CHAPTER 8

DURABILITY

INTRODUCTION

Corrugated steel pipe (CSP) has been used successfully since 1896 for storm sewers and culverts throughout North America and in other countries. It continues to provide long service life in installations that cover a wide variety of soil and water conditions.

Since the initial applications before the turn of the century, an estimated 50,000 installations have been the subject of critical investigative research to establish durability guidelines. The behavior of both the soil side and the effluent side of the pipe have been studied. These studies have shown that CSP generally provides outstanding durability with regard to soil side effects, and that virtually any required service life can be attained by selecting appropriate coatings and/or pavings for the invert.

Of course, all pipe materials show some deterioration with time, and such effects vary with site conditions. To aid the engineer in evaluating site conditions and selecting the appropriate CSP system, the main factors affecting durability and the results of field studies will be reviewed before presenting specific guidelines. A summary of the basic metallic coatings and additional nonmetallic protective coatings available for CSP storm sewers concludes this chapter.

FACTORS AFFECTING CSP DURABILITY

Durability in Soil

The durability of metal pipe in soil is a function of several interacting parameters including soil resistivity, acidity (pH), moisture content, soluble salts and oxygen content (aeration). However, all of the corrosion processes involve the flow of current from one location to another (a corrosion cell). Thus, the higher the resistivity, the greater the durability. Table 8.1 lists typical ranges of resistivity values for the primary soil types.

Most soils fall in a pH range of 6 to 8, and that is favorable to durability. Soils with lower pH values (acid soils), which are usually found in areas of high rainfall, tend to be more corrosive.

Granular soils that drain rapidly enhance durability. Conversely, soils with a moisture content above 20 percent tend to be corrosive. High clay content soils tend to hold water longer and therefore are more corrosive than well drained soils. Soil moisture may also contain various dissolved solids removed from the soil itself; this can contribute to corrosion by lowering the resistivity. Conversely, many soil chemicals form insoluble carbonates or hydroxides at buried metal surfaces; this can reduce soil-side corrosion. High levels of chlorides and sulfates will make a soil more aggressive. The relative corrosivity of soils of various physical characteristics is described in Table 8.2.

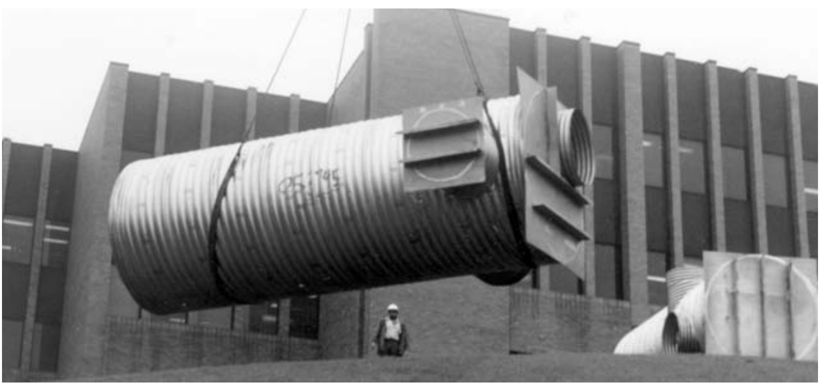
Table 8.1 Typical Soil Resistivities

Classification	Resistivity Ohm-cm
Clay	750- 2000
Loam	2000-10000
Gravel	10000-30000
Sand	30000-50000
Rock	50000-Infinity*

*Theoretical

Table 8.2 Corrosiveness of Soils

Soil Type	Description of Soil	Aeration	Drainage	Color	Water Table
I Mildly Corrosive	1. Sands or sandy loams 2. Light textured silt loams 3. Porous loams or clay loams thoroughly oxidized to great depths	Good	Good	Uniform color	Very low
II Moderately Corrosive	1. Sandy loams 2. Silt loams 3. Clay loams	Fair	Fair	Slight mottling	Low
III Extremely Corrosive	1. Clay loams 2. Clays	Poor	Poor	Heavy texture Moderate mottling	2 feet to 3 feet below surface
IV Severely Corrosive	1. Muck 2. Peat 3. Tidal marsh 4. Clays and organic soils	Very poor	Very poor	Bluish-gray mottling	At surface; or extreme impermeability



Lifting stormwater detention tank components into place.

