LANE Enterprises, Inc.
3905 Hartzdale Drive, Suite 514
Camp Hill, PA 17011
P: 717.761.8175 • F: 717.761.5055
lane-enterprises.com

LANE Facilities

PENNSYLVANIA

Bedford	814.623.1191
Carlisle	717.249.8342
King of Prussia	610.272.4531
Pulaski	724.652.7747
Shippensburg	717.532.5959

VIRGINIA

Bealeton	540.439.3201
Dublin	540.674.4645
Wytheville	276.223.1051

NEW YORK

Ballston Spa	518.885.4385
Bath	607.776.3366

NORTH CAROLINA

Statesville	704.872.2471

TEXAS

Temple	254.727.3346

CORPORATE HEADQUARTERS

Camp Hill	717.761.8175

LANE Products

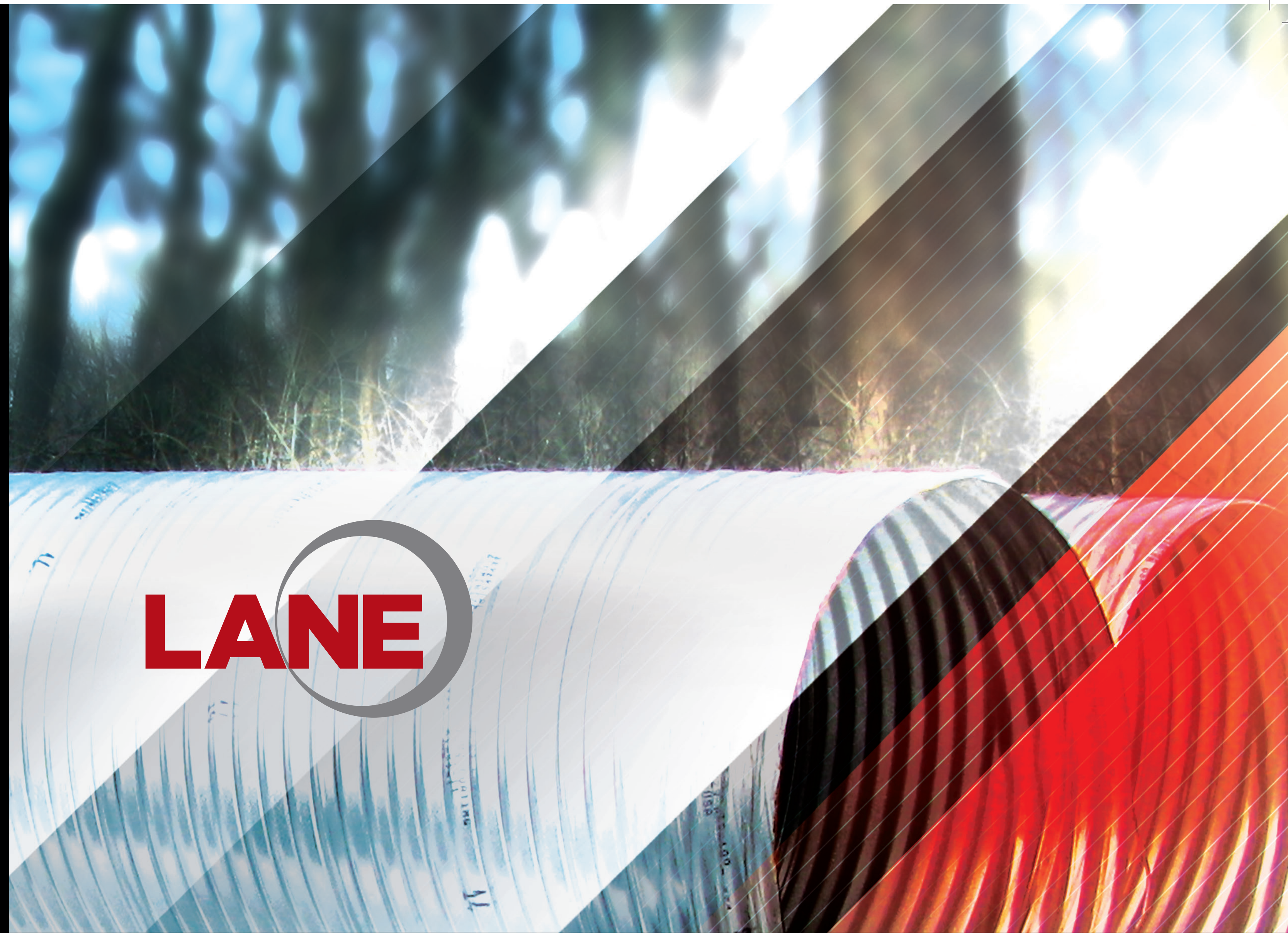
Corrugated Metal Pipe
Spiral Rib Pipe
Corrugated HDPE Pipe
Corrugated Polypropylene Pipe
Structural Plate Pipe and Arches
Structural Plate Box Culverts
Storm Water Collection Chambers
Storm Water Management Systems
Storm Water Filters
CFT (HDPE) Water Quality Unit
CMP Sandfilter
Open Top Slotted Drain
Welded Wire Mesh Gabions
Structural Plate Headwall-Culvert Systems
Custom Fabrications (Pond Kits, Trash Racks, etc.)
Long Span Bridge & Culvert Services
Rebar and Custom Powder Coatings

NCSPA
STEEL. PROVEN 100-YEARS STRONG
ncspa.org

Plastics Pipe Institute®
plasticpipe.org

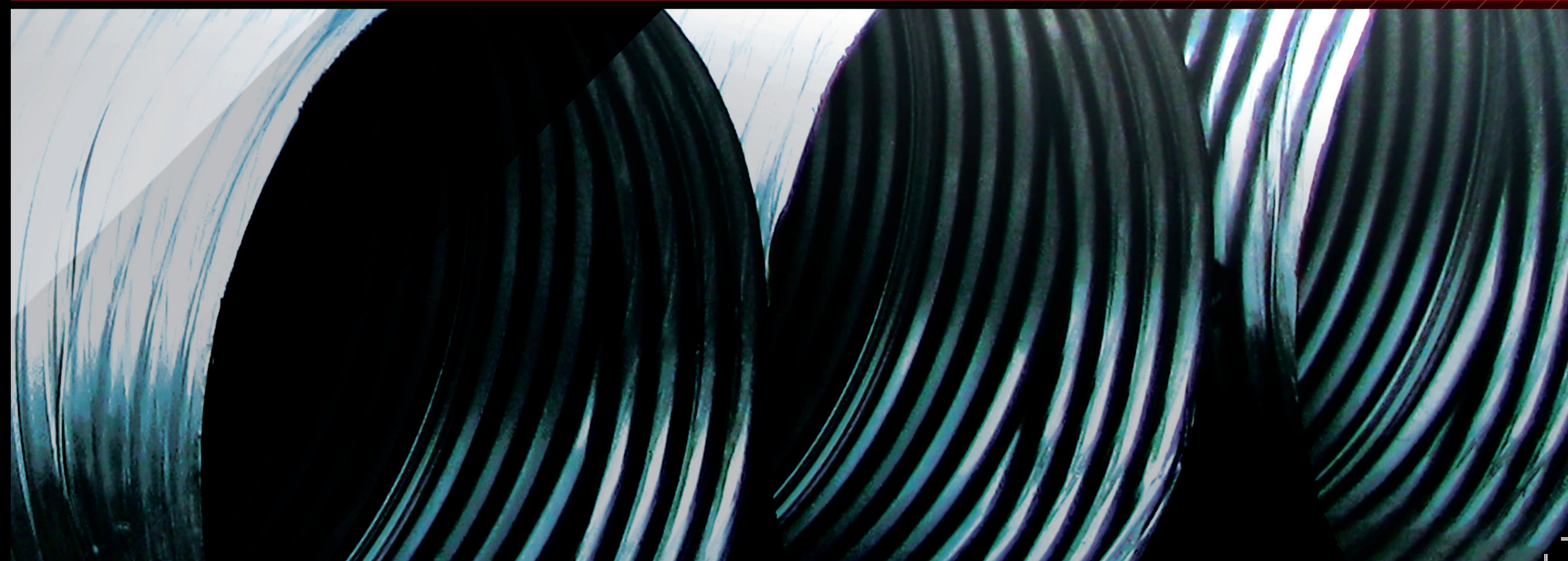
ESOP
An Employee-Owned Company

RAKZID LLC-9/21-AA



CMP TECHNICAL GUIDE

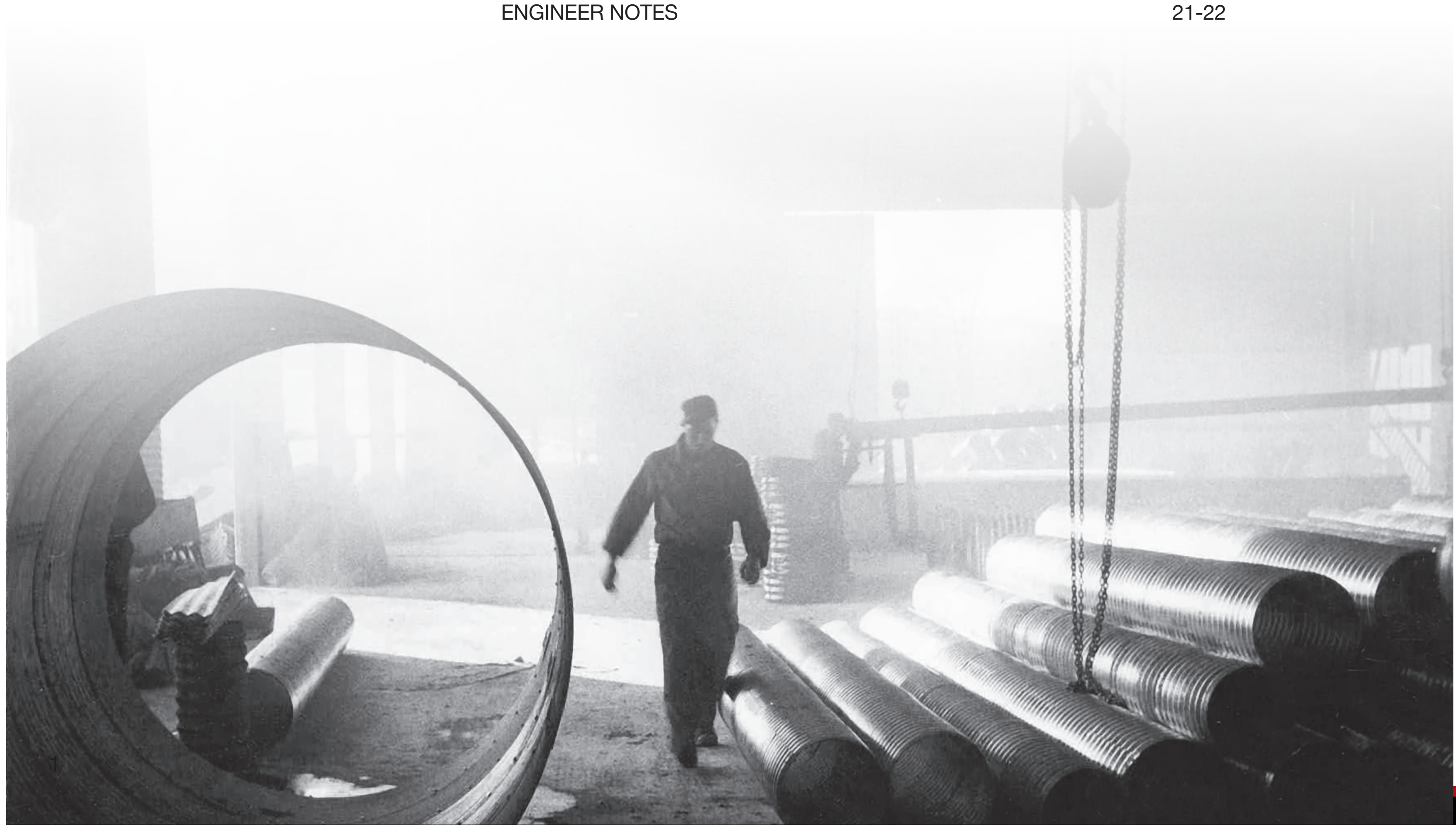
A guide to using corrugated metal pipe



CMP TECHNICAL GUIDE

A GUIDE TO USING CORRUGATED METAL PIPE

Corrugated Steel Pipe (CSP)
Corrugated Aluminum Alloy Pipe (CAAP)



SPECIFICATION GUIDE OVERVIEW

Specifying CMP products involves some familiarity with the industry publications, and this Specification Guide serves as a locus of these standards. In general, the design engineer will need to:

1. Select an appropriate CMP material type, manufacturing standard, and joint performance (pages 2-4).
2. Ensure the CMP material meets a structural design standard in relation to burial depths and live loads (page 5).
3. Incorporate a corresponding installation standard into the project documents (page 5).

