CHAPTER 8 Durability

INTRODUCTION

Corrugated steel pipe (CSP) has been used successfully since 1896 for storm sewers and culverts throughout the United States and 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 [1,2]. 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 for the waterside 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 non-metallic protective coatings available for CSP storm sewers concludes this chapter.

FACTORS AFFECTING CSP DURABILITY

Durability in Soil

The durability of steel pipe in soil is a function of several interacting parameters including soil resistivity, acidity (pH), moisture content, soluble salts, oxygen content (aeration), and bacterial activity[3, 4, 5]. However, all of the corrosion processes involve the flow of current from one location to another (a corrosion cell). Thus, the higher the resistivity and/or lower the soil moisture content, the greater the durability. Table 8.1 lists typical ranges of resistivity values for the primary soil types[6].

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[7]. 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[8].

Table 8.1 Typical soil resistivities[6]

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[8]

Soil type	Description of soil	Aeration	Drainage	Color	Water Table
I Lightly 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 Badly corrosive	1. Clay loams 2. Clays	Poor	Poor	Heavy texture Moderate mottling	600 mm to 900 mm (2 to 3 ft) below surface
IV Unusually 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

Durability in Water

There is little difference in the durability of steel in still 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[9]. The influence of dissolved gases is probably the most important factor here. 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 films that frequently develop on pipe surfaces, particularly in hard waters. Dissolved salts can increase durability by decreasing oxygen solubility, but can increase corrosion if they ionize and decrease resistivity.

Field studies have shown that the portion the pipe most susceptible to corrosion is the invert[10, 11, 12]. This should not be surprising because the invert 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 the corrosivity of water[13,14].

Plain galvanized CSP satisfied service life requirements for storm drains in this environment.

Resistance to Abrasion

In most cases, storm sewers tend to have modest slopes and do not have a bedload present to experience any significant abrasion problems. However, abrasion can become significant where flow velocities are high, over about 5 m/s (15 ft/s) and bedload is present. 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. In most cases, abrasion level 2 as defined in this chapter, should be used for service life prediction. 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 state, federal, and industry investigators and now provide a wealth of accumulated information.

State Studies

California surveyed the condition of pipe at hundreds of locations and developed a method to estimate life based on pH and resistivity1[15, 16]. A design chart derived from this work will be presented subsequently. Investigations in Florida[17], Louisiana[18], Idaho[19], Georgia[20], Nebraska[21], and Kansas[22] 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 indicated that the method might be too liberal in those regions because of the prevalence of soft water. A more recent study has been conducted by Vermont[23].

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. Its generally conservative nature for storm sewer applications can be judged by reviewing the basis of the study.

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. Thus, the method should be conservative for storm sewers where the effects of abrasion are modest.

Where the pH was greater than 7.3, the study was based on pipes in the semi-arid and desert areas in the southern part of California[16]. Durability under those conditions, which was generally excellent, would be dominated by soil-side corrosion because the average rainfall was less than 250mm (10 in.) 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.

Joining factory made CSP into large structural plate storm drain.

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 have ages ranging from 20 to 74 years. Soil resistivities range from 1326 to 77000 ohm-cm, and the pH ranges from 5.6 to 10.3. Both galvanized and asphalt-coated pipes are included.

The study[24], 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 have been developed on a statistical basis. As observed by others, invert pavements and coatings 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. Examination 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 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 (1½ in.) 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 and resistivity. The service life was estimated to exceed 100 years on all but two structures.

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 design 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.

COATINGS FOR CORRUGATED STEEL PIPE

All corrugated steel pipes have a metallic coating for corrosion protection. When the metallic coating selected does not provide the required service life, a different non-metallic coating and/or paving can be added. Often the required service life can also be achieved by increasing the steel pipe wall thickness; this alternative should be weighed against the cost of supplemental coatings. Galvanizing is the most widely used metallic coating and is the basis for the service life Chart shown in Figure 8.3.

Metallic Coatings

Zinc-coated (Galvanized) Steel (AASHTO M36, ASTM 929) is produced with a coating weight of 610 g/m^2 (2 oz/ft^2) of surface (total both sides) to provide zinc coating thickness of 43 mm (0.0017 in.) on each surface.

