.0	4.5	4.0	5.0
21	4.5	4.5	4.5	4.5	4.5	5.0	4.5	5.5
24	4.5	5.0	4.5	5.0	4.5	5.5	4.5	6.0
27	5.0	5.0	5.0	5.5	5.0	6.0	5.0	6.5
30•	5.5	5.5	5.5	6.0	5.5	6.5	5.5	7.0
33	5.5	6.0	5.5	6.5	5.5	7.0	5.5	7.5
36	6.5	6.5	6.5	7.0	6.5	7.5	6.5	8.0
42	7.0	7.5	7.0	7.5	7.0	8.5	7.0	9.0
48	7.5	8.0	7.5	8.5	7.5	9.0	7.5	10.0
54	8.5	9.0	8.5	9.5	8.5	10.0	8.5	11.0
60	9.0	9.5	9.0	10.0	9.0	11.0	9.0	12.0
66	9.5	10.0	9.5	11.0	9.5	12.0	9.5	12.5
72	10.0	11.0	10.0	11.5	10.0	13.0	10.0	13.5
78	10.5	11.5	10.5	12.0	10.5	13.5	10.5	14.5
84	11.0	12.0	11.0	13.0	11.0	14.5	11.0	15.5
90	12.0	12.5	12.0	13.5	12.0	15.0	12.0	16.5
96	12.5	13.0	12.5	14.0	12.5	16.0	12.5	17.0
102	13.0	13.5	13.0	15.0	13.0	17.0	13.0	18.0
108	13.5	14.5	13.5	15.5	13.5	17.5	13.5	19.0

N = narrow trench: minimum width
W = wide trench: transition width
Source: CRETEX Precast Concrete Products

Table 2.4 Trench Fill Height for Concrete Pipe with Class B Bedding

Circular Concrete Pipe Height of Backfill in Feet for Class B Bedding Measured at Top of Pipe in Feet, 120 PCF Soil Density								
Pipe Class	Class II		Class III		Class IV		Class V	
Trench Type / Pipe Diameter	N	W	N	W	N	W	N	W
12	8	8	11	11	16	16	*	24
15	8	8	11	11	16	16	*	24
18	8	8	11	11	23	17	*	25
21	8	8	11	11	23	17	*	25
24	9	8	11	11	23	17	*	25
27	9	9	13	12	23	17	*	26
30	9	9	13	12	23	17	*	26
33	9	9	13	12	23	17	*	26
36	9	9	13	12	23	17	*	26
42	10	9	14	12	24	18	*	26
48	10	9	14	12	24	18	*	26
54	10	9	14	12	24	18	*	27
60	11	10	15	12	24	18	*	27
66	11	10	15	12	25	18	*	27
72	11	10	16	13	26	18	*	27
78	11	10	16	13	27	18	*	27
84	12	10	17	13	27	18	*	27
90	12	11	17	13	27	19	*	27
96	12	11	17	14	27	19	*	27
102	12	11	17	14	27	19	*	27
108	12	11	17	14	27	19	*	27

N = narrow trench: minimum width
W = wide trench: transition width
* Fill height greater than 40 feet, D-load equation must be used.
Source: CRETEX Precast Concrete Products

Table 2.5 Trench Width for Concrete Pipe with Class C Bedding

Circular Concrete Pipe
Narrow and Wide Trench Widths in Feet for
Class C Bedding, Measured at Top of Pipe in Feet