Selecting the Appropriate Pipe Material Type and Standard
Specifying CMP products first involves an understanding of the application. Typical applications such as road culverts and storm drains will involve size and shape determinations for hydraulic capacity. Other applications may involve perforated CMP for various subsurface drainage purposes. Secondary considerations may be towards CMP material types to meet any durability or service life requirements. Subsequent decisions to economize the product are based on strength demands so that the lightest gauge or metal thickness is selected.

There are three primary ASTM CMP standards (AASHTO equivalents in parenthesis). One for metallic coated steel pipe, another for polymer coated steel pipe, and a third for aluminum alloy pipe. Each standard uses the same classification system to identify the pipe type, and each standard makes provisions for the different corrugations and metal thicknesses available.

STEP 1, Select Pipe Type. This primarily involves selecting either a round or pipe-arch shape, and secondarily whether a standard corrugation (sinusoidal arc-and-tangent) or smooth interior is needed for the application. Pipe-Arch shapes are for low cover conditions that require more hydraulic capacity than round pipe can deliver at the same invert elevation (figure 7, page 17). Opting for a round shape when possible will provide greater economy for the project. Round pipes used for underdrains or for underground disposal of water will require the additional step of selecting either a Class1 or Class 2 perforation pattern.

STEP 1. PIPE CLASSIFICATION	
Type I	Round Pipe, Exterior/Interior Corrugations
Type IR	Round Pipe, Smooth Interior (Spiral Rib Pipe)
Type II	Type I Pipe Reformed into a Pipe-Arch
Type IIR	Type IR Pipe Reformed into a Pipe-Arch
Type III	Type I Pipe with Class 1 or Class 2 Perforations

Corrugation	*Description*	*Steel*	*Aluminum*
1½ x ¼ in.	*Sinusoidal*	*6-10 in.*	
2⅔ x ½ in.	*Sinusoidal*	*12-72 in.*	*12-72 in.*
3 x 1 in.	*Sinusoidal*	*48-102 in.*	*36-120 in.*
5 x 1 in.	*Sinusoidal*	*48-144 in.*	
¾ x ¾ x 7½ in.	*Spiral Rib*	*15-102 in.*	*15-84 in.*

Perforated Pipe. Most applications require non-perforated pipe. Where applications for perforated pipe are necessary there are two perforation patterns available, Class 1 and Class 2, and the CMP standards use parallel classification systems for each. Inherent in the classification systems are the size, spacing and placement of the perforations.

Class 1, Partially Perforated Pipe (Subsurface Drainage). Class 1 perforations are for pipe intended to be used for subsurface drainage, where the pipe maintains an unperforated segment above the invert for a flow channel. Perforations have nominal diameters of ⅜-in arranged in rows parallel to the axis of the pipe with one perforation in each row for each corrugation. Rows of perforations are arranged in two equal groups placed symmetrically on each side of the lower unperforated segment corresponding to the flow line of the pipe.

Table 1. Class 1 Perforation Rows

D (in.)	Total Rows	H_{max} (in.)	$L_{min.}$ (in.)
6	4	2.8	3.8
8	4	3.7	5.1
10	4	4.6	6.4
12	6	5.5	7.7
15	6	8.9	9.6
18	6	8.3	11.5
21	6	9.7	13.4
≥ 24	8	0.46D	0.64D

Table 2. Class 1 Perforation Inlet Area

Corrugation	Inlet Area
1½ x ¼ in.	3.53 in²/ft (6,8,10 in)
2⅔ x ½ in.	2.98 in²/ft (12-21 in)
2⅔ x ½ in.	3.98 in²/ft (≥24 in)
3 x 1 in.	3.53 in²/ft (all diameters)
5 x 1 in.	2.12 in²/ft (all diameters)

Inlet areas based on a nominal 3/8-in. diameter perforation.

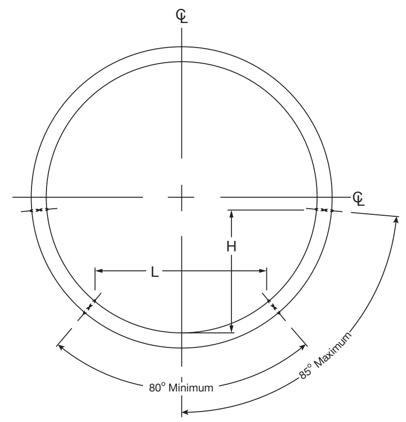


Figure 1. Class 1 Perforations

Class 2, Fully Perforated Pipe (Subsurface Disposal). Class 2 perforations are for pipe intended to be used for subsurface disposal of water. Perforations around the entire periphery of the pipe allows both infiltration and complete exfiltration (i.e. disposal into the ground). The common use of Class 2 perforations is for pipe used in groundwater recharge systems. Class 2 perforations provide a minimum inlet area of 3.3 in²/ft². Thirty 3/8-in diameter perforations per square foot of surface satisfies this requirement.

STEP 2, Select Pipe Material. This step presumes a service life is defined for the project so that the most economical decision can be made and the proper pipe standard specified. See page 9 for a review of anticipated service life along with the references cited there for a more in-depth treatment.

STEP 2. PIPE STANDARD
ASTM A760 (AASHTO M36) Galvanized or Aluminized Steel Pipe
ASTM A762 (AASHTO M245) Polymer-Coated Steel Pipe
ASTM B745 (AASHTO M196) Aluminum Alloy Pipe

See page 9 for Service Life Assignments

Galvanized Coil	Coating weight	2 oz/sf of coil
Aluminized Coil	Coating weight	1 oz/sf of coil
Polymer Coil	Laminate thickness	10 mil each side

STEP 3, Select Lightest Gauge. Industry guidelines have established empirical flexibility limits that a gauge-span combination should have to be safely handled and installed. While these limits are quantified by a standard computation called the Flexibility Factor (FF), in the final analysis the limits represent a subjective approach in defining when a structure may not be rigid enough to withstand compaction forces alongside the pipe. When the FF is slightly exceeded the designer should specify a more readily compacted embedment material such as crushed stone. Beyond that, the gauge will generally increase with higher fill heights to meet strength requirements as illustrated on the cover height tables located on pages 10-14.

Explanatory notes provide additional clarification to the various cover height tables and can also be correlated to the structural design standards listed on page 5. It should be noted that gauge considerations for the pipe-arch shapes are not always governed by flexibility limits since some of the corrugation patterns require a heavier gauge to properly form the arch shape, and sharp corner radii provide for an entirely different design consideration (see the Pipe-Arch Design Supplemental, page 15).

STEP 3. PIPE GAUGE

Gauge	Steel	Aluminum	Gauge	Steel	Aluminum
18 GA	0.052 in.		12 GA	0.109 in.	0.105 in.
16 GA	0.064 in.	0.060 in.	10 GA	0.138 in.	0.135 in.
14 GA	0.079 in.	0.075 in.	8 GA	0.168 in.	0.164 in.

See pages 10-14 for Cover Height Tables

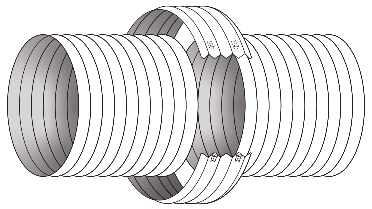


Figure 2. Wrap-around metal band.

STEP 4, Select Joint Performance. Each of the above-mentioned CMP standards also provides corresponding joint performance criteria based upon the ability of the joining system to control leakage or material infiltration.

Soil Tight – (default criteria) resists infiltration of soil particles larger than those passing a No. 200 Sieve

Silt Tight – resists infiltration of soil particles equivalent to an apparent opening size (AOS) of 70

Leak Resistant - leakage limited to 200 gal/in-dia/mile/day at a defined pressure head from 0-25ft

Special Design - zero leakage for 10 min at a defined pressure head from 10-25ft in a laboratory setting

Pipe joining systems defined in the CMP standards include several wrap-around styles of metal bands (see figure 2 above) of the same material as the pipes being joined, albeit in a lighter gauge. The different types of coupling bands and connecting hardware are shown on the following page. The tables below show minimum width and thickness requirements identified in the CMP standards.

MIN BAND GAUGE

Pipe	Band
18-12 GA	18 GA
10 GA	16 GA
8 GA	14 GA

MIN BAND WIDTH (CSP)

Dia.	Band
12-36 in.	7 in.
42-144 in.	10½ in.

For pipe with annular corrugated ends

MIN BAND WIDTH (CAAP)

Corrugation	Dia.	Annular	Dimple
2⅔ x ½ in.	12-36 in.	7 in.	10½ in.
	42-72 in.	10½ in.	10½ in.
	78-120 in.	10½ in.	16¼ in.
3 x 1 in.	30-72 in.	12 in.	10½ in.
	78-120 in.	12 in.	16¼ in.

Specifying Joint Performance. In general, all styles of metal bands will provide soil-tight performance but will need additional materials to meet higher demands. Silt-tight performance will require, at a minimum, a geotextile wrap around the banded joint. The various leak resistant or special design performances will require the addition of a gasket that meets the material requirements of ASTM D1056 (see following page).

For additional information on specifying joint performance see below standard, which provides definitions of joint performance terms, a rational design methodology for appropriate joint performance requirements, and uniform criteria for manufacturers' joint qualifications.

AASHTO R82, Standard Practice for Pipe Joint Selection for Highway Culvert and Storm Drains

SPECIFICATION GUIDE

COUPLING BANDS

Pipe corrugations are helically formed but the CMP standards make provisions for the pipe ends to be reformed into annular corrugations to allow a continuous index or seal to be made around the entire periphery of the pipe end, and to better engage certain coupling bands.

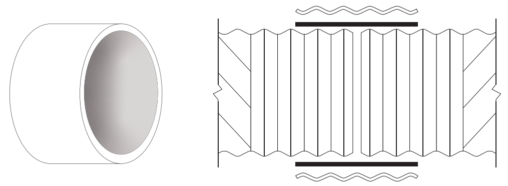


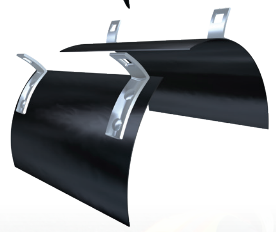
Figure 3. Sleeve Gaskets.

All annular corrugated ends are reformed with a 2⅔ x ½-in corrugation by a process commonly known as rerolling.

Corrugated Bands*
Annular corrugated bands are available in nominal widths of 7, 12 and 24-in.

Partially Corrugated Bands*
Flat bands with one annular corrugation along each edge are available in nominal widths of 7 and 12-in.

Flat Bands*
Bands with no corrugations or projections are available in nominal widths of 7, 12 and 24-in.



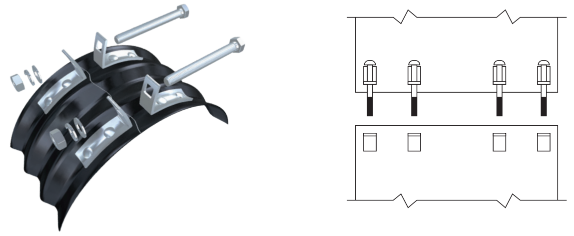
Dimple Bands
Bands with dimple projections in annular rows. Along with flat bands they may be used on pipe with helical or annular corrugations. Dimple bands are available for 12 through 54-in CMP.

Sleeve Gaskets
A ⅜-in thick neoprene material that slides over the pipe ends and underlays the connecting band to enhance the leak resistance quality of the joint. Sleeve gaskets are available in 7, 12, and 24-in widths. See figure 3 above.

