CORRUGATED STEEL PIPE

There are many different corrugated steel pipe and arch products used for a variety of purposes. This article is devoted principally to round corrugated steel pipe.

HISTORY

Corrugated Steel Pipe, which was the first introduced to the construction industry in 1896, has had many revisions to the basic metal composition, corrugation patterns, and coatings since that date.

In conjunction with the manufacturing developments, many State Highway Departments and various agency engineers have conducted numerous durability studies to determine the life expectancy of corrugated steel pipe.

The general consensus of these studies is that corrugated steel pipe has a life expectancy of 10 years to about 35 years before perforation* of the metal occurs. This has caused the industry to seek a solution via coatings, both applied and bonded. A more in-depth discussion on durability is found below.

> * The Federal Highway Administration's (FHWA) Culvert Inspection Manual states that perforation of a corrugated steel pipe culvert would indicate "poor condition". On a rating scale of 0 (critical condition) to 9 (new), any pipe with perforations is rated no better than a 3, which is rated as "poor" and only one step above "critical condition". A critical rating requires immediate replacement.

DESIGN

Gage determination is based on the intended use, applied loads in the buried condition, and material life of the culvert. *"Underground conduits are subject to two principal kinds of loads: dead loads developed by the embankment or trench backfill, plus stationary superimposed surface loads, uniform or concentrated; and live loads -- moving loads, including impact."*[(1)] Accordingly, the design of CSP should consider the gage of material required for:

1. Installation and handling
2. Deflection
3. Wall compression
4. Buckling
5. Strain limits (damage to coatings)
6. Riveted seam strength

Table 1

CONVERSION OF NOMINAL GAGE TO THICKNESS					
Gage No.	16	14	12	10	8
Uncoated Thickness -- in.	0.0598	0.0747	0.1046	0.1345	0.1644
Galvanized Thickness -- in.	0.064	0.079	0.109	0.138	0.168
Galvanized Thickness -- mm.	1.63	2.01	2.77	3.51	4.27

BASE METAL AND METALLIC COATINGS

The traditional metallic coatings are: zinc coated steel; aluminum coated steel (aluminized); and aluminum-zinc coated steel.

Base metal composition for galvanized corrugated steel pipe shall meet the requirements of AASHTO M 218, Table 1, and for aluminum coated pipes, AASHTO M 274, Table 1. It should be noted that the base metal is the same for all metallic coatings.

Galvanizing zinc coating to the base metal shall be at the rate of 2 oz. per sq. ft. on each side.(2) Aluminum cladding shall be at the rate of 1 oz. per sq. ft. on each side.(3)

SEAM TYPES

"Standard methods of shop-fabricating the seams of annularly corrugated steel pipe and pipe-arches are riveting or resistance spot welding; for helically corrugated, a lock seam or continuous welding."(4) The most common seam type is the lock seam, which is used exclusively with helical corrugated steel pipe.

CORRUGATION PATTERNS

Corrugated steel pipe derives most of its inherent strength from the corrugations formed into the metal sheets at the time of fabrication. *"For riveted or resistance spot-welded pipe with annular (circumferential) seams, the corrugations are 2-2/3" by 1/2" and 3" by 1". For lock seam pipe, the seams and corrugations run helically (or spirally) around the pipe using 1-1/2" by 1/4", 2-2/3" by 1/2", 3" by 1", and 5" by 1".*(5) *The most* common corrugation pattern for pipes is 2-2/3" by 1/2".

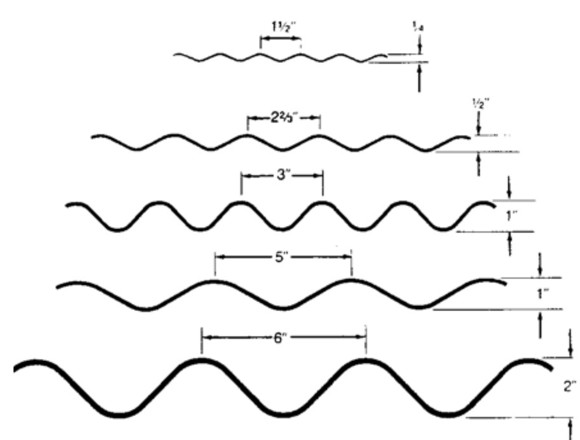


Figure 1

See Rinker Materials Info Series No. 301 for a detailed discussion on Spiral Rib CSP and Info Series No. 302 for Spiral Rib Aluminum Pipe.