Pipe Class	Class II		Class III		Class IV		Class V	
Pipe Diameter \ Trench Type	N	W	N	W	N	W	N	W
12	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
15	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.5
18	4.0	4.0	4.0	4.0	4.0	4.5	4.0	5.0
21	4.5	4.5	4.5	4.5	4.5	5.0	4.5	5.5
24	4.5	4.5	4.5	5.0	4.5	5.0	4.5	6.0
27	5.0	5.0	5.0	5.5	5.0	5.5	5.0	6.5
30	5.5	5.5	5.5	5.5	5.5	6.0	5.5	7.0
33	5.5	6.0	5.5	6.0	5.5	6.5	5.5	7.0
36	6.5	6.5	6.5	6.5	6.5	7.0	6.5	7.5
42	7.0	7.5	7.0	7.5	7.0	8.0	7.0	8.5
48	7.5	7.5	7.5	8.0	7.5	9.0	7.5	9.5
54	8.5	8.5	8.5	9.0	8.5	9.5	8.5	10.5
60	9.0	9.0	9.0	9.5	9.0	10.5	9.0	11.5
66	9.5	9.5	9.5	10.0	9.5	11.5	9.5	12.0
72	10.0	10.0	10.0	11.0	10.0	12.0	10.0	13.0
78	10.5	10.5	10.5	11.5	10.5	13.0	10.5	14.0
84	11.0	11.5	11.0	12.0	11.0	13.5	11.0	15.0
90	12.0	12.0	12.0	13.0	12.0	15.0	12.0	15.5
96	12.5	12.5	12.5	13.5	12.5	15.5	12.5	16.5
102	13.0	13.0	13.0	14.0	13.0	16.0	13.0	17.5
108	13.5	13.5	13.5	14.5	13.5	16.5	13.5	18.0

N = narrow trench: minimum width
W = wide trench: transition width
Source: CRETEX Precast Concrete Products

Table 2.6 Trench Fill Height for Concrete Pipe with Class C Bedding

Circular Concrete Pipe
Height of Backfill in Feet for Class C Bedding
Measured at Top of Pipe in Feet, 120 PCF Soil Density

Pipe Class	Class II		Class III		Class IV		Class V	
Trench Type / Pipe Diameter	N	W	N	W	N	W	N	W
12	6	6	9	9	13	13	21	19
15	6	6	9	9	13	13	22	19
18	7	7	9	9	14	13	34	20
21	7	7	9	9	14	14	34	20
24	7	7	9	9	14	14	34	20
27	7	7	9	9	16	14	34	20
30	7	7	10	9	16	14	34	20
33	7	7	10	9	16	14	34	20
36	7	7	10	9	17	14	34	21
42	7	7	10	9	17	14	34	21
48	8	8	11	10	18	14	34	21
54	8	8	11	10	18	14	34	21
60	8	8	11	10	18	14	34	21
66	8	8	11	10	18	14	34	21
72	8	8	12	11	19	14	34	21
78	9	8	12	11	20	15	34	21
84	9	9	12	11	20	15	34	21
90	9	9	12	11	20	15	34	22
96	9	9	13	11	20	15	34	22
102	9	9	13	11	20	16	34	22
108	9	9	13	12	20	16	34	22

N = narrow trench: minimum width
W = wide trench: transition width
Source: CRETEX Precast Concrete Products

Table 2.7 Embankment Fill Height for Concrete Pipe

Circular Concrete Pipe
Embankment Fill Height in Feet
Measured from Top of Pipe in Feet, 120 PCF Soil Density

Pipe Class	Class II				Class III				Class IV				Class V			
Diameter \ Bedding	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
12	16	10	8	5	21	13	11	6	31	19	16	10	*	29	24	15
15	16	10	8	5	21	13	11	7	32	19	16	10	*	30	25	15
18	16	10	8	5	21	13	11	7	32	20	17	10	*	30	25	15
21	16	10	8	5	22	14	12	7	33	20	17	10	*	31	25	15
24	17	10	9	5	22	14	12	7	33	21	17	11	*	31	26	16
27	17	10	9	6	22	14	12	7	33	21	18	11	*	31	26	16
30	17	10	9	6	23	14	12	7	33	21	18	11	*	31	26	16
33	17	11	9	6	23	14	12	7	34	21	18	11	*	31	26	16
36	17	11	9	6	23	14	12	8	34	22	18	11	*	32	27	16
42	17	11	9	6	24	15	12	8	34	22	18	11	*	32	27	16
48	18	11	9	6	24	15	13	8	34	22	18	11	*	32	27	17
54	18	11	10	7	24	15	13	8	35	22	18	11	*	32	27	17
60	18	11	10	7	25	15	13	9	35	22	18	11	*	33	27	17
66	18	11	10	7	25	15	13	9	35	22	19	11	*	33	27	17
72	19	12	11	7	25	15	13	9	35	22	19	11	*	33	27	17
78	19	12	11	7	25	15	13	9	36	22	19	11	*	33	27	17
84	19	12	11	7	25	15	13	10	36	22	19	12	*	33	28	17
90	19	12	11	8	25	15	13	10	36	22	19	12	*	33	28	17
96	19	12	11	8	25	15	13	10	36	22	19	12	*	33	28	17
102	19	13	12	8	25	15	14	10	36	22	19	12	*	33	28	17
108	19	13	12	8	25	16	15	10	36	22	19	13	*	33	28	18

