CORRUGATED METAL PIPE

Technical Guide

Pipe Material

There are several ASTM specifications (AASHTO equivalents in parenthesis) used to identify the different CMP materials. Each specification makes provisions for the different corrugations and metal thicknesses available for CMP. Using height of cover tables the design engineer can relate the pipe size, corrugation and metal thickness to the varied structural and hydraulic parameters for the application. Each of the pipe specifications also makes use of an analogous classification system as follows:

Type I *Round Pipe with Exterior and Interior Corrugations*
Type IR *Round Pipe with a Smooth Interior (i.e. 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*

Once the pipe type, size, corrugation and metal thickness is determined the engineer can cite the desired ASTM standard to completely specify the piping material of choice:

Specify ASTM A760 (AASHTO M36) for a galvanized or aluminized coated steel pipe
Specify ASTM A849 (AASHTO M190) for asphalt-coated galvanized ASTM A760 pipe
Specify ASTM A762 (AASHTO M245) for a polymer-coated galvanized steel pipe
Specify ASTM B745 (AASHTO M196) for corrugated aluminum alloy pipe

Please refer to the *CMP Service Life Guide* for information and methods qualifying the selection of the appropriate corrugated steel pipe product.

Perforated Pipe

ASTM A760, A762 and B745 use a parallel classification system for perforated pipe depending on whether fully or partially (standard) perforated pipe is desired. Inherent in the classification systems are the size, spacing and placement of the perforations. Class 2 perforations provide a minimum open area of 3.3 in^2/ft^2 of pipe surface.

Specify Class 1 perforations for partially perforated pipe to be used for subsurface drainage
Specify Class 2 perforations for fully perforated pipe to be used for subsurface disposal

Joint Performance

Each of the above-mentioned pipe standards also provides corresponding joint performance criteria based upon the ability of the joining system to control leakage and/or material infiltration.

Soil Tight[1] - 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

[1]Soil tight joints are the default criteria for joint performance and will be used unless otherwise specified.

Pipe Joining Systems

Typical joining systems included in the pipe standards involve wrap-around type metal bands with appropriate connecting hardware. Depending on the pipe size the connecting bands may be a one or two-piece assembly. Since pipe corrugations are typically helical the pipe standards allow the pipe ends to be reformed into annular corrugations to better engage certain coupling bands. The annular corrugated ends are reformed with a 2⅔"x ½" corrugation. Some of the more common connecting bands include the following:

Corrugated Bands - annular corrugated bands for pipe with annular corrugated ends
Partially Corrugated Bands - flat bands with one annular corrugation along each edge
Dimple Bands - bands with dimple projections in annular rows
Flat Bands - bands with no corrugations or projections

Specify plain metal connecting bands (i.e. no fabric or gasket) for soil tight performance
Specify metal connecting bands with a fabric wrap for silt tight performance
Specify metal bands with an ASTM D1056 gasket for leak resistant and special design joints

CMP Installation

Corrugated metal pipe (CMP) is a flexible pipe material that derives structural rigidity from the strength and relative stiffness of the backfill envelope. The backfill-culvert interaction attained 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

CMP Structural Design

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 following standards are listed with the qualifying remark that the AASHTO method is, for all intents and purposes, used exclusively 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	Manual for Railway Engineering, Section 4.9, Design Criteria for Corrugated Metal Pipes
AASHTO	LRFD Bridge Design Specifications, Section 3, Loads and Load Factors
AASHTO	LRFD Bridge Design Specifications, Section 12, Buried Structures and Tunnel Liners

CMP Specification Example

Pipe shall be a 16 Gage 48-in Diameter Aluminized-Coated Corrugated Steel Pipe with a 2⅔"x ½" corrugation in accordance with ASTM A760 for Type I pipe. Pipe joints shall meet the soil tight performance criteria of ASTM A760 and installation shall conform to Section 26 of the AASHTO LRFD Bridge Construction Specifications.

Supplemental Publications

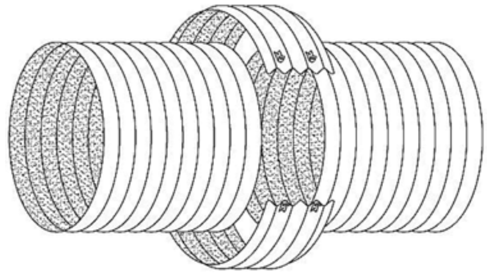
NCSPA Corrugated Steel Pipe Design Manual
NCSPA Service Life Selection Guide (www.ncspa.org)
AREMA Manual for Railway Engineering, Section 4, Culverts

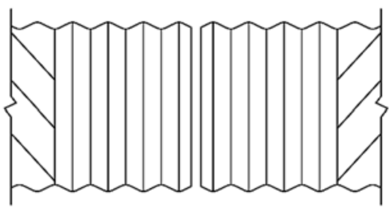
LANE

CMP CONNECTION GUIDE

Pipe Joining Systems

Standard pipe joining systems involve wrap-around style metal bands with connecting hardware. Connecting bands change from a one-piece to a two-piece assembly beginning with 60-in diameter CMP.

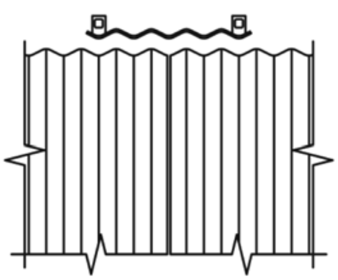




Pipe corrugations are helically formed but pipe standards allow the pipe ends to be reformed into annular corrugations to better engage certain coupling bands. Regardless of the actual pipe corrugation used the annular corrugated ends are reformed with a 2⅔"x ½" corrugation.

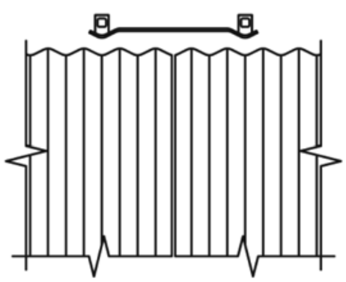
Corrugated Bands

Annular corrugated bands are available in nominal widths of 7, 12 and 24 inches.



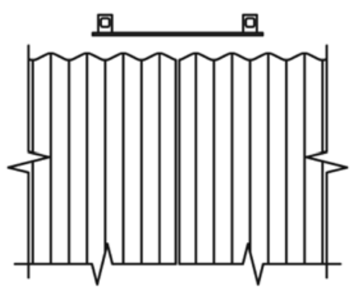
Partially Corrugated Bands

Flat bands with one annular corrugation along each edge are available in nominal widths of 7 and 12 inches.

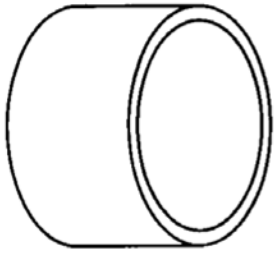


Flat Bands

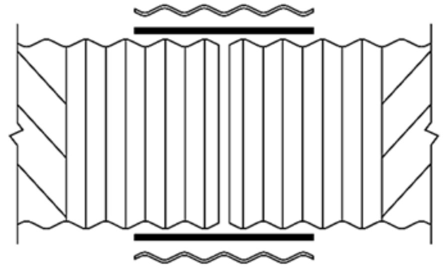
Bands with no corrugations or projections are available in nominal widths of 7, 12 and 24 inches.