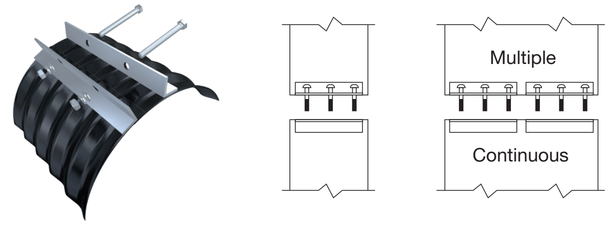
*NOTE: *Polymer coated bands shown for contrast.*

CONNECTING BAND HARDWARE

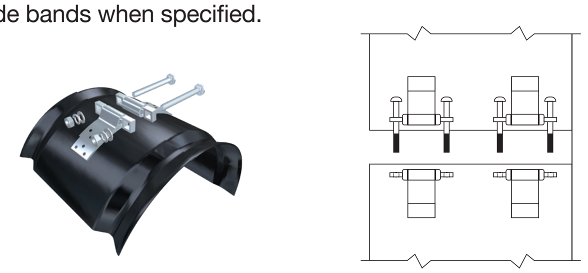
Standard Lug Connector*
Assembly typically uses the dual lug configuration (left). The multiple lug configuration (right) is for 24-in wide bands.



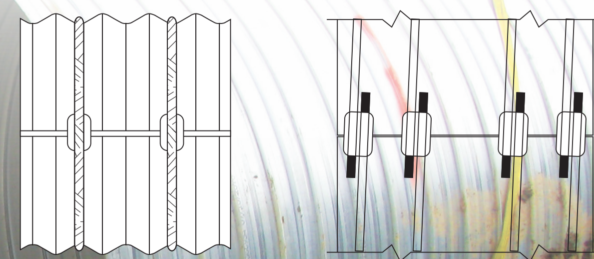
Angle Connection*
Assembly uses the two-bolt configuration for 7-in bands (left), a three-bolt configuration for 12-in bands (middle), and a six-bolt configuration for 24-in bands (right).



Bar and Strap Connector*
Assembly typically consists of the single-strap configuration (left). The multi-strap configuration (right) can be used for 12-in wide bands when specified.



Rod and Lug (½-in Ø SILO ROD & LUG)
Assembly typically consists of the dual rod configuration (left) and may be used on corrugated or partially corrugated bands. The multiple rod configuration (right) is used for 24-in corrugated bands only.



SELECTING THE APPROPRIATE STRUCTURAL STANDARD

CMP Structural Design Standards

Standard methods of structural analysis are generally based on research adopted by AASHTO. Standards with slight variations have also been adopted by ASTM. The railway industry, represented by AREMA, maintains distinct material and design standards to ensure railway live loading (E80) and its effects are appropriately managed.

The cover height tables on pages 10 and 13 show results generated by the AISI method, an Allowable Stress Design method for corrugated steel pipe that's fully outlined in the first three general industry references below.

Note that cover height tables were not prepared for railway applications since these tables are included in the AREMA Manual for Railway Engineering publication cited below for both steel and aluminum round and pipe-arch shapes.

The following standards are listed with the qualifying remark that the AASHTO method is the primary design standard outside railway applications:

ASTM A796 Practice for Structural Design of Corrugated Steel Pipe, Pipe-Arches, and Arches for Storm and Sanitary Sewers and Other Buried Applications

ASTM B790 Practice for Structural Design of Corrugated Aluminum Pipe, Pipe-Arches, and Arches for Culverts, Storm Sewers, and Other Buried Conduits

ASTM A998 Practice for Structural Design of Reinforcements for Fittings in Factory–Made Corrugated Steel Pipe for Sewers and Other Applications

AREMA 2020 Manual for Railway Engineering, Section 4.13, Design Criteria for Corrugated Metal Pipes

AASHTO LRFD Bridge Design Specifications, Section 3, Loads and Load Factors [9th Edition]

AASHTO LRFD Bridge Design Specifications, Section 12, Buried Structures and Tunnel Liners [9th Edition]

For an important resource visit www.candeforculverts.com. CANDE is a free special purpose, 2D finite element computer program developed for the structural design and analysis of soil bridges, buried culverts and underground structures. See especially its Solution Methods and Formulations for a thorough understanding of CMP behavior and modelling considerations

SELECTING THE APPROPRIATE INSTALLATION STANDARD

CMP Installation Standards

Corrugated metal pipe (CMP) is a flexible pipe material that derives structural support from the strength and stiffness of the backfill envelope. The backfill-culvert interaction system defines the ability of CMP to withstand service loads. Installation specifications illustrating backfill envelopes, addressing appropriate backfill material selection, and identifying proper compaction guidelines help ensure acceptable levels of backfill-culvert interaction are realized:

ASTM A798 Practice for Installing Factory-Made Corrugated Steel Pipe for Sewers

ASTM B788 Practice for Installing Factory-Made Corrugated Aluminum Culverts and Storm Sewer Pipe

AASHTO LRFD Bridge Construction Specifications, Section 26, Metal Culverts

AREMA Manual for Railway Engineering, Section 4.12, Assembly and Installation of Pipe Culverts

See especially the National Corrugated Steel Pipe Association Installation Manual at NCSPA.org
For a highly recommended general resource see Pipeline Installation 2.0 by Amster Howard [2nd Edition 2015]

GENERAL INDUSTRY REFERENCES

Corrugated Steel Pipe Design Manual by the National Corrugated Steel Pipe Association (NCSPA) [2nd Edition 2018]
Handbook of Steel Drainage & Highway Construction Products by the American Iron and Steel Institute (AISI) [1994 Edition]
Modern Sewer Design by the NCSPA and the AISI [4th Edition, 1999]

2020 AREMA Manual for Railway Engineering, Chapter 1, Part 4 Culverts

GENERAL OVERVIEW

Pipe should be unloaded and handled with reasonable care to avoid any undue damage, especially to the coatings. Using two equally spaced lift points for the larger sizes will prevent the pipe ends from striking objects or being dragged along the ground.

Pipe installation generally progresses in an upstream fashion beginning at the outlet of the drainage improvement to be constructed and should be uniformly supported on grade throughout the alignment.

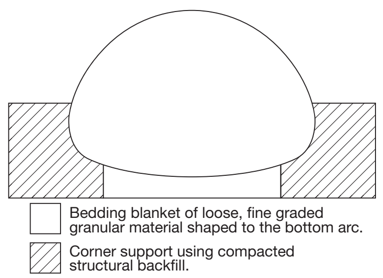
Joint gaps for circular pipe up to one inch can be expected. A joint gap for circular pipe between one and two inches is not a cause for any undue concern but should be investigated to determine if any corrective actions are necessary. Greater joint gaps may be encountered with the arch shapes in the larger sizes due to the manufacturing process. Specifying a 2-ft wide connecting band with an underlying gasket typically offsets any joint gap issues. Where leakage is not a concern the gasket requirement may be mitigated by the inclusion of a non-woven geotextile wrap around the joint exterior.

The **foundation** of a pipe installation is ideally the undisturbed native material resulting from a carefully graded excavation. Replacing soft or unyielding material with additional bedding will help ensure uniform pipe support. ASTM A798 notes that unsuitable foundation materials are replaced across the width of the trench to a depth of one-half inch per foot of design fill over the pipe with a 24-inch maximum.

Note: materials used for foundation improvements (and all backfill materials) must have gradations compatible with adjacent soils to avoid migration or be separated with a non-woven geotextile.

Pipe **bedding** is constructed in a manner to provide uniform pipe support to the design line and grade, with the middle-third beneath round pipe left loose to cradle the pipe so that the load is better distributed along the bottom segment of the pipe.

For pipe-arch shapes, however, a shaped bedding width corresponding to the flat bottom arc will be needed to eliminate the challenge of filling this area after-the-fact. The shaped bedding width must not exceed this width as select, compacted material is needed beneath the sharp corners for structural support.



A minimum bedding thickness of two times the corrugation depth is generally recommended. The bedding material is typically the same material used for pipe embedment, ideally a clean, cohesionless, free-draining soil with particles that move around easily in order to conform to the shape of the pipe bottom.

Pipe **haunching** is carried out on both sides simultaneously to avoid rolling the pipe. Gently dumping small amounts of material on top of the pipe will provide some stability while material falling beside the pipe can be pushed into the haunch zone. Filling adjacent sidefill zones will provide lateral support to the haunch material during the process. Loose layers in four to six-inch lifts will permit the backfill material to be worked into the haunch zone.

Material should be manually placed in the haunches. Techniques such as rodding, knifing, or shovel slicing are effective to ensure the haunch is filled. Mechanical tampers, manual tampers, or other means that fill voids and meet specified compaction levels must be used carefully. Controlling the compaction force will prevent the pipe from lifting off grade. Do not permit compaction equipment to contact the pipe.

Pipe **embedment** is constructed by placing select materials equally on each side of the pipe in loose layers of 6 to 12 inches. Each layer is then compacted before adding the next lift. Lift construction progressing equally along each side of the pipe is necessary for pipe support. For convenience, lift construction may alternate from side to side such that the differential is never more than one lift. Pipe embedment is generally concluded when select fill is extended to the minimum cover height.

Bedding and Embedment Materials

Bedding and structural backfill is commonly a well-graded granular material free of organics, rock fragments larger than three inches, chunks of highly plastic clay, frozen lumps, and corrosive or otherwise deleterious materials. Gravel-sand mixtures are ideal.

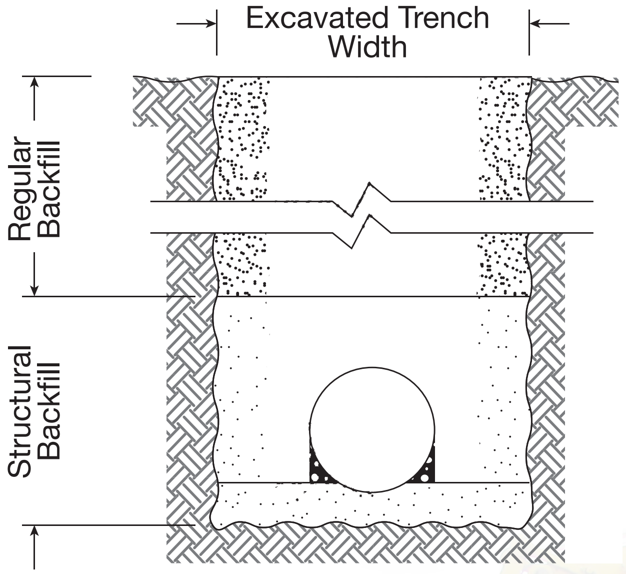
Poorly graded clean crushed rock with 100% passing the 1½-in sieve provides excellent pipe support and is ideal when compactive forces need to be lessened to the extent possible for highly flexible conduits.

Processed aggregates with angular interlocking particles provide the best support with a minimum of compaction effort over a wide range of moisture content and lift depth. Uniform-graded materials are typically angular rock fragments with a nominal size distribution from ¾ to 1½-in.

Trench Installation

Pipe installations in cut trenches can begin once the bedding has been properly constructed over a suitable foundation. Trench sidewalls must be stable, supported, or laid back according to OSHA regulations. Narrower trench widths normally provide better pipe support if the native soils forming the trench wall are stable, but the width must be sufficient for proper haunching, side fill compaction, and safe working conditions.

Pipe should be placed on bedding shaped to the pipe invert for a width of one-half the diameter or span where the distance between the pipe and trench wall is less than 2-ft.



Trench Width. As a guide, AASHTO indicates the minimum trench width should not be less than the greater of the pipe diameter plus 16 inches or the pipe diameter times 1.5 plus 12 inches.

Structural Backfill. Select materials are specified for use in the structural backfill or embedment zone, consisting of a bedding layer beneath the pipe, the critical haunch zones beneath the pipe sides and the bedding layer, the side zones, and a distance above the pipe equivalent to the minimum cover (see below).

Minimum Bedding Thickness. Loosely placed to a depth of at least two-times the corrugation depth.

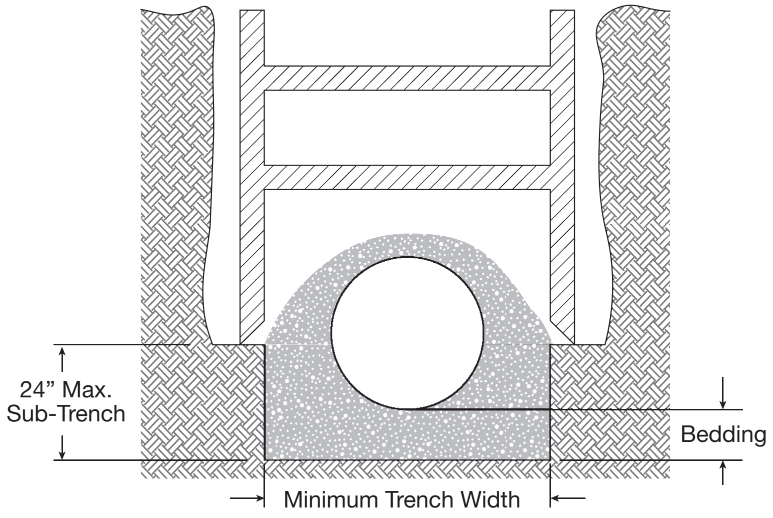
Minimum Cover. A distance above the pipe equivalent to the greater of one-eighth the pipe span or 12 inches.