Aluminum Coated Type 1 (AASHTO M36, ASTM 929) is an aluminum coating with 5 to 11% silicon. It is produced with a coating weight of 305 g/m^2 (1 oz/ft^2) of surface (total both sides) to provide a coating thickness of 48 mm (0.0019 in.) on each surface. **Aluminum Coated Type 2** (AASHTO M274, ASTM 929) is a pure aluminum coating (no more than 0.35% silicon). It is produced with a coating weight of 305 g/m^2 (1 oz/ft^2) of surface (total both sides) to provide a coating thickness of 48 mm (0.0019 in.) on each surface.

Non-Metallic Coating and Pavings

Asphalt Coated (AASHTO M190, ASTM A849). An asphalt coating is applied to the interior and exterior surface of the pipe with a minimum thickness of 1.3 mm (0.05 in.) in both fully coated and half coated.

Invert Paved with Asphalt Material (AASHTO M190, ASTM A849). A asphalt material is used to fill the corrugations and provide a minimum thickness 3.2 mm (1/8 in.) above the crest of the corrugations for at least 25% of the circumference of round pipe and 40% of the circumference for pipe arch.

Invert Paved with Concrete Material (ASTM A849, ASTM A979). A 75 mm (3 in.) thick high strength concrete layer is placed in the installed pipe for at least 25% of the circumference of round pipe and 40% of the circumference for pipe arch.

Fully Lined with Asphalt Material (ASTM A849). An asphalt material is used to fill the corrugations and provide a minimum thickness 3.2 mm (1/8 in.) above the crest of the corrugations providing a smooth surface over the entire pipe interior.

Fully Lined with Concrete Material (ASTM A849, ASTM A979). A high strength concrete material is used to fill the corrugations and provide a minimum thickness 3.2 mm (1/8 in.) above the crest of the corrugations providing a smooth surface over the entire pipe interior.

Invert Coated with Polymerized Asphalt Material (ASTM A849). A polymer modified asphalt material is used to provide a minimum thickness 1.3 mm (0.05 in.) for at least 25% of the circumference of round pipe and 40% of the circumference for pipe arch.

Invert Paved with Polymerized Asphalt Material (ASTM A849). A polymerized asphalt material is used to fill the corrugations and provide a minimum thickness 1.3 mm (0.05 in.) above the crest of the corrugations for at least 25% of the circumference of round pipe and 40% of the circumference for pipe arch.

Polymer Precoated (AASHTO M245, ASTM A742). Typically film applied laminates over protective metallic coatings. The 10/10 grade (10 mils thickness, each side) is the primary product used.

Aramid Fiber Bonded Asphalt Coated (ASTM A885). Provides an aramid fiber fabric embedded in the zinc coating while it is still molten, which improves bonding to the asphalt coating.

PROJECT DESIGN LIFE

The question often arises as to what project life to use for designing a storm sewer system. In a survey of 14 cities in the southeastern United States, appropriate agencies were asked, “In designing storm sewer systems, what life and use expectancy is used?” Of the total, 71 percent responded that 50 years or less was acceptable for storm sewer life[25]. Obviously, excessively long design lives are undesirable as they tend to inflate the initial cost and ignore the possibility of function obsolescence.

DURABILITY GUIDELINES

Coating selection and service life prediction can be determined using the Durability Guidelines below. Product Usage Guidelines in Figure 8.1 should be considered as general guidance when considering coatings for specific environments and should be used in conjunction with the Environmental Ranges and the Environmental Guidelines that follow.

Figure 8.1 Product Usage Guidelines for CSP

COATING	Normal Conditions	Mildly Corrosive	Corrosive	Provides Add’l Soil Side Protection	Non-Abrasive Level 1	Low Abrasion Level 2	Moderate Abrasion Level 3	High Abrasion Level 4
Zinc Coated (Galvanized)	(see Fig. 8.3)							
Aluminum Coated Type 1								
Aluminum Coated Type 2								
Asphalt Coated								
Asphalt Coated & Paved								
PolymerIzed Asphalt Invert Coated*								
Polymer Precoated								
Polymer Precoated and Paved								
Aramid Fiber Bonded Asphalt Coated								
Aramid Fiber Bonded & Asphalt Paved								
High Strength Concrete Lined								
Concrete Paved Invert (75mm (3”) Cover)								

