NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE

# 50

# DURABILITY OF DRAINAGE PIPE

TRANSPORTATION RESEARCH BOARD
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE **50**

# DURABILITY OF DRAINAGE PIPE

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:
HIGHWAY DRAINAGE
GENERAL MATERIALS

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1978

## NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

## NCHRP Synthesis 50

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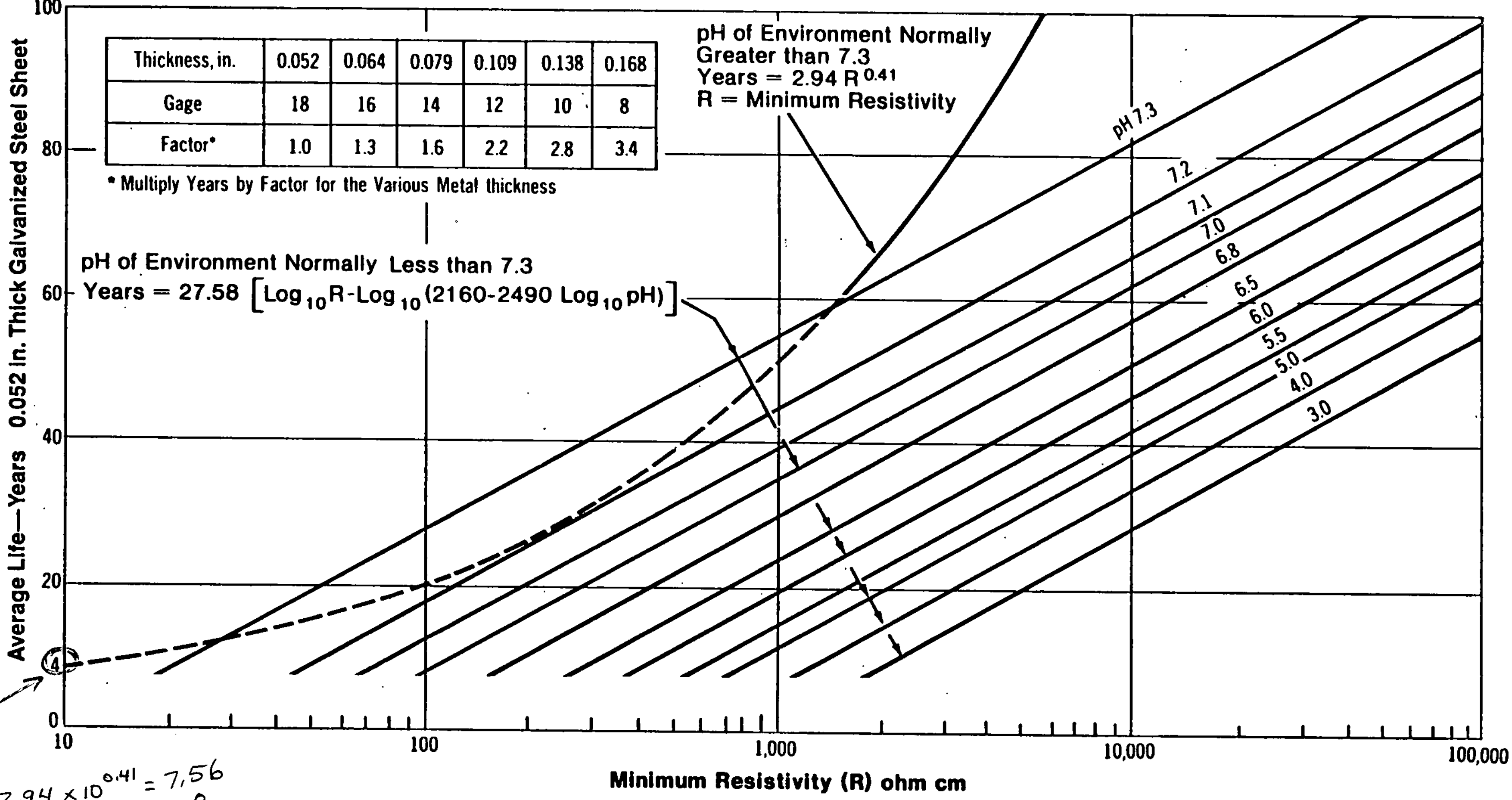
Figure 5-4
CHART FOR ESTIMATING AVERAGE LIFE OF PLAIN GALVANIZED CULVERTS



| Thickness, in. | 0.052 | 0.064 | 0.079 | 0.109 | 0.138 | 0.168 |
|---|---|---|---|---|---|---|
| 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

$2.94 \times 10^{0.41} = 7.56$
or 8

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## PREFACE

There exists a vast storehouse of information relating to nearly every subject of concern to highway administrators and engineers. Much of it resulted from research and much from successful application of the engineering ideas of men faced with problems in their day-to-day work. Because there has been a lack of systematic means for bringing such useful information together and making it available to the entire highway fraternity, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize the useful knowledge from all possible sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series attempts to report on the various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which they are utilized in this fashion will quite logically be tempered by the breadth of the user's knowledge in the particular problem area.

## FOREWORD

*By Staff*
*Transportation*
*Research Board*

This synthesis will be of special interest and usefulness to design and materials engineers and others seeking information on corrosion and abrasion of drainage pipe. Durability guidelines are presented to permit selection of appropriate pipe materials for given design conditions.

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Administrators, engineers, and researchers are faced continually with many highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information often is fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem frequently is not assembled in seeking a solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of synthesizing and reporting on common highway problems. Syntheses from this endeavor constitute an NCHRP report series that collects and assembles the various forms of information into single concise documents pertaining to specific highway problems or sets of closely related problems.

Design of drainage pipe involves recognition of a number of factors, including hydraulic, hydrologic, and structural considerations as well as material availability and durability. This Transportation Research Board report deals with material durability; that is, the ability of drainage pipe to endure the processes of corrosion and abrasion. It does not address structural durability, which reflects the ability to withstand fatigue stresses and strains generated by loads on the pipe. Total durability, necessary for satisfactory service life, relies on the interdependence of material and structural durability.

Available findings from field and laboratory studies carried out in about one-half of the states on corrosion and abrasion of drainage pipe are reviewed, evaluated, and summarized in this report. The report recommends that guidelines for selection of pipe materials should be developed or modified, based on local conditions, and that meaningful information on durability can be obtained from the performance of pipe materials subjected to closely similar environmental conditions.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researchers in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

# CONTENTS

## ACKNOWLEDGMENTS

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William G. Gunderman, Engineer of Materials and Construction, Transportation Research Board, and Lawrence F. Spaine, Engineer of Design, Transportation Research Board, assisted the Special Projects Staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies and by industry associations. Their cooperation and assistance were most helpful.

# DURABILITY OF DRAINAGE PIPE

## SUMMARY

Drainage pipes, although an important part of a transportation facility, are largely unseen. Natural processes of corrosion, abrasion, and erosion are the principal nonstructural factors that affect durability; such processes can deteriorate and destroy culvert and storm-drain material of all types. However, proper analysis of soil and water at the drainage site and its watershed can form the basis for selection of materials and types of pipe that should have the required service life.

Corrosion is the deterioration or dissolution of or destructive attack on a material by chemical or electrochemical reaction with its environment. The main corrosion medium affecting drainage facilities is water and the chemicals dissolved in or transported by water. Metal corrosion is an electrical process involving an electrolyte (moisture), an anode (the metallic surface where oxidation occurs), a cathode (the metallic surface that accepts electrons and does not corrode), and a conductor (the metal pipe itself).

Erosion or abrasion is the wearing or grinding away of material by water laden with sand, gravel, or stones. Often erosion or abrasion acts with corrosion to produce greater deterioration than either would by itself.

Field and laboratory tests have been used to predict deterioration rates for a given environment. Corrosion indicators used include pH of soil and water, soil resistivity or conductivity, polarization curves, oxidation-reduction potential, soil chemical and physical properties, precipitation, and stream-flow velocities.

Materials used for drainage pipe include steel, aluminum, concrete, vitrified clay, stainless steel, cast iron, and plastic. Pipe protection measures include extra material thickness, coatings of various types, linings, and cathodic protection.

Detection of corrosion-abrasion deterioration in culverts requires periodic inspection. In less corrosive environments, field inspection may be conducted at intervals of ten years or more. Culverts in more aggressive environments should be examined at least every three years, and more often if already heavily corroded or abraded. Properly trained and equipped inspectors should determine the nature of electrolyte; flow rate and bedload; soil and water resistivity and pH; location, extent, and type of corroded areas; measurements of thickness and thickness loss; and preventive measures used and reasons for deficiencies or failures. A rating system may be helpful in evaluating drainage pipes, and adequate records of all inspections should be kept.

Maintenance and repair are required in order for drainage pipes to continue to meet hydraulic and structural requirements. Because there are a wide variety of corrosion-abrasion causes and combinations thereof, there is also a broad assortment of repair techniques. These should be carefully analyzed from standpoints of

practicality, compatibility with the existing installation, prospective performance, and economics.

One way of defining culvert service life is by the years of relatively maintenance-free performance. Service life of culvert materials has been evaluated in several types of studies. Field performance studies have been done, and, as future experience is accumulated, accuracy in predicting service life will improve. Field prototype tests under aggressive environments can be used with corrosion indicators to predict corrosion rates. Laboratory tests of material samples can give some idea of corrosion rates, although such tests do not reproduce the exact effects found in the field. Analytical methods, used by several agencies, are based on performance studies of existing culverts and can be used readily for a given material to select culverts (and protection measures) that have the required service life for a specific condition. However, analytical methods do not enable selection of one of the several alternative materials and methods that may be appropriate for the conditions.

In the location, design, construction, and maintenance of culverts, one should keep in mind the following principles:

- Soils testing programs should obtain soil and water information for laboratory culvert durability evaluation.
- Consideration should be given to future changes in land and water use that could affect corrosion-abrasion rates (urbanization, industrialization, mining, shift from forest to agricultural use, etc.).
- Contract proposals, if service-life predictions are equal, should include other pipe materials as contractor's options or alternative bid items.
- Galvanic couples should be avoided (such as aluminum extensions in contact with steel pipe).
- Clean sand, crushed stone, or gravel for culvert bedding and backfill should be considered where in-situ soils might be corrosive. Precautions must be taken to prevent seepage or piping in such sands and gravels.
- Materials that may cause corrosion must be removed from drainage trenches and from material used for bedding and backfill.
- Obstructions within culverts that may accumulate debris or block flow should be cleared.
- Access for personnel and equipment should be provided to permit periodic maintenance and inspection.