Regular Backfill. Depends on final use of surface and is per project plans and specifications.

Trench Box Installation

The use of a trench box for the deeper installations typically challenges the ability to maintain side fill support as the trench box is advanced.

Voids left by the trench box walls, as well as the void left between the trench box and the excavation must be addressed to ensure compacted support extends to the undisturbed native materials. Any sloughed material against the outside of the trench box must also be addressed.



Trench width requirements correspond to the distance between the interior walls of the trench box and therefore the excavation width will increase accordingly.

Do not compact embedment material against the walls of the trench box so as not to disturb the installed pipe and its embedment when moving the trench box.

Proper placement and compaction of the side fill is done below the bottom edge of the trench box as it is raised vertically in approximate 12 inch increments, removing any sloughed material as the process continues.

The practice of using a sub-trench will mitigate the challenges associated with haunch and side fill placement and compaction.

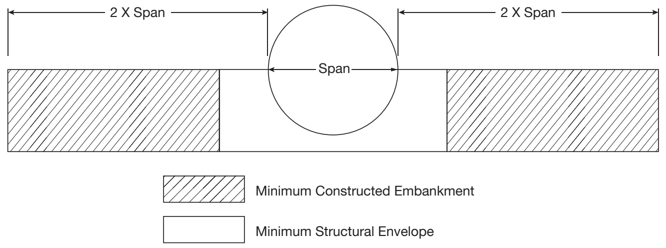
Where sub-trenches are not allowed the trench box should be widened to mitigate the challenges.

Using manufactured aggregates that require little compactive effort will produce the best results for trench box installations.

INSTALLATION GUIDE

Embankment Installation

Embankments may be constructed in lifts with the pipe in place or constructed to a height corresponding to the pipe springline before excavating a trench for installing the pipe. In any case a minimum width of structural envelope is needed for lateral restraint.



As a guide, AASHTO indicates the minimum width of structural envelope on each side of the pipe should not be less than one span for diameters (or spans) less than 24 inches, 2-ft for spans between 24 and 144 inches, and 5-ft for spans exceeding 144 inches.

Also, the combined width of the structural envelope and the embankment beyond the envelope must be adequate to support all the loads on the pipe. A good practice is to provide a total combined width of two pipe spans on each side of the pipe.

Lift Construction Above The Pipe

For lift construction to the minimum cover height only walk-behind compaction equipment shall be used. Once minimum cover has been established small dozers may be used to track back and forth with no twisting/turning. Tracked excavators and smooth drum vibratory soil compactors may be used once 24 inches have been established above the pipe.

Multiple Pipe Runs

Installation methods for multiple runs of pipe shall be consistent with trench and embankment installations with the added condition that backfilling progress evenly across all pipe runs. Spacing between pipes shall be sufficient to permit the proper placement and compaction of structural backfill in the haunch and between the structures. As a guide, AASHTO indicates the minimum spacing between pipes should not be less than that shown in the tables below:

PIPE DIAMETER	MINIMUM SPACING
Up to 24 in.	12 in.
24-72 in.	½D
Greater than 72 in.	36 in.

PIPE-ARCH SPAN	MINIMUM SPACING
Up to 36 in.	12 in.
36-108 in.	S/3
Greater than 108 in.	36 in.

Temporary Construction Cover

As an added measure of protection during the construction process additional (temporary) compacted cover may be needed over the pipe due to the high frequency of traffic and the potential for rutting associated with large tread rubber tires. The following table provides industry guidelines based on axle weights:

MINIMUM TEMPORARY COVER FOR CONSTRUCTION LOADS (FT)				
Span (in.)	Axle Loads (KIPS)			
	18-50	50-75	75-110	110-150
12 to 42	2.0	2.5	3.0	3.0
48 to 72	3.0	3.0	3.5	4.0
78 to 120	3.0	3.5	4.0	4.0
126 to 144	3.5	4.0	4.5	4.5

Designations for Bedding and Backfill

Soils meeting the requirements of Soil Groups GW, GP, GM, GC, SW and SP as defined in ASTM D2487 are generally acceptable when properly compacted. Soil Groups SM and SC are acceptable but will require closer control to obtain the specified density. AASHTO M145 groups A-1, A-2 or A-3 are minimum AASHTO requirements. Commonly used AASHTO designations for crushed rock are AASHTO Nos. 57, 67 and 8.

ASTM D2487	AASHTO M145	DESCRIPTION
GW GP SP	A-1-a	Well-graded gravel
GM SM SP	A-1-b	Gravelly sand
GM SM ML SP GP	A-2-4	Sand and gravel with low plasticity silt
SC GC GM	A-2-5	Sand and gravels with elastic silt
SC GC	A-2-6	Sands with clay fines
SC GC	A-2-7	Sands with highly plastic clay fines
SW SP SM	A-3	Fine sands, such as beach sand

The above table shows a descending order of backfill quality where non-plastic sands and gravels are preferred, especially for the larger, more flexible pipe, higher fills, and trench box installations. Compaction to 90% SPD is generally sufficient for all cases.

Filter Fabric

The migration of fines into the pipe embedment can result in loss of pipe support. The gradation and relative size of the embedment and adjacent materials must be compatible to minimize this migration. When coarse and open-graded material is placed adjacent to a finer material a filter fabric (or other acceptable means) should be used.

Corrugated Steel Pipe (CSP) has been in use since the early 20th century, much of this time available with only a galvanized coating. With the addition of several coating options CSP has increased its value and usefulness in providing extended service life over a broader range of environmental conditions.

Environmental conditions can vary considerably from site to site but there are only several variables used to predict service life. The pipe interior (water-side durability) is impacted by effluent abrasion, pH and resistivity, and is typically the controlling factor in service life assignments. The pipe exterior (soil-side durability) is affected by soil pH and resistivity, and is generally not the limiting factor in estimating CSP service life.

Abrasion is a function of the bed load carried by the effluent and its velocity. Abrasion levels are correlated to the classification system developed by the Federal Highway Administration (FHWA).

FHWA ABRASION		BED LOAD	VELOCITY
Level 1	None	None	
Level 2	Low	Sand/gravel	< 5 fps
Level 3	Moderate	Sand/gravel	5-15 fps
Level 4	Severe	Heavy gravel/rock	>15 fps

The **pH** ranges between 0 and 14 and is a measurement of acidity (pH < 7.0) or alkalinity (pH > 7.0). **Resistivity, R** [ohm-cm] is a measure of how strongly a material opposes the flow of electric current. A low resistivity indicates a material that readily allows the movement of electric charge and results in greater corrosion rates.

Normal environmental conditions have a pH range between 5.8 and 8.0 with a resistivity greater than 2000 ohm-cm. **Mildly corrosive** environments have a pH range from 5.0 to 5.8 and a resistivity between 1500 and 2000 ohm-cm. **Corrosive** environments are characterized by pH's less than 5.0 and resistivities below 1500 ohm-cm.

Galvanized CSP provides a zinc coating weight of two ounces per square foot of surface area. Galvanized CSP has been in use longer than any other material and much has been learned about the service life of this material. A field investigation conducted in the 1960's evaluated the service life of roughly 7,000 culverts in terms of pH and resistivity alone, and was subsequently quantified in the following service life equations:

For pH ≤ 7.3

Service Life (Years) = $35.85[\log_{10} R - \log_{10} (2160 - 2490 \log_{10} pH)]$

For pH > 7.3

Service Life (Years) = $3.82R^{0.41}$

The equations relate the service life for 16 gauge CSP based on a 25% loss of steel in the pipe invert. Longer service life may be achieved with the heavier gauges. For gauges 14, 12, 10 and 8, apply factors 1.3, 1.8, 2.3 and 2.8, respectively.

For pH's ≤ 7.3 the equation should be applied to both the water-side and soil-side of the pipe. When pH > 7.3 the soil-side is the controlling factor.

An important factor later discovered to have a significant impact on the service life of galvanized coated CSP is the presence of soft water (CaCO3 < 50 ppm). Hard water has an excess of this dissolved salt which is deposited on the pipe in the form of a scale that protects the underlying coating. Had the impact of soft water been recognized at the time of installation the resultant equations would have predicted significantly longer service life for galvanized CSP installed within the environmental guidelines of today. **Aluminized CSP** will not be adversely affected by the presence of soft water and therefore is the recommended substitute to galvanized CSP in soft water applications

Aluminized CSP, also referred to as Aluminized Type 2 (ALT2), has a pure aluminum coating of one ounce per square foot of surface area. The aluminum coating develops a passive aluminum oxide film that withstands a wider range of environmental conditions. The film is quite stable in neutral and acidic environments, does not break down in alkaline environments until the pH exceeds 9.0, and develops regardless of the $CaCO_3$ concentration. ALT2 therefore has the advantage over galvanized CSP in the lower pH and soft water environments.

Polymer Coated CSP is the premier CSP coating, manufactured from galvanized steel coils that have been coated with a 10-mil laminate film on each side. The polyolefin laminate has strong adhesion characteristics with the galvanized sheet and is the most durable CSP coating available today, outperforming the other coatings in both the more abrasive and chemically aggressive environments. Installations now dating back nearly 50 years show no signs of degradation.

Service Life Assignments - CSP Coatings

There have been some major research undertakings over the past couple decades to supplement the vast field surveys and findings. Laboratory testing conducted by the primary coating suppliers along with ongoing field monitoring and other research endeavors combine to provide the following service life assignments for CSP coatings:

SERVICE LIFE	ENVIRONMENT	ABRASION	CSP COATING
Minimum 100 years	5.0 ≤ pH ≤ 9.0	Level 3	Polymer
	R > 1500	Level 2	ALT2 (14ga)
Minimum 75 Years	4.0 ≤ pH ≤ 9.0 R > 750	Level 3	Polymer
	5.0 ≤ pH ≤ 9.0 R > 1500	Level 2	ALT2
Minimum 50 Years	3.0 ≤ pH ≤ 12.0 R > 250	Level 3	Polymer
Average 50 Years	6.0 ≤ pH ≤ 10.0 2000 < R < 10000 Hard Water, $CaCO_3$ > 50 ppm	Level 2	Galvanized

Consult the NCSPA Service Life Selection Guide for a fuller treatment of service life for CSP coatings (www.ncspa.org).

Service Life Assignments

Corrugated Aluminum Alloy Pipe Minimum 75-Year Service Life in the Recommended Environment

The core material for aluminum alloy pipe is specially formulated to resist the effects of corrosion and abrasion. Corrosion resistance is further improved by cladding each surface of the core with a higher grade aluminum alloy that totals 10% of the total sheet thickness. Corrugated aluminum alloy pipe provides a minimum 75-yr service life in the recommended environment (pH 4-9, R > 500 ohm-cm). Aluminum drainage products are especially appropriate for brackish and seawater (35 ohm-cm) environments when the pipe is backfilled with a clean, free draining granular material.