*Use Asphalt Coated Guidelines for Fully Coated Product

Notes:

1. This Guide provides environmental ranges for CSP products. Service Life of CSP will vary within these ranges. Refer to the Service Life Prediction section in this chapter for estimating average invert service life or the Durability chapters of the AISI publication *Handbook of Steel Drainage & Highway Construction Products* or the *Modern Sewer Design.*
2. The environmental ranges shown below for Aluminum Coated Type 1 are recommendations from manufacturer Wheeling-Nisshin and the ranges for Aluminum Coated Type 2 are recommendations from manufacturer AK Steel.
3. This Guide is not a substitute for professional engineering advice and is made without guarantee or representation as to results. Although every reasonable effort has been made to assure its accuracy, neither the National Corrugated Steel Pipe Association nor any of its members or representatives warrants or assumes liability or responsibility for its use or suitability for any given application.

Environmental Ranges

- Normal Conditions: pH = 5.8 – 8.0 for R > 2000 ohm-cm
- Mildly Corrosive: pH = 5.0 – 5.8 for R > 1500 ohm-cm
- Corrosive: pH < 5.0 for R < 1500 ohm-cm

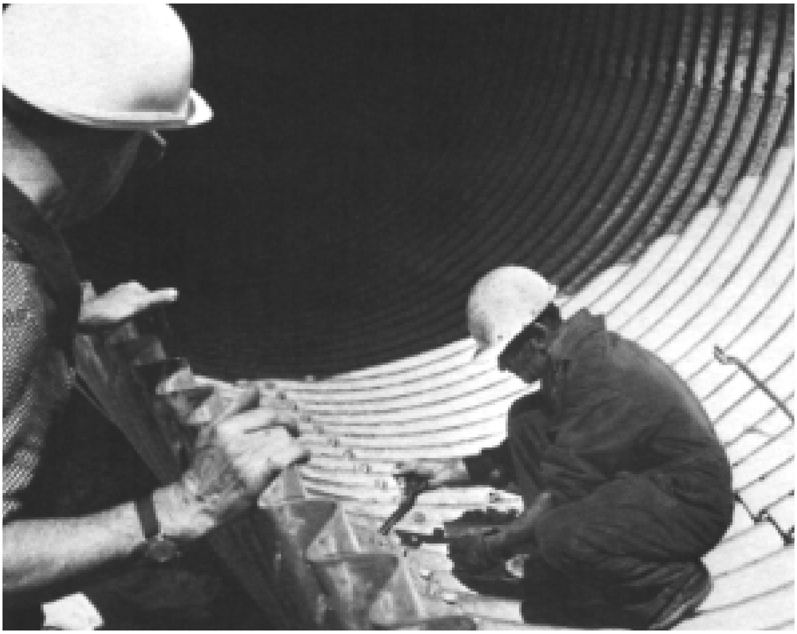
Metallic Coated Ranges:

- Zinc Coated (Galvanized): pH = 5.8 – 10.0 for R = 2000 – 10,000 ohm-cm
  pH = 5.0 – 12.0 for R > 10,000 ohm-cm
- Aluminum Coated Type 1: pH = 5.0 – 9.0 for R > 1500 ohm-cm
- Aluminum Coated Type 2: pH = 5.0 – 9.0 for R > 1500 ohm-cm

Abrasion:

Invert Protection/Protective Coatings can be applied in accordance with the following criteria. Abrasion velocities should be evaluated on the basis of frequency and duration. Consideration should be given to mean annual discharge ($Q_{2.33}$) or less for velocity determination.

- Level 1: Non-Abrasive – No bedload.
- Level 2: Low Abrasion – Minor bedloads of sand and gravel and velocities of 1.5 m/s (5 ft/s) or less or storm sewer applications.
- Level 3: Moderate Abrasion – Bedloads of sand and gravel with velocities between 1.5 and 5 m/s (5 and 15 ft/s).
- Level 4: Severe Abrasion – Heavy bedloads of gravel and rock with velocities exceeding 5 m/s (15 ft/s).



Construction crew assembling structural plate pipe.