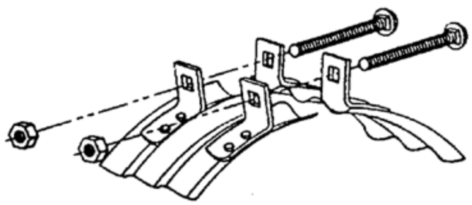
Dimple Bands (not shown) are bands with dimple projections in annular rows. Along with flat bands they may be used on pipe with helical ends (i.e. ends that have not been reformed with annular corrugations). Dimple bands are available for 12 through 54 inch CMP.



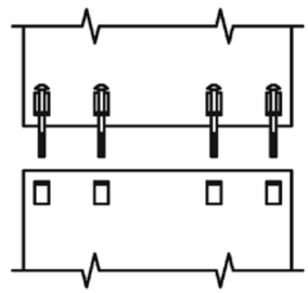
Sleeve Gaskets are typically a ⅜" thick neoprene material. The gaskets slide over the pipe ends and underlay the connecting band to enhance the leak resistance quality of the joint. Sleeve gaskets are available in 7, 12 and 24 inch widths.

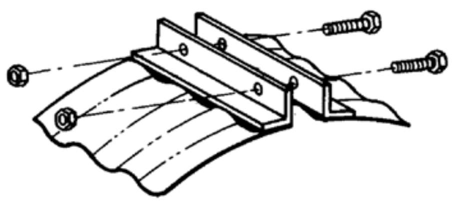


Connecting Band Hardware is available in the different configurations shown below:

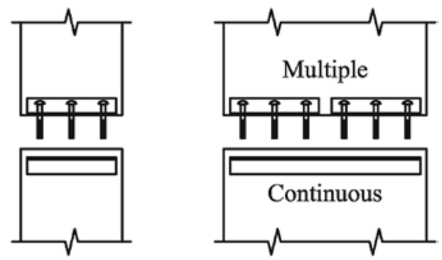


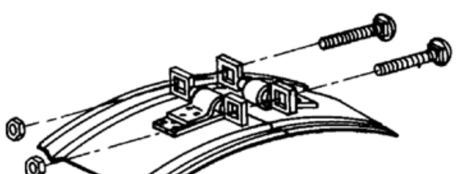
Standard Lug Connector
Assembly typically uses the dual lug configuration (left). The multiple lug configuration (right) is for 24-in wide bands.



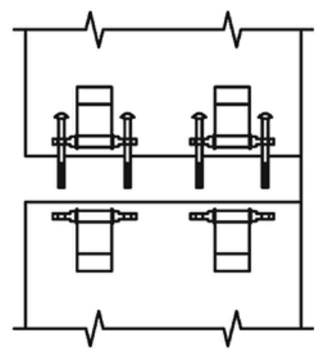


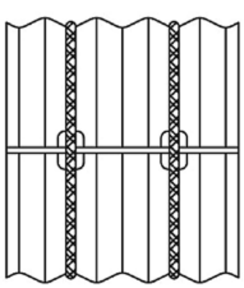
Angle Connector
Assembly uses the two-bolt configuration for 7-in bands (left), a three-bolt configuration for 12-in bands (right), and a six-bolt configuration for 24-in bands (far right).



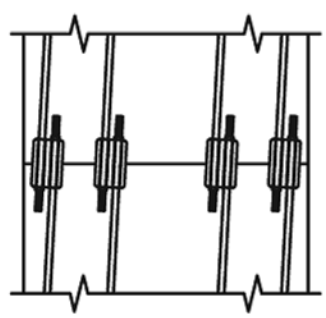


Bar and Strap Connector
Assembly typically consists of the single-strap configuration (left). The multi-strap configuration (right) can be used for 12-in wide bands when specified.





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



CMP PERFORATION GUIDE

PERFORATIONS PER ASTM A760, A762 AND B745

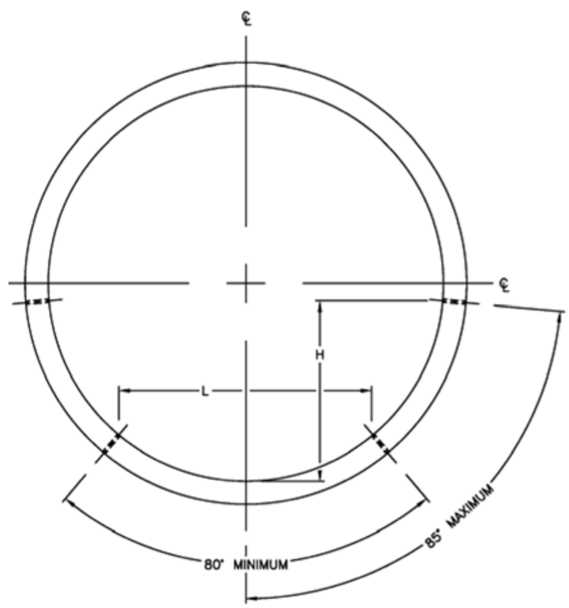
CLASS 1 PERFORATIONS (STANDARD OR PARTIALLY PERFORATED PIPE)

Class 1 perforations are for pipe intended to be used for subsurface drainage. As such, the pipe maintains an unperforated segment above the invert to serve as a flow channel. Unless specified otherwise, perforations shall conform to Class 1.

Perforations have nominal diameters of ⅜" 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 a lower unperforated segment corresponding to the flow line of the pipe.

Diameter, D (in)	Total No. of 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	6.9	9.6
18	6	8.3	11.5
21	6	9.7	13.4
24 and up	8	0.46D	0.64D



Corrugation	Inlet Area (using ⅜" perforations)
1½"x ¼"	3.53 in²/ft (6", 8", 10")
2⅔"x ½"	2.98 in²/ft (12"-21"), 3.98 in²/ft (24" and up)
3"x 1"	3.53 in²/ft (all available diameters)
5"x 1"	2.12 in²/ft (all available diameters)

CLASS 2 PERFORATIONS (FULLY PERFORATED PIPE)

Class 2 perforations are for pipe intended to be used for subsurface disposal of water, but may also be used for subsurface drainage. 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/ft. Thirty perforations (⅜" diameter) per square foot of surface area satisfies this requirement.

SERVICE LIFE OVERVIEW

Corrugated metal pipe (CMP) has been used for more than 100 years in storm sewer and culvert applications, available only as a galvanized coated steel pipe for the first half of this period. With the addition of a number of material options over the past 50 years CMP 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 CMP 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 LEVELS		
Level 1	None	No bed load
Level 2	Low	Minor sand/gravel bed loads ($v \leq 5$ ft/sec)
Level 3	Moderate	Sand/gravel bed loads ($5 < v \leq 15$ ft/sec)
Level 4	Severe	Heavy gravel/rock bed loads ($v > 15$ ft/sec)

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

Galvanized CSP provides a zinc coating weight of two ounces per square foot of surface area, resulting in a coating thickness of approximately 0.0017 inches (each side). Galvanized CSP has been in use longer than any other material and much has been learned about the service life of this product. 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) = $35.85[\text{Log}_{10} R - \text{Log}_{10}(2160 - 2490 \text{Log}_{10} \text{pH})]$
For pH > 7.3 Service Life (Years) = $3.82R^{0.41}$

The equations relate the service life for 16 gage based on a 25% loss of steel in the pipe invert. Longer service life may be achieved with the heavier gages. For gages 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 ($CaCO_3$ < 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 predict 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 (see following discussion).