Selection of an anticorrosion system is based on technical factors; however, the final decision on material type and protection measures also depends on economic considerations. A selection procedure would include:

1. Hydrologic and hydraulic considerations.
2. Structural considerations.
3. Availability and suitability of pipe types and sizes for the site.
4. Durability of the commonly used drainage materials that are satisfactory for the first three steps.

CHAPTER ONE

# INTRODUCTION

## THE PROBLEM

Drainage facilities, although largely unseen, are an important and integral part of any highway or other transportation facility and are responsible for about 10 percent of the total cost. Normally they receive infrequent inspection, except during and following floods or abnormally heavy rainfalls. During these periods, the operational problems of drainage facilities can disrupt traffic and can damage or destroy highways or railways. Less spectacular, but in many cases as troublesome and as costly to prevent or remedy, are the effects of corrosion, abrasion, and erosion on drainage facilities. These processes can deteriorate and destroy all commonly accepted culvert and storm-drain materials.

This synthesis addresses only the durability of culvert pipe materials from a corrosion and abrasion viewpoint. It is recognized that there are other important factors in the selection of pipe materials, such as hydrologic and hydraulic considerations, structural design and durability needs, and availability and suitability of types and sizes of needed pipes; however, these factors have been excluded from discussion here.

Many states analyze the soil and water of the drainage site as well as the contributing watershed as a basis for selecting durable pipe materials. Durability is the quality of being able to last or the capability to withstand wear and decay. In culverts and storm drains, durability is a means of comparing actual material life to desired service life or of comparing the life of one material to that of another. Service life is defined as the number of years of relatively maintenance-free life (see Chapter Seven). The desired service life of a culvert or other underground drainage pipe varies with the importance of the highway or other facility and with factors such as the location, size, and depth of cover of the pipe.

The culvert that is severely deteriorated by corrosion, abrasion or erosion, or their combined effects presents a challenging task. Once such damage has occurred, it is irreversible; in many cases, however, further damage can be prevented and the useful life of such structures extended. Although many alternative corrective measures are possible, most are difficult and costly and in some cases conflict with the original design objectives of the structure. Inserting a smaller pipe liner in a drainage facility can greatly reduce hydraulic capacity. Dewatering and drying pipe surfaces to apply coatings, linings, or pavements can be a difficult field repair job. However, repair costs may be much less than those of a replacement structure, particularly where a culvert is located beneath a high fill.

Although much has been written about the corrosion and abrasion (or erosion) of metals, concrete, and other materials, the problem as it pertains to culverts and storm drains is quite complex with many influencing factors. Most corrosion-abrasion problems involve the sciences of electrochemistry, metallurgy, physical chemistry, hydrology, and soils. For this and other reasons, many agencies do not have the complete in-house expertise needed for a comprehensive analysis. Therefore, designers should review the available methods for appraising the corrosion-abrasion severity of a drainage site and for selecting those culvert or storm-drain materials that offer the desired durability with economy. It is advantageous for designers to investigate the need for and, if necessary, to specify (for initial construction) culvert life-extending and protective measures such as a thicker wall, use of select backfill material, invert paving, inside and/or outside coatings, linings, and sacrificial metals.

Drainage pipes are subject to corrosion, pitting or penetration, roughening or loss of section, and ultimately loss of the pipe invert or the weakening of it to the extent that it can be structurally unsound and the hydraulic capacity impaired (Fig. 1). Because most drainage facilities for highways and other transportation systems are underground, they are not exposed to daily observation and inspection, as pavements, bridge decks, guardrails, and other system components are. Detection of problems in drainage structures, therefore, has been after the fact.

Whenever economically feasible, design analysis also should consider possible changes in the drainage environment that could result from changes in land or water use (e.g., industrialization, mining, or urbanization). Stormwater flow from sewered urban areas may include significant concentrations of corrosive pollutants and abrasive sediments. A change from a timbered watershed to a farming watershed can cause a serious increase in the corrosion rates of downstream drainage structures. A bituminous coating or paved invert can be dissolved by petroleum wastes, destroyed by the burning of vegetative debris in the streambed and pipe, or eroded by fast-flowing water carrying abrasive material.

In addition, designers must consider not only the characteristics of the natural waters and native soil but also those of any backfill material transported to the site. This is a task much broader and more involved than simply sizing, selecting, and installing a pipe.

If only a small portion of the vast amount of pipe now existing in highway and other transportation facilities is subject to corrosion-abrasion damage, the total annual loss would be enormous. (In the U.S., more than 17 million linear ft—$5 \times 10^6$ m—were installed in 1972 alone.) One agency has reported that it spends approximately $200,000 (not including installation costs) for replacement pipe each year (*23*).* Therefore, highway designers should know

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* Numbers refer to sequence of references in Appendix A, "Selected Bibliography."

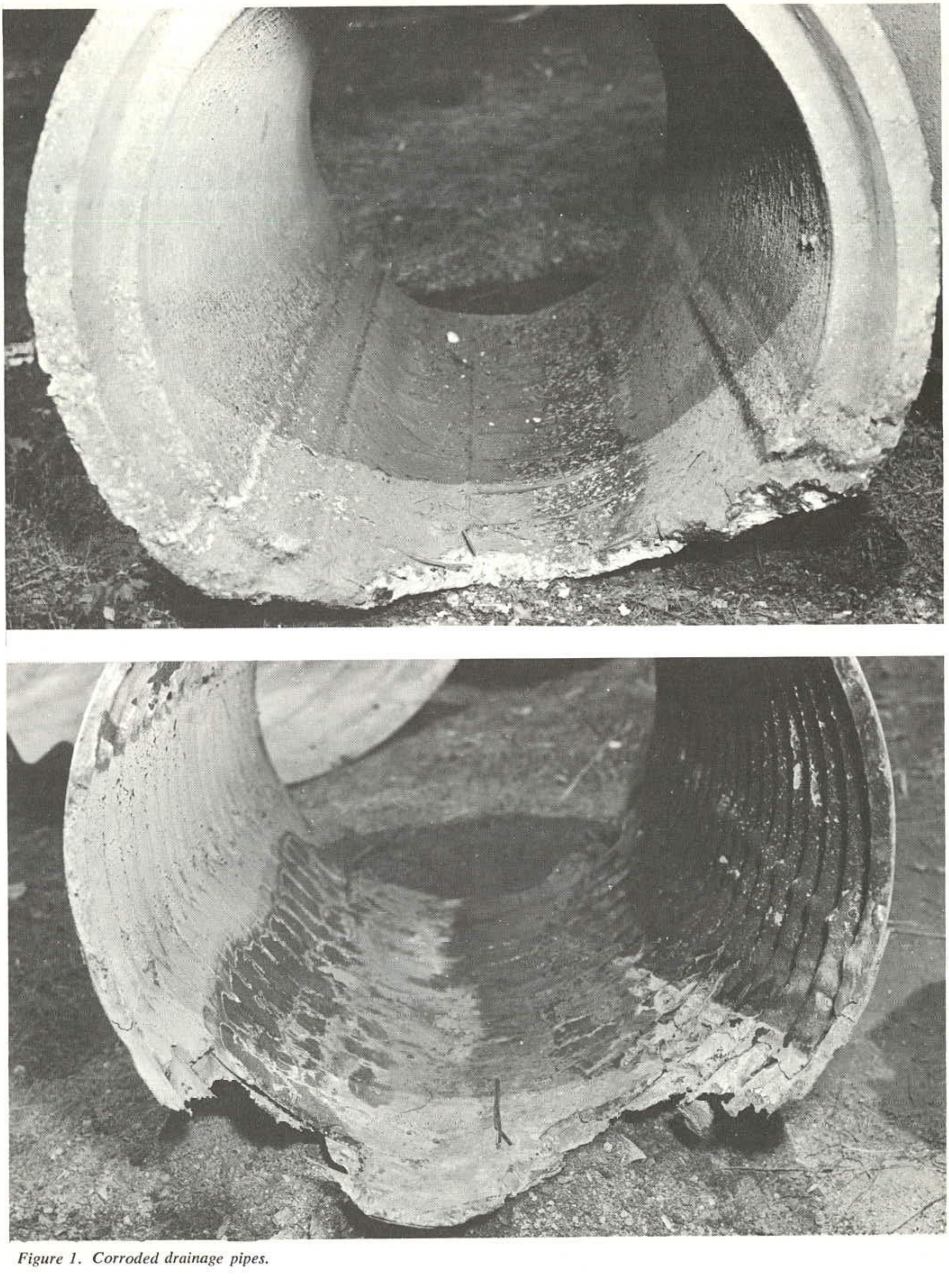

*Figure 1. Corroded drainage pipes.*

what will provide the desired life of the structure at the least cost.

## SOURCES OF INFORMATION

Many states have undertaken studies of the performance of highway drainage structures with respect to corrosion and abrasion (Fig. 2). These studies have included field observations and laboratory tests on a total of more than 43,000 culverts. Many studies have included testing of soil and surface water. Some field surveys delineated severity of corrosion susceptibility statewide; others were limited to geographical areas with problem soils or waters. Certain studies were directed toward comparisons in durability of two or more types of pipe or of various protective coatings under the specific field conditions encountered. In general, each state in its research efforts has attempted to solve its own culvert durability problems and to derive design and maintenance criteria that are applicable to its own situation rather than to broad or even nationwide use.

In the 30-year period ending in 1952, the National Bureau of Standards (NBS) conducted the most comprehensive field investigation ever made of the behavior of metals in soils. These tests involved 36,500 specimens of 333 types of materials placed underground at 128 test sites in diverse environments across the length and breadth of the United States. The results of these studies provide background for many corrosion control procedures developed later by other researchers (*43*).

The NBS work consisted of burial of metal test specimens and their removal after successive 2-year periods up to 14 years, at which time they were cleaned to remove corrosion products, weighed to compute metal loss, and measured to determine extent and depth of pitting. It was found that underground corrosion is affected by many specific and interrelated factors and seldom proceeds at a uniform rate throughout the period of exposure. Researchers can learn much from the NBS studies about methods of testing; relative corrosivity of various soils on different metals, alloys, and protective coatings; effects of soil aeration and moisture content; interconnection of different metals; effects of corrosion on strength; and applicable theories. Although the NBS studies provide a wealth of information on soil-structure corrosion interaction, they address the corrosion problem only at the pipe-soil interface and do not evaluate the corrosion of the interior surfaces caused by the action of liquids, dissolved and suspended substances, and the atmosphere.