Table 2

Diameters for corrugated steel pipe range from 4" to 144".[(6)]

Inside Diameter Range	Corrugation Pattern
4" to 18"	1-1/2" x 1/4" **
12" to 84"	2-2/3" x 1/2" * **
36" to 144"	3" x 1" * **
36" to 144"	5" x 1" **

* Riveted or resistance spot-welded (annular)
** Lock seam (Helical)

LENGTH

Corrugated steel pipe is usually fabricated in 20' and 24' lengths; however, longer or shorter lengths can be supplied.

During the fabrication operation of helical pipe, and when the newly formed pipe is sawed to make the proper length of pipe, the manufacturer should mark each end for proper assembly at the construction site. Wide dimensional variances may occur during fabrication, which can result in poor matching of the pipe ends during installation, thus making soil tight-joints difficult, if not impossible. Example: When one pipe with an undersized diameter (say 60" minus 1% = 59.40") is joined with the same nominal diameter pipe, but oversized (60" plus 1% = 60.60" -- a difference of 1-1/4"), the coupler will be tight against the larger diameter pipe, but loose against the smaller diameter pipe, thus the joint will not be soil-tight.

APPLIED COATINGS

Applied coatings refers to any material that is applied to the pipe after the base metal has been either zinc galvanized or cladded with aluminum. The applied coatings can be sprayed, painted, dipped, or adhered either before or after fabrication. Bituminous, or asphalt coatings, are the most commonly used applied coatings.

The performance history of these coatings is marginal, at best. Some State DOT's have rated the added service life of a corrugated steel culvert with applied coatings from 0 years to 10 years.

For design purposes, it would be reasonable to add an additional 5 years to the expected life of the corrugated steel pipe.

Since most applied coatings are a petroleum base material, the risk of fire is ever present. Once a bituminous or asphalt coating ignites, it is virtually impossible to extinguish the fire. If a corrugated steel pipe has experienced a fire of this magnitude, it should be replaced. See Info Brief #2011 - Fire Hazard Potentials.

MANUFACTURING TOLERANCES

"The average inside diameter of circular pipe shall not vary more than one percent or one-half inch, whichever is greater, from the nominal diameter when measured on the inside crest of the corrugation."[(7)] Inspectors should be alerted to this requirement and measure each pipe or a representative sampling of pipe delivered to the project site. Undersized pipe is reason for rejection.

Table 3

MINIMUM INSIDE DIAMETERS ALLOWED (in inches)			
Nominal Diameter	Minimum Diameter	Nominal Diameter	Minimum Diameter
12"	11.50"	48"	47.50"
15"	14.50"	54"	53.46"
18"	17.50"	60"	59.40"
21"	20.50"	72"	72.28"
24"	23.50"	84"	83.16"
27"	26.50"	96"	95.04"
30"	29.50"	108"	106.92"
36"	35.50"	120"	118.80"
42"	41.50"	144"	142.56"