ALUMINIZED TYPE 2 (ALT2) CSP

ALT2 is a pure aluminum coating with a weight of one ounce per square foot of surface area, which produces a coating thickness of approximately 0.0019 inches (each side). 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

The polymer coating is a laminate film applied to galvanized coils to a thickness of 10 mils (0.010 inches) 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 more than 40 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 related 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 the principal CSP coatings:

Service Life	Environment	FHWA Abrasion	CSP Coating
Minimum 100 years	$5.0 \le pH \le 9.0$ $R > 1500$	Level 3	Polymer Coated
		Level 2	Aluminized Type 2 (14ga)
Minimum 75 Years	$4.0 \le pH \le 9.0$ $R > 750$	Level 3	Polymer Coated
	$5.0 \le pH \le 9.0$ $R > 1500$	Level 2	Aluminized Type 2
Minimum 50 Years	$3.0 \le pH \le 12.0$ $R > 250$	Level 3	Polymer Coated
Average 50 Years	$6.0 \le pH \le 10.0$ $2000 < R < 10000$ Hard Water ($CaCO_3 > 50$ ppm)	Level 2	Galvanized Add-on service life of 10 yrs with asphalt coating.

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

ALUMINUM ALLOY CMP (MINIMUM 75-YR 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.

INSTALLATION OVERVIEW

In general and unless directed otherwise, pipe installation shall progress in an upstream fashion beginning at the outlet of the drainage improvement to be constructed. Joint gaps for circular pipe should not exceed one inch. Joint gaps for circular pipe between one and two inches require engineering discretion before a remediation determination is made. Larger joint gaps may be encountered with the arch shapes in the larger diameters due to the manufacturing process. Pipe joint gaps between two and four inches for the circular and arch shapes may be allowed with a properly installed 2-ft wide corrugated connecting band and gasket. Where leakage is not a concern the gasket requirement may be mitigated by the presence of a suitable geotextile wrap around the joint exterior.

Pipe shall be uniformly supported on grade throughout the alignment. Unsuitable or otherwise undesirable foundation material shall be replaced with structural backfill. Unless directed differently by the project engineer, undercut unsuitable material to a depth not less than six inches below the top of the foundation across the entire width of the trench.

Materials used for foundation improvements, bedding and structural backfill must have gradations compatible with adjacent soils to avoid migration. Where material gradations cannot be properly controlled, adjacent materials must be separated with a suitable geotextile.

BEDDING AND STRUCTURAL BACKFILL

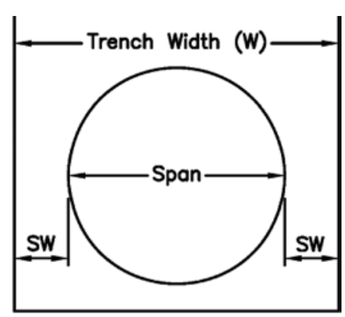
Bedding and structural backfill for metal culverts shall be a granular material meeting, as a minimum, the gradation requirements of AASHTO M145 for A-1, A-2 or A-3 materials. Bedding and backfill shall be free of organics, rock fragments larger than 2½", chunks of highly plastic clay, frozen lumps, and corrosive or otherwise deleterious materials.

Bedding shall be a minimum of four inches in depth, left loosely placed under the middle-third of the span for circular pipe but roughly shaped to the bottom arc of pipe-arch structures. The shaped bedding shall be left loosely placed, scarified or otherwise uncompacted.

Structural backfill shall be placed in loose lifts not exceeding 8-in and compacted to a minimum 90% AASHTO T99 Standard Proctor Density. The backfill shall be placed and compacted with care under the haunches of the pipe and shall be raised evenly on both sides of the pipe by working backfill operations from side to side. The side to side backfill differential shall not exceed 24-in or one-third of the rise of the structure, whichever is less (generally not exceeding more than one lift difference). Structural backfill shall continue to not less than 1-ft above the top of pipe. Backfill material used for the remainder of the burial shall be as defined in the project specifications or as directed by the engineer.

TRENCH INSTALLATION[1]

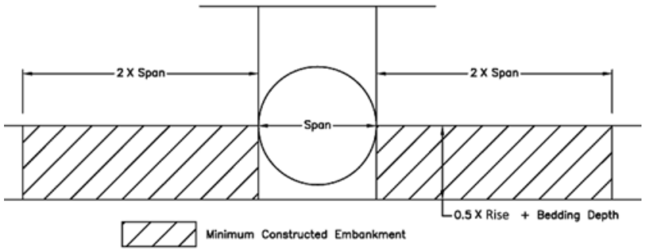
Pipe installations within cut trenches shall not begin until the bedding has been properly formed over a suitable foundation. The trench should be kept to the minimum width needed to safely place pipe and adequately compact sidefill. In no case shall the trench width be less than 1.25 times the pipe span plus one foot unless provisions are in place for alternate backfill and backfilling methods. Once the pipe is secured on the bedding the structural backfill operation shall progress in the manner described above.



$W_{min} = 1.25$ Span + 1.0 ft
$SW_{min} = 0.125$ Span + 0.5 ft

[1]Trench sidewalls shall be stable, supported, or laid back according to OSHA regulations.

EMBANKMENT INSTALLATION



Pipe installations within the limits of embankment construction shall not begin until the fill operation has progressed to an elevation not less than the proposed invert plus one-half the rise of the pipe, and to a width that encompasses at least two pipe spans on each side of the pipe. Once the fill operation has reached these limits a trench may be excavated in the constructed embankment and the installation may progress in accordance with the trench installation procedures.

TEMPORARY CONSTRUCTION COVER

All pipes shall be protected with sufficient cover before permitting heavy construction equipment to pass over them during construction in accordance with the table at right:

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

MULTIPLE PIPE RUNS

Installation methods for multiple runs of pipe shall be consistent with trench and/or 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 below the haunch and between the structures. Minimum spacing between pipes and pipe-arches shall be as defined below. The minimum side width (SW) between the pipe and trench shall be consistent with the minimum trench width formula.

Pipe Diameter	Minimum Spacing
Up to 24"	12"
24" to 72"	½D
Greater than 72"	36"

Pipe-Arch Span	Minimum Spacing
Up to 36"	12"
36" to 108"	⅓S
Greater than 108"	36"

ADDENDA TO THE CMP INSTALLATION GUIDE

The foregoing installation specification may be supplemented or moderated by the following notes:

A GUIDE TO TRENCH WIDTH

The trench should be kept to the minimum width needed to safely place pipe and adequately compact sidefill. 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.

A GUIDE TO SPECIFYING BEDDING DEPTH, d

When the natural soil does not provide a suitable bed, a bedding blanket shall be provided with a minimum thickness of twice the corrugation depth. For all instances this would provide a bedding depth of 2 inches and less. Since it may not be practical to specify a bedding depth less than 2 inches, a 2-in minimum is recommended. Typical practice is to use a bedding depth of 4 to 6 inches.

A Guide to Specifying Bedding Material

The bedding blanket is a thin layer of loosely placed granular material (less than 35% fines) that cushions the pipe invert and allows the corrugation to nest or seat into it. A well-graded granular material containing rock fragments as large as three inches will allow the pipe to settle into the bedding in this fashion. Uniform-graded materials should be limited to angular rock fragments with a nominal size distribution from ¾" to 1½". See Table 1 for examples of acceptable material gradations.

A Guide to Specifying Structural Backfill Material

Structural backfill should be a readily compacted granular material (less than 35% fines). Select materials such as bank-run gravels or processed granular materials with angular interlocking particles are preferred. Desired end results can be obtained with this type of material with a minimum of compaction effort over a wide range of moisture content and lift depth. Uniform-graded materials should be limited to angular rock fragments with a nominal size distribution from ¾" to 1½". See Table 1 for examples of acceptable material gradations.