Throughout this synthesis, the term *culverts* is used to describe a wide range of drainage pipes, such as storm drains; cross-, side-, or edge-drains; and subdrains for transportation systems. The synthesis examines the problem of culvert and pipeline material selection and offers suggested methods and guidelines for providing durable drainage systems for transportation facilities.

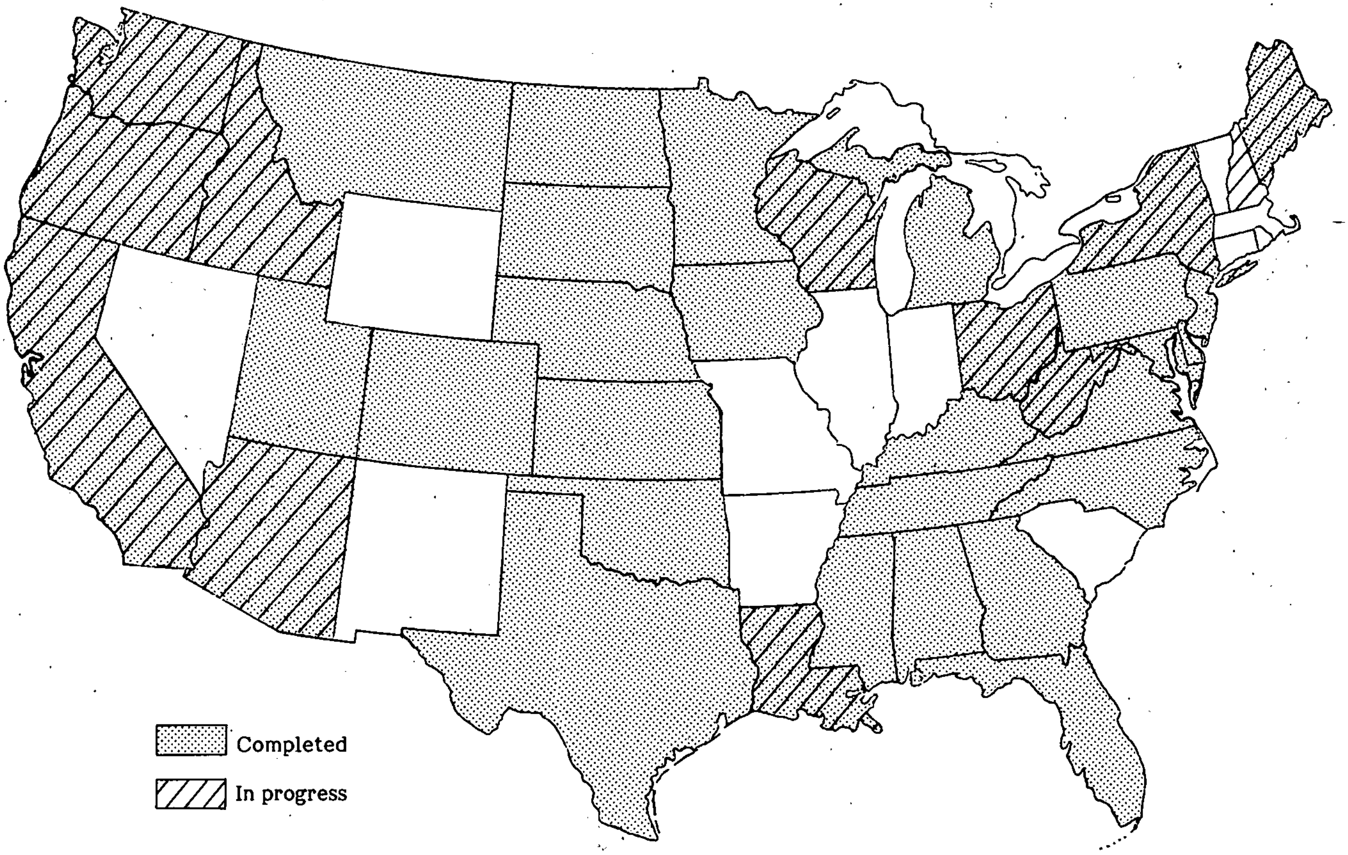

*Figure 2. Field and laboratory studies of drainage pipe durability.*

CHAPTER TWO

# THEORY AND MECHANISMS

## CORROSION: WHAT IS IT?

Corrosion is the deterioration or dissolution of or destructive attack on metal or its properties by chemical or electrochemical reaction with the environment. Corrosion occurs on the surface of a metallic object. When the portion of the surface affected is large, it is termed general corrosion; when small, localized corrosion. If confined to small points so that definite indentations form in the metal surface, it is called pitting.

Corrosion also is described as a return of metals to their native state as oxides or salts. Only the more noble metals (platinum, gold, and silver) and copper exist in nature in the metallic state. Other metals are refined with great effort, usually by applying energy in the form of heat. Unless protected from the environment, these metals then revert (by the process of corrosion) from their temporary metallic state to a more natural state. When corrosion has occurred, it is irreversible.

Corrosion affects all metals and alloys, although at widely varying rates, depending on chemical and physical properties and the environmental conditions to which they are exposed. For example, rust is the well-known product of the corrosion of iron in the presence of water and air. It consists mainly of an iron oxide ($Fe_2O_3$), which, as hematite, is the most common ore of iron. Several metals when corroding develop a corrosion-resistant surface layer—such as a layer of aluminum oxide, zinc oxide, or copper carbonate—that separates the underlying metal from moisture and other corrosion-inducing environmental elements.

In recent years, corrosion has been considered more broadly as affecting many nonmetallic substances, such as stone, concrete, ceramics, plastics, wood, and leather.

## CORROSION AND THE ENVIRONMENT

Culverts and other drainage pipes are subject to corrosion in many different soils and waters. These can contain acids, alkalies, dissolved salts, organics, industrial wastes or other chemicals, mine drainage, sanitary effluents, and dissolved or free gases. However, the main corrosion medium affecting drainage facilities is water and the chemicals that have reacted with, become dissolved in, or been transported by the water.

Although most chemical elements and their compounds are present in soils, only a limited number exert an important influence on corrosion (*43*). In areas of high rainfall, the passage of eons of time generally has resulted in the leaching of soluble salts and other compounds; thus, the residual soil has become acidic. Conversely, in arid locations soluble salts are brought to the upper soil layers through capillary and evaporative processes, causing the soil to be strongly alkaline. It may be concluded, therefore, that rainfall and evaporation are important factors in corrosion because they affect the basic chemistry of surface and groundwater flow. The resulting groundwater and dissolved minerals are the primary corrodents affecting the durability of drainage pipe, and rainfall intensity, duration, and frequency have major effects on corrosion-abrasion factors determining the service life of drainage installations.

Pipe in soils whose groundwaters contain aggressive chemicals is usually not attacked as rapidly as pipe of the same quality exposed to the flow of surface runoff of the same chemical content. This is because the soil reduces the rate of renewal of these chemicals at the pipe surface. Although tight clay soils are used less often as bedding or backfill for drainage pipelines, the presence of such low-permeability soils close to the pipe reduces movement of chemical corrodents to the very low amounts transmitted through diffusion and capillary action.

Cinders, particularly coal cinders, in backfill have been found to be extremely corrosive to cast-iron, galvanized steel, or aluminum pipe, because the cinders are likely to carry acid or acid-forming compounds. Cinders also contain some unburned carbon, which is cathodic to these pipe materials and which with a high galvanic potential difference can cause rapid corrosion.

## ELECTROLYTIC CORROSION CELLS

When a metal corrodes, it releases the energy gained when it was refined; the energy is released not in the form of heat, light, or sound, but in the form of electrical energy. Every corrosion cell includes four basic components, as follows:

1. *Electrolyte*—moisture or a liquid carrying ionic current between two metal surfaces, the anode and the cathode.
2. *Anode*—a metallic surface on which oxidation occurs, giving up electrons with metal ions going into solution or forming an insoluble compound of the metal.
3. *Cathode*—a surface that accepts electrons and does not corrode.
4. *Conductor*—a metallic connection (in drainage facilities, usually the pipe itself) that permits electrical current flow by completing the circuit.

Current flows because of a voltage difference between the two metal surfaces or between two points on the same surface. This difference in potential can be from an outside source, as in the stray currents from a nearby direct current source (such as electric railways or cathodically protected utility pipelines). In drainage culverts, however, the difference is generally the result of an internal source. Whenever a metallic object such as a culvert is in contact with an electrolyte, it develops an electropotential. Two pieces of metal or two portions of the same sheet of metal in an electrolyte seldom have the same potential. The amount of this potential difference (or voltage) depends on the nature of the metal, the condition of its surface, the nature of the electrolyte, and the presence of different material at the interface of the metal and electrolyte. This material could be an impurity or a dissolved gas such as oxygen. There are many possible variations of these factors that result in corrosion cells.

An exact value of the electropotential of a metal can not always be estimated because of corrosion-affecting factors such as the environment in which the metal is situated, the temperature, and the presence of soluble salts and oxygen. (Additional information on electropotential is contained in References *8*, *51*, and *53*.)

Corrosion cells can be created by:

1. Variations in the nature of the metal.
2. Changes in the condition of the surface of the metal.
3. Variations in the electrolyte.
4. Presence of foreign materials at the interface of the metal and electrolyte.

Through combinations of the foregoing, many corrosion-inducing causes are possible, all based on a corrosion cell that must include an electrically connected anode, a cathode, and an electrolyte (*51*). Corrosion prevention is accomplished by rendering ineffective one or more of these components, a procedure for which there are only limited economical options in drainage practice.

Oxygen concentration cells, a major type of corrosion mechanism, are commonly developed on buried pipelines and culverts. Pipe is usually placed on compacted or relatively undisturbed soil at the bottom of a trench. When backfill material is more permeable, it provides a shorter pathway to the surface and is more accessible to diffused oxygen, forming a cell. The bottom outside surface of the pipe becomes the anode; the rest of the pipe is the cathode; the moist soil is the electrolyte; and the metal pipe itself is the electrical connecting circuit.

The portion of a culvert under a highway or other pavement usually has less access to oxygen than those parts under the unpaved shoulders (Fig. 3). A cell is formed in which the anode is the pipe under the pavement, the cathode is the outer extremities of the pipe, the electrolyte is the soil, and the connecting circuit is the pipe. Although all of the pipe under the pavement is anodic, most of the attack occurs on the pipe under the pavement edge in this situation.