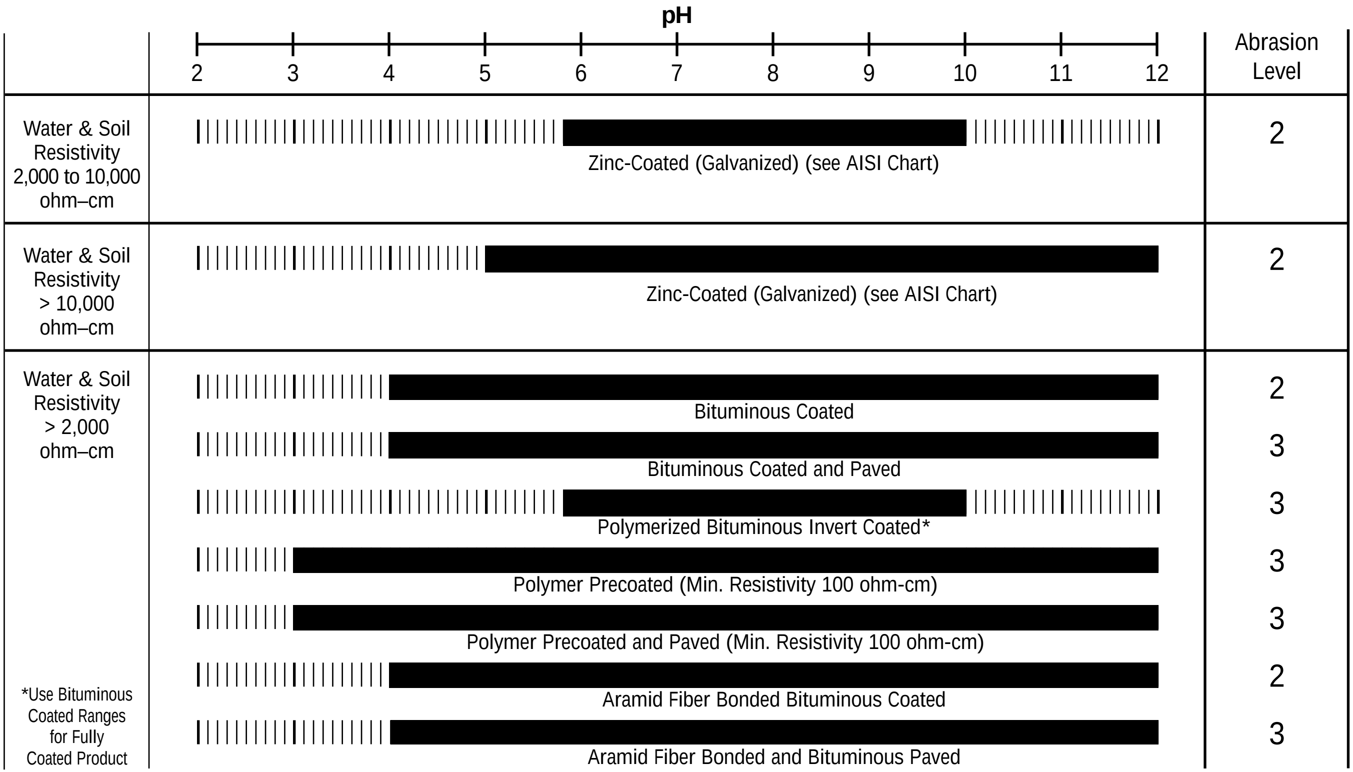
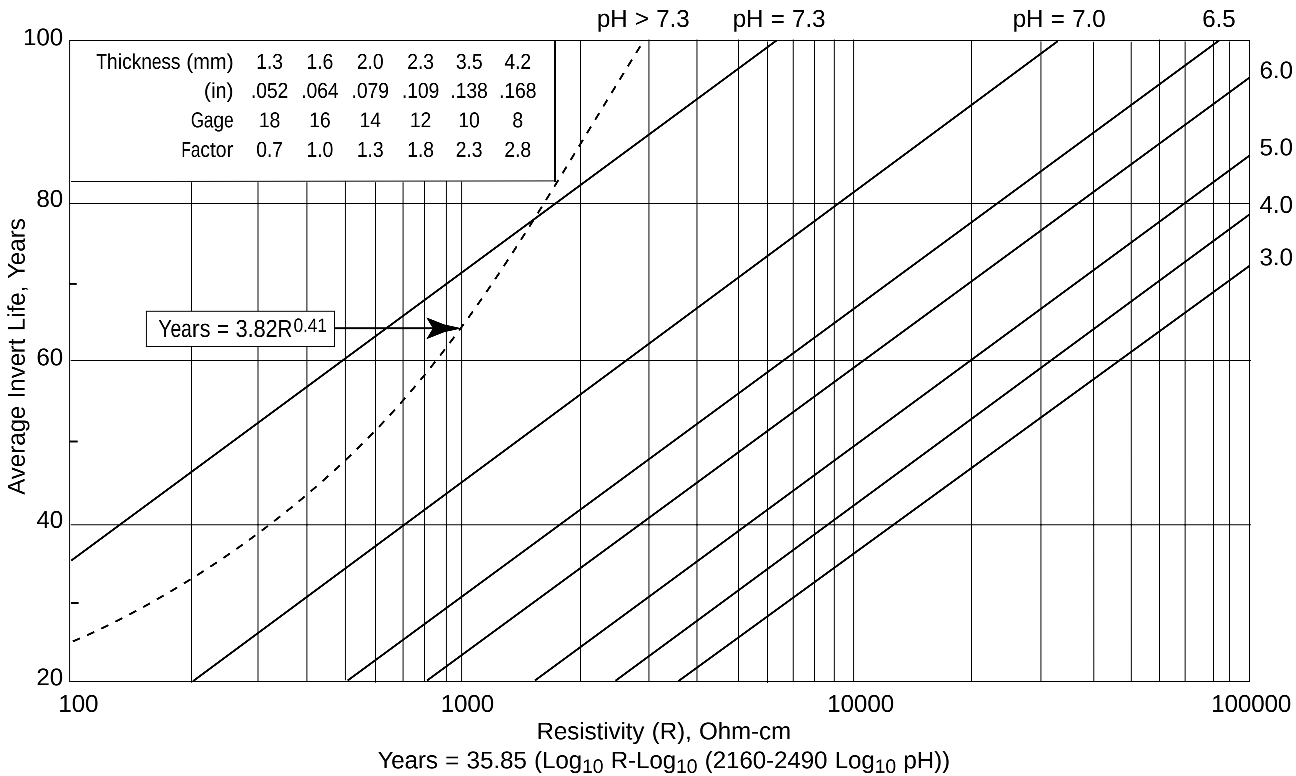