Fill heights are based on a 0.7 settlement ratio
Projection ratios are as follows: Class A = 0.7, Class B = 0.5, Class C = 0.7 and Class D = 0.9
* Fill height greater than 45 feet, D-load equation must be used.
Source: CRETEX Precast Concrete Products

2.5.3 Metal Pipe Load Tables

Metal load tables are provided for common metal types, shapes and sizes. The tables are based on the following criteria:

- Maximum heights of cover by AASHTO Design H25 Wheel Loading
- Minimum soil corner bearing pressure for pipe-arch = 4000 lbs/ft ^{2}
- Maximum covers for a given gage fluctuate as span increases due to varying ratio of top radius to corner radius.
- Minimum cover height is measured from top of pipe to top of rigid pavement, or bottom of flexible pavement.
- Equivalent diameter in metal pipe-arch tables refers to the diameter of round corrugated steel pipe from which a pipe-arch or other shape is formed.

Table 2.8 2 ⅔" x ½" Corrugated Steel Round Pipe

Span (Inches)	Minimum Cover (ft)	Maximum Cover (Feet) by Thickness (Inches) and Gage				
		0.064 16	0.079 14	0.109 12	0.138 10	0.168 8
12	1	213	266			
15	1	170	212			
18	1	142	177			
21	1	121	152			
24	1	106	133	186		
30	1	85	106	149		
36	1	71	88	124	159	
42	1	60	76	106	137	167
48	1	53	66	93	119	146
54	1		59	82	106	130
60	1			74	95	117
66	1				87	106
72	1				79	97
78	1					86
84	1					75

Limits for Checks:

Flexibility Factor = 0.0430

Wall Area FS = 2

Buckling FS = 2

Constants:

Soil Density = 120 # / CU FT

Modulus of Elasticity = 2.9E+07 PSI

Minimum Yield Point = 33000 PSI

Min. Tensile Strength = 45000 PSI

Notes:

Helical Pipe (lock seam or weld seam)

Source: CONTECH Construction Products Inc.

Table 2.9 3" x 1" or 5" x 1" Corrugated Steel Round Pipe

Span (Inches)	Minimum Cover (ft)	Maximum Cover (Feet) by Thickness (Inches) and Gage				
		0.064 16	0.079 14	0.109 12	0.138 10	0.168 8
54	1	48	60	84	109	133
60	1	43	54	76	98	120
66	1	39	49	69	89	109
72	1	36	45	63	81	100
78	1	33	41	58	75	92
84	1	31	38	54	70	85
90	1	29	36	50	65	80
96	1		34	47	61	75
102	1.5		32	44	57	70
108	1.5			42	54	66
114	1.5			40	51	63
120	1.5			38	49	60
126	1.5				46	57
132	1.5				44	54
138	1.5				42	52
144	1.5					50

Limits for Checks:

Flexibility Factor = 0.0330

Wall Area FS = 2

Buckling FS = 2

Constants:

Soil Density = 120 # / CU FT

Modulus of Elasticity = 2.9E+07 PSI

Minimum Yield Point = 33000 PSI

Min. Tensile Strength = 45000 PSI

Notes:

- Helical Pipe (lock seam or weld seam)
- Maximum cover for 5" x 1" pipe are shown.
- For 3" x 1" pipe increase values by 13%

Source: CONTECH Construction Products Inc.