## PERFORATION

Perforation, the complete penetration of the metal, is an indication of impending need for maintenance of a culvert or storm drain. Continuation of this type of deterioration can lead to exfiltration of water or infiltration of fine-grained noncohesive backfill and loss of subgrade support. However, carefully selected backfill can minimize this concern. Many designers do not consider perforation a serious condition in a drainage culvert unless it occurs early in its design life. It is generally conceded that life to perforation is a basis for comparison rather than the end of culvert usefulness.

## EROSION OR ABRASION

The processes of erosion or abrasion wear down or grind away metals, concrete, clay, plastics, and other pipe materials and coatings. The process occurs when water that is laden with sand, gravel, or stones flows through a culvert. Often corrosion and erosion or abrasion operate together to produce far greater deterioration jointly than either would by itself. Erosion can accelerate corrosion by removing protective coatings and passivating films. Waters flowing at a velocity high enough to create appreciable turbulence can cause severe localized corrosion from the combined action of mechanical abrasion and corrosion. Known as corrosion-abrasion, corrosion-erosion, or erosion-corrosion, this includes both *impingement* attack and *cavitation*. *Impingement* is caused by suspended solid particles or gas bubbles striking the surface or by turbulence alone. Impingement breaks down the protective layer developed on a metal or concrete surface. Such a condition occurs at pipe entrances, at sharp bends, at protrusions (such as rivets or joints), near deposits, and at other abrupt changes in flow patterns. *Cavitation* causes erosion damage from high-velocity flow in which high-pressure and subatmospheric low-pressure areas are developed with bubbles forming and collapsing at the solid-liquid interface. Cavitation damage rarely occurs in culverts or storm drains because of their relatively low operating heads and velocities.

Flow velocities depend on the drainage channel material,

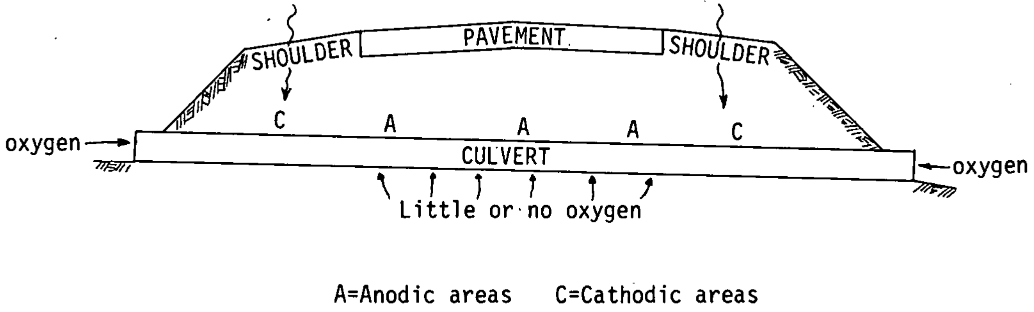

*Figure 3. Oxidation corrosion cells in pavement drainage structures (adapted from Ref.* 8)

slope, and depth of flow. Velocity increases with channel slope and with an increase in discharge, such as during floods. Also, the steeper the watershed topography, the greater the amount of eroded material carried by runoff into the streams. Doubling the velocity of a stream carrying a bedload increases its abrasive power approximately fourfold. Under the same conditions its ability to transport rock fragments of a given size is multiplied as much as 32 times.

The invert or lower quadrant of a pipe is most subject to corrosion and erosion-abrasion damage because (a) erosive forces are most active, (b) both an electrolyte and oxygen are present, and (c) any corrodents in the water are in contact with the culvert material. It is also along the lower segments of pipe that protective coatings, linings, and pavements are first worn off, cracked, or delaminated by erosion-abrasion.

## ADDITIONAL EFFECTS

The entrance and exit ends of the culvert invert are especially vulnerable to additional destructive influences such as sunlight (ultraviolet light), ambient temperature changes, and often the exposure of both the inner and outer surfaces to air and water.

Backfill settlement, effects of live loads, other earth movements, and structural design deficiencies in pipe that result in movement can cause cracking in rigid pipe and in mortared joints. Severe cracking could result in corrosive attack on the reinforcing steel as well as infiltration and exfiltration. Similarly, in flexible materials such as corrugated metal, such movement can damage a rigid invert pavement or lining, thus affording corrosive agents access to the underlying unprotected metal surfaces.

## CORROSION INDICATORS

Generally, the most frequently considered indicators of corrosion susceptibility are pH, resistivity and conductivity, polarization curves, oxidation-reduction potential, soil characteristics, precipitation, and flow velocity. In various studies, these indicators, either singularly or in groups, have predicted tendency to corrode to some extent. In other studies, none of these indicators has correlated with a tendency to corrode.

### pH Value

The pH value is defined as the log of the reciprocal of the hydrogen ion concentration ($H^+$) of a solution. A pH value of 7.0 is neutral; values of less than 7.0 are acid; values of more than 7.0 are alkaline. For culvert purposes, soils or waters having a pH of 5.5 or less are strongly acid, and those 8.5 or more are strongly alkaline. A change of one unit of pH represents a difference of 10 times in relative acidity or alkalinity. For example, a solution with a pH of 4 is 10 times more acid than one with a pH of 5, or 100 times as acid as one with a pH of 6.

Although relatively simple colorimetric methods are available for field determination of pH, these methods are sometimes inaccurate because the suspension or the turbidity of the test solution obscures the color end-point. Indicating papers for field determination of pH can be convenient. For greater reliability, there are electrical apparatuses for pH determination, including portable models for field use.

The most commonly used index of corrosion potential is the pH of the soil or water. The most severe exposure would be a continuously flowing low-pH stream with constant replenishment. A similar pH in the soil groundwater at the exterior would constitute a less severe exposure because replenishment normally would be low. The use of these values, however, has its limitations. Several studies find little relationship between pH and rates of corrosion of aluminum or steel (*31, 41, 51*). Uhlig states that for bare steel "within the range of about pH 4 to 10, the corrosion rate is independent of pH, and depends only on how rapidly oxygen diffuses to the metal surface. . . . Oxygen concentration, temperature, and velocity of the water alone determine the reaction rate. These facts are important because almost all natural waters fall within the pH range 4 to 10. . . . In the acid range (pH $< 4$) oxygen diffusion is no longer controlling" (*51*). Therefore, one should not rely solely on pH, when it is in the middle range, as indicating absence of corrosive soils or waters.

Kentucky has concluded in situations involving acid runoff waters that pH, in itself, is an acceptable indicator of corrosion susceptibility of various pipe and protective coating materials (*19*). Virginia has examined several chemical parameters but relies largely on pH as a corrosion-potential index under a variety of exposures, including acid mine wastewater; brackish tidal water; and swamp, pasture, and hillside drainage (*34, 35*).

The Alabama Geological Survey, under state highway department sponsorship, has investigated soil and water constituents affecting pipe performance throughout Alabama (*22, 29*). Critical parameters recommended for examination include (a) pH, resistivity, dissolved oxygen content, and flow conditions of the water and (b) pH, resistivity, and character and drainage conditions of the soil at tentative drainage structure sites. For preliminary planning, iso-pH maps of soils and waters are prepared.

New York found no correlation between pH and corrosion of galvanized steel culverts (*20*). The pH of the water in 152 culverts "was found to range within the narrow limits of 6.2 to 9.0. The majority of the culverts (142) contained water with pH's of 7.0 to 8.9." The pH of the soil surrounding each of 787 culverts "varied from a minimum of 3.8 (one site) to a maximum of 9.4 (one site), with 728 sites (92 percent) between 6.0 and 8.9" (*20*).

### Resistivity

According to NBS, the simplest criterion for estimating the corrosivity of a given soil to metals is its resistivity (*43*). This electrical measurement depends largely on the nature and amount of dissolved salts in the soil and is also affected by the temperature, moisture content, and compactness of the soil and by the presence of inert materials such as stones and gravel. The greater the resistance of the electrolyte, the less the flow of current associated with corrosion. Conversely, higher moisture content and temperature result in lower soil resistivity and a greater prospect of corrosion.

Soil resistivity generally decreases as depth increases (*16*). It is, therefore, important that tests be conducted (where practicable) at depths approximating those of the proposed culvert installations. Consideration must also be given to the fact that culverts may be in "imported" fill or structural backfill soils.

Consideration should also be given to seasonal variations in flow and water-table position and their impact on soil resistivity and corrosivity. Resistivity should be determined under the most critical conditions, such as when the water table is at its seasonally highest level. If not, an allowance should be made for such conditions. California's test method, like that of NBS, attempts to account for the influence of moisture content on soil resistivity by testing under standardized conditions (*5, 43*). In this way, the soil has a comparable resistivity independent of seasonal and other variations in soil-moisture content.

Laboratory and field methods are available for measuring soil resistivity in ohm-centimeters (ohm-cm). The resistance between opposite faces of an isolated 1-cm cube would be its resistivity in ohm-cm. In actuality, a larger mass of material is tested from which unit resistivity can be calculated. Because resistivity varies with temperature, tables are available to convert the resistivity at the test temperature to that at a uniform temperature of 60 F (15.6 C) (*37*). Typical approximate resistivity values for various types of soil and water are given in Table 1. Some investigators conclude that there is little basis for these relationships.

Several states rely on soil and water resistivity measurements as an important index of the corrosion potential. The California method (*5*), discussed in detail in Chapter Seven, uses the pH and electrical resistivity of soil and water to estimate the corrosivity of steel at proposed culvert sites (also see Appendix B).

In California, corrosion rate was found to correlate with the content of certain chemical compounds known to be corrosion agents, the sulfates and chlorides (*48*). The derived relationship was:

$$E = \frac{784{,}000}{R^{1.15}} \tag{1}$$

in which

$E$ = sum of sulfate ($SO_4^{--}$) and chloride ($Cl^-$) ions in parts per million (ppm) (or mg/litre) and

$R$ = minimum resistivity in ohm-cm.

This relationship was found to be unreliable when $E$ was less than 100 ppm. Where there is a strong probability that sulfates and/or chlorides are in the corrosion range, use of the equation can be an economical shortcut to chemical analysis; however, such analysis should be performed if soil resistivity is below 1000 ohm-cm.