For an exhaustive treatment of service life for all highway culvert types see NCHRP SYNTHESIS 474, Service Life of Culverts, A Synthesis of Highway Practice [2015]

Corrugated Steel Pipe (CSP)
AISI ASD (H20 and H25 Live Load)
Minimum and Maximum Cover Depths (ft)

CSP 2 ⅔ x ½ in

Dia.	Min	Maximum Cover				
(in)	Cover	16ga	14ga	12ga	10ga	8ga
12	1.00	247	309			
15	1.00	198	247			
18	1.00	165	206			
21	1.00	141	176	247		
24	1.00	123	154	216		
30	1.00	99	123	173	223	
36	1.00	82	103	144	185	
42	1.00	70	88	123	159	194
48	1.00	61	77	108	139	170
54	1.00	(53)	66	94	121	150
60	1.00		(56)	79	103	127
66	1.00			67	88	109
72	1.00			(57)	74	92
78	1.00			(47)	(62)	78
84	1.00			(39)	(52)	65

Spiral Rib Steel Pipe (SRP)
AISI ASD (H20 and H25 Live Load)
Minimum and Maximum Cover Depths (ft)

SRSP ¾ x ¾ x 7½ in

Dia.	Min	Maximum Cover			
(in)	Cover	16ga	14ga	12ga	10ga
15	1.00	130	182		
18	1.00	108	151	252	
21	1.00	93	130	216	
24	1.00	81	113	189	
30	1.00	65	91	151	
36	1.00	54	75	126	
42	1.00	46	65	108	
48	1.00	40	56	94	
54	1.13	(36)	50	84	
60	1.25	(32)	45	75	109
66	1.38	(29)	(41)	68	99
72	1.50		(37)	62	88
78	1.63		(34)	55	78
84	1.75			(48)	68
90	1.88			(43)	60
96	2.00			(38)	53
102	2.13			(33)	(46)

Corrugated Steel Pipe (CSP)
AISI ASD (H20 and H25 Live Load)
Minimum and Maximum Cover Depths (ft)

CSP 3 x 1 in

Dia.	Min	Maximum Cover				
(in)	Cover	16ga	14ga	12ga	10ga	8ga
48	1.00	71	88	124	160	196
54	1.00	63	79	110	142	174
60	1.00	56	71	99	128	157
66	1.00	51	64	90	116	142
72	1.00	47	59	83	107	130
78	1.00	43	54	76	98	120
84	1.00	40	50	71	91	112
90	1.00	37	47	66	85	104
96	1.00	35	44	62	80	98
102	1.06	33	41	58	75	92
108	1.13	(30)	38	53	69	85
114	1.19	(28)	35	49	64	78
120	1.25	(25)	(32)	45	59	72
126	1.31		(29)	42	54	66
132	1.38		(27)	38	50	61
138	1.44		(25)	35	46	56
144	1.50			(32)	42	52

Corrugated Steel Pipe (CSP)
AISI ASD (H20 and H25 Live Load)
Minimum and Maximum Cover Depths (ft)

CSP 5 x 1 in

Dia.	Min	Maximum Cover				
(in)	Cover	16ga	14ga	12ga	10ga	8ga
48	1.00	63	79	111	142	174
54	1.00	56	70	98	127	155
60	1.00	50	63	88	114	139
66	1.00	46	57	80	103	127
72	1.00	42	52	74	95	116
78	1.00	39	48	68	87	107
84	1.00	36	45	63	81	99
90	1.00	33	42	59	76	93
96	1.00	31	39	55	71	87
102	1.06	29	37	52	67	82
108	1.13	(28)	35	49	63	77
114	1.19	(26)	32	45	58	72
120	1.25	(24)	30	42	54	66
126	1.31	(22)	(27)	39	50	61
132	1.38		(25)	36	46	57
138	1.44		(23)	33	43	53
144	1.50			(30)	39	49

NOTES:

1. Tables are based on the methods set forth by the American Iron and Steel Institute (AISI) and is an Allowable Stress Design (ASD).
2. Minimum cover is governed by general equations in all cases (span/8 ≥ 12 in, except for spiral rib pipe where span/4 ≥ 12 in).
3. Minimum cover is measured from the top of pipe to the bottom of flexible pavement or the top of rigid pavement.
4. Cover depths shown are based on installations in accordance with ASTM A798.
5. Corrugated steel pipe manufacturing standards are per ASTM A760 for metallic coatings or ASTM A762 for polymer coatings.
6. Fill heights in parentheses require higher installation standards due to the higher flexibility of the span-gauge combination. This may be accommodated using trench construction methods with crushed rock backfill materials.
7. Aluminized and polymer coated steel is available in gauges 16 through 10. Consult manufacturer before specifying polymer coated steel in gauges 12 and 10.

Corrugated Steel Pipe (CSP)
AASHTO LRFD (HL-93 Live Load)
Minimum and Maximum Cover Depths (ft)

CSP 2⅔ x ½ in

Dia.	Min	Maximum Cover				
(in)	Cover	16ga	14ga	12ga	10ga	8ga
12	1.00	218	273			
15	1.00	174	218			
18	1.00	145	182			
21	1.00	124	155	218		
24	1.00	109	136	191		
30	1.00	87	109	152	196	
36	1.00	72	90	127	163	
42	1.00	62	77	109	140	171
48	1.00	54	68	95	122	150
54	1.00		60	84	109	133
60	1.00			76	98	120
66	1.00				89	109
72	1.00				81	100
78	1.00					88
84	1.00					76

Spiral Rib Steel Pipe (SRP)
AASHTO LRFD (HL-93 Live Load)
Minimum and Maximum Cover Depths (ft)

SRSP ¾ x ¾ x 7½ in

Dia.	Min	Maximum Cover			
(in)	Cover	16ga	14ga	12ga	10ga
15	1.00	114	160		
18	1.00	95	133	222	
21	1.00	81	114	190	
24	1.00	71	100	166	
30	1.00	57	80	133	
36	1.00	47	66	111	
42	1.00	40	57	95	
48	1.00	35	50	83	
54	1.13	(31)	44	74	
60	1.25		39	66	96
66	1.38		(36)	60	88
72	1.50			55	80
78	1.63			51	74
84	1.75			(47)	69
90	1.88				64
96	2.00				(59)
102	2.13				(53)

Corrugated Steel Pipe (CSP)
AASHTO LRFD (HL-93 Live Load)
Minimum and Maximum Cover Depths (ft)

CSP 3 x 1 in

Dia.	Min	Maximum Cover				
(in)	Cover	16ga	14ga	12ga	10ga	8ga
48	1.00	62	78	109	141	173
54	1.00	55	69	97	125	154
60	1.00	50	62	87	113	138
66	1.00	45	56	79	102	126
72	1.00	41	52	73	94	115
78	1.00	38	48	67	87	106
84	1.00	35	44	62	80	99
90	1.00	33	41	58	75	92
96	1.00		39	54	70	86
102	1.06		36	51	66	81
108	1.13			48	62	76
114	1.19			46	59	72
120	1.25			43	56	69
126	1.31				53	65
132	1.38				51	62
138	1.44				49	60
144	1.50					57

Corrugated Steel Pipe (CSP)
AASHTO LRFD (HL-93 Live Load)
Minimum and Maximum Cover Depths (ft)

CSP 5 x 1 in

Dia.	Min	Maximum Cover				
(in)	Cover	16ga	14ga	12ga	10ga	8ga
48	1.00	55	69	97	126	154
54	1.00	49	62	87	112	136
60	1.00	44	55	78	100	123
66	1.00	40	50	71	91	112
72	1.00	37	46	65	84	102
78	1.00	34	42	60	77	94
84	1.00	31	39	55	71	88
90	1.00	29	37	52	67	82
96	1.00		34	48	62	77
102	1.06		32	45	59	72
108	1.13			43	55	68
114	1.19			41	52	64
120	1.25			39	50	61
126	1.31				47	58
132	1.38				45	55
138	1.44				43	53
144	1.50					51

NOTES:

1. Tables are based on the methods set forth in Section 12 of the AASHTO LRFD Bridge Design Specifications.
2. Minimum cover is governed by general equations in all cases (span/8 ≥ 12 in, except for spiral rib pipe where span/4 ≥ 12 in).
3. Minimum cover is measured from the top of pipe to the bottom of flexible pavement or the top of rigid pavement.
4. Cover depths shown are based on installations in accordance with Section 26 of the AASHTO LRFD Bridge Construction Specifications.
5. Corrugated steel pipe manufacturing standards are per AASHTO M36 for metallic coatings or AASHTO M245 for polymer coatings.
6. Spiral rib pipe fill heights in parentheses require higher installation standards due to the higher flexibility of the span-gauge combination. This may be accommodated using trench construction methods with crushed rock backfill materials.
7. Aluminized and polymer coated steel is available in gauges 16 through 10. Consult manufacturer before specifying polymer coated steel in gauges 12 and 10.

Corrugated Aluminum Alloy Pipe (CAAP)
AASHTO LRFD (HL-93 Live Load)
Minimum and Maximum Cover Depths (ft)

CAAP 2⅔ x ½ in

Dia.	Min	Maximum Cover				
(in)	Cover	16ga	14ga	12ga	10ga	8ga
12	1.00	132				
15	1.00	105	132			
18	1.00	88	110	154		
21	1.00	75	94	132		
24	1.00	66	82	115		
30	1.00		66	92		
36	1.00		55	77	99	121
42	1.00			66	85	103
48	1.00			57	74	90
54	1.00			51	66	80
60	1.00				55	68
66	1.00					56
72	1.00					45

Spiral Rib Aluminum Alloy Pipe (SRAAP)
AASHTO LRFD (HL-93 Live Load)
Minimum and Maximum Cover Depths (ft)

SRAAP ¾ x ¾ x 7½ in

Dia.	Min	Maximum Cover			
(in)	Cover	16ga	14ga	12ga	10ga
15	1.00	56	77		
18	1.00	47	64		
21	1.00	40	55		
24	1.00	35	48	78	
30	1.25	28	38	62	
36	1.50	(23)	32	51	
42	1.75		(27)	44	
48	2.00			38	55
54	2.00			34	48
60	2.00			(30)	43
66	2.00				39
72	2.18				(36)

Corrugated Aluminum Alloy Pipe (CAAP)
AASHTO LRFD (HL-93 Live Load)
Minimum and Maximum Cover Depths (ft)

CAAP 3 x 1 in

Dia.	Min	Maximum Cover				
(in)	Cover	16ga	14ga	12ga	10ga	8ga
30	1.00	60	76			
36	1.00	50	63	88		
42	1.00	43	54	76		
48	1.00	37	47	66	89	105
54	1.00	33	42	59	79	93
60	1.00	30	38	53	71	83
66	1.00	27	34	48	64	76
72	1.00	24	31	44	59	69
78	1.00		29	40	54	64
84	1.00			37	50	59
90	1.00			35	47	55
96	1.00			33	44	52
102	1.06				41	49
108	1.13				39	46
114	1.19					42
120	1.25					38

NOTES:

1. Tables are based on the methods set forth in Section 12 of the AASHTO LRFD Bridge Design Specifications.
2. Minimum cover is governed by general equations in all cases (span/8 ≥ 12 in, except for spiral rib pipe where span/2 ≥ 12 in for spans ≤ 48in and span/2.75 ≥ 24 in for spans > 48 in).
3. Minimum cover is measured from the top of pipe to the bottom of flexible pavement or the top of rigid pavement.
4. Cover depths shown are based on installations in accordance with Section 26 of the AASHTO LRFD Bridge Construction Specifications.
5. Corrugated aluminum pipe manufacturing standards are per AASHTO M196.
6. Spiral rib pipe fill heights in parentheses require higher installation standards due to the higher flexibility of the span-gauge combination. This may be accommodated using trench construction methods with crushed rock backfill materials.

Corrugated Steel Pipe-Arch
AISI ASD (H20 and H25 Live Loads)
Minimum and Maximum Cover Depths

Pipe-Arch 2⅔ x ½ in

Equivalent Diameter (in)	Design Span x Rise (in)	Minimum Steel Gauge	Minimum Cover (ft)	Maximum Cover (ft)
15	17 x 13	16	1.0	15
18	21 x 15	16	1.0	15
21	24 x 18	16	1.0	16
24	28 x 20	16	1.0	15
30	35 x 24	16	1.0	15
36	42 x 29	16	1.0	15
42	49 x 33	16	1.0	15
48	57 x 38	16	1.0	15
54	64 x 43	12	1.0	15
60	71 x 47	12	1.0	15
66	77 x 52	8	1.0	15
72	83 x 57	8	1.0	15

Spiral Rib Steel Pipe-Arch
AISI ASD (H20 and H25 Live Loads)
Minimum and Maximum Cover Depths

Pipe-Arch ¾ x ¾ x 7½ in

Equivalent Diameter (in)	Design Span x Rise (in)	Minimum Steel Gauge	Minimum Cover (ft)	Maximum Cover (ft)
18	20 x 16	16	1.0	19
21	23 x 19	16	1.0	18
24	27 x 21	16	1.0	16
30	33 x 26	14	1.0	16
36	40 x 31	14	1.0	16
42	46 x 36	12	1.0	16
48	53 x 41	12	1.1	16
54	60 x 46	12	1.3	25
60	66 x 51	12	1.4	24
66	73 x 55	12	1.5	24
72	81 x 59	10	1.7	20
78	87 x 63	10	1.8	20
84	95 x 67	10	2.0	20

Corrugated Steel Pipe-Arch
AISI ASD (H20 and H25 Live Loads)
Minimum and Maximum Cover Depths