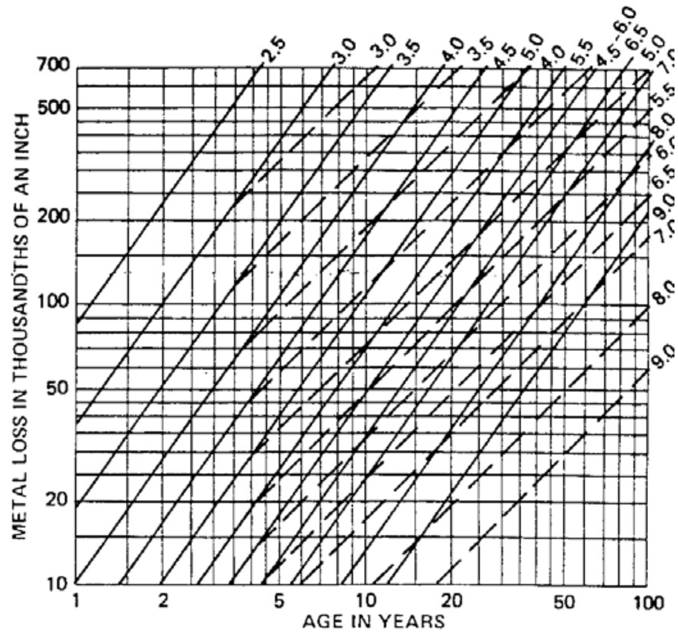
DURABILITY AND CORROSION

"Durability refers to the ability of a material to resist corrosion and abrasion. Corrosion is the deterioration of metal due to electrochemical or chemical reactions."[(8)] It should be noted that corrosion often occurs from both the soil side, as well as the water side of a corrugated metal pipe, and generally shows up first in the invert portion of the metal pipe.

There have been numerous durability studies conducted by various State Departments of Transportation (DOT), as well as cities, counties, districts, etc. as to the extent of corrosion on corrugated metal pipes. These studies typically consider deterioration from the inside of the metal pipe only and ignore deterioration from the soil-side.

One of the more thorough reports was conducted by the Ohio Department of Transportation, which covered an 11 year period where 1,616 culverts were inspected. A chart (Figure 2) indicating Predicted Metal Loss for Corrugated Metal Pipe Culverts shows, for an example, that a 16 gage CSP in a neutral (pH = 7.0) environment would have a predicted life of 20 years if complete perforation of the metal is allowed. Structural adequacy of the reduced wall was not addressed.

The Missouri Department of Transportation's Study of Use and Cost of Corrugated Steel Pipe states that *"current field reports show that CSP is being replaced as early as 20 years of age due to rusting out of the lower portions of the flowline (invert)".*



— CMP WITH ABRASION ML $-5040\,(AGE)^{1.4569}\,(pH)^{-4.4691}$
-- CMP WITHOUT ABRASION ML $-\ 7210(AGE)^{1.0164}\,(pH)^{-4.3076}$

Figure 2.
Predicted Metal Loss for Corrugated Metal Pipe

ABRASION

It is generally thought that abrasion occurs only with steep slopes and excessive bedload. It can also occur with flat slopes and continuously moving bedload. When abrasion is anticipated, a concrete paved invert should be considered. If a concrete paved invert is needed, the need for a Least Cost Analysis is even more critical to determine the lowest cost pipe material for the design life of the culvert or storm drain.

LEAST COST

A Least Cost Analysis based on competent data, such as design life, material life, cost factors, etc., should be performed on each installation to determine the true present value design life cost of the pipe.

Generally, if a conduit is replaced only once during the design life of that installation, it is more economical to use reinforced concrete pipe for the initial installation.

DESIGN SERVICE LIFE

Nearly all the State Departments of Transportation use a design service life of 50-75 years minimum for primary highways. Many cities, counties, districts, etc., also follow their State DOT design specifications. Such a design life would require metal culverts to be replaced twice.

CAUSES FOR REJECTION AND REPAIR

ASTM A 760, Para. 10, as well as the National Corrugated Steel Pipe Association, lists a number of reasons for rejecting CSP:

- Variation from a straight centerline.
- Elliptical shape in pipe intended to be round.
- Dents or bends in the metal.
- Metallic coating which has been broken or damaged.
- Lack of rigidity.
- Illegible markings on the steel sheet.
- Ragged or diagonal sheared edges.
- Uneven laps in riveted or spot welded pipe.
- Loose, unevenly lined, or unevenly spaced rivets.
- Defective spot welds or continuous welds.
- Loosely formed lockseams.