Table 2.10 3/4" x 3/4" x 7-1/2" Steel Spiral Rib Round Pipe

Span (Inches)	Minimum Cover (feet)	Maximum Cover (Feet) by Thickness (Inches) and Gage			
		0.064 16	0.079 14	0.109 12	0.138 10
18	1	93	131		
21	1	80	112		
24	1	70	98		
27	1	62	88		
30	1	56	78		
36	1	46	65	109	
42	1	40	56	93	138
48	1	35	49	81	121
54	1.5	**31**[1]	43	72	107
60	1.5		39	65	96
66	1.5		**35**[1]	59	88
72	1.5			54	80
78	2			50	73
84	2			**46**[1]	69
90	2			**43**[1]	64
96	2				59
102	2.5				**53**[1]

Limits for Checks:

Wall Area FS = 2
Buckling FS = 2

Constants:

Soil Density = 120 # / CU FT
Modulus of Elasticity = 2.9E+07 PSI
Minimum Yield Point = 33000 PSI
Min. Tensile Strength = 45000 PSI

Notes:

- Helical Pipe (lock seam or weld seam)
- Embankment Installation

[1] Bold values are for Trench Installation only

Source: CONTECH Construction Products Inc.

Table 2.11 2 ⅔" x ½" Corrugated Steel Pipe-Arch

Equivalent Pipe Diameter (inches)	Span (inches)	Rise (inches)	Minumum Cover (feet)	Maximum Cover (Feet) by Thickness (Inches) and Gage				
				0.064 16	0.079 14	0.109 12	0.138 10	0.168 8
15	17	13	1	13	13			
18	21	15	1	13	13			
21	24	18	1	13	13			
24	28	20	1	13	13	13		
30	35	24	1	13	13	13		
36	42	29	1	13	13	13	13	
42	49	33	1		13	13	13	13
48	57	38	1			12	12	12
54	64	43	1			12	12	12
60	71	47	1				12	12
66	77	52	1					12
72	83	57	1					12

Notes: - Helical pipe (lock seam or weld seam)

Limits for Checks:

Flexibility Factor = 0.0430
Wall Area FS = 2
Buckling FS = 2

Constants:

Soil Density = 120 # / CU FT
Modulus of Elasticity = 2.9E+07 PSI
Minimum Yield Point = 33000 PSI
Min. Tensile Strength = 45000 PSI

Source: CONTECH Construction Products Inc.

Table 2.12 3" x 1" or 5" x 1" Corrugated Steel Pipe-Arch

Equivalent Pipe Diameter (inches)	Span (inches)	Rise (inches)	Minimum Cover (feet)	Maximum Cover (Feet) by Thickness (Inches) and Gage		
				0.109 12	0.138 10	0.168 8
54	60	46	1.25	20	20	20
60	66	51	1.25	20	20	20
66	73	55	1.5	20	20	20
72	81	59	1.5	17	17	17
78	87	63	1.5	17	17	17
84	95	67	1.5	17	17	17
90	103	71	1.5	16	16	16
96	112	75	1.75	16	16	16
102	117	79	1.75	16	16	16
108	128	83	2		16	16
114	137	87	2		16	16
120	142	91	2			16

Notes: - Helical pipe (lock seam or weld seam)

Limits for Checks:

Flexibility Factor = 0.0330
Wall Area FS = 2
Buckling FS = 2

Constants:

Soil Density = 120 # / CU FT
Modulus of Elasticity = 2.9E+07 PSI
Minimum Yield Point = 33000 PSI
Min. Tensile Strength = 45000 PSI

Source: CONTECH Construction Products Inc.

Table 2.13 3/4" x 3/4" x 7 ½" Steel Spiral Rib Pipe-Arch

Equivalent Pipe Diameter (inches)	Span (inches)	Rise (inches)	Minimum Cover (feet)	Maximum Cover (Feet) by Thickness (Inches) and Gage		
				0.064 16	0.079 14	0.109 12
18	20	16	1	16	16	
21	23	19	1	15	15	
24	27	21	1	14	14	
30	33	26	1	14	14	
36	40	31	1	13	13	13
42	46	36	1	13	13	13
48	53	41	1.25	13	13	13
54	60	46	1.5		13	13
60	66	51	1.5			13
66	73	55	1.75			13
72	81	59	1.75			13

Limits for Checks:

Wall Area FS = 2
Buckling FS = 2

Constants:

Soil Density = 120 # / CU FT
Modulus of Elasticity = 2.9E+07 PSI
Minimum Yield Point = 33000 PSI
Min. Tensile Strength = 45000 PSI

Notes:

- Helical pipe (lock seam or weld seam)
- Spiral Rib Pipe; Type I Installation (Embankment Condition)

Source: CONTECH Construction Products Inc.