Table 1. Examples of Acceptable Bedding and Backfill Gradations for Corrugated Metal Pipe

Material Passing No. 40 Sieve: Max Liquid Limit = 25, Max Plasticity Index = 6

Sieve Size	A % Passing	B % Passing	C % Passing	D % Passing	E % Passing	F % Passing	G % Passing	H % Passing
2½ inch	—	—	—	—	—	—	—	100
2 inch	100	—	—	—	—	—	—	—
1½ inch	—	100	100	—	—	—	—	—
1 inch	70 to 100	—	95 to 100	100	—	—	—	70 to 100
¾ inch	50 to 90	80 to 100	—	90 to 100	—	—	100	—
½ inch	—	—	25 to 60	—	—	—	—	—
⅜ inch	—	60 to 90	—	20 to 55	100	100	80 to 100	—
No. 4	30 to 60	30 to 90	0 to 10	0 to 10	90 to 100	95 to 100	60 to 100	25 to 100
No. 8	—	—	0 to 5	0 to 5	65 to 100	70 to 100	45 to 95	—
No. 16	—	—	—	—	40 to 85	38 to 80	—	—
No. 30	9 to 33	3 to 20	—	—	20 to 60	18 to 60	—	—
No. 40	—	—	—	—	—	—	—	10 to 50
No. 50	—	—	—	—	7 to 40	5 to 30	7 to 55	—
No. 100	—	—	—	—	0 to 20	0 to 10	—	—
No. 200	0 to 20	0 to 20	—	—	0 to 10	0 to 5	0 to 15	5 to 15

A Guide to Using ASTM 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.

A Guide to Using AASHTO Designations for Bedding and Backfill

Commonly used AASHTO designations for bedding and backfill are AASHTO No. 57, No. 67 and No. 8.

A Guide to Using Filter Fabric

The migration of fines from the sides and bottom of the excavation into adjacent pipe embedment voids 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) must be used to prevent particle migration.

Corrugated Steel Pipe (CSP)
AASHTO LRFD Cover Heights
Soil density 120 pcf

CSP 2⅔" x ½"

Diameter (in)	Min Cover (ft)	Maximum Cover Height (ft) 16ga	14ga	12ga	10ga	8ga
12	1.00	218	272	382		
15	1.00	174	218	305		
18	1.00	145	181	254	327	
21	1.00	124	155	218	280	
24	1.00	108	136	190	245	
30	1.00	87	108	152	196	
36	1.00	72	90	127	163	
42	1.00	62	77	108	140	171
48	1.00	54	67	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	99
78	1.00					88
84	1.00					76

Corrugated Steel Pipe (CSP)
AASHTO LRFD Cover Heights
Soil density 120 pcf

CSP 3" x 1"

Diameter (in)	Min Cover (ft)	Maximum Cover Height (ft) 16ga	14ga	12ga	10ga	8ga
48	1.00	62	78	109	141	173
54	1.00	55	69	97	125	153
60	1.00	49	62	87	112	138
66	1.00	45	56	79	102	125
72	1.00	41	51	72	94	115
78	1.00	38	47	67	86	106
84	1.00	35	44	62	80	98
90	[1]1.00	32	41	58	75	92
96	1.00		38	54	70	86
102	1.06		36	51	66	81
108	1.13			48	62	76
114	1.19			45	59	72
120	1.25			43	56	68
126	1.31				53	65
132	1.38				51	62
138	1.44				48	59
144	1.50					57

[1]Minimum cover for 14ga and heavier. The 16ga minimum cover for 90" is 1.1-ft.

LANE

Corrugated Steel Pipe (CSP)
AASHTO LRFD Cover Heights
Soil density 120 pcf

CSP
5" x 1"

Diameter (in)	Min Cover (ft)	Maximum Cover Height (ft) 16ga	14ga	12ga	10ga	8ga
48	1.00	55	69	97	125	153
54	1.00	49	61	86	111	136
60	1.00	44	55	78	100	123
66	1.00	40	50	70	91	111
72	1.00	36	46	64	83	102
78	1.00	33	42	59	77	94
84	[1]1.00	31	39	55	71	87
90	[1]1.00	29	36	51	66	81
96	1.00		34	48	62	76
102	1.06		32	45	58	72
108	1.13			43	55	68
114	1.19			40	52	64
120	1.25			38	50	61
126	1.31				47	58
132	1.38				45	55
138	1.44				43	53
144	1.50					50

[1]Minimum covers for 14ga and heavier. The respective 16ga minimum covers for 84" and 90" are 1.1 and 1.2-ft.

LANE

Corrugated Steel Pipe (CSP)
AASHTO LRFD Cover Heights
Soil density 120 pcf

CSP
¾"x ¾"x 7½"
Spiral Rib

Diameter (in)	Min Cover (ft)	Maximum Cover Height (ft) 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	49	83	
54	[1]1.00	[2]31	44	73	
60	1.00		39	66	96
66	1.00		[2]36	60	87
72	1.00			55	80
78	1.00			50	74
84	1.00			[2]47	68
90	1.00				64
96	1.00				[2]59
102	1.06				[2]52

[1]Minimum cover for 14ga and heavier. The 16ga minimum cover for 54" is 1.1-ft.

[2]Trench installation only. Embankment installations may be used for the heavier gages.

LANE

Corrugated Steel Pipe (CSP)
AASHTO LRFD Cover Heights
Corner bearing capacity 4 ksf
Soil density 120 pcf

CSP Pipe-Arch
2⅔" x ½"

Span x Rise (in)	Equiv Dia (in)	Min Gage	Min Cover (ft)	Max Cover (ft)
17 x 13	15	16	1.9	12
21 x 15	18	16	2.0	12
24 x 18	21	16	1.9	12
28 x 20	24	16	2.0	12
35 x 24	30	16	2.0	12
42 x 29	36	16	2.0	12
49 x 33	42	14	2.0	12
57 x 38	48	12	2.0	11
64 x 43	54	12	2.0	11
71 x 47	60	10	2.0	11
77 x 52	66	8	2.0	12
83 x 57	72	8	2.0	12

LANE

Corrugated Steel Pipe (CSP)
AASHTO LRFD Cover Heights
Corner bearing capacity 4 ksf
Soil density 120 pcf

CSP Pipe-Arch
3" x 1"

Span x Rise (in)	Equiv Dia (in)	[1]Min Gage	Min Cover (ft)	Max Cover (ft)
53 x 41	48	14	2.0	11
60 x 46	54	14	2.0	20
66 x 51	60	14	1.2	20
73 x 55	66	14	1.2	20
81 x 59	72	14	1.5	16
87 x 63	78	14	1.5	16
95 x 67	84	14	1.5	16
103 x 71	90	14	1.5	16
112 x 75	96	12	1.5	16
117 x 79	102	12	1.5	16
128 x 83	108	10	1.5	16
137 x 87	114	10	1.6	16
142 x 91	120	10	1.6	16

[1]Manufacturing limitations include a 14 gage minimum for 3"x 1" Pipe-Arch

Corrugated Steel Pipe (CSP)
AASHTO LRFD Cover Heights
Corner bearing capacity 4 ksf
Soil density 120 pcf

CSP Pipe-Arch
5" x 1"

Span x Rise (in)	Equiv Dia (in)	[1]Min Gage	Min Cover (ft)	Max Cover (ft)
53 x 41	48	12	2.0	11
60 x 46	54	12	1.2	20
66 x 51	60	12	1.2	20
73 x 55	66	12	1.2	20
81 x 59	72	12	1.5	16
87 x 63	78	12	1.5	16
95 x 67	84	12	1.5	16
103 x 71	90	12	1.5	16
112 x 75	96	12	1.5	16
117 x 79	102	12	1.5	16
128 x 83	108	10	1.5	16
137 x 87	114	10	1.6	16
142 x 91	120	10	1.6	16

[1]Manufacturing limitations include a 12 gage minimum for 5"x 1" Pipe-Arch

Corrugated Steel Pipe (CSP)
AASHTO LRFD Cover Heights
Corner bearing capacity 4 ksf
Soil density 120 pcf

CSP Pipe-Arch
¾"x ¾"x 7½"
Spiral Rib Pipe

[1]Span x Rise (in)	Equiv Dia (in)	Min Gage	Min Cover (ft)	Max Cover (ft)
20 x 16	18	16	1.6	15
23 x 19	21	16	1.7	14
27 x 21	24	16	1.8	13
33 x 26	30	16	1.8	13
40 x 31	36	16	1.9	13
46 x 36	42	16	1.8	13
53 x 41	48	[2]16	1.9	13
60 x 46	54	14	1.3	20
66 x 51	60	[2]14	1.3	20
73 x 55	66	12	1.3	20
81 x 59	72	[2]12	1.5	16
87 x 63	78	10	1.5	16
95 x 67	84	10	1.5	16
103 x 71	90	[2]10	1.5	16

[1]ASTM A760 makes provisions for two additional sizes: 112"x 75" and 117"x 79".

