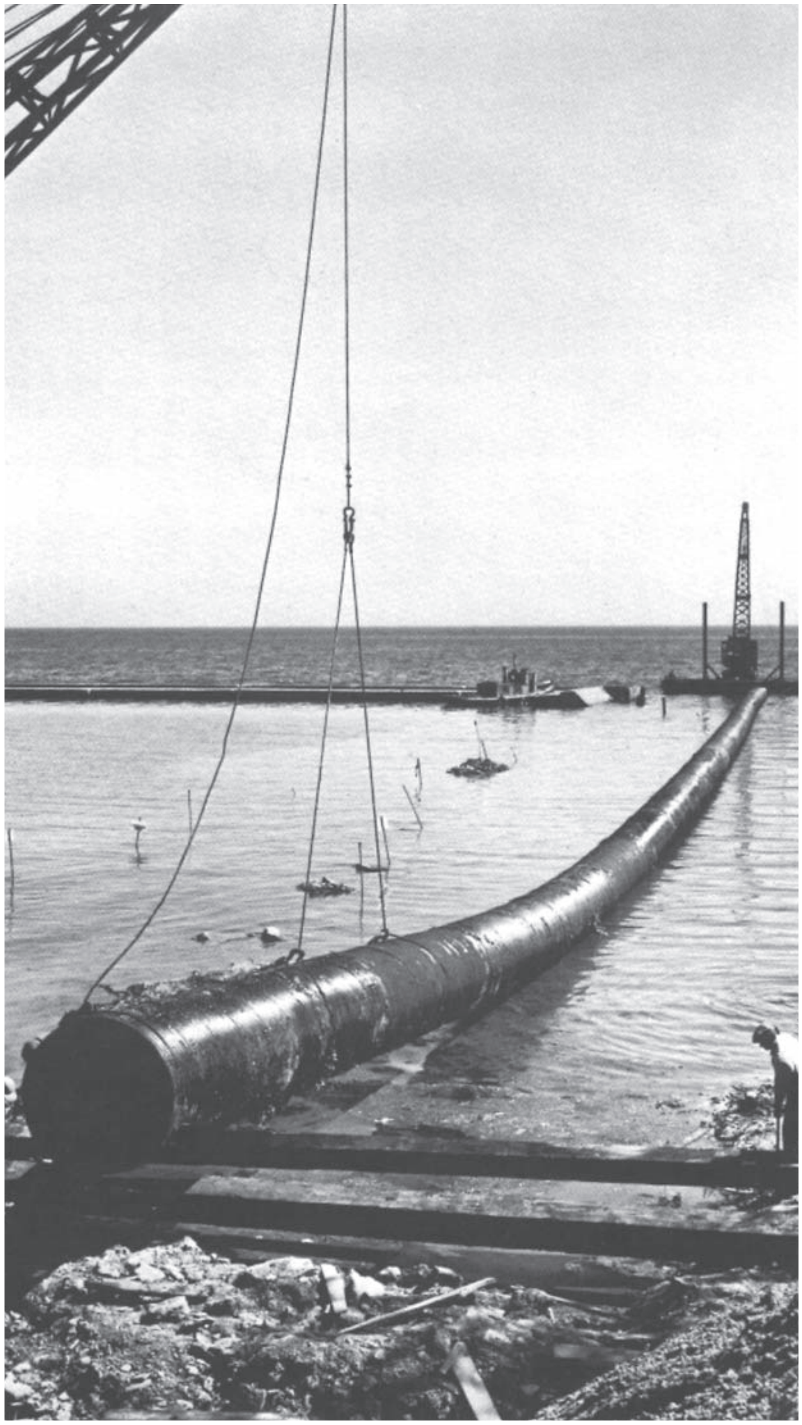


Installing subaqueous corrugated steel sewer pipe.

CHAPTER 8 Durability

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 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 metal 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, 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).

Durability in Water

There is little difference in the durability of steel in 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 (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 of 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).

Resistance to Abrasion

In many cases, storm sewers tend to have modest slopes and do not experience significant abrasion problems. However, abrasion can become significant where flow velocities are high (over about 5 m/s). 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 state, federal, and industry investigators and now provide a wealth of accumulated information.

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

Joining factory made CSP to large structural plate storm drain.

State Studies

California surveyed the condition of pipe at hundreds of locations and developed a method to estimate life based on pH and resistivity (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 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 have ages ranging from 20 to 74 years. Soil resistivities range from 1326 to 77,000 ohm-cm, and the pH ranges from 5.6 to 10.3. Both bare 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 are being 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 indicates 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 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 acheived 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 chemisty 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.