Pipe-Arch 3 x 1 or 5 x 1 in

Equivalent Diameter (in)	Nominal Span x Rise (in)	Design Span x Rise (in)	3 x 1 in Min Gauge Steel	5 x 1 in Min Gauge Steel	Minimum Cover (ft)	Maximum Cover (ft)
48	53 x 41	53 x 41	14	12	1.0	14
54	60 x 46	58½ x 48½	14	12	1.0	25
60	66 x 51	65 x 54	14	12	1.0	24
66	73 x 55	72½ x 58¼	14	12	1.0	24
72	81 x 59	79 x 62½	14	12	1.0	20
78	87 x 63	86½ x 67¼	14	12	1.0	20
84	95 x 67	93½ x 71¾	14	12	1.0	20
90	103 x 71	101½ x 76	14	12	1.1	20
96	112 x 75	108½ x 80½	14	12	1.1	19
102	117 x 79	116½ x 84¾	14	12	1.2	19
108	128 x 83	123½ x 89¼	12	12	1.3	19
114	137 x 87	131 x 93¾	12	12	1.4	19
120	142 x 91	138½ x 98	12	12	1.4	19

NOTES:

1. Tables are based on the methods set forth by the American Iron and Steel Institute (AISI) and is an Allowable Stress Design (ASD).
2. Minimum cover is governed by general equations in all cases (span/8 ≥ 12 in, except for spiral rib pipe which is span/4 ≥ 12 in), as opposed to the 4ksf corner bearing pressure limit.
3. Minimum cover is measured from the top of pipe to the bottom of flexible pavement or the top of rigid pavement.
4. Maximum cover is limited to heights that produce corner bearing pressures of 4ksf or less.
5. Allowable cover depths shown are based on an installation in accordance with ASTM A798.
6. Minimum cover shall be applied to the "Design" rise (3 x 1 and 5 x 1 in shapes have a nominal rise and a design rise).
7. Corrugated steel pipe manufacturing standards are per ASTM A760 for metallic coatings or ASTM A762 for polymer coatings.
8. Provisions for three larger steel pipe-arches are made in the ASTM standards for the spiral rib corrugation but require special design: 103 x 71 in (90-in eq), 112 x 75 in (96-in eq), and 117 x 79 in (102-in eq).

Corrugated Steel & Aluminum Alloy Pipe-Arch
AASHTO LRFD (HL-93 Live Load)
Minimum and Maximum Cover Depths

Pipe-Arch 2⅔ x ½ in

Equivalent Diameter (in)	Design Span x Rise (in)	Minimum Gauge Steel/Alum	Minimum Cover (ft)	Maximum Cover (ft)
15	17 x 13	16/16	1.5	19
18	21 x 15	16/16	1.6	18
21	24 x 18	16/16	1.6	18
24	28 x 20	16/14	1.6	17
30	35 x 24	16/14	1.4	17
36	42 x 29	16/12	1.3	16
42	49 x 33	14/12	1.3	16
48	57 x 38	12/10	1.4	15
54	64 x 43	12/10	1.4	15
60	71 x 47	10/8	1.3	15
66	77 x 52	**8/SD**	1.3	15
72	83 x 57	**8/SD**	1.3	16

Spiral Rib Steel & Aluminum Alloy Pipe-Arch
AASHTO LRFD (HL-93 Live Load)
Minimum and Maximum Cover Depths

Pipe-Arch ¾ x ¾ x 7½ in

Equivalent Diameter (in)	Design Span x Rise (in)	Minimum Gauge Steel/Alum	Minimum Cover (ft) Steel/Alum	Maximum Cover (ft)
18	20 x 16	16/16	1.2/1.2	23
21	23 x 19	16/16	1.4/1.4	21
24	27 x 21	16/14	1.5/1.5	19
30	33 x 26	14/14	1.1/1.4	19
36	40 x 31	14/12	1.2/1.7	18
42	46 x 36	12/12	1.2/1.9	18
48	53 x 41	12/10	1.2/2.0	17
54	60 x 46	12/10	1.3/2.0	25
60	66 x 51	12/10	1.4/2.0	25
66	73 x 55	**12/SD**	**1.5/SD**	24
72	81 x 59	**10/SD**	**1.7/SD**	21
78	87 x 63	**10/NA**	**1.8/NA**	21
84	95 x 67	**10/NA**	**2.0/NA**	20

Corrugated Steel & Aluminum Alloy Pipe-Arch
AASHTO LRFD (HL-93 Live Load)
Minimum and Maximum Cover Depths

Pipe-Arch 3 x 1 or 5 x 1 in

Equivalent Diameter (in)	Nominal Span x Rise (in)	Design Span x Rise (in)	3 x 1 in Min Gauge Steel/Alum	5 x 1 in Min Gauge Steel	Minimum Cover (ft)	Maximum Cover (ft)
48	53 x 41	53 x 41	14/14	12	1.0	18
54	60 x 46	58½ x 48½	14/14	12	1.0	26
60	66 x 51	65 x 54	14/14	12	1.0	26
66	73 x 55	72½ x 58¼	14/14	12	1.0	26
72	81 x 59	79 x 62½	14/12	12	1.0	22
78	87 x 63	86½ x 67¼	14/12	12	1.0	21
84	95 x 67	93½ x 71¾	14/12	12	1.0	20
90	103 x 71	101½ x 76	14/10	12	1.1	21
96	112 x 75	108½ x 80½	12/8	12	1.1	21
102	117 x 79	116½ x 84¾	12/8	12	1.2	20
108	128 x 83	123½ x 89¼	**10/SD**	10	1.3	20
114	137 x 87	131 x 93¾	**10/SD**	10	1.4	20
120	142 x 91	138½ x 98	**10/SD**	10	1.4	20

NOTES:
(see also Pipe-Arch Design Supplemental)

1. Cover depth limitations for pipe-arch shapes are largely governed by the bearing capacity of the embedment and in situ materials around the sharp corners, and therefore the steel and aluminum tables have been combined. Minor differences reflect either flexibility and arching limitations (minimum gauge) or different AASHTO minimum cover equations (spiral rib pipe).
2. Information not shown for aluminum shapes in one or more of the larger sizes indicates either a special design is required (SD) or the shape is not available (NA).
3. Allowable cover depths shown are based on an installation in accordance with Section 26 of the AASHTO LRFD Bridge Construction Specifications using the stiffer embedment materials (gravel and gravel-sand mixtures).
4. Minimum cover is measured from the top of pipe to the bottom of flexible pavement or the top of rigid pavement.
5. Minimum cover shall be applied to the "Design" rise (3 x 1 and 5 x 1 in shapes have a nominal rise and a design rise).
6. Corrugated steel pipe manufacturing standards are per AASHTO M36 for metallic coatings or AASHTO M245 for polymer coatings.
7. Corrugated aluminum pipe manufacturing standards are per AASHTO M196.
8. Provisions for three larger steel pipe-arches are made in the ASTM and AASHTO standards for the spiral rib corrugation but require special design: 103 x 71 in (90-in eq), 112 x 75 in (96-in eq), and 117 x 79 in (102-in eq).

LANE

PIPE-ARCH DESIGN

In similar fashion as round shapes properly embedded, pipe-arches transfer the overlying pressure to the surrounding backfill and enable the resultant pipe forces to flow freely around the periphery to mobilize the full compressive and buckling strengths of the corrugation profile – a phenomenon more technically known as ring compression theory.

Unlike round shapes, however, pipe-arches generate radial corner pressures greater than the applied pressure at the top of the structure (Figure 4). The embedment material directly adjacent to the small radius corners must therefore provide enough bearing capacity to sustain these pressures.

To better enable the haunch zone to resist these higher pressures it is necessary that the haunch fill be more densely compacted with select backfill materials (Figure 5). The AREMA Manual for Railway Engineering publishes bearing capacity values for the more select materials (Table 1).

TABLE 1. ALLOWABLE BEARING PRESSURES FOR DESIGN (KSF)	
Compacted gravel or sand and gravel	12.0
Loose gravel or compacted coarse sand	8.0
Loose coarse sand or gravel and sand	6.0

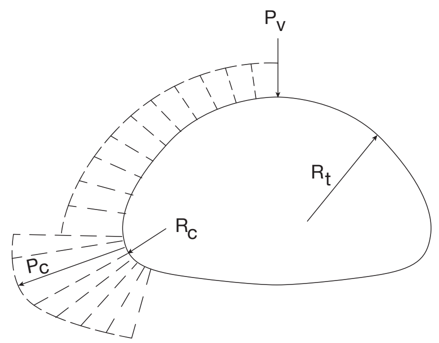


Figure 4. Overlying pressure (P_V) acting over the top radius (R_T) results in a greater pressure (P_C) radiating outward from the small radius corner (R_C).

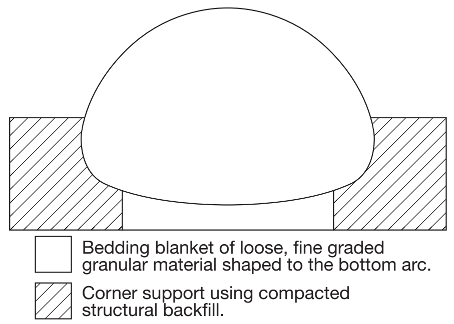


Figure 5.

CORNER PRESSURE AT A DISTANCE FROM THE STRUCTURE

A good design approach is to limit the radial pressure at the pipe-arch corner (P_C) to a value consistent with the embedment material and its relative compaction before allowing that pressure to dissipate over a certain distance (D_1) to a value more consistent with the native or embankment materials (P_1).

As shown in Figure 6, the bedding blanket is a relatively thin layer compared to the sidefill width (S_W) making D_1 the maximum distance over which P_C can dissipate.

Based on AASHTO LRFD BDS Eq. 12.8.5.3-1, D_1 is represented by the expression $(P_C R_C/P_1) - R_C$, where $P_C R_C$ is the total dead and live load thrust (T) in the structure.

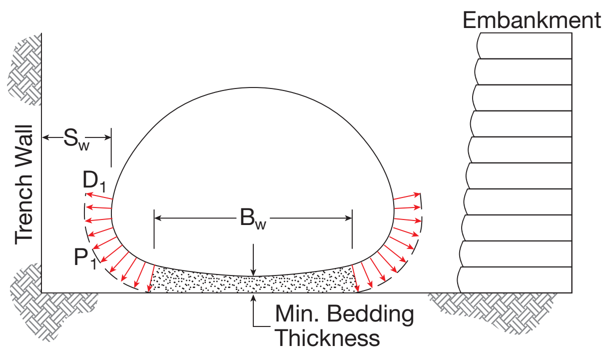
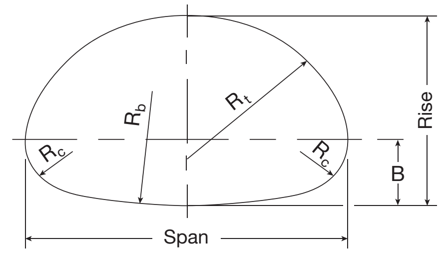


Figure 6. Installation detail shows the maximum distance (D_1) over which P_C can dissipate to the allowable bearing capacity of the native or embankment materials.

DESIGN NOTES

1. Traditional methods of developing height of cover tables simply limited P_C to the allowable bearing pressure of the native or embankment materials, typically taken as 4 ksf, while the above method was reserved for special designs.
2. Since pipe-arch structures are typically used in shallow cover applications, this more precise method finds greater value in designing for minimum cover.
3. Minimum bedding thickness is taken as 2x's the corrugation depth.
4. Sidefill width (S_W) may be taken as the minimum spacing between pipes per Table C12.6.7-1 of the AASHTO LRFD BDS, which varies with the span as follows: 12 in for spans up to 36 in, span/3 for spans between 36 and 108 in, and 36 in for spans larger than 108 in (see also C12.6.6.1 for an alternative derivation).
5. The maximum bedding width (B_W) is the chord length of the bottom radius arc.

Tables apply to both CSP and CAAP. However, CAAP sizes have a more limited range. See the cover height tables for correlation.