Table 2.14 6" x 2" Steel Structural Plate Round

Span (Inches)	Minimum Cover (Feet)	Maximum Cover (Feet) by Thickness (Inches) and Gage						
		0.109 12	0.138 10	0.168 8	0.188 7	0.218 5	0.249 3	0.280 1
60	1	46	68	90	103	124	146	160
66	1	42	62	81	93	113	133	145
72	1	38	57	75	86	103	122	133
78	1	35	52	69	79	95	112	123
84	1	33	49	64	73	88	104	114
90	1	31	45	60	68	82	97	106
96	1	29	43	56	64	77	91	100
102	1.5	27	40	52	60	73	86	94
108	1.5	25	38	50	57	69	81	88
114	1.5	24	36	47	54	65	77	84
120	1.5	23	34	45	51	62	73	80
126	1.5	22	32	42	49	59	69	76
132	1.5	21	31	40	46	56	66	72
138	1.5	20	29	39	44	54	63	69
144	1.5	19	28	37	43	51	61	66
150	2	18	27	36	41	49	58	64
156	2	17	26	34	39	47	56	61
162	2	17	25	33	38	46	54	59
168	2	16	24	32	36	44	52	57
174	2	16	23	31	35	42	50	55
180	2	15	22	30	34	41	48	53
186	2	15	22	29	33	40	47	51
192	2		21	28	32	38	45	50
198	2.5		20	27	31	37	44	48
204	2.5		20	26	30	36	43	47
210	2.5			25	29	35	41	45
216	2.5			25	28	34	40	44
222	2.5			24	27	33	39	43
228	2.5			23	27	32	38	42
234	2.5			23	26	31	37	41
240	2.5				25	31	36	40
246	3				25	30	35	39
252	3					29	34	38
258	3					28	34	37
264	3					28	33	36
270	3						32	35
276	3						31	34
282	3						31	34
288	3.5						30	33
294	3.5							32
300	3.5							32
306	3.5							31

Limits for Checks:

Flexibility Factor	= 0.0200
Wall Area FS	= 2
Seam Strength	= 3
Buckling FS	= 2

Constants:

Soil Density	= 120 # / CU FT
Modulus of Elasticity	= 2.9E+07 PSI
Minimum Yield Point	= 33000 PSI
Min. Tensile Strength	= 45000 PSI

Notes:

- Seam strength values are based on four 3/4 inch diameter A449 bolts/foot.

Source:

CONTECH Construction Products Inc.

Table 2.15 6" x 2" Steel Structural Plate Pipe-Arch

Span (inches)	Rise (inches)	Minimum Cover (Feet)	Maximum Cover (Feet) by Thickness (Inches) and Gage						
			0.109 12	0.138 10	0.168 8	0.188 7	0.218 5	0.249 3	0.280 1
73	55	1	16	16	16	16	16	16	16
76	57	1	15	15	15	15	15	15	15
81	59	1	14	14	14	14	14	14	14
84	64	1	14	14	14	14	14	14	14
87	63	1	13	13	13	13	13	13	13
92	65	1	13	13	13	13	13	13	13
95	67	1	12	12	12	12	12	12	12
98	69	1.5	12	12	12	12	12	12	12
103	71	1.5	11	11	11	11	11	11	11
106	73	1.5	11	11	11	11	11	11	11
112	75	1.5	10	10	10	10	10	10	10
114	77	1.5	10	10	10	10	10	10	10
117	79	1.5	10	10	10	10	10	10	10
123	81	1.5	9	9	9	9	9	9	9
128	83	1.5	9	9	9	9	9	9	9
131	85	1.5	9	9	9	9	9	9	9
137	87	1.5	8	8	8	8	8	8	8
139	89	1.5	8	8	8	8	8	8	8
142	91	1.5	8	8	8	8	8	8	8
148	93	2	8	8	8	8	8	8	8
150	95	2	8	8	8	8	8	8	8
152	97	2	7	7	7	7	7	7	7
154	100	2	7	7	7	7	7	7	7
159	112	2	12	12	12	12	12	12	12
162	114	2	12	12	12	12	12	12	12
168	116	2	12	12	12	12	12	12	12
170	118	2	12	12	12	12	12	12	12
173	120	2	11	11	11	11	11	11	11
179	122	2	11	11	11	11	11	11	11
184	124	2	11	11	11	11	11	11	11
187	126	2	11	11	11	11	11	11	11
190	128	2	10	10	10	10	10	10	10
195	130	2.5	10	10	10	10	10	10	10
198	132	2.5	10	10	10	10	10	10	10
204	134	2.5	10	10	10	10	10	10	10
206	136	2.5	10	10	10	10	10	10	10
209	138	2.5	9	9	9	9	9	9	9
215	140	2.5	9	9	9	9	9	9	9
217	142	2.5	9	9	9	9	9	9	9
223	144	2.5	9	9	9	9	9	9	9
225	146	2.5	9	9	9	9	9	9	9
231	148	2.5		8	8	8	8	8	8
234	150	2.5		8	8	8	8	8	8
236	152	2.5		8	8	8	8	8	8
239	154	2.5		8	8	8	8	8	8
245	156	3		8	8	8	8	8	8
247	158	3		8	8	8	8	8	8