*Conductivity*

Some agencies determine the corrosivity of soils by measuring conductivity in addition to pH, alkalinity, and soluble sulfates. Conductivity, the reciprocal of resistivity, is determined using a portable meter and is expressed in millimhos per centimeter (m-mho/cm). When borrow is to be used for pipe backfill, both it and the in-situ soils are tested. Montana considers soils in which conductivity values are less than 0.5 m-mho/cm ($R \geq 2000$ ohm-cm) suitable for steel culverts and those less than 1.25 m-mho/cm ($R \geq 800$ ohm-cm) suitable for aluminum pipe, provided the results of the other soil test parameters are also acceptable. Georgia uses concrete pipe if the site conductivity is 1.0 m-mho/cm ($R \leq 1000$ ohm-cm) or more, and the state also requires coatings if industrial acids are present.

**Polarization Curves**

Another electrical measurement technique, the use of polarization curves, is available for predicting the rate of corrosion of the exterior surface of buried structures. Schwerdtfeger proved its usefulness in extensive studies of

TABLE 1

TYPICAL RESISTIVITY VALUES (*53*)

| SOIL | | WATER | |
|---|---|---|---|
| Classification | Ohm-cm | Source | Ohm-cm |
| Clay | 750 - 2,000 | Seawater | 25 |
| Loam | 3,000 - 10,000 | Brackish | 2,000 |
| Gravel | 10,000 - 30,000 | Drinking water | 4,000+ |
| Sand | 30,000 - 50,000 | Surface water | 5,000+ |
| Rock | 50,000 - Infinity* | Distilled water | Infinity* |

*Theoretical

buried metals (*44*). Lindberg adopted this method to estimate the corrosion rate of exterior surfaces of aluminum and galvanized steel culverts (*30*). Electrical measurements were made from the highway surface, eliminating the necessity for excavation to the underground pipes.

The method involves application of electrical current and measurement of the resulting potential changes. One electrode can be placed over the centerline of the culvert on the highway shoulder surface and another also on the surface several feet (metres) away from the culvert. Current is applied progressively in small increments and recorded with the resultant change in soil-to-culvert potential. The change in pipe-to-soil potential versus the logarithm of the current is plotted (Fig. 4). Breakpoints or abrupt changes in the respective anodic and cathodic polarization curves indicate the anodic current, $I_a$, and cathodic current, $I_c$, as shown. The corrosion current, $I_{corrosion}$, is computed from Pearson's equation:

$$I_{corrosion} = \frac{I_a \times I_c}{I_a + I_c} \qquad (2)$$

From this, Faraday's law can be used to calculate the weight loss of metal resulting from this corrosion current in a given time. Therefore, by means of polarization curves, the corrosion rate of different buried metal structures can be compared in a specific environment at a specific time.

Arizona reports that the polarization method correlates with field corrosion better than does the resistivity test method but that it is more complicated to perform (*13*). Michigan uses the polarization method along with other test parameters but points out that the method estimates total weight loss and does not take into account localized corrosion or pitting, which may lead to perforation and failure (*16*); it also should be pointed out that the test depicts corrosion conditions only during the actual time of the test. At other times, measurements could vary greatly, depending on differing moisture, temperature, and other soil conditions. New York found no correlation between measured metal loss and computed metal loss using the polarization method.

**Oxidation-Reduction Potential**

Oxidation-reduction potential, also commonly known as the "redox potential," is used as a primary indicator of anaerobic bacterial corrosion. This type of corrosion at the soil-metal interface is most severe in wet, poorly drained soils, such as swamps, marshes, and brackish water with pH in the neutral range. There, iron in deaerated water but in the presence of sulfate-reducing bacteria (*sporovibrio desulfuricans*) corrodes at an accelerated rate, often with the odor of hydrogen sulfide gas. These bacteria do not flourish where there is ample dissolved oxygen. Measurement of the redox potential requires an inert metal electrode, such as platinum, and a delicate, not readily portable electrical test apparatus more suitable for the laboratory than the field. Although bacterial corrosion has been noted at culvert sites in many sections of the country, it is not among the more common mechanisms for culvert material deterioration noted in studies by corrosion engineers. Wisconsin is engaged in a study of the oxidation-reduction approach and its applicability. A general relationship of corrosivity of underground steel pipe to soil redox potential is given in Table 2.

Beaton and Stratfull found a relationship between soil types that support anaerobic and aerobic bacteria in limited areas of California (*4*). However, they also found the pH-resistivity correlation to be broader and more accurate than soil type in predicting corrosion (*5*).

**Soil Characteristics**

Several investigators have considered soil characteristics such as the chemical and physical properties, which vary widely in their effects on the corrosivity and erodibility of metals and other materials. In corrosion studies, chemical analyses of soils usually center on determination of water-soluble constituents. Typical constituents are the base-forming elements (sodium, potassium, calcium, and magnesium) and the acid-forming radicals (carbonate, chloride, sulfate, and nitrate). Chlorides and other dissolved salts increase the electrical conductivity, promoting the flow

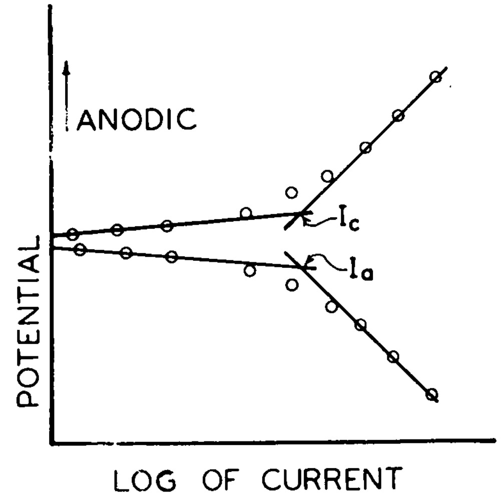

*Figure 4. Schematic polarization curve* (30).

TABLE 2

REDOX POTENTIAL VS. CORROSIVENESS FOR STEEL PIPE (*43*)

| Soil Redox Potential (millivolts) | Classification of Corrosiveness |
|---|---|
| Below 100 | Severe |
| 100 - 200 | Moderate |
| 200 - 400 | Slight |
| Above 400 | Noncorrosive |

of corrosion currents. Sulfate soils and waters can be corrosive to metals and harmful to concrete. The permeability of soil to water and to oxygen is an important physical property in corrosion.

Studies have been completed in several states, including Iowa (*33*), Minnesota (*27*), and Nebraska (*3*), for which maps have been prepared to show soil classifications according to the Great Soil Groups (Marbut, *Atlas of American Agriculture*—Part III: "Soils of the U.S.," U.S. Govt. Printing Office, Washington, D.C., 1935), with each group characterized as to its corrosivity. South Dakota has rated the corrosivity of all soils in the state.

### Precipitation

Generally, in areas of considerable rainfall, the soil and water pH are acidic, whereas the opposite is true in areas of little rainfall. In areas where there is abundant rainfall, corrosion probability is great. However, in areas of little rainfall, such as in the desert, corrosion can also occur because of the highly saline, alkaline soils.

### Flow Velocity

Stream- or drainage-channel flow velocity can be important in estimating erosion-abrasion rates and sediment transport. These, together with pipe slope, affect corrosion potential and type and amount of protective treatment required.

From the foregoing, it is apparent that (a) durability considerations in the design of drainage structures must encompass evaluations beyond a textbook and test-tube appraisal of culvert material and the soil and water affecting them and (b) past culvert experience in the area should be evaluated.

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CHAPTER THREE

# PIPE MATERIALS

## GENERAL

In this synthesis, culvert and storm-drain materials are considered from a durability standpoint. However, there are other important factors in the selection of drainage materials, such as structural and hydraulic considerations, installation methods, maintenance properties, local availability, and economics. Principal materials for drainage pipe include steel, aluminum, and concrete. Other pipe materials with advantages for special purposes but less often specified for drainage installations are asbestos-cement, vitrified clay, stainless steel, cast iron, and, more recently, plastics.

## SPECIFICATIONS

The reports on durability investigations used in this synthesis evaluate the performance of materials produced under specifications available at the time of the reports. Specifications for culvert and pipe materials are periodically reviewed and revised. Current specifications for drainage materials are given in Table 3.

## MATERIAL CHARACTERISTICS

### Steel

Corrugated iron has been in use in the United States and Europe for about a hundred years, with reports of use in culverts since 1896. Galvanized corrugated steel pipe, its successor, has attracted wide use in this country in the past half-century. Although steels with minor variations in composition, including copper content, are produced by different manufacturers, corrosion specialists conclude that these variations are mainly for workability and structural improvement and do not appreciably affect corrosion susceptibility. Galvanized copper-bearing pure iron and copper-steel have been standardized by specification since 1967. A discussion of galvanizing can be found in Chapter Four.

In soil or water with an approximate pH value of less than 4, ordinary iron or steel corrodes rapidly, because a protective corrosion product usually does not form. In the pH range of 4 to 9.5, an oxide of iron forms, reducing the rate of corrosion to the rate at which oxygen can diffuse through this layer. The reactions of ferrous materials are complex and depend on electropotential, thermodynamic conditions, and other factors, such as chloride and sulfate content of the electrolyte.

When carbonates in water exceed the saturation level, the excess is deposited as a coating on the surface of conduits. On steel, such a coating is protective, helping to retard corrosion. Chlorides accelerate corrosion by damaging the protective film on anodic areas and by increasing conductivity of the electrolyte.