[2]Trench installation only. Embankment installations may be used for the heavier gages.

Corrugated Aluminum Alloy Pipe (CAAP)
For Alclad Alloy 3004-H32 (F_u = 27 ksi, F_y = 20 ksi)
AASHTO LRFD Cover Heights
Soil density 120 pcf

CAAP 2⅔" x ½"

Diameter (in)	Min Cover (ft)	Maximum Cover Height (ft) 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	65	82	115		
30	1.00		65	92		
36	1.00		54	76	99	121
42	1.00			65	84	103
48	1.00			57	74	90
54	1.00			50	65	80
60	1.00				54	68
66	1.00					56
72	1.00					45

Corrugated Aluminum Alloy Pipe (CAAP)
For Alclad Alloy 3004-H32 (F_u = 27 ksi, F_y = 20 ksi)
AASHTO LRFD Cover Heights
Soil density 120 pcf

CAAP 3" x 1"

Diameter (in)	Min Cover (ft)	Maximum Cover Height (ft) 16ga	14ga	12ga	10ga	8ga
30	1.00	60	76			
36	1.00	50	63	88		
42	1.00	43	54	75		
48	1.00	37	47	66	88	104
54	[1]1.00	33	42	58	78	93
60	[1]1.00	29	37	52	71	83
66	[1]1.00	27	34	48	64	76
72	[2]1.00	24	31	44	59	69
78	[3]1.00		28	40	54	64
84	1.00			37	50	59
90	1.00			35	47	55
96	1.00			32	44	52
102	1.06				41	49
108	1.13				38	46
114	1.19					42
120	1.25					38

[1]Minimum cover for 14ga and heavier. The 16ga minimum covers for 54", 60" and 66" are 1.1, 1.2 and 1.3-ft, respectively.
[2]Minimum cover for 12ga and heavier. The 16ga and 14ga minimum covers are 1.4 and 1.1-ft, respectively.
[3]Minimum cover for 12ga and heavier. The 14ga minimum cover is 1.2-ft.

Corrugated Aluminum Alloy Pipe (CAAP)
For Alclad Alloy 3004-H32 (F_u = 27 ksi, F_y = 20 ksi)
AASHTO LRFD Cover Heights
Soil density 120 pcf

CAAP ¾"x ¾"x 7½" Spiral Rib

[1]Diameter (in)	Min Cover (ft)	Maximum Cover Height (ft) 16ga	14ga	12ga	10ga
15	1.00	56	77		
18	1.00	46	64		
21	1.00	40	55		
24	1.00	34	48	77	
30	1.25	27	38	62	
36	1.50	[2]22	31	51	
42	1.75		[2]27	44	
48	2.00			38	54
54	2.00			34	48
60	2.00			[2]30	43
66	2.00				39
72	2.18				[2]36

[1]ASTM B745 makes provisions for two additional sizes, 78" and 84".
[2]Trench installation only. Embankment installations may be used for the heavier gages (10 gage max).

Corrugated Aluminum Alloy Pipe (CAAP)
For Alclad Alloy 3004-H32 (F_u = 27 ksi, F_y = 20 ksi)
AASHTO LRFD Cover Heights
Corner bearing capacity 4 ksf
Soil density 120 pcf

CAAP Pipe-Arch
2⅔" x ½"

[1]Span x Rise (in)	Equiv Dia (in)	Minimum Gage	Minimum Cover (ft)	Maximum Cover (ft)
17 x 13	15	16	1.9	12
21 x 15	18	16	2.0	12
24 x 18	21	16	1.9	12
28 x 20	24	14	2.0	12
35 x 24	30	14	2.0	12
42 x 29	36	12	2.0	12
49 x 33	42	12	2.0	12
57 x 38	48	10	2.0	11
64 x 43	54	10	2.0	11
71 x 47	60	8	2.0	11

[1]ASTM B745 makes provisions for two additional larger sizes: 77"x 52" and 83"x 57".

Corrugated Aluminum Alloy Pipe (CAAP)
For Alclad Alloy 3004-H32 (F_u = 27 ksi, F_y = 20 ksi)
AASHTO LRFD Cover Heights
Corner bearing capacity 4 ksf
Soil density 120 pcf

CAAP Pipe-Arch
3" x 1"

[1]Span x Rise (in)	Equiv Dia (in)	Minimum Gage	Minimum Cover (ft)	Maximum Cover (ft)
53 x 41	48	16	2.0	11
60 x 46	54	16	1.3	20
66 x 51	60	16	1.3	20
73 x 55	66	14	1.3	20
81 x 59	72	12	1.5	16
87 x 63	78	12	1.5	16
95 x 67	84	12	1.5	16
103 x 71	90	10	1.5	16
112 x 75	96	8	1.6	15
117 x 79	102	8	1.6	16

[1]ASTM B745 makes provisions for three additional larger sizes: 128"x 83", 137"x 87" and 142"x 91".

Corrugated Aluminum Alloy Pipe (CAAP)
For Alclad Alloy 3004-H32 (F_u = 27 ksi, F_y = 20 ksi)
AASHTO LRFD Cover Heights
Corner bearing capacity 4 ksf
Soil density 120 pcf

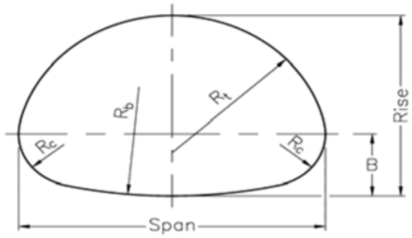
CAAP Pipe-Arch
¾"x ¾"x 7½"
Spiral Rib Pipe

[1]Span x Rise (in)	Equiv Dia (in)	Minimum Gage	Minimum Cover (ft)	Maximum Cover (ft)
20 x 16	18	16	1.6	15
23 x 19	21	16	1.7	14
27 x 21	24	16	1.8	13
33 x 26	30	16	1.8	13
40 x 31	36	14	1.9	13
46 x 36	42	[2]14	1.9	13
53 x 41	48	12	2.0	13
60 x 46	54	[2]12	2.0	20
66 x 51	60	10	2.0	20
73 x 55	66	[2]10	2.2	20

[1]ASTM B745 makes provisions for one additional size, 81"x 59".

[2]Trench installation only. Embankment installations may be used for the heavier gages (10 gage max).