Durability in Water

There is little difference in the durability of steel in still natural waters in the pH range of 4.5 to 9.5, because the corrosion products maintain a pH of 9.5 at the steel surface. However, fluctuating water removes these products and increases the level of dissolved gases. Increasing levels of dissolved oxygen and carbon dioxide can accelerate corrosion. The most important effect of carbon dioxide in water relates to its interference with the formation of the protective calcium carbonate scale. This scale develops on pipe surfaces in hard (high calcium carbonate content) flowing waters. Dissolved salts can increase durability by decreasing oxygen solubility and neutralizing acidity, but can increase corrosion if they ionize and decrease resistivity. Field studies have shown that the portion of the pipe most susceptible to corrosion is the invert as it tends to be exposed to water flow for a longer time and, in some cases, it may also be subject to abrasion. New approaches have been offered to evaluate corrosivity of water.

Resistance to Abrasion

In many cases, storm sewers tend to have modest slopes and do not experience significant abrasion problems. However, many culverts may have steeper slopes and more significant bed loads. Abrasion can become significant where flow velocities are high (over about 5 mps). The amount of wear increases if rock or sand is washed down the invert, but is small when the bed load is of a less abrasive character. Various invert treatments can be applied if significant abrasion is anticipated.

FIELD STUDIES OF DURABILITY

Reference to field studies of CSP performance in the region of application under consideration is often the most positive way to appraise CSP durability. Over many years, such studies have been made by various government, and industry investigators and now provide a wealth of accumulated information.

State Studies

California surveyed the condition of culvert pipes at hundreds of locations and developed a method to estimate life based on pH and resistivity. A design chart derived from this work will be presented subsequently. Investigations in Florida, Idaho, Georgia, and Nebraska showed that the method was too conservative compared to their actual service experience. Conversely, studies in the northeast and northwest regions of the United States and more recently in Northern Canada indicated that the method might be too liberal in those regions because of the prevalence of soft water (water containing less than 70 ppm calcium carbonate ($CaCO_3$)).

The results of the various investigations illustrate the variety of conditions that can be found throughout the country, and emphasize the need to use local information when available. Nevertheless, the California method appears to be the most reasonable basis available for general use.

The California study included the combined effects of soil corrosion, water corrosion, and abrasion on the durability of CSP culverts that had not received special maintenance treatment. The pipe invert, which could easily be paved to extend life, was found to be the critical area.

The predictive method developed depended on whether the pH exceeded 7.3. Where the pH was consistently less than 7.3, the study was based on pipes in high mountainous regions with the potential for significant abrasion. Also, at least 70 percent of the pipes were expected to last longer than indicated by the chart.

Where the pH was greater than 7.3, the study was based on pipes in the semiarid and desert areas in the southern part of California. Durability under those conditions, which was generally excellent, would be dominated by soilside corrosion because the average rainfall was less than 250 mm per year and the flow through the invert was only a few times per year.

AISI Study

In 1978 the AISI made a survey of 81 storm sewers located in the states of Florida, Minnesota, South Dakota, Utah, California, Ohio, Indiana, North Carolina, Virginia, Maryland, and Kansas. The study showed that out of the 81 sites inspected, 77 were still in good condition. The age of the sewers ranged from 16 to 65 years. The four that needed maintenance work had an average age of 32 years. One was in an extremely corrosive environment; the resistivity was only 260 ohm-cm, well below recognized minimum values.

NCSPA/AISI Study

In 1986, the NCSPA, with the cooperation of the AISI, commissioned Corrpro Companies, Inc., a corrosion consulting firm located in Medina, Ohio, to conduct a condition and corrosion survey on corrugated steel storm sewer and culvert pipe. The installations investigated were located in 22 states scattered across the United States, and had ages ranging from 20 to 74 years. Soil resistivities ranged from 1326 to 77,000 ohm-cm, and the pH ranged from 5.6 to 10.3.

The study showed that the soil-side corrosion was relatively minimal on most of the pipes examined. Where significant interior corrosion was observed, it was typically limited to the pipe invert. Specific predictive guidelines were developed on a statistical basis. As observed by others, invert pavements can be provided, either factory or field applied, to provide significant additional durability. The data indicate that CSP systems can be specified to provide a service life of 100 years in a variety of soil and water conditions.