Based on numerous studies and experience in various states, a soil or water pH range of 6.0 to 9.5 appears to be generally accepted for uncoated galvanized steel. Conditions in some states permit varying ranges of acceptability of uncoated galvanized steel, such as pH of 6.5 to 8.5 in

TABLE 3

CURRENT SPECIFICATIONS FOR DRAINAGE PIPE

| PIPE MATERIAL | SPECIFICATION | | | |
|---|---|---|---|---|
| | AASHTO | ASTM | Federal | Other |
| Steel | | | | |
| Galvanized Corrugated Steel | M 36 | | WW-P-405 | |
| Corrugated Steel Structural Plate | M 167 | | WW-P-405 | |
| Precoated, Galvanized Steel | M 245 | | WW-P-405 | |
| Aluminum | | | | |
| Corrugated Aluminum Alloy | M 196 | | WW-P-402 | |
| Aluminum Alloy Structural Plate | M 219 | | WW-P-402 | |
| Concrete | | | | |
| Reinforced | M 170 | C 76 | | |
| Reinforced, Box Sections | M 259 | C 789<br>C 850 | | |
| Reinforced, Elliptical | M 207 | C 507 | | |
| Nonreinforced | M 86 | C 14 | | |
| Cast-in-place, Nonreinforced | | | | ACI* 346 |
| Reinforced Arch | M 206 | C 506 | | |
| Asbestos-Cement | M 217 | C 428<br>C 663 | SS-P-331 | |
| Cast Iron | M 64 | A 142 | WW-P-421 | |
| Clay | M 65 | C 700 | SS-P-361 | |
| Clay Liner Plates | | C 479 | | |
| Plastic | | | | |
| Polyethylene (PE) | M 252 | F 405 | | |
| Polyvinyl Chloride (PVC) | | D 3033<br>D 3034 | | |
| Acrylonitrile-Butadiene-Styrene (ABS) | M 264 | D 2680<br>D 2751 | | |
| Fiberglass-Reinforced (FRP) | | D 2996<br>D 2997 | | |
| Stainless Steel, Culvert Grade | | | | AISI**<br>Type 409 |

* American Concrete Institute
** American Iron and Steel Institute

Alabama, 6.0 and greater in Georgia, 6.0 to 9.0 in Montana, and 5.0 to 8.5 in eastern Washington. All are subject to other durability parameters. A number of states have found little or no correlation between pH and culvert durability. Chapter Four contains a discussion of the possible use of various coatings, linings, and pavements that broaden the acceptable pH range of galvanized steel pipe materials.

Resistivity and conductivity also are used as an index of corrosion potential for steel pipe. Some states have found a correlation between culvert durability and pH and resistivity; however, other states have not been able to confirm this.

**Aluminum**

Clad-aluminum-alloy pipe became available for highway use in 1960. Since then, an extensive program of research and field evaluation has been carried out by industry (*28, 30, 31, 32*) and prospective users (*7, 11, 16, 20, 22, 23, 29, 34, 35, 38, 41*) to provide information on design and serviceability of this material. For a discussion of cladding and other coatings, see Chapter Four.

Aluminum is suitable for use in neutral and mildly acid environments, but not in most strongly acid environments. Aluminum does perform well in organic acid environments, however. As pH increases into the alkaline range, corrosion resistance of aluminum normally decreases. Industry advocates the use of aluminum pipe when soil and water pH are between 4 and 9 and soil resistivity is not less than 500 ohm-cm as determined in the laboratory (*32*). Acceptability ranges that have been established by states include (a) California, a pH of 6 to 8, with resistivity at least 2000 ohm-cm; (b) Georgia, a pH of 4 to 8.5; (c) Montana, pH 5 to 8.5; (d) Oregon, a pH of 4 to 9, with resistivity not less than 1500 ohm-cm; (e) Washington, a pH of 5 to 8.5; and (f) Virginia, pH 4 to 9.

The presence of heavy metals (copper, iron, etc.) in bedding or backfill of aluminum pipe increases the possibility of corrosion. Although several states have soils that contain copper, only one state has identified a problem that could be attributed to heavy metals in backfill material. The pipe at the problem location is still in service.

An analytical appraisal of the abrasion resistance of aluminum culvert subjected to various degrees of erosive attack is given in an industry-sponsored report (*28*). Field data were used to develop the analytical approach. The report concludes that with the proper gauge selection for structural requirements (increased where necessary for abrasive bedload) the desired service life from a standpoint of abrasive wear can be obtained.

### Concrete

Much has been written on the effects of aggressive fluids on concrete that indicates that concrete of good quality is resistant to many chemicals occurring in nature (*50*). When properly proportioned, placed, and cured, concrete is relatively impervious to most soil, water, and atmospheric corrosive agents.

Use of high-compressive-strength concrete increases resistance to abrasive wear as much as five times (*54*). Hardness of aggregate, especially that of the coarse aggregate, is also important to abrasion resistance.

Concrete pipes are subject to attack by acid effluents with a pH of 5.5 or less. Because concrete is basic with a pH of about 13, it is not resistant to strongly acid solutions and is damaged by exposure to them, particularly by the sulfuric and sulfurous acids from mine drainage. Attack by sulfuric acid is partly due to the acidity and partly to harmful chemical reactions involving the sulfate ion (*54*). Quality concrete is normally not damaged by a mild acid such as carbonic acid, common in runoff from natural mountain streams, or humic acid in runoff from marshes. Increased protection for concrete pipes in a low-pH environment can be provided by specifying calcareous aggregates for backfill and bedding.

An effluent pH of 5.0 or greater appears to be generally accepted for concrete pipe. Ranges that have been established by states include (a) Georgia, pH 4.0 or greater and 3.0 to 4.0 with organic coating; (b) Idaho, pH 5.0 and greater; and (c) Montana, pH 6.0 and greater.

Sulfates, mainly those of sodium, calcium, and magnesium, may be found in many areas of the United States but occur mainly in western arid sections. Soils or waters containing these sulfates are known as alkali soils and waters and can prove harmful to concrete. Estimates of conservative limits of sulfate content in solutions range from 100 to 1000 ppm. Various authorities label such solutions beyond these limits as aggressive. Investigators have found that limitation of the tricalcium aluminate content of the cement is the most important factor in improving the resistance of concrete to attack by sulfates.

The Bureau of Reclamation has designed concrete drainage pipe to withstand sulfate concentrations ranging up to 4.61 percent. Important aspects are increased cement content (reduced water-cement ratio), use of ASTM Type V cement, a lower maximum limit on water absorption, and a lengthy controlled curing procedure. The bureau also uses approved pozzolans as an additive for high-sulfate locations. The bureau has rated types of cement in order of their effectiveness in producing sulfate-resistant concrete, as follows (with the best first): Type V, Type II, Type IV, Type III, and Type I (*6*). California's criteria for sulfate-resistant concrete pipe are given in Table 4.

Although there is concern about deleterious effects on culverts of runoff containing such deicing salts as sodium and calcium chloride, no reports have been found to date of culvert corrosion attributed to runoff of deicers.

Concrete pipe that is totally and continually under water, even in seawater, is less susceptible to exposure to oxygen and carbon dioxide and to variations in temperature, moisture, and conductivity, all of which are conducive to corrosion. Drainage structures in the tidal range, however, are subjected to alternate exposures to the atmosphere and the sea and have a much more severe environment to withstand. Mather discusses the resistant nature of suitably designed concrete and the various chemical constituents in seawater that are aggressive to it (*50*). Concrete for use in seawater should be made with fresh water and portland cement containing not more than 8 percent tricalcium aluminate.

Much of the discussion on concrete pipe is also applicable to asbestos-cement pipe.

### Vitrified Clay

Clay pipe made by primitive methods has been used for conveying hot and cold water underground in Crete for more than 5,000 years. Vitrified clay is manufactured from clays and shales, which are "vitrified" by burning in kilns at temperatures of about 2000 F (1 100 C), producing a fused, chemically stable and inert material. Although these inert materials are resistant to corrosion, they are limited in structural strength. Vitrified clay pipe, although somewhat subject to abrasive damage, can withstand aggressive chemical environments encountered in drainage facilities.

### Stainless Steel

Stainless steel, such as the commonly specified AISI Type 409, which has a composition of 11 percent chromium and 0.5 percent each of silicon and titanium, has good corrosion resistance in most acid and some alkali environments. Stainless steel pipe has performed well in the acid drainage exposures of the Morton's Gap, Kentucky, test site, where most other pipe materials tested reached a terminal condition. Pennsylvania also reported excellent performance of stainless steel pipe for deep mine seepage

TABLE 4

GUIDE FOR SULFATE-RESISTANT CONCRETE PIPE AND OTHER CONCRETE DRAINAGE STRUCTURES *

| Water-soluble sulfate ($SO_4^{=}$) in soil sample (Percent) | Sulfate ($SO_4^{=}$) in water sample (Parts per million) | Type of cement | Cement factor |
|---|---|---|---|
| 0-0.2 | 0-2000 | II | Minimum required by specifications |
| 0.2-0.5 | 2000-5000 | V | Minimum required by specifications |
| | | or II | 7 sacks** |
| 0.5-1.5 | 5000-15000 | V | Minimum required by specifications |
| | | or II | 7 sacks |
| Over 1.5 | Over 15000 | V | 7 sacks |

* Recommended measures for cement type and factor based on sulfate content of soil and water (California 7-851.3D)

** 7-sack cement = 390 kg of cement/$m^3$ of concrete

waters with pH 2.7 to 3.8. Stainless steel Type 409 is not resistant to seawater, hydrochloric acid, chlorides, or certain organic acids such as oxalic, formic, or lactic acid (*51*). Limited field tests of stainless steel led to the conclusion in Colorado that it should not be installed in certain alkaline environments (*11*). Perforation of stainless steel occurred there in less than a year because of chloride salts in the soil. Field tests of performance of stainless steel pipe, begun in 1968 in an acid environment in Ohio, are continuing. Laboratory tests show abrasion resistance in a sand-charged acid solution to be superior to that of carbon steel and galvanized steel.

### Cast Iron

Cast-iron underground durability has been extensively investigated by the National Bureau of Standards (*43*). It should provide adequate service life in soils or waters of pH 4 to 8.5, provided resistivity is not less than 1500 ohm-cm and sulfides are not present. Its performance has been excellent in Mississippi drainage waters of pH 5.5 to 8.5. Some rusting and pitting has been noted in slightly alkaline wastes along the Gulf Coast, but moist salt air could have been the cause (*17*).

### Plastic

Several types of smooth-wall plastic pipe have been used extensively in residential, municipal, and industrial applications, principally for water mains and service lines, sanitary and storm sewers, building drains, and cable conduit. In addition, many thousands of miles of perforated corrugated polyethylene tubing have been installed for agricultural subsurface drainage, mainly in the last decade. In the past few years, several state highway agencies have used this tubing in underdrain applications, either experimentally or as an alternative to conventional piping systems.

Many aspects of durability of plastic pipe have been evaluated in laboratory and field studies and through field experience. Plastics used in drainage pipe are highly resistant to the various corrosive agents found in soils and drainage waters. High concentrations of some organic-based chemicals and concentrated acids and bases (which would constitute accidental spillage rather than runoff) may stress-crack or soften plastics. Some generic types of plastic pipe are used in favor of conventional piping for the transport of slurries containing highly abrasive mine tailings. Generally, plastic pipe has satisfactory resistance to abrasion by relatively small aggregates transported by water flowing at normal flow rates; the effects of continuous abrasion by larger debris, such as stones and cobbles, and high velocity flow have not been evaluated. Plastic pipe used for drainage does not resist prolonged exposure to sunlight unless the plastic is specifically formulated to resist UV degradation; typically, fine carbon black fillers provide the most effective UV resistance. Plastics used in pipe are resistant to microbiological deterioration; thin sections of plastic material can be gnawed by rodents or insects, but experience indicates that this is not a known problem with plastic pipe. Plastics burn, and plastic pipe should be protected from possible exposure to grass fires, for example, at locations such as drainage outlets.