CORRUGATED METAL PIPE (CMP)
PIPE-ARCH SIZES AND LAYOUT DETAILS



Pipe-Arch with 2⅔" x ½" Corrugations

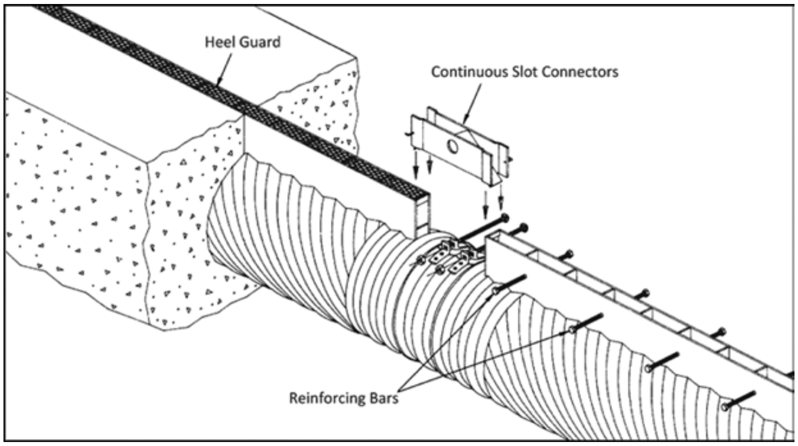
Equivalent Diameter (in)	Design Span (in)	Design Rise (in)	Waterway Area (ft²)	B (in)	R_c (in)	R_t (in)	R_b (in)
15	17	13	1.1	4⅛	3½	8⅝	25⅝
18	21	15	1.6	4⅞	4⅛	10¾	33⅛
21	24	18	2.2	5⅝	4⅞	11⅞	34⅝
24	28	20	2.9	6½	5½	14	42¼
30	35	24	4.5	8⅛	6⅞	17⅞	55⅛
36	42	29	6.5	9¾	8¼	21½	66⅛
42	49	33	8.9	11⅜	9⅝	25⅛	77¼
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" Corrugations

Equivalent Diameter (in)	Nominal Span x Rise (in)	Design Span x Rise (in)	Waterway Area (ft²)	B (in)	R_c (in)	R_t (in)	R_b (in)
48	53 x 41	53 x 41	11.7	15¼	10 3/16	28 1/16	73 7/16
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	37⅞	33	67⅜	149½
120	142 x 91	138½ x 98	74.5	39½	34¾	71⅝	162⅜

Spiral Rib Pipe-Arch with ¾"x¾"x7½" Corrugations

Equivalent Diameter (in)	Design Span (in)	Design Rise (in)	Waterway Area (ft²)	B (in)	R_c (in)	R_t (in)	R_b (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



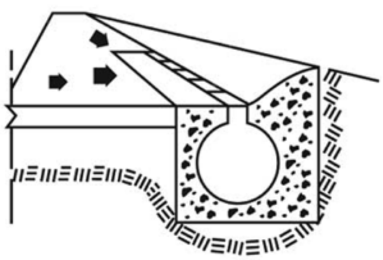
CMP Slotted Drain Offerings

Pipe Diameters 12" through 36"
Pipe Thicknesses 16 and 14 Gage
Standard Slot Heights of 2½"and 6"
Variable Slot Heights*
Slot Width 1¾"
Corrugated Band Connectors
Heel Guard*
Continuous Slot Connector*

*when specified

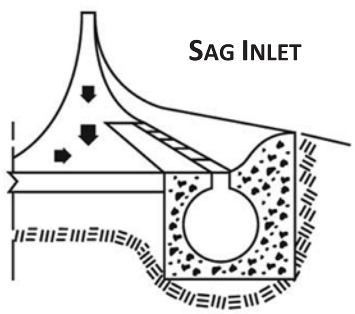
Slotted drain pipe is used for typical curb-and-gutter applications as an **on-grade opening**, at the bottom of a slope as a **sag inlet**, or as a **sheet flow intercept** for wide, flat areas. Figures A, B and C on the following page are used to determine the lengths of slotted drain pipe needed for a particular application and a design flow rate.

On-Grade Opening



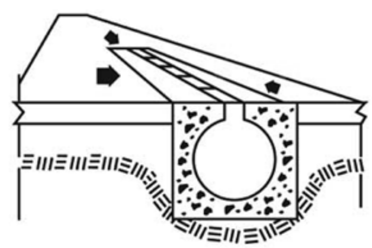
For a given cross slope (S_x) and longitudinal gutter slope (S) the required slotted drain pipe length can be determined for a given flow rate. A cost-effective practice is to carry up to 35% of the total flow to the next inlet. Figure C shows a carryover efficiency curve to utilize this practice.

Sag Inlet



Where slotted drain pipe is installed at a low point or sag in the grade, the slotted length is calculated from the equation $L_R = 1401\ Q/d^{½}$. The depth of flow (d) is found from Figure A.

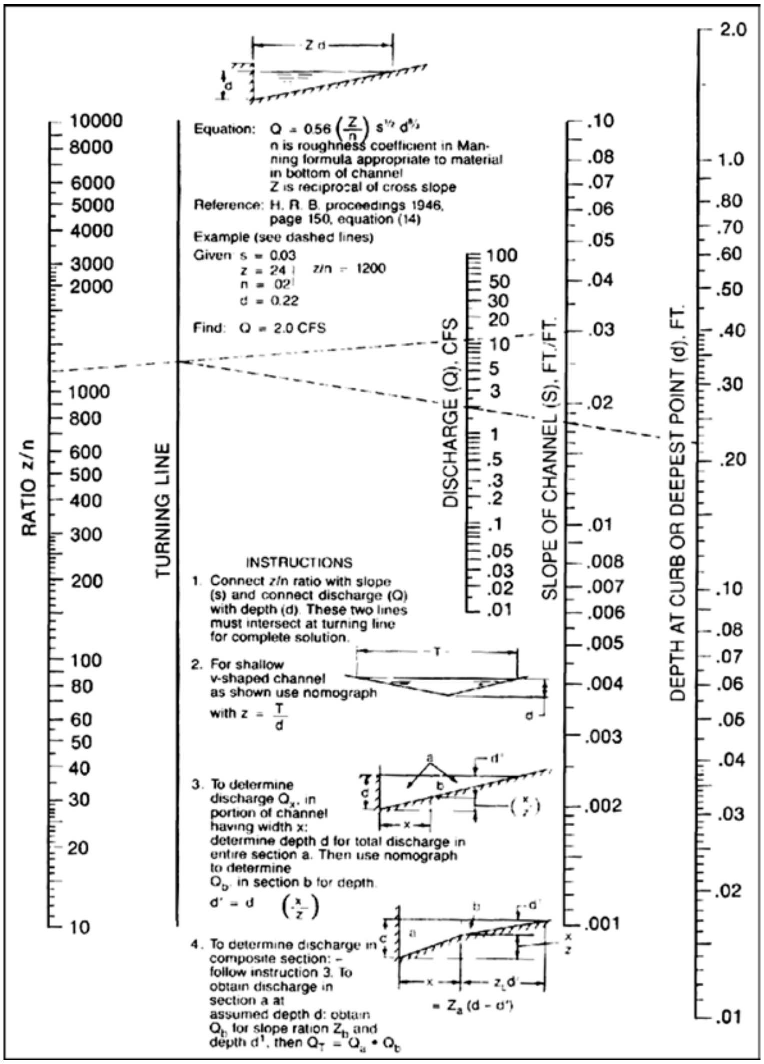
Sheet Flow Intercept



An effective use of slotted drain pipe is to intercept sheet flow from wide, flat areas (e.g. parking lots, airport terminals, highway medians, loading docks). The slotted drain pipe is placed transversely to the grade to intercept flow uniformly along its length.