PIPE-ARCH WITH 2⅔ X ½ IN CORRUGATIONS

Equivalent Diameter (in)	Design Span (in)	Design Rise (in)	Waterway Area (ft²)	B (in)	Rc (in)	Rt (in)	Rb (in)
15	17	13	1.1	4⅛	3½	8⅝	25⅝
18	21	15	1.6	4⅞	4⅛	10¾	33⅛
21	24	18	2.2	5⅝	4⅞	11⅞	34⅝
24	28	20	2.9	6½	5½	14	42¼
30	35	24	4.5	8⅛	6⅞	17⅞	55⅛
36	42	29	6.5	9¾	8¼	21½	66⅛
42	49	33	8.9	11⅜	9⅝	25⅛	77¼
48	57	38	11.6	13	11	28⅝	88¼
54	64	43	14.7	14⅝	12⅜	32¼	99¼
60	71	47	18.1	16¼	13¾	35¾	110¼
66	77	52	21.9	17⅞	15⅛	39⅜	121¼
72	83	57	26.0	19½	16½	43	132¼

PIPE-ARCH WITH 3 X 1 AND 5 X 1 IN CORRUGATIONS

Equivalent Diameter (in)	Nominal Span x Rise (in)	Design Span x Rise (in)	Waterway Area (ft²)	B (in)	Rc (in)	Rt (in)	Rb (in)
48	53 x 41	53 x 41	11.7	15¼	10³⁄₁₆	28¹⁄₁₆	73⁷⁄₁₆
54	60 x 46	58½ x 48½	15.6	20½	18¾	29⅜	51⅛
60	66 x 51	65 x 54	19.3	22¾	20¾	32⅝	56¼
66	73 x 55	72½ x 58¼	23.2	25⅛	22⅞	36¾	63¾
72	81 x 59	79 x 62½	27.4	23¾	20⅞	39½	82⅝
78	87 x 63	86½ x 67¼	32.1	25¾	22⅝	43⅜	92¼
84	95 x 67	93½ x 71¾	37.0	27¾	24⅜	47	100¼
90	103 x 71	101½ x 76	42.4	29¾	26⅛	51¼	111⅝
96	112 x 75	108½ x 80½	48.0	31⅝	27¾	54⅞	120¼
102	117 x 79	116½ x 84¾	54.2	33⅝	29½	59⅜	131¾
108	128 x 83	123½ x 89¼	60.5	35⅝	31¼	63¼	139¾
114	137 x 87	131 x 93¾	67.4	37⅝	33	67⅜	149½
120	142 x 91	138½ x 98	74.5	39½	34¾	71⅝	162⅜

SPIRAL RIB PIPE-ARCH WITH ¾ X ¾ X 7½ IN CORRUGATIONS

Equivalent Diameter (in)	Design Span (in)	Design Rise (in)	Waterway Area (ft²)	B (in)	Rc (in)	Rt (in)	Rb (in)
18	20	16	1.7	5⅛	5	10¼	27½
21	23	19	2.3	5⅞	5⅜	11⅝	34¼
24	27	21	3.0	6¾	5¾	13½	40⅞
30	33	26	4.7	8¾	7⅛	16⅝	51⅜
36	40	31	6.7	10⅜	8⅜	20¼	62½
42	46	36	9.2	12⅜	9¾	23¼	73
48	53	41	12.1	14	11⅛	26⅝	83½
54	60	46	15.6	20½	18¾	29⅜	51⅛
60	66	51	19.3	22¾	20¾	32⅝	56¼
66	73	55	23.2	25⅛	22⅞	36¾	63¾
72	81	59	27.4	23¾	20⅞	39½	82⅝
78	87	63	32.1	25¾	22⅝	43⅜	92¼
84	95	67	37.0	27¾	24⅜	47	100¼
90	103	71	42.4	29¾	26⅛	51¼	111⅝
96	112	75	48.0	31⅝	27¾	54⅞	120¼
102	117	79	54.2	33⅝	29½	59⅜	131¾

ROUND PIPE

Dia. (in)	A (ft²)	R (ft)	Manning's, n 1½ x ¼ in	2⅔ x ½ in	3 x 1 in	5 x 1 in	¾ x ¾ x 7½ in
8	0.35	0.167	0.012				
10	0.55	0.208	0.014				
12	0.79	0.250		0.011			
15	1.23	0.313		0.012			0.012
18	1.77	0.375		0.013			0.012
21	2.41	0.438		0.014			0.012
24	3.14	0.500		0.015			0.012
30	4.91	0.625		0.017			0.012
36	7.07	0.750		0.018	0.022		0.012
42	9.62	0.875		0.019	0.022		0.012
48	12.57	1.000		0.020	0.023	0.022	0.012
54	15.90	1.125		0.021	0.023	0.022	0.012
60	19.63	1.250		0.021	0.024	0.023	0.012
66	23.76	1.375		0.021	0.025	0.024	0.012
72	28.27	1.500		0.021	0.026	0.024	0.012
78	33.18	1.625		0.021	0.027	0.025	0.012
84	38.48	1.750		0.021	0.027	0.025	0.012
90	44.18	1.875			0.027	0.025	0.012
96	50.27	2.000			0.027	0.025	0.012
102	56.75	2.125			0.027	0.025	0.012
108	63.62	2.250			0.027	0.025	
114	70.88	2.375			0.027	0.025	
120	78.54	2.500			0.027	0.025	
126	86.59	2.625			0.027	0.025	
132	95.03	2.750			0.027	0.025	
138	103.87	2.875			0.027	0.025	
144	113.10	3.000			0.027	0.025	

Manning's Equation, Q (cfs) = $1.486\,(A\,R^{2/3}\,S^{1/2})/n$

A = Cross-Sectional Area (ft²)
R = Hydraulic Radius (ft)
A and R values for full flow conditions

n = Manning's Roughness Coefficient
S = Slope (ft/ft)

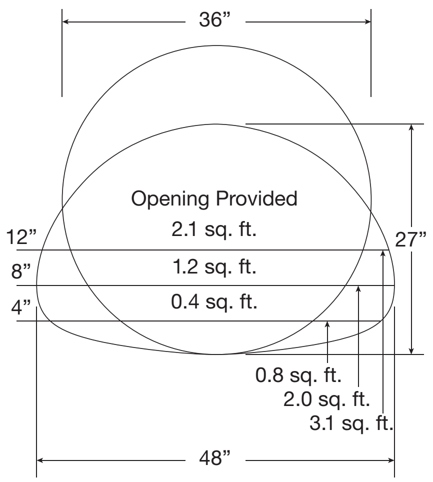


Figure 7. Comparison of Waterway Cross- Sectional Areas at Equal Depths of Flow in Round and Pipe-Arch Shapes.

See any of the general industry references on page 5 for further hydraulic information, including Manning's roughness coefficients, partial flow values, inlet and outlet nomographs, etc.

Note: The pipe-arch handles a larger volume at the lower levels of flow.

PIPE-ARCH

Rise x Span (in)	A (ft²)	R (ft)	Manning's n 2⅔ x ½ in
17 x 13	1.1	0.280	0.013
21 x 15	1.6	0.340	0.014
24 x 18	2.2	0.400	0.015
28 x 20	2.9	0.462	0.016
35 x 24	4.5	0.573	0.018
42 x 29	6.5	0.690	0.019
49 x 33	8.9	0.810	0.020
57 x 38	11.6	0.924	0.021
64 x 43	14.7	1.040	0.022
71 x 47	18.1	1.153	0.022
77 x 52	21.9	1.268	0.022
83 x 57	26.0	1.380	0.022

PIPE-ARCH

Rise x Span (in)	A (ft²)	R (ft)	Manning's n 3 x 1 in	5 x 1 in
53 x 41	11.7	0.931	0.024	0.023
60 x 46	15.6	1.104	0.024	0.023
66 x 51	19.3	1.230	0.025	0.024
73 x 55	23.2	1.343	0.026	0.025
81 x 59	27.4	1.454	0.027	0.025
87 x 63	32.1	1.573	0.028	0.026
95 x 67	37.0	1.683	0.028	0.026
103 x 71	42.4	1.800	0.028	0.026
112 x 75	48.0	1.911	0.028	0.026
117 x 79	54.2	2.031	0.028	0.026
128 x 83	60.5	2.141	0.028	0.026
137 x 87	67.4	2.259	0.028	0.026
142 x 91	74.5	2.373	0.028	0.026

PIPE-ARCH

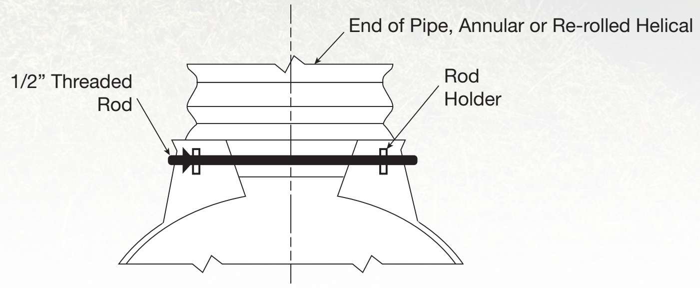
Rise x Span (in)	A (ft²)	R (ft)	Manning's n ¾ x ¾ x 7½ in
20 x 16	1.7	0.361	0.012
23 x 19	2.3	0.418	0.012
27 x 21	3.0	0.477	0.012
33 x 26	4.7	0.598	0.012
40 x 31	6.7	0.711	0.012
46 x 36	9.2	0.837	0.012
53 x 41	12.1	0.963	0.012
60 x 46	15.6	1.103	0.012
66 x 51	19.3	1.229	0.012
73 x 55	23.2	1.343	0.012
81 x 59	27.4	1.454	0.012
87 x 63	32.1	1.572	0.012
95 x 67	37.0	1.682	0.012
103 x 71	42.4	1.800	0.012
112 x 75	48.0	1.910	0.012
117 x 79	54.2	2.030	0.012

End treatments are essential elements in protecting both the road culvert and embankment from scour and undermining. Additionally, they retain fill slope, dress-up the appearance of the inlet and outlet and provide a hydraulic efficiency that can be used for capacity analyses.

End treatments vary considerably depending on the fill slope to be retained. For the higher embankments where a culvert cannot be extended into the more gradual slopes a headwall may be required. Where the slope permits the use of more subtle treatments rip-rap armoring details may be employed. In any event the inlet and outlet should have a toe wall of sufficient depth to prevent flows from scouring or undermining the culvert ends.

Metal flared end sections provide an economical solution with hydraulic efficiencies when a full headwall is not necessary. The ends are beveled and flared and include a toe plate to eliminate the construction of a concrete toe wall.

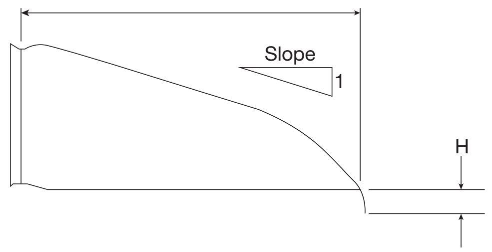
Flared end sections are made from either galvanized steel, aluminized steel, or aluminum alloy for both round and pipe-arch shapes. The end sections are easily joined to the culvert ends using standard connecting hardware to form a continuous, convenient one-piece structure. The integrated toe plate is punched to accept an optional 8-in toe plate extension.



SLOPE

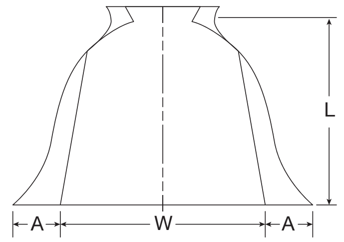
The beveled profile blends into the embankment and provides soil retention characteristics. The slope of the embankment does not need to match that of the end section, as the fill can be gradually transitioned to meet the top edge of the end section. As shown on the following page, the slope varies from 2.5:1 to 1.5:1 over the size range.

As mentioned above, the integrated toe plate with standard depth H (see detail on the following page) is punched to accept an optional 8-in toe plate extension.



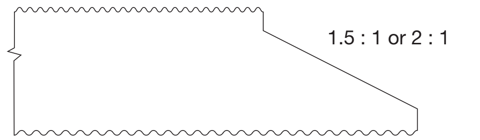
FLARE

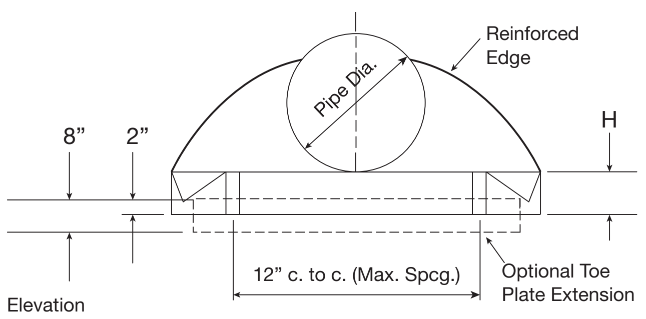
The width and flare of the end section creates the funneled shape that minimizes hydraulic losses. The entrance loss coefficient for an end section conforming to fill slope is 0.5 per the NCSPA Design Manual. The tables on the following page list dimensions corresponding to the diagram at right.