Further discussion of the suitability and limitations of specific types of plastic pipe and tubing in underground drainage facilities for highways can be found in the final report on NCHRP Project 4-11, "Buried Plastic Pipe for Drainage of Transportation Facilities."

CHAPTER FOUR

# PIPE PROTECTIVE MEASURES

Pipe protective measures include extra material thickness; many types of coating, lining, and paving materials; and cathodic protection.

## EXTRA THICKNESS OF PIPE

For some aggressive environments, it may be economical to provide extra thickness of concrete or metal to be corroded or eroded over the years (*18*). The economics of extra thickness should be evaluated in comparison with the other available protective measures.

## BITUMINOUS COATINGS

Bituminous coatings have been in use for more than 4,000 years, dating back at least to the days of the Egyptian Empire. Recorded use of coatings for metal pipe dates back to the beginning of this century. Although used mainly on both sides of corrugated-iron and corrugated-steel culverts (AASHTO M 190), bituminous coatings (usually asphalt) can be applied on other culvert materials. To date, such coatings have been used only to a minor extent on aluminum, stainless steel, or concrete pipe. Bituminous coatings are used mostly as an insulating barrier to moisture, oxygen, and electrical currents and are mainly of value on the outer surface of the pipe in contact with soil.

Although asphalt coatings have a low initial cost and also afford some protection from erosion-abrasion of the pipe interior surfaces, they have the following disadvantages: vulnerability to damage from ice, heavy debris, and other floatables or abrasive bedload; solubility in petroleum waste spillages; and inflammability. Field studies and laboratory tests indicate that bacterial attack on asphalt pipe coatings could affect their ability to protect pipes (*58*). This problem has not been reported specifically in highway drainage systems, however. When plain bituminous coatings do not provide the desired durability, asbestos-impregnated bituminous coatings, with their better adhesion properties, can offer better protection in acid, alkaline, or brackish water environments.

A coating material is only as good as its application. Bituminous coatings are more satisfactory when the metal surface of the pipe is thoroughly cleaned and prepared prior to coating. The asphalt and the pipe must be heated to specified temperatures. Thickness of application is usually 0.05 in. (1.3 mm). Careful handling during transportation, storage, and installation is required to avoid damage to the coating. Field repairs, although not as satisfactory as factory applications, should be made where bare metal has been exposed during transportation or installation.

The extreme divergence in performance of bituminous coatings as reported by various investigators ranges from completely satisfactory to unacceptable. Arizona finds bituminous coatings very effective, even in its saline soils and soils in semi-arid areas, and recommends their use on metal pipe if the soil resistivity is less than 2100 ohm-cm (*13*). Arizona also suggests applying zinc paint to all bare metal exposed accidentally or through mishandling of coated pipe. Oklahoma advocates bituminous coatings to assure 50 years' metal culvert performance at locations that are subject to moderate-to-severe corrosion, including in saline soils (*21*). Alabama states that bituminous-coated galvanized steel pipe has served satisfactorily for more than 25 years (*22*). California reports that bituminous coating normally protects the pipe exterior from corrosive effects of the backfill soil and groundwater for at least 25 years (*4*).

Florida estimates that bituminous coatings add about 10 years to the service life of galvanized steel pipe. Tennessee had a statewide problem of cracking, scaling, and erosion of bituminous coatings and pavements in corrugated metal pipe. A strict, detailed application procedure was formulated in 1967, and no such problems have been reported since. However, recent study has shown that the coatings do not provide increased life commensurate with the additional cost, and they are no longer used in Tennessee.

After extensive field tests in highly acid (pH 3.5) sites, Kentucky concluded that galvanized steel pipe with bituminous coatings would last 3 to 6 years and that galvanized pipe lacking this coating had a life of only about one month (*18, 19*). Although bituminous coatings served effectively at other Kentucky sites, they are not advocated for use in chemically aggressive waters where long-term durability is required. These Kentucky tests were conducted over a 20-year time span, during which the various materials, with few exceptions, reached a terminal condition.

Limited tests in Maine indicate a good life span for bituminous-coated pipe in soils with resistivities higher than 2400 ohm-cm (*23*). Recent comprehensive field surveys of more than 3500 bituminous-coated corrugated steel pipes in Maryland (*26*) and Kansas (*55*) indicate uneconomical life increases averaging only three to four years. A major cause for such poor performance was a lack of adhesion to the metal; abrasion was mentioned as a secondary cause. As a result, investigators have recommended that use of bituminous coatings in Maryland and Kansas be discontinued. Field investigations in Virginia (*35*) and North Carolina (*52*) of metal pipes with and without bituminous coatings indicate that such coatings are prolonging the service life of galvanized metal culverts at a wide range of sites, including a strip-mining site with a sulfurous runoff having a pH of 3.2.

Field investigations of 992 corrugated steel pipes in Ohio indicate satisfactory performance of bituminous coatings at many locations but problems in the pipe interior where high-velocity flow is coupled with an abrasive bedload (*36*). The Ohio investigation concludes that bituminous coating without invert paving is of little value under such conditions. Poor adherence of coatings to metal was a common problem. Protection of the pipe exterior surface appears to be a negligible factor in culvert design in Ohio. It was determined that, unlike the much thinner, standard corrugated steel pipe without coating, the galvanized structural-plate pipe without coating could withstand Ohio's environmental conditions adequately. This conclusion is to be reevalauted wherever low-pH or more abrasive site conditions are encountered. The Ohio study is continuing and should yield further definitive results in the near future.

New York's experience has shown that asphalt coating alone is not sufficiently beneficial, and its use without paved invert is not recommended (*9*).

Replies to a questionnaire on use of aluminum pipe indicate that four states required bituminous coatings under all or most conditions for both steel and aluminum (*41*). Five states used such coatings where there was a corrosive or aggressive environment, and several other states specified coated aluminum pipe only for limited or experimental uses.

Asphalt coatings on the pipe interior are estimated to increase the service life of galvanized steel pipe from a few years to as much as 50 years, with shorter service life for abrasive and highly acid locations and longer service life for milder environments. The most common estimates of the increase in service life through use of reliable interior asphalt coatings range from 10 to 15 years. Although exterior bituminous coating of culverts is not essential in all soils, it is usually more practical to apply a bituminous coating on both sides at the same time. Less has been learned about exterior coating performance because of the comparatively limited opportunities for examination.

## BITUMINOUS-PAVED INVERTS

Bituminous-paved invert pipe was first used in 1925. This method of protection was developed to protect against abrasive bedloads. The bituminous paving is normally at least ⅛ in. (3 mm) thick over the inner crests of the metal pipe corrugations and thus at least ⅝ in. (16 mm) thick over the corrugation valleys. Generally only the lower quadrant of the pipe interior is paved. Designers less often specify paving the lower half of the pipe interior.

Areas particularly susceptible to corrosion-abrasion inside the culvert are the upper two edges of the bituminous pavements when flow frequently is at that level. Therefore, especially when flows are expected to be corrosive or abrasive, the paved portion of the culvert's inner periphery should extend high enough to protect this area.

Another problem zone is the last few feet at each end of a culvert where exposure to sunlight (ultraviolet rays) and temperature extremes frequently results in the development of deep cracks, up to ¼ in. (6 mm) wide, which expose the underlying metal. These end areas are then prone to the loss of the pavement and coating by delamination. Early attempts on the Blue Ridge Parkway in North Carolina to reinforce the invert by inserting a curved metal plate, as reported by Welborn and Olsen (*52*), were not successful.

Performance of paved inverts varies. Florida estimates that provision of both an asphalt coating and pavement extends the life of galvanized steel pipe by about 28 years. In a New York study it was found that service life was extended 15 years or more by coating and paving (*20*); later surveys indicate a 25-year extension. Abrasion was not a factor in the New York observations.

## ASBESTOS-IMPREGNATED BITUMINOUS COATINGS

Since its introduction in 1936, asbestos-impregnated (also known as asbestos-protected, Asbestos-Bonded, fiber-bonded, or asbestos-treated) bituminous coatings have been used at sites having corrosion-abrasion susceptibilities for which conventional bituminous coatings would not provide adequate protection. Although asbestos fibers are not themselves abrasion-resistant, they are used to make the bituminous coating adhere tightly to the metal. An asbestos-impregnated bituminous coating starts with a layer of asbestos fibers pressed into the molten-zinc galvanizing coating of the steel sheet. Immediately after the zinc solidifies, the asbestos mass is saturated with asphalt, after which any excess asphalt is squeezed out. This treatment of the steel sheets takes place before they are corrugated and formed into pipe in the usual manner. Additional bituminous coatings or paved inverts are applied later.

Although the asbestos fibers themselves may or may not contribute to improved corrosion resistance, investigations in Louisiana (*1*), Ohio (*36*), Utah (*41, 57*), and Washington (*7*) report superior adhesion of asbestos-impregnated compared with plain bituminous-coated metal pipe during performance in corrosive environments. However, asbestos-impregnated bituminous-coated steel pipe, as well as all other common pipe materials (including concrete but not clay) eventually failed in Kentucky's highly corrosive (pH 3.5) Morton's Gap test environment (*18*).

In laboratory tests, samples were immersed in several common corrosive solutions: seawater, 5 to 18 percent NaCl, 1 to 10 percent $H_2SO_4$, 2 to 5 percent $Na_2CO_3$, 2 to 5 percent $Na_2SO_4$, and 2 to 5 percent $(NH_4)_2CO_3$. The asbestos-impregnated bituminous coatings showed much greater resistance to delamination than plain bituminous coatings (*12*). Under laboratory "rocker" abrasion testing with sand and gravel bedload, the plain bituminous coatings often showed greater wear resistance than the asbestos-impregnated bituminous-coated specimens, except at low temperatures (where no difference was noted) (*12*).