Installation

Lengths of slotted drain pipe are placed, aligned and banded together in a prepared trench. Care is taken to make sure the slot matches grade throughout the alignment. The pipe is then encased in concrete or lean concrete grout up to the top of the pipe. The finish course of pavement is then installed up to the top of the slot.



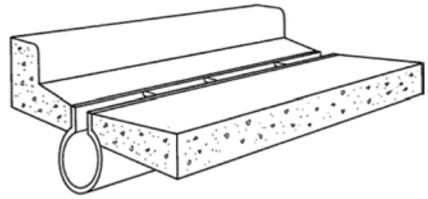


FIGURE A. NOMOGRAPH FOR FLOW IN TRIANGULAR CHANNELS

TERMS AND DEFINITIONS

S Longitudinal Gutter or Channel Slope (ft/ft)

S_x Transverse Slope (ft/ft)

Z Transverse Slope Reciprocal (ft/ft)

d Depth of Flow (ft)

Q Discharge (cfs)

L_R Length of Slot Required for Total Interception (ft)

L_A Actual Length of Slot (ft)

Q_D Total Discharge at an Inlet (cfs)

Q_A An Assumed Discharge (cfs)

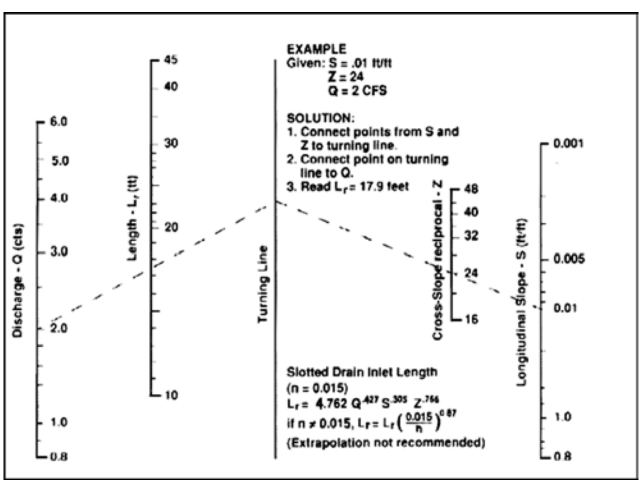


FIGURE B. DESIGN NOMOGRAPH

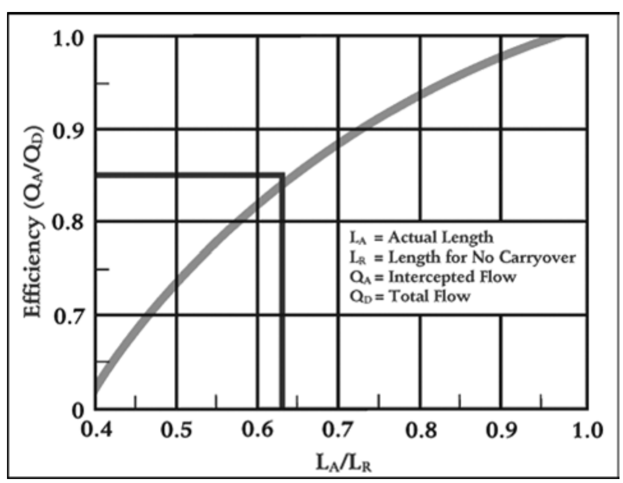


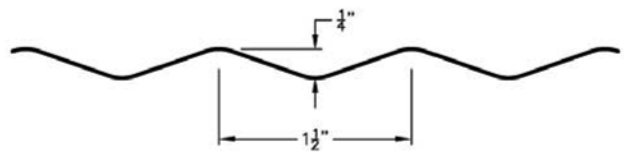
FIGURE C. CARRYOVER EFFICIENCY CURVE

LANE
CMP UNDERDRAIN GUIDE

Pavement Underdrain Systems

Although underdrain systems can involve pipe of any size, the focus of this guide is the typical 6, 8 and 10-in corrugated metal pipe diameters. Please refer to the CMP Perforation Guide (PG-1) and the CMP Connection Guide (CG-1, CG-2) for information involving the larger sizes. Pipe shall meet the applicable ASTM, AASHTO or AREMA specifications. Refer to the CMP Specification Guide (SG-1, SG-2) for further information.

Corrugations for 6, 8 and 10-in CMP are helically formed with a 1½" x ¼" corrugation with either an 18 or 16 gage thickness with corrugation section properties as shown at right.



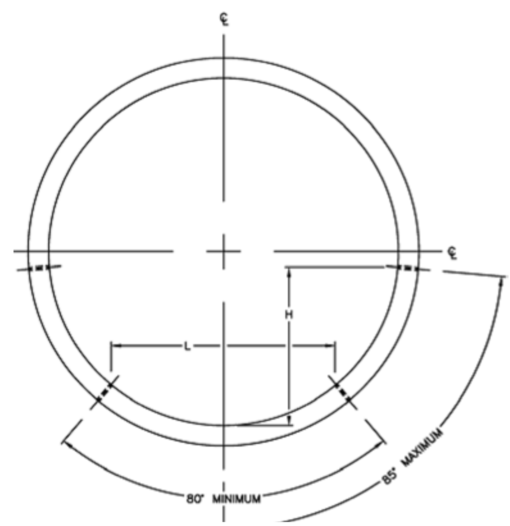
Steel — **CSP 1½"x ¼" Corrugation**

Gage	T (in)	A (in^2/ft)	I (in^4/in)	r (in)	FF_{max} (in/kip)
18	0.052	0.608	0.000344	0.0824	43
16	0.064	0.761	0.000439	0.0832	43

Class 1 Perforations for 1½"x ¼" Corrugation

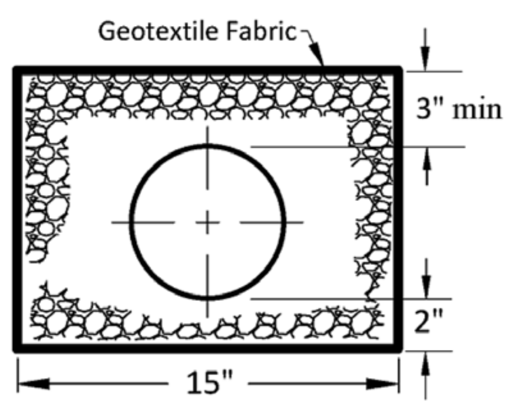
Diameter, D (in)	Total No. of Rows	H_{max} (in)	L_{min} (in)
6	4	2.8	3.8
8	4	3.7	5.1
10	4	4.6	6.4

Water inlet area for 6, 8 and 10-in perforated pipe is 3.53 in^2/ft.



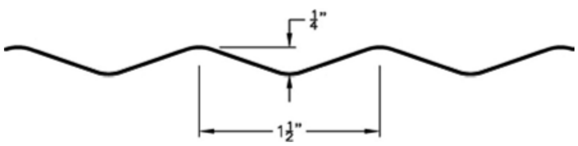
Class 1 Perforation Layout

CMP underdrain for the 6, 8 and 10-in diameters are connected together with a sleeve coupler, also known as a bell-bell coupler (perforations not shown in sketch).