The metallic and non-metallic coatings that are applied to the material before fabrication into the finished product can be damaged during manufacturing due to extreme pressure applied by the roller dies used to form the corrugation patterns and bending of the material to form the lock seam. Also, when helical CSP is fabricated, the pipe ends are often recorrugated to form annular ends for coupler bands.

Pipes with damaged coatings shall be repaired or replaced prior to installation.

HYDRAULICS

The latest edition of the FHWA Hydraulic Design of Highway Culverts, Hydraulic Design Series No. 5, states the following Manning's "n" values for various corrugation patterns:

Table 4

CORRUGATION PATTERNS	"n" VALUE RANGE
2-2/3" x 1/2"	0.022 - 0.027
3" x 1"	0.027 - 0.028
5" x 1"	0.025 - 0.026

A general rule-of-thumb is that when comparing corrugated metal pipe to reinforced concrete pipe, there should be at least a two-size differential for the same amount of flow through each pipe. Example: a 48" RCP is approximately equal to a 60" CSP, as to flow capacity.

It is recommended that Helical CSP Manning's "n" values be the same as for the annular corrugated CSP. See Info Brief #3001 - Helical "n" Values for CSP.

Culvert inlet geometry is an important factor to evaluate when considering corrugated steel pipe. A projecting thin edge culvert is the least efficient inlet of the four illustrated below:

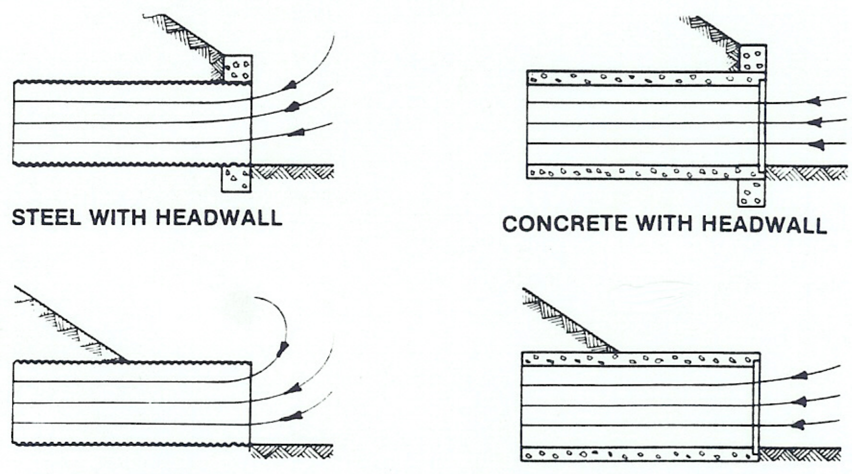


Figure 3

Applied coatings (bituminous, asphaltic, etc.) do not improve the hydraulic characteristics of corrugated steel pipe. According to a Missouri DOT Durability Report, *"coatings such as bituminous or polymer materials cannot be used to lower the coefficient of roughness for CMP because the coating will be lost first, leaving the hydraulic conditions controlled by the uncoated CMP."*[9]

COUPLINGS AND JOINTS

There are a variety of pipe coupling systems used to join sections of corrugated metal pipe together. Coupling bands may be of the following types:[10]

- Bands with annular corrugations
- Bands with helical corrugations
- Bands with projections (dimples)
- Channel bands for upturned flanges
- Flat bands
- Smooth sleeve-type couplers

Some joints are classified as soil-tight joints and must demonstrate the ability to pass a 2-psi hydrostatic test without leakage to be considered soil-tight.[11] Water-tight joints are not obtainable with corrugated steel pipe.

PIPE FLOTATION

Whenever the water table level will be above the invert of the pipe, the weight of the buried pipe is most significant in resisting buoyancy forces. The design engineer needs to consider the possibility of flotation when selecting the pipe material to be used. There are documented cases where CSP has risen out of its buried position due to the hydrostatic uplift and failed to perform as desired, thus needing to be replaced by new pipe.

INSTALLATION

The trench width should be at least 2-feet wider than the pipe outside diameter for standard installations. For installations in poor soils, a wider trench may be necessary.