Limits for Checks:

Flexibility Factor	= 0.030
Wall Area FS	= 2
Buckling FS	= 2
Seam Strength	= 3

Constants:

Soil Density	= 120 # / CU FT
Modulus of Elasticity	= 2.9E+07 PSI
Minimum Yield Point	= 33000 PSI
Min. Tensile Strength	= 45000 PSI

Notes:
- 159" to 247" spans have 31" corner radius
- 73" to 154" spans have 18" corner radius
- Seam strength values are based on four 3/4 inch diameter A449 bolts/foot.

Source:
CONTECH Construction Products Inc.

Table 2.16 2 ⅔" x ½" Corrugated Aluminum Round Pipe

Span (Inches)	Minimum Cover (Feet)	Maximum Cover (Feet) by Thickness (Inches) and Gage				
		0.060 16	0.075 14	0.105 12	0.135 10	0.164 8
12	1	155	193			
15	1	124	154			
18	1	103	129			
21	1	88	110			
24	1	77	96	135		
27	1		86	120		
30	1		77	108		
36	1		64	90	116	
42	1			77	99	
48	1.25			66	86	106
54	1.25			54	70	87
60	1.5				57	71
66	1.5					57
72	1.5					45

Limits for Checks:
Flexibility Factor

For 16 gage = 0.031
For 14 gage = 0.061
For 12 gage = 0.092
Wall Area FS = 2
Buckling FS = 2

Constants:
Soil Density = 120 # / CU FT
Modulus of Elasticity = 1E+07 PSI
Minimum Yield Point = 24000 PSI
Min. Tensile Strength = 31000 PSI

Notes:
Helical pipe lock seam

Source:
CONTECH Construction Products Inc.

Table 2.17 3" x 1" Corrugated Aluminum Round Pipe

Span (Inches)	Minimum Cover (Feet)	Maximum Cover (Feet) by Thickness (Inches) and Gage				
		0.060 16	0.075 14	0.105 12	0.135 10	0.164 8
30	1	71	89			
36	1	59	74	104		
42	1	50	63	89		
48	1	44	55	78	104	
54	1.25	39	49	69	92	109
60	1.25	35	44	62	83	98
66	1.5	32	40	56	75	89
72	1.5	29	37	52	69	81
78	1.75		34	48	64	75
84	1.75			44	59	70
90	2			41	55	65
96	2			38	51	60
102	2				46	54
108	2				41	49
114	2					44
120	2					40

Limits for Checks:
Flexibility Factor = 0.0600
Wall Area FS = 2
Buckling FS = 2

Constants:
Soil Density = 120 # / CU FT
Modulus of Elasticity = 1E+07 PSI
Minimum Yield Point = 24000 PSI
Min. Tensile Strength = 31000 PSI

Notes:
Helical pipe lock seam

Source: CONTECH Construction Products Inc.