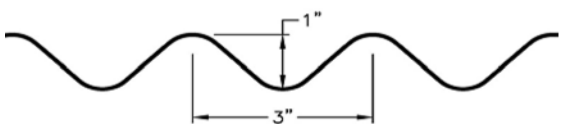
Typical Trench Detail

EFFECTIVE SECTION PROPERTIES FOR CORRUGATED METAL PIPE



Steel — **CSP 1½"x ¼" Corrugation**

Gage	T (in)	A (in^2/ft)	I (in^4/in)	r (in)	FF_{max} (in/kip)
18	0.052	0.608	0.000344	0.0824	43
16	0.064	0.761	0.000439	0.0832	43

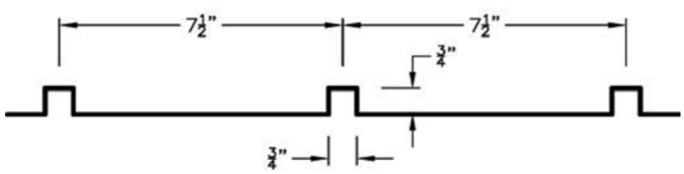


Steel — **CSP 3"x 1" Corrugation**

Gage	T (in)	A (in^2/ft)	I (in^4/in)	r (in)	FF_{max} (in/kip)
16	0.064	0.890	0.008659	0.3417	33
14	0.079	1.113	0.010883	0.3427	33
12	0.109	1.560	0.015459	0.3448	33
10	0.138	2.008	0.020183	0.3472	33
8	0.168	2.458	0.025091	0.3499	33

Aluminum — **CAAP 3"x 1" Corrugation**

Gage	T (in)	A (in^2/ft)	I (in^4/in)	r (in)	FF_{max} (in/kip)
16	0.064	0.890	0.008659	0.3417	60
14	0.079	1.118	0.010883	0.3427	60
12	0.109	1.560	0.015459	0.3448	60
10	0.138	2.088	0.020183	0.3472	60
8	0.168	2.458	0.025091	0.3499	60

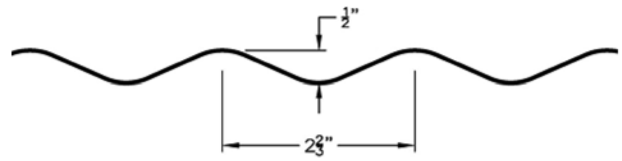


Steel — **CSP ¾"x ¾"x 7½" Corrugation (Spiral Rib)**

Gage	T (in)	A (in^2/ft)	I (in^4/in)	r (in)	$FF_{max, E}$ (in/kip)	$FF_{max, T}$ (in/kip)
16	0.064	0.509	0.002821	0.2580	30.66	37.16
14	0.079	0.712	0.003701	0.2500	33.57	40.68
12	0.109	1.184	0.005537	0.2370	38.39	46.53
10	0.138	1.717	0.007433	0.2280	42.35	51.33

Aluminum — **CAAP ¾"x ¾"x 7½" Corrugation (Spiral Rib)**

Gage	T (in)	A (in^2/ft)	I (in^4/in)	r (in)	$FF_{max, E}$ (in/kip)	$FF_{max, T}$ (in/kip)
16	0.060	0.415	0.002558	0.2720	46.50	57.44
14	0.075	0.569	0.003372	0.2670	50.98	62.98
12	0.105	0.914	0.005073	0.2580	58.42	72.17
10	0.135	1.290	0.006826	0.2520	64.50	79.67

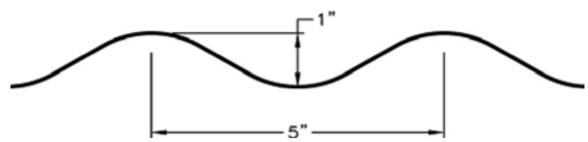


Steel — **CSP 2⅔"x ½" Corrugation**

Gage	T (in)	A (in^2/ft)	I (in^4/in)	r (in)	FF_{max} (in/kip)
16	0.064	0.775	0.001892	0.1712	43
14	0.079	0.968	0.002392	0.1721	43
12	0.109	1.356	0.003425	0.1741	43
10	0.138	1.744	0.004533	0.1766	43
8	0.168	2.133	0.005725	0.1795	43

Aluminum — **CAAP 2⅔"x ½" Corrugation**

Gage	T (in)	A (in^2/ft)	I (in^4/in)	r (in)	FF_{max} (in/kip)
16	0.060	0.775	0.001892	0.1712	31
14	0.075	0.968	0.002392	0.1721	61
12	0.105	1.356	0.003425	0.1741	92
10	0.135	1.745	0.004533	0.1766	92
8	0.164	2.130	0.005725	0.1795	92



Steel — **CSP 5"x 1" Corrugation**

Gage	T (in)	A (in^2/ft)	I (in^4/in)	r (in)	FF_{max} (in/kip)
16	0.064	0.794	0.008850	0.3657	33
14	0.079	0.992	0.011092	0.3663	33
12	0.109	1.390	0.015650	0.3677	33
10	0.138	1.788	0.020317	0.3693	33
8	0.168	2.186	0.025092	0.3711	33

Corrugation Section Properties

T = metal thickness
A = wall area
I = moment of inertia
r = radius of gyration
E = modulus of elasticity (steel 29,000 ksi, alum 10,000 ksi)
F_y = minimum yield stress (steel 33 ksi, alum 20 ksi)

Flexibility Factor (FF)

Minimum pipe stiffness requirements for practical handling and installation without undue care or bracing have been established through experience and formulated. The resultant flexibility factor (S^2/EI) limits the size of each combination of corrugation and metal thickness. Higher values can be used with special care or where experience has so proved. ASTM and AASHTO publish different values for Spiral Rib in embankment and trench installations.

MANNING'S n-VALUES FOR CMP

Diameter (in)	Area (ft^2)	Hydraulic Radius, R (ft)	Manning's Roughness Coefficient, n 1½"x ¼"	2⅔"x ½"	3"x 1"	5"x 1"	¾"x ¾"x 7½"
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	

Pipe-Arch Rise x Span (in)	Corrugations 2⅔"x ½" Area (ft^2)	Hydraulic Radius, R (ft)	Manning's n
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)	Corrugations 3"x 1" and 5"x 1" Area (ft^2)	Hydraulic Radius, R (ft)	Manning's n 3"x 1"	5"x 1"
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)	Spiral Rib ¾"x ¾"x 7½" Area (ft^2)	Hydraulic Radius, R (ft)	Manning's n
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

Manning's Formula to Determine Flow Rate, Q (cfs)

$$Q = 1.486 \frac{AR^{2/3}S^{1/2}}{n}$$

A = Cross-Sectional Area (ft^2)
R = Hydraulic Radius (ft)
S = Slope
n = Manning's Roughness Coefficient

Using the values of A and R on this sheet will yield flow rate values for a pipe flowing full.

Manning's n-value notes:

Taken from the NCSPA Corrugated Steel Pipe Design Manual (P. 188).
Values are assumed independent of pipe material and/or coating.
Values for 21" pipe or pipe-arch derivative are interpolated values.
Values for 3"x 1" and 5"x 1" pipe-arch based on a relationship between the 2⅔"x ½" pipe/pipe-arch.
Values for spiral rib pipe-arch are assumed constant with respect to sprial rib pipe.

Corrugated Steel Pipe (Galvanized and Aluminized)

Approximate Handling Weights by Gage (lbs/ft)

Corrugation	Dia. (in)	18 Gage	16 Gage	14 Gage	12 Gage	10 Gage	8 Gage
1½"x ¼"	6	4	5				
	8	5	6				
	10	7	8				
2⅔"x ½"	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"	48		39	48	65	83	100
	54		44	54	73	93	114
	60		48	59	81	104	126
3"x1" values found by increasing 5"x1" weights by 12%.	66		53	65	89	114	138
	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"	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 Gage (lbs/ft)

Corrugation	Dia. (in)	16 Gage	14 Gage	12 Gage	10 Gage	8 Gage
2⅔"x ½"	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"	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"	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	

CORRUGATED METAL PIPE
Technical Guide

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