Canadian Studies

Many studies have been performed in Canada over the years. One of the earliest investigations was carried out by Golder in 1967. Examinations of CSP in Southwestern Ontario (London) confirmed that the California method was appropriate for predicting service life for local conditions. More recently (1993), British Columbia's Ministry of Transportation and Highways inspected 21 structural plate and galvanized bin-type retaining walls. The installations were all more than 20 years old, the oldest was installed in 1933. The test procedure called for 37 mm diameter coupons to be cut from the structures and be examined for coating thickness in the lab. The soil (and water, where appropriate) was tested for pH resistivity. The service life was estimated to exceed 100 years on all but two structures, abrasion had significantly reduced the service life of the two structures in question.

A very comprehensive study was conducted in the province of Alberta in 1988, inspecting 201 installations for zinc loss, measuring soil and water pH, resistivity as well as electrical potential between the pipe and the soil. The study generated one of the best technical databases to date. The report concluded that a minimum service life of 50 years would be achieved 83% of the time and the average life expectancy was 81 years. Where a longer life was required, a simple check of the site soil and water chemistry could confirm the average service life. Where site conditions indicated that this might be a problem, solutions such as thicker pipe walls or alternate coatings can be cost effective options.

DESIGN LIFE

The project design life of a roadway varies by province and municipality. Many agencies do not have specific requirements. Where a project design life is established, it depends upon the class of roadway and, to some extent difficulties anticipated with future growth, need changes and rehabilitation. Lives of 25 or 50 years are typical with longer design lives used in some cases.

The average service life of a culvert, as with other materials used in highway construction, does not need to meet the project design life. For example, pavements, bridge decks, etc. are often replaced or rehabilitated several times during the project life. The material selection for a culvert or storm sewer should recognize the overall economics including initial cost, maintenance and rehabilitation or replacement costs (see Chapter 9).

DURABILITY GUIDELINES

CSP With Only Metallic Coating

The original California method referred to previously was based on life to first perforation of an unmaintained culvert. However, the consequences of small perforations in a storm sewer are usually minimal. Therefore, the curves on the chart were converted by R. F. Stratfull to average service life curves, using data developed on weight loss and pitting of bare steel samples by the NIST (National Institute of Standards and Technology, formerly the National Bureau of Standards).

Figure 8.1 shows the resulting chart for estimating the average invert service life when designing CSP culverts and storm sewers. This chart, developed for 1.3 mm through 4.2 mm thickness pipe, is often used to determine the average service life for steel structural plate applications as well. Because of its 915 g/m^2 zinc coating, and steel thickness often greater than 4.2 mm, using Figure 8.1 for structural plate may be overly conservative. Where abrasive flow conditions are a factor, structural plate structures can have the invert plates increased in thickness. Arch structures, without an invert, alleviate abrasion concerns.

CSP With Protective Coatings and Pavings

Although there are other types of coatings and pavings, guidelines will only be given for the historically most common type (bituminous). Consult with CSP suppliers for specific information on other types. Polymeric coatings are often used instead of bituminous coatings.

1.Pipe Exterior. Under average conditions, an asphalt coating on the exterior of the pipe can be expected to add about 25 years to service life. Arid regions represent typical environments in which service life is based on the pipe exterior, but it should be remembered that such conditions tend to promote long service lives for pipe with only metallic coatings.

2.Pipe Interior. Invert paving is the preferred method of increasing service life in most cases. In the most common application, an asphalt paving is applied to the bottom 25 percent of the circumference of a round pipe over an asphalt coating. However, it must be realized that under severe abrasive conditions, such paving will erode rapidly. In those cases, a concrete paving can be engineered to meet service requirements. Table 8.3 gives the expected estimated life for an asphalt paved invert