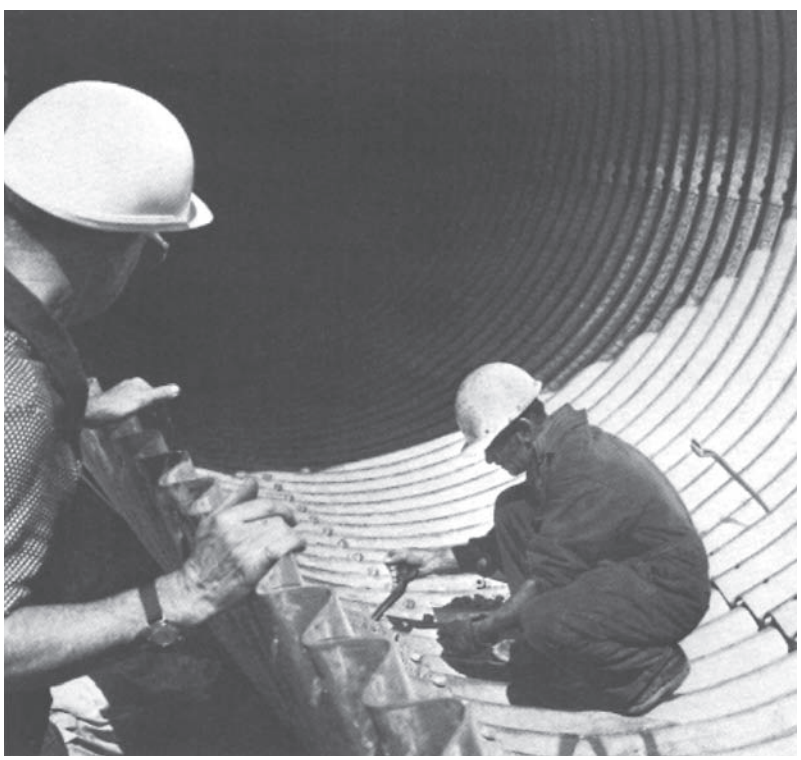
PROJECT DESIGN LIFE

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.

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) (3, 4).



Construction crew assembling structural plate pipe.

Figure 8.1 shows the resulting chart for estimating the average invert service life when designing CSP storm sewers. The chart assumes that a metal loss of 25 percent in the invert is a reasonable value to limit service life. Only about 13 percent average metal loss occurs at first perforation, based on the calculations with the NIST data. This results in a 2 to 1 ratio between the service life and the time to first perforation.

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.

CSP with Protective Coatings and Pavings

Although there are other types of coatings and pavings, guidelines will only be given for the 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, a bituminous 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, a bituminous paving is applied to the bottom 25 percent of the circumference of a round pipe, often over a bituminous coating.

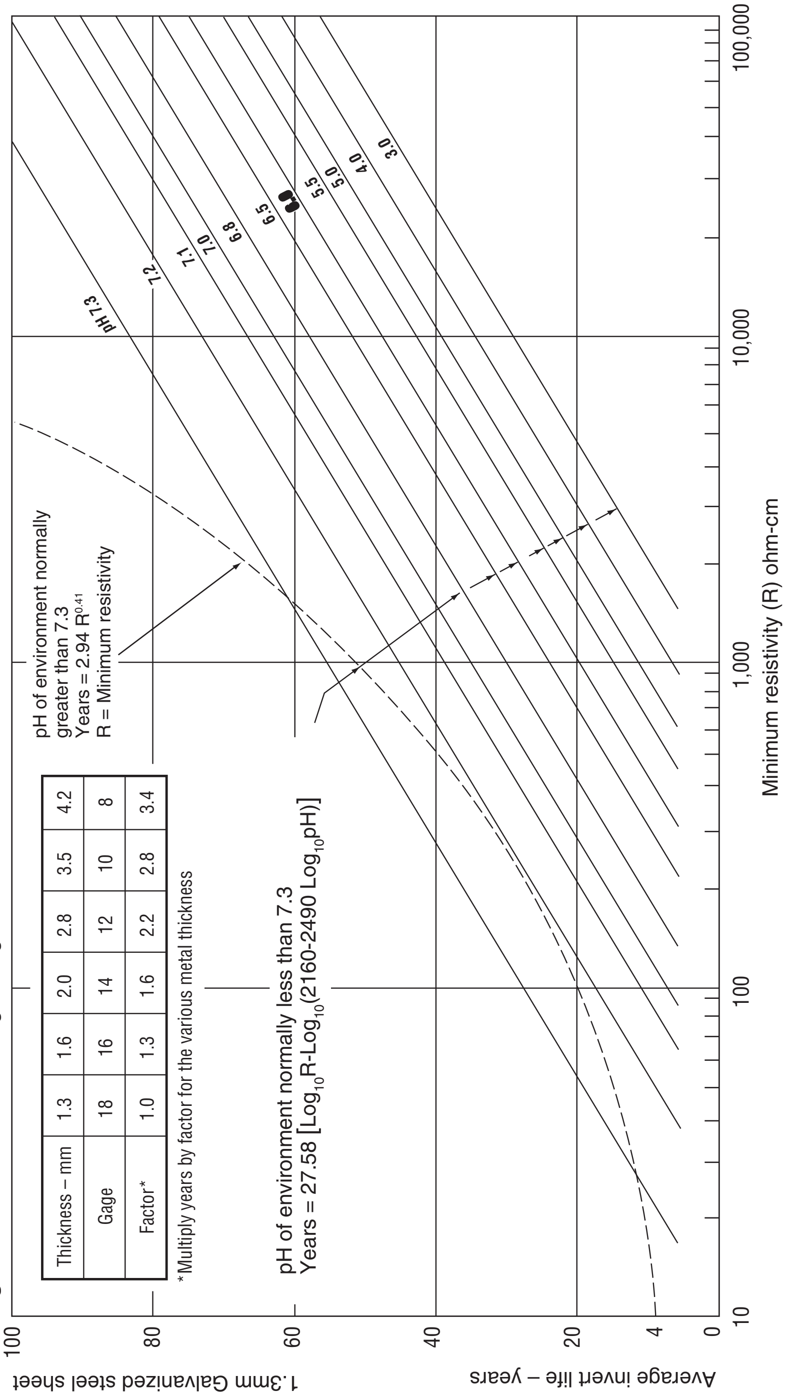
Table 8.3 gives the expected estimated life for a bituminous paved invert under average conditions as a function of pipe slope (from 1 to 4 percent) and abrasion conditions (characterized as either mild or significant). The added service life ranges from 35 to 15 years, depending on the conditions present.