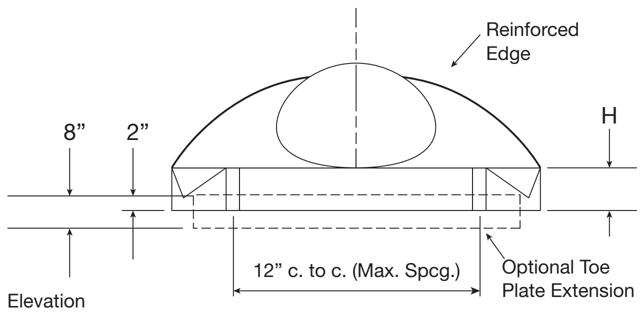


STEP-BEVELED END

As an alternate to the flared end section the manufacturer can miter the pipe ends to form a beveled profile. A two-step bevel is typically fabricated to retain stiffness at the crown and added stiffness at the invert. Alternatively, the end may be a full bevel or a one-step bevel (top or bottom). The bevel slope is consistent with that used for flared end sections. With the addition of a concrete toe wall, the beveled end is usually secured by casting a concrete collar around the entire opening.







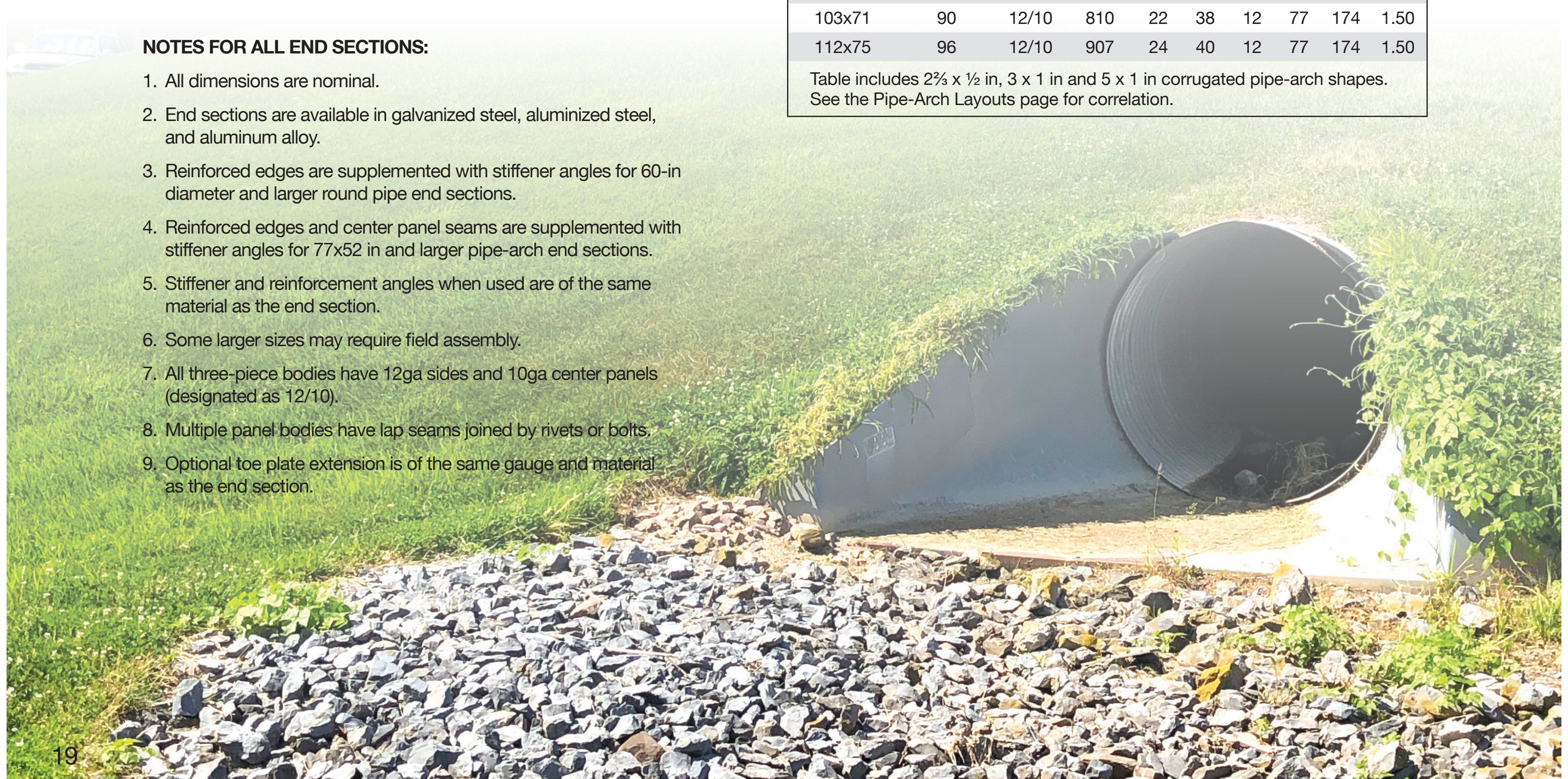
END SECTION PROPERTIES FOR ROUND PIPE

Dia. (in)	Gauge	Weight (lbs)	A (in)	B (in)	H (in)	L (in)	W (in)	Slope S:1
12	16	27	6	6	6	21	24	2.50
15	16	37	7	8	6	26	30	2.50
18	16	49	8	10	6	31	36	2.50
21	16	55	9	12	6	36	42	2.50
24	16	74	10	13	6	41	48	2.50
30	16	128	12	16	8	51	60	2.50
36	16	184	14	19	9	60	72	2.50
42	14	320	16	22	11	69	84	2.50
48	14	375	18	27	12	78	90	2.25
54	12	440	18	30	12	84	102	2.25
60	12/10	610	18	33	12	87	114	2.00
66	12/10	697	18	36	12	87	120	2.00
72	12/10	720	18	39	12	87	126	2.00
78	12/10	810	18	42	12	87	132	1.50
84	12/10	850	18	45	12	87	138	1.50
90	12/10	910	24	37	12	87	144	1.50
96	12/10	985	25	35	12	87	150	1.50

END SECTION PROPERTIES FOR PIPE-ARCH

Span x Rise (in)	Equiv. Dia. (in)	Gauge	Weight (lbs)	A (in)	B (in)	H (in)	L (in)	W (in)	Slope S:1
17x13	15	16	28	7	9	6	19	30	2.50
21x15	18	16	36	7	10	6	23	36	2.50
24x18	21	16	43	8	12	6	28	42	2.50
28x20	24	16	55	9	14	6	32	48	2.50
35x24	30	14	95	10	16	8	39	60	2.50
42x29	36	14	140	12	18	9	46	75	2.50
49x33	42	12	233	13	21	9	53	85	2.50
57x38	48	12	315	18	26	12	63	90	2.50
53x41	48	12	330	18	25	12	63	90	2.50
64x43	54	12	357	18	30	12	70	102	2.00
60x46	54	12	375	18	34	12	70	102	2.00
71x47	60	12/10	480	18	33	12	77	114	1.50
66x51	60	12/10	487	18	33	12	77	116	1.50
77x52	66	12/10	616	18	36	12	77	126	1.50
73x55	66	12/10	625	18	36	12	77	126	1.50
83x57	72	12/10	670	18	39	12	77	138	1.50
81x59	72	12/10	680	18	39	12	77	138	1.50
87x63	78	12/10	729	22	38	12	77	148	1.50
95x67	84	12/10	755	22	34	12	77	162	1.50
103x71	90	12/10	810	22	38	12	77	174	1.50
112x75	96	12/10	907	24	40	12	77	174	1.50

Table includes 2⅔ x ½ in, 3 x 1 in and 5 x 1 in corrugated pipe-arch shapes. See the Pipe-Arch Layouts page for correlation.



NOTES FOR ALL END SECTIONS:

1. All dimensions are nominal.
2. End sections are available in galvanized steel, aluminized steel, and aluminum alloy.
3. Reinforced edges are supplemented with stiffener angles for 60-in diameter and larger round pipe end sections.
4. Reinforced edges and center panel seams are supplemented with stiffener angles for 77x52 in and larger pipe-arch end sections.
5. Stiffener and reinforcement angles when used are of the same material as the end section.
6. Some larger sizes may require field assembly.
7. All three-piece bodies have 12ga sides and 10ga center panels (designated as 12/10).
8. Multiple panel bodies have lap seams joined by rivets or bolts.
9. Optional toe plate extension is of the same gauge and material as the end section.

Corrugated Steel Pipe (Galvanized and Aluminized)
Approximate Handling Weights by Gauge (lbs/ft)

Corrugation	Dia. (in)	18 Ga	16 Ga	14 Ga	12 Ga	10 Ga	8 Ga
1½ x ¼ in	6	4	5				
	8	5	6				
	10	7	8				
2⅔ x ½ in	12	8	10	12	16		
	15	10	12	15	20		
	18	12	15	18	24		
	21	14	17	21	29		
	24	15	19	24	33	41	
	27		22	27	37	47	
	30		24	30	41	52	
	36		29	36	49	62	75
	42		34	42	57	72	87
	48		38	48	65	82	100
	54			54	73	92	112
	60				81	103	124
	66				89	113	137
	72					123	149
	78						161
5 x 1 in	48		39	48	65	83	100
	54		44	54	73	93	114
3 x 1 in	60		48	59	81	104	126
Increase these	66		53	65	89	114	138
values by 12%.	72		58	71	97	123	150
	78		62	77	105	134	163
	84		68	83	113	144	175
	90		72	88	121	154	187
	96		77	94	129	165	201
	102		82	100	136	174	212
	108			106	145	186	225
	114			112	153	195	238
	120				161	206	250
	126				172	217	263
	132				180	228	276
	138				187	238	289
	144					248	303
¾ x ¾ x 7½ in	15		13	16			
	18		15	19	26		
	21		18	22	30		
	24		20	25	34		
	27		22	27	38		
	30		25	30	42		
	33		27	33	46		
	36		30	36	50		
	42		34	42	58		
	48		39	48	66	83	
	54		44	54	74	94	
	60		49	60	82	104	
	66			66	90	114	
	72			72	99	124	
	78			78	107	135	
	84				115	145	
	90				123	155	
	96				131	165	
	102				139	176	
	108					186	
	114					196	
	120					206	

Corrugated Aluminum Alloy Pipe
Approximate Handling Weights by Gauge (lbs/ft)

Corrugation	Dia. (in)	16 Ga	14 Ga	12 Ga	10 Ga	8 Ga
2⅔ x ½ in	12	3.2	4.0	5.5		
	15	3.9	4.9	6.8		
	18	4.7	5.9	8.1		
	21	5.4	6.8	9.4		
	24	6.2	7.8	10.7	13.8	
	27	7.0	8.7	12.1	15.4	
	30	7.8	9.6	13.4	17.1	
	36		11.5	16.0	20.5	
	42			18.6	23.8	
	48			21.2	27.2	32.7
	54			23.8	30.5	36.7
	60				33.9	40.8
	66				37.2	44.8
	72					48.8
	78					52.9
	84					56.9
3 x 1 in	30	8.9	11.2	15.5	19.9	
	36	10.7	13.4	18.5	23.7	
	42	12.4	15.5	21.5	27.5	
	48	14.1	17.7	24.5	31.4	37.8
	54	15.8	19.9	27.5	35.2	42.4
	60	17.6	22.0	30.5	39.0	47.0
	66	19.3	24.2	33.5	42.9	51.7
	72		26.3	36.5	46.7	56.2
	78		28.5	39.5	50.5	60.8
	84		30.7	42.5	54.3	65.4
	90			45.4	58.2	70.0
	96			48.4	62.0	74.6
	102			51.4	65.8	79.3
	108			54.4	69.7	83.9
	114			57.4	73.5	88.5
	120			60.4	77.3	93.1
¾ x ¾ x 7½ in	15	4.1	5.1			
	18	4.9	6.1			
	21	5.7	7.1			
	24	6.5	8.0	11.0		
	27	7.2	9.0	12.5		
	30	8.0	10.0	13.9		
	33	8.8	10.9	15.2		
	36	9.6	11.9	16.6		
	42	11.3	14.0	19.3		
	48		15.9	22.0	28.2	
	54		17.9	24.7	31.7	
	60			27.4	35.1	
	66			30.1	38.6	
	72			32.9	42.0	
	78				45.4	
	84				48.6	

ENGINEER NOTES