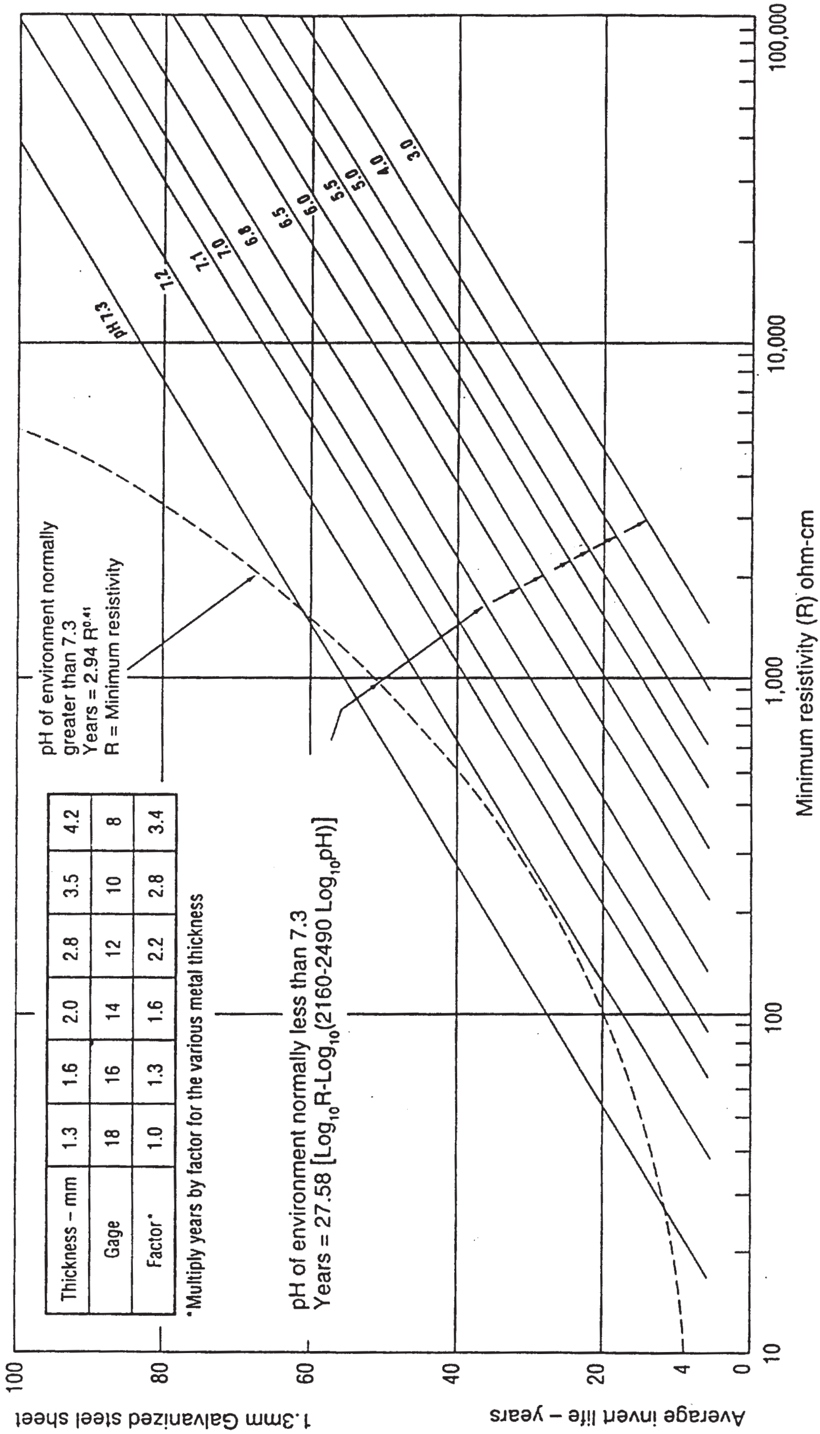


Figure 8.1 Average Service Life Prediction for CSP.

under average conditions as a function of pipe slope (from 1 to 4 percent) and abrasion conditions (characterized as either mild or significant). The added service life ranges from 35 to 15 years, depending on the conditions present.

Example of Durability Design

The following example illustrates the use of Figure 8.1 for designing a culvert project.

Pipe sizes are in the 1 to 3 meter range. Site investigation shows native soils to have a pH of 7.2 and a resistivity of 5,000 ohm-cm. Storm flow is estimated to have a pH of 6.5, a resistivity of 4,500 ohm-cm, and low abrasive conditions. Required average invert service life of the installation is 50 years.

Referring to Figure 8.1 the following life may be obtained for uncoated 1.3 mm thick pipe:

Outside condition 64 years
Inside condition 41 years (controls)
Required multiplier for increased thickness:
50 years/41 year = 1.22

Referring to the multiplier table in Figure 8.1 a metal thickness of 1.6 mm has a multiplier of 1.3, which is greater than the required value of 1.22. Therefore, a thickness of 1.6 mm is satisfactory.

All storm sewer materials and coatings can be degraded by abrasive flows at high velocity. If significant abrasive flow is indicated, a paved invert should be added.

Many different combinations of pipe and coating systems are possible. However, economic considerations will usually dictate the selection of no more than two or three allowable alternatives.

COATINGS FOR CSP

Galvanized steel is the material most used in the CSP industry. Other metallic coatings, and supplemental nonmetallic coatings, are also used for specific applications. The available coatings are described below.