Table 2.18 3/4" x 3/4" x 7 ½" Aluminum Spiral Rib Round Pipe

Span (inches)	Minimum Cover (Feet)	Maximum Cover (Feet) by Thickness (Inches) and Gage			
		0.060 16	0.075 14	0.105 12	0.135 10
18	1	55			
21	1	47			
24	1	41	57		
30	1.25	33	45	73	
36	1.5	**27** [1]	38	61	86
42	1.5		**32** [1]	52	74
48	1.5			46	65
54	1.75			40	57
60	2			**36** [1]	52
66	2				47
72	2.25				**43** [1]

Limits for Checks:

Wall Area FS = 2
Buckling FS = 2

Constants:
Soil Density = 120 # / CU FT
Modulus of Elasticity = 1E+07 PSI
Minimum Yield Point = 24000 PSI
Min. Tensile Strength = 31000 PSI

Notes:
- Helical pipe lock seam
- Type I Embankment Installation
[1] Bold values are for Type I Trench Installation

Source:
CONTECH Construction Products Inc.

Table 2.19 2 ⅔" x ½" Corrugated Aluminum Pipe-Arch

Equivalent Pipe Diameter (inches)	Span (inches)	Rise (inches)	Minimum Cover (Feet)	Maximum Cover (Feet) by Thickness (Inches) and Gage				
				0.060 16	0.075 14	0.105 12	0.135 10	0.164 8
15	17	13	1	13	13			
18	21	15	1	13	13			
21	24	18	1	13	13			
24	28	20	1	13	13	13		
30	35	24	1	13	13	13		
36	42	29	1	13	13	13	13	
42	49	33	1.25			13	13	
48	57	38	1.25			12	12	12
54	64	43	1.5				12	12
60	71	47	1.5					12

Limits for Checks:
Flexibility Factor
For 16 gage = 0.031
For 14 gage = 0.061
For 12 gage and heavier = 0.092
Wall Area FS = 2
Buckling FS = 2

Constants:
Soil Density = 120 # / CU FT
Modulus of Elasticity = 1E+07 PSI
Minimum Yield Point = 24000 PSI
Min. Tensile Strength = 31000 PSI

Notes:
- Helical pipe lock seam

Source:
CONTECH Construction Products Inc.

Table 2.20 3" x 1" Corrugated Aluminum Pipe-Arch

Equivalent Pipe Diameter (inches)	Span (inches)	Rise (inches)	Minimum Cover (Feet)	Maximum Cover (Feet) by Thickness (Inches) and Gage			
				0.075 14	0.105 12	0.135 10	0.164 8
54	60	46	1.25	20	20	20	20
60	66	51	1.5	20	20	20	20
66	73	55	1.75	20	20	20	20
72	81	59	1.75		17	17	17
78	87	63	2		17	17	17
84	95	67	2		17	17	17
90	103	71	2			16	16
96	112	75	2				16

Notes: - Helical pipe lock seam

Limits for Checks:
Flexibility Factor = 0.0600

Wall Area FS = 2
Buckling FS = 2

Constants:
Soil Density = 120 # / CU FT
Modulus of Elasticity = 1E+07 PSI
Minimum Yield Point = 24000 PSI
Min. Tensile Strength = 31000 PSI
Source: CONTECH Construction Products Inc.

Table 2.21 3/4" x 3/4" x 7-1/2" Aluminum Spiral Rib Pipe-Arch

Equivalent Pipe Diameter (inches)	Span (inches)	Rise (inches)	Minimum Cover (Feet)	Maximum Cover (Feet) by Thickness (Inches) and Gage			
				0.064 16	0.079 14	0.109 12	0.135 10
18	20	16	1	16			
21	23	19	1	15			
24	27	21	1.25	14	14		
30	33	26	1.5	14	14	14	
36	40	31	1.5		13	13	13
42	46	36	1.5			13	13
48	53	41	1.75			13	13
54	60	46	1.75				13
60	66	51	1.75				13

Limits for Checks:
Wall Area FS = 2
Buckling FS = 2

Constants:
Soil Density = 120 # / CU FT
Modulus of Elasticity = 1E+07 PSI
Minimum Yield Point = 24000 PSI
Min. Tensile Strength = 31000 PSI

Notes:
- Helical pipe lock seam
- Spiral Rib Pipe; Type I Installation (Embankment Condition)

Source:
CONTECH Construction Products Inc.

2.6 REFERENCES

American Association of State Highway and Transportation Officials (AASHTO), 1999. *Highway Drainage Guidelines, Volume XIV, Highway Drainage Guidelines for Culvert and Inspection and Rehabilitation.* Task Force on Hydrology and Hydraulics, AASHTO Highway Subcommittee on Design. ISBN: 1-56051-128-1.