A layer of loosely placed, uncompacted granular material should be placed directly under the pipe, allowing the bedding material to conform to the outside diameter of the pipe. This decreases point loading on the pipe.

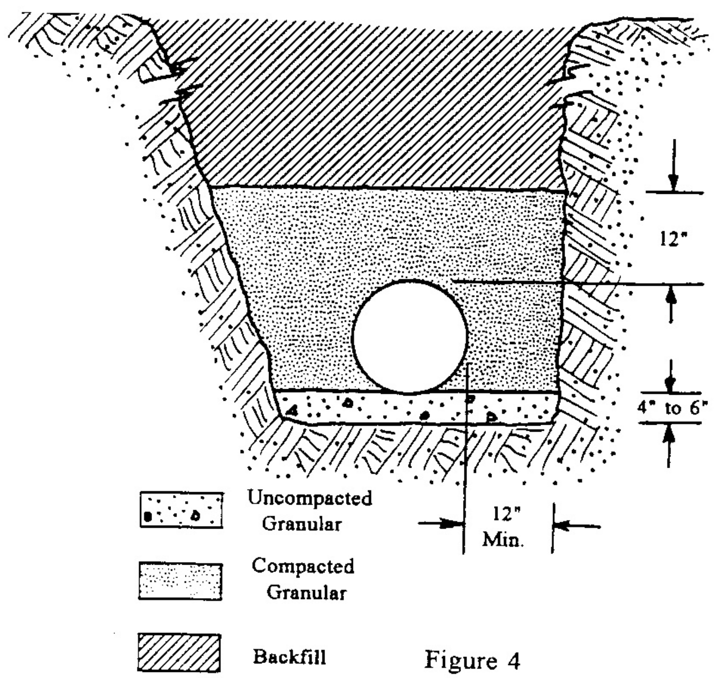


Figure 4

Well graded granular material should be placed from the bedding material to 12-inches over the top of the pipe and compacted to 95% relative density. The material should be placed in a series of shallow lifts and compacted, with special attention to the haunch area. Care must be taken to not over-deflect the CSP due to improper compaction. In some cases, it will be necessary to strut the pipe to prevent deflection.

The purpose of having quality embedment material and a high level of compaction around the pipe is to meet the design needs of the pipe. Design standards are based on the soil envelope being the major component in providing field structural strength. Uniform material and compaction completely around the pipe is most important to control deflection and distortion.

RECOMMENDATIONS

1. The minimum gage thickness for steel culverts and storm drains should be not less than 16 gage. The gage thickness required for all performance modes should be determined for each installation based on soil type, height of fill, and compaction of that soil.

2. Durability of the product should be considered and a Life Cycle Cost Analysis completed to determine present value costs for the design life of the intended use.

3. Finished product dimensions should be checked for compliance, in particular at pipe ends, for assurance of obtaining the specified functional joint system.

4. The finished product should be examined for damage to surface coatings, in particular at radii developed in forming the corrugations and the lock-seams.

REFERENCES

(1) "Handbook of Steel Drainage & Highway Construction Products", Third Edition, American Iron and Steel Institute, 1981, p. 101.

(2) AASHTO M 218, Para. 7.2, Table 3, and ASTM A 444, Note 4

(3) AASHTO M 274, Para. 7.2, Table 4.

(4) "Handbook of Steel Drainage & Highway Construction Products", Third Edition, American Iron and Steel Institute, 1981, p. 41.

(5) Ibid, p. 41.

(6) Ibid, p. 40.

(7) AASHTO M 36, Para. 8.1.1.

(8) FHWA Culvert Inspection Manual, May 1986, p. 100.

(9) "Study of Use, Durability, and Cost of Corrugated Steel Pipe on the Missouri Highway and Transportation Department's Highway System", Report MR 87-1, p. 6.

(10) AASHTO M 36, Para. 9.

(11) AASHTO Standard Specifications for Highway Bridges, Section 23.3.1.5.4.