EXAMPLE OF DURABILITY DESIGN

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

> Pipe sizes are in the 900 to 2400 mm 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)

Figure 8.1 Chart for estimating average invert life of uncoated storm sewers.



Thickness – mm	1.3	1.6	2.0	2.8	3.5	4.2
Gage	18	16	14	12	10	8
Factor*	1.0	1.3	1.6	2.2	2.8	3.4

*Multiply years by factor for the various metal thickness

Required multiplier for increased thickness:

50 years/41 years = 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 STORM SEWERS

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.

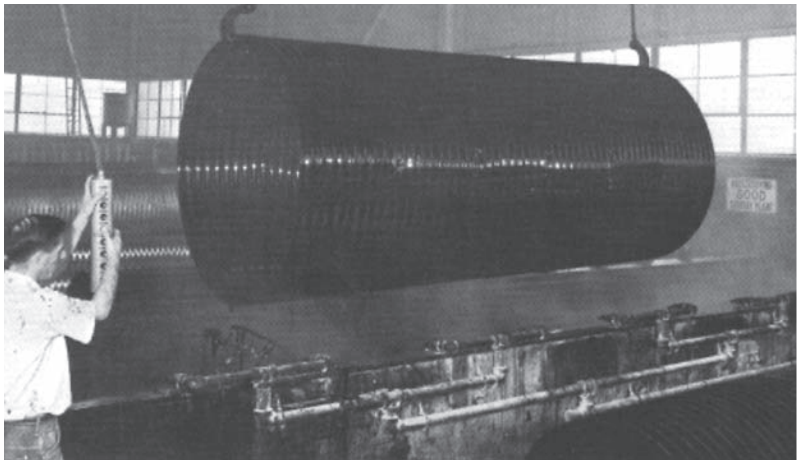
Sheet produced for the manufacture of CSP is supplied with one of the following coatings:

1. Galvanized sheet for CSP is produced in accordance with ASTM A444 or AASHTO M-218 with a coating weight of 610 grams per square metre of sheet (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.
2. Aluminum-zinc alloy coated sheet for CSP is produced in accordance with ASTM A 806 and AASHTO M-289. It is also produced on high speed lines. The coating weight is 214 grams per square metre of sheet and the coating thickness is 0.03 mm on each side.
3. ASTM A 806 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. Furnished in coils and cut lengths, Aluminum-coated T2 100 has a 305 grams per square metre coating weight. The coating thickness is approximately 0.05 mm on each surface.

Non-metallic Coatings

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

1. There are several varieties of polymer coatings used for CSP, in cluding those applied as a film (ethylene acrylic) or as a liquid dispersion (polyvinyl chloride plastisol). These systems are applied over any of the metallic coatings mentioned above. Polymeric coatings are furnished in three grades; $^{250}/_{0}$, $^{250}/_{25}$, and $^{250}/_{250}$ where the number designates the coating thickness in micrometres (µm). The $^{250}/_{250}$



Bituminous coating corrugated steel pipe.

grade is generally the only product used today. These products are furnished to the requirements of ASTM A 762M or AASHTO M-245.

2. A fiber-bonded material is produced according to ASTM A 885 on a continuous zinc coating line by embedding an aramid nonwoven fabric into the molten zinc as the strip leaves the coating pot. This material is furnished in coils or uncurved corrugated sheets for subsequent forming into pipe. The fabric provides a bonding medium for subsequently applied asphalt coatings.
3. Post-coated pipe, where bituminous coatings or linings are applied to the pipe after fabrication, is produced according to ASTM A 849. Bituminous coating and paving, the oldest known system, has been used for over 60 years. For enhanced soil-side protection, coating only is often specified. For enhanced interior protection, coating with invert paving is often specified.

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 (26, 27, 28, 29), and is usually available upon request.

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	Colour	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 colour	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	600mm to 900mm 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

Table 8.3 Years of life added to structures with bituminous paved invert

Slope of pipe	Abrasion	Added years
Less than 1%	Mild	35
	Significant	25
1%-2%	Mild	30
	Significant	20
3%-4%	Mild	25
	Significant	20
Greater than 4%	Mild	20
	Significant	15

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