Figure 8.2 Environmental Guidelines for Corrugated Steel Pipe



Thickness (mm)	1.3	1.6	2.0	2.3	3.5	4.2
(in)	.052	.064	.079	.109	.138	.168
Gage	18	16	14	12	10	8
Factor	0.7	1.0	1.3	1.8	2.3	2.8

Figure 8.3 AISI Chart for Estimating Average Invert Life for Galvanized CSP

AISI Method for Service Life Prediction

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)[10].

Figure 8.3 provides the resulting chart for estimating the average invert service life for CSP storm sewers. The chart limits useful service life to a 25% metal loss Even with a minimum design factor of safety, this provides a structural factor of safety of 1.5 at the end of the average service life.

The calculations used to convert the original chart to an average service life chart were conservative because they were based on corrosion rates for bare steel. The same data set showed that galvanized specimens corrode at a much lower rate.

Steps in Using the AISI Chart

This durability design chart can be used to predict the service life of galvanized CSP and to select the minimum thickness for any desired service life. Add-on service life values are provided in Table 8.4 for additional coatings.

1) Locate on the horizontal axis the soil resistivity (R) representative of the site.
2) Move vertically to the intersection of the sloping line for the soil pH. If pH exceeds 7.3 use the dashed line instead.
3) Move horizontally to the vertical axis and read the service life years for a pipe with 1.6 mm (0.064 in.) wall thickness.
4) Repeat the procedure using the resistivity and pH of the water; then use whichever service life is lower.
5) To determine the service life for a greater wall thickness, multiply the service life by the factor given in the inset on the chart.

Additional Service Life

Additional service life can be provided by increasing the thickness of the base steel in accordance with the factors shown in the Chart for Estimating Average Invert Service Life or with the use of additional coating systems. Add-on service life values are provided in the Table 8.4.