Metallic Coatings

Sheet produced for the manufacture of CSP is supplied with one of the following coatings:

1. Galvanized sheet for CSP is produced in accordance with CSA G401, ASTM A929/A929M or AASHTO M36 with a coating weight of 610 g/m^2 of surface (total both sides). This material is produced on high speed, continuous coating lines with a high degree of uniformity of both coating weight and distribution. It is supplied by the steel producer to the pipe fabricator either as coils or as cut lengths. Continuous coating lines produce a product with a minimal iron/zinc alloy layer. This provides excellent coating adherence and allows forming and lockseaming without damage to the zinc coating. The thickness of the zinc is approximately 0.04 mm on each surface. Other galvanized coatings are also available with different zinc coating weights. Consult the fabricator for details.

2. Aluminum-zinc alloy coated sheet for CSP is in accordance with CSA G401, ASTM A929 / A929M or AASHTO M36. It is also produced on high speed lines. The coating weight is 214 g/m^2 of surface and the coating thickness is 0.03 mm on each surface.

3. CSA G401, ASTM A929 / A929M and AASHTO M-274 provide for the use of a pure aluminum coated product for CSP called Aluminum-coated Type 2. This material is produced on the same type of line as much of the galvanized product, and is furnished in coils and cut lengths. Aluminum coated Type 2 100 has a 305 g/m^2 coating weight. The coating thickness is approximately 0.05 mm on each surface.

Nonmetallic Coatings

CSP can be furnished with one of the following additional coatings to extend its service life:

1. The polymer coating used for CSP is applied as a film or laminate (polyethylene acrylic acid copolymer). This system is applied over the galvanized sheet described above. The polymeric coating is furnished in one grade: 10/10 [250/250]. The numbers designate the minimum coating thickness in mils (thousandths of an inch) and in µm (thousandths of a meter). This product is furnished to the requirements of CSA G401, ASTM A742 / A742M or AASHTO M-245.

Polymer Laminated CSP.

2. Pipe and plate can be post-coated in the plant or field after fabrication with a number of selected polymer materials to meet specific site requirements.

3. Post-coated pipe, where bituminous or concrete coatings or linings are applied to the pipe after fabrication, is produced according to CSA G401 and ASTM A 849.

Bituminous coating and paving, the oldest known system has been used for over 60 years. For enhanced soil-side protection, a coating only is often specified. For enhanced interior protection, a coating with invert paving is often specified. As an alternative to bituminous paving, concrete pavings can be engineered to provide required service life.

Supplier Information

For more specific information on available coatings, linings, and pavings, consult with CSP suppliers. Their experience can prove valuable, particularly when making life-cycle cost analyses, and is usually available upon request.

Table 8.3 Add-on service life for non-metallic coatings, in years

This chart is intended to provide guidelines in determining add-on service life for protective coatings applied to metallic coated CSP. Add-on service life will vary within environmental ranges.

Specific add-on values should be selected based on environmental conditions (abrasion, pH, and resistivity) and experience in comparable environments. Upper limits should be considered for the most favorable environmental conditions while low limits should be considered for the maximum abrasion level and most corrosive environments.

	Water Side		
COATING	Add-On Years	Maximum Abrasion Level	Soil Side Add-On Years
Asphalt Coated	2 - 20	2	25 - 50
Asphalt Coated and Paved	10 - 30	3	25 - 50
Polymerized Bituminous Invert Coated	15 - 40	3	N/A*
Polymer Precoated	25-100	3	50-100
Polymer Precoated and Paved	30-100	3	50-100
Concrete Invert Paved (75 mm cover) -- Notes 1, 2	25 -75	4	N/A

* Use Asphalt Coated values for fully coated product

Note 1: The abrasive resistance of the concrete lining is due to the high strength concrete used in the lining.
Note 2: The abrasive resistance of the concrete paving is due to the 75 mm depth of concrete cover over the steel.

Not all manufacturers in all regions supply these products. Consult the manufacturer

Abrasion Level 1: Non-Abrasive - No bedload.
Abrasion Level 2: Low Abrasion - Minor bedloads of sand and gravel and velocities of 1.5 m/s or less or storm sewer applications.
Abrasion Level 3: Moderate Abrasion - Bedloads of sand and gravel with velocities between 1.5 and 4.5 m/s.
Abrasion Level 4: Severe Abrasion - Heavy bedloads of gravel and rock with velocities exceeding 4.5 m/s.

Compaction parallel to pipe.

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