Table 8.3 Minimum Service Life for Metallic Coatings (in AISI multipliers)

Coating	Water Side		Soil Side	Notes
	AISI Factor	Maximum Abrasion Level		
Zinc Coated (Galvanized)	1.0	2	1.0	Note 1
Aluminum Coated Type 1	Note 2	Note 2	Note 2	Note 2
Aluminum Coated Type 2	1.3 min	2	1.3	Note 3

Notes:

1. See AISI Chart on page 232 for service life prediction for 610 g/m^2 (2 oz/ft^2) zinc coating.
2. Accelerated independent laboratory tests have shown similar performance to other metallic coatings however there is insufficient in-ground service to accurately predict field performance.
3. The factor shown for Aluminum Coated Type 2 represents a multiplier to be applied to the service life predicted for galvanized pipe using the AISI Chart on page 232. Values will vary within the environmental ranges.

Table 8.4 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, resistivity, and soil moisture content) and experience in comparable environments. Upper limits should be considered for the most favorable environmental conditions (non-abrasive, high pH and resistivity) while low limits should be considered for the maximum abrasion level and most corrosive environments.

Table 8.4 Add-On Service Life for Non-Metallic Coatings, in years

	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 Asphalt Invert Coated	15 - 40	3	N/A*
Polymer Precoated	20 - 70	3	50 - 75
Polymer Precoated and Paved	30 - 80	3	50 - 75
Aramid Fiber Bonded Asphalt Coated	15 - 50	2	30 - 50
Aramid Fiber Bonded and Asphalt Paved	20 - 60	3	30 - 50
High Strength Concrete Lined — Note 1	25 - 75	3	N/A
Concrete Invert Paved (75mm (3 in.) cover) — Notes 1, 2	25 - 75	4	N/A

*Use Asphalt Coated values for fully coated product

Notes:

1. The abrasive resistance of the concrete lining is due to the high strength concrete used in the lining.
2. The abrasive resistance of the concrete paving is due to the 75mm (3 in.) depth of concrete cover over the steel.

EXAMPLE OF DURABILITY DESIGN

The following example illustrates the use of Figure 8.3 for designing a storm sewer project.

Pipe sizes are in the 900 to 2400 mm (36 to 96 in.) range. Site investigation shows native soils to have a pH of 7.2 and a resistivity of 5000 ohm-cm. Storm flow is estimated to have a pH of 6.5, a resistivity of 4500 ohm-cm, and low abrasive conditions. Required service life of the installation is 50 years.

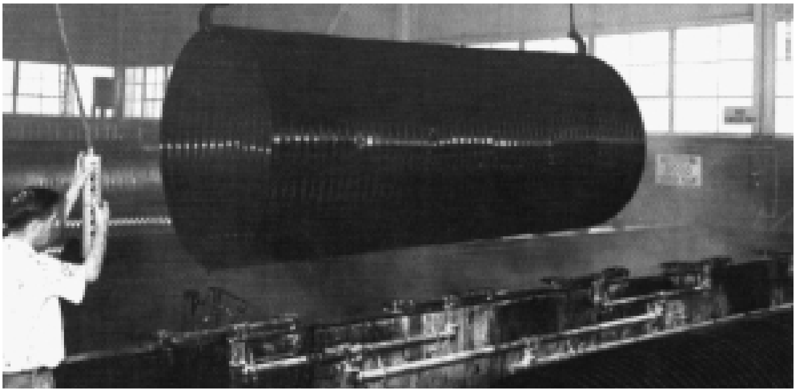
Referring to Figure 8.3, the following life may be obtained for galvanized 1.63 mm (.064 in.) thick pipe:

Outside condition . . . . .85 years
Inside Condition . . . . 55 years (controls)

Therefore, a thickness of 1.63 mm (.064 in.) is satisfactory.

All storm sewer materials and coatings can be degraded by abrasive flows at high velocity. If significant abrasive flow is indicated or additional service life is desired, an appropriate coating or invert treatment 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.



Asphalt coating corrugated steel pipe.

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Well points and wide trenches were necessary to install full-bituminous coated and full-paved CSP in this unstable ground.