## PRECOATED GALVANIZED STEEL

The newly developed mill-applied polymeric-coated galvanized steel pipe (AASHTO M 245) is reported to show better resistance to corrosion and abrasion than bituminous coatings (*12, 49*). This material is a polymeric coating with a minimum thickness of 0.010 in. (0.25 mm) applied to only one side of a galvanized culvert sheet (Type A) or to one side of a sheet with a thinner coating on the other side (Type B). The coatings must be flexible enough to withstand corrugating, culvert-forming, and lock-seaming operations.

The main mode of failure is wear in the highly abraded areas such as the crests of corrugations. In field installations, no delamination from the base metal has been observed even in effluents with a pH of 2.2. The Pennsylvania

Department of Transportation conducted laboratory corrosion- and abrasion-resistance tests of corrugated steel pipe coated with (a) asphalt, (b) asbestos-impregnated asphalt, and (c) polymeric coatings (AASHTO M 245). The department's conclusion was that polymeric coatings proved superior in corrosion resistance (under accelerated exposure, salt spray, weatherometer, and chemical tests including acids and alkalis). The 12-mil-thick (0.3-mm-thick) polymeric coating in Pennsylvania proved comparable to the conventional 50-mil-thick (1.3-mm-thick) asphalt coating when subjected to sandblast abrasion tests. According to West Virginia laboratory tests, advantages of precoated, galvanized steel pipe over pipes with conventional asphalt coatings include lower damage susceptibility in shipping and handling and fewer effects from temperature change and aging.

### EPOXY COATINGS AND LININGS

Kentucky has tried epoxy-coated concrete pipe successfully in its highly acid Morton's Gap and Western Kentucky Parkway projects (*18*). The pipe was coated internally to a height of at least 1 ft (0.3 m) above the invert with a polysulfide epoxy-resin primer, which was overlaid with epoxy-resin mortar troweled on while the prime coat was still tacky. The primer and mortar were pigmented to produce clearly distinguishable colors. The result was a hard, durable finish that is reported to have shown no worn or etched areas after 13 years' service in waters of pH 3.5 to 5.5.

### MORTAR COATINGS

*NCHRP Report 116* (*29*) describes the use of hand-applied multilayered mortar protective coatings on concrete culvert inverts in eastern European countries such as Hungary and Poland. Labor costs dictate against this practice in the United States.

### CEMENT-MORTAR LININGS

Centrifugally applied low-slump concrete or cement-mortar lining about 1 in. (25 mm) thick has been used successfully in concrete and metal pipe. This is classified as a repair technique rather than a conventional procedure for new construction and is discussed further in Chapter Six.

### FIBERGLASS COATINGS

Concrete pipe and box culverts have been experimentally coated internally with fiberglass in Idaho and other locations, but results were unsatisfactory.

### CLAY LINING

Clay, which is chemically the most inert of commonly available materials, has been used to withstand corrosion in the more aggressive acid soils or runoff situations encountered in the field. For large concrete pipe or box culverts, clay can be used in the form of liner plates (ASTM C 479) inserted with acid- and sulfate-resistant dry silica sand mortar; however, this operation is labor-intensive. Installation requires careful handling to ensure that there is no loss of seal between plates.

### METALLIC COATINGS

Certain metals can be mechanically, electrically, or chemically deposited on other metals or alloys. Metallic coatings can be classified as anodic (sacrificial) or cathodic (nonsacrificial) (*8*). Sacrificial coatings in pipe are those that are progressively sacrificed electrically to protect the underlying metal to which they are applied. Zinc and aluminum are most frequently used as coatings.

#### Galvanizing

Soon after the development of corrugated iron pipe in this country in 1896, the need for improving its corrosion resistance was recognized. As a result, galvanized corrugated steel pipe was introduced in 1907 and gained increasingly wide use for highway and railroad drainage. Galvanizing consists of the application of a thin layer of zinc to steel by hot-dipping; the zinc is deposited as a layer of flattened plates that are vulnerable to abrasion. Between this zinc layer and the steel an intermediate layer of zinc-iron alloy forms that also provides corrosion protection and is resistant to pitting. The protection provided is proportional to the thickness of the zinc layer. Most pipe specifications require a 2-oz zinc coating (i.e., 2 oz/ft$^2$—610 g/m$^2$), which consists of a zinc deposit averaging not less than 1 oz/ft$^2$ (305 g/m$^2$) on each side of the steel sheet. Heavier coatings, such as 3 oz (915 g/m$^2$), are specified for structural-plate pipe but do not appear practical under present manufacturing methods for conventional galvanized pipe.

In acid or highly alkaline environments, the principal mode of attack on the galvanizing is by hydrogen gas. When pH is greater than 12, zinc reacts rapidly to form soluble zinc compounds. Montana reports (in an unpublished study) that zinc galvanizing is not an effective protection for steel in soils whose pH is outside the range of 6.0 to 9.0. In the Montana installations with highly alkaline soils (pH 10), zinc was completely stripped from the underlying steel, which was subsequently unaffected.

Questions have arisen as to relative corrosion resistance of culvert sheets galvanized by the old pot-dip process and those produced by modern steel mills by the continuous-strip galvanizing method. Field tests in Washington (*49*) revealed no significant difference in corrosion resistance provided by the two galvanizing methods.

#### Galvannealing

Steel with an iron-zinc surface alloy is termed "galvannealed" steel. Although recent research (*49*) has shown its corrosion resistance to be similar to that of galvanized steel, galvannealed steel has not been widely used as a culvert material.

#### Aluminum-Zinc

A coating developed primarily to protect the cut edges of aluminized steel and to extend the life of galvanized steel in industrial atmospheres, aluminum-zinc-alloy coated steel presently is being tested as a coating for culverts. During 1973 and 1974, 962 ft (293 m) of aluminum-zinc coated culvert pipe and a similar length of galvanized steel pipe were installed experimentally at 16 locations in 9 eastern states. A 1977 survey of these pipes indicated that 0.6 oz/ft$^2$ (180 g/m$^2$) aluminum-zinc-alloy pipe is performing at least as well as 2 oz/ft$^2$ (610 g/m$^2$) galvanized pipe, after up to three years of service.

## CLADDING

Aluminum culvert sheet is a sandwich with an inner core of aluminum-magnesium-manganese alloy 3004 between two layers of aluminum-zinc alloy 7072 "cladding," which is anodic or sacrificial to the core material (*31, 32*). All three layers of the sandwich are bonded metallurgically during the rolling operation, with each outer cladding layer constituting 5 percent of the final sheet thickness. Under corrosion attack, the cladding is galvanically expended, protecting the core material until large areas of cladding are gone.

Laboratory tests by California show that cladding is sensitive to abrasion; field data also indicate that the cladding was abraded by bedloads containing shattered angular rocks (*38*).

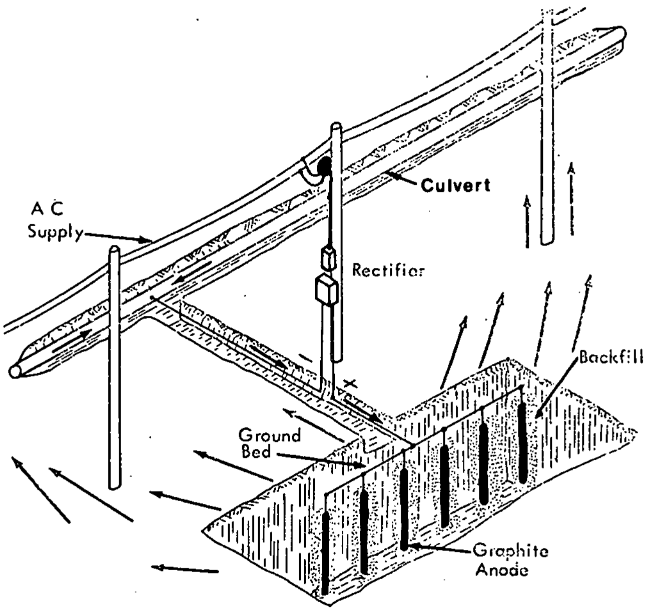
## SEVERE ABRASION PROTECTION

Experiences in California, Oregon, and other states indicate that special consideration is required for pipes with a steep gradient and heavy bedload. Increased thicknesses of invert plates, rail steel set in concrete, and other special protection techniques have been used to protect new and old pipes.

## CATHODIC PROTECTION

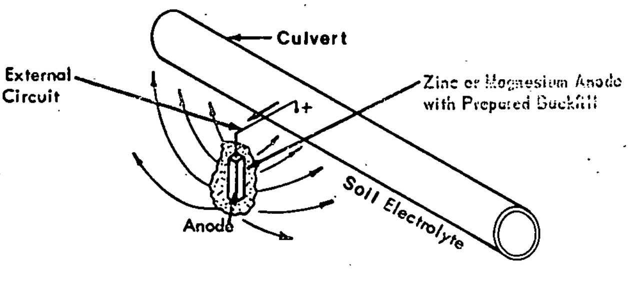
Cathodic protection is the reduction or prevention of corrosion by making the entire culvert a cathode. This electrochemical procedure has been commonly used for more than a century to protect underground oil and gas lines, storage tanks, ship hulls and propellers, and bridges. Corrosion is prevented by controlling the flow of currents. This is done by applying current from an outside source (Fig. 5) or by connecting the structure to be protected to a remotely installed anodic or sacrificial metal (Fig. 6), usually magnesium or zinc (*8*). Typical current densities for pipe in soil range from 1 to 50 milliamperes (mA)/ft$^2$ (11 to 540 mA/m$^2$) of bare pipe exterior surface being protected, although a good protective coating on the culvert would reduce these values considerably. In medium- and high-resistivity soils, researchers have found that corrosion rates decrease rapidly after the first few years of exposure, so that one should defer decision on the need for cathodic protection, where possible, at least for that length of time (*13, 44*).

Although cathodic protection could be used for drainage culverts, only one report of its use for this purpose was found. At several locations in Arizona, magnesium anodes were installed in an effort to prevent corrosion of galvanized



| Advantages | Disadvantages |
|---|---|
| Wide range of voltage and current possible | Must be carefully designed to avoid cathodic interference |
| Long life | Subject to power failure |
| Greater area coverage from one installation | Inspection and maintenance required |
|  | Overprotection (of aluminum) is possible |

*Figure 5. Impressed-current method for cathodic protection of culvert exterior surface.*



| Advantages | Disadvantages |
|---|---|
| No external power source | Limited anode life or large number of anodes usually required |
| Regulation not required |  |
| Simpler installation |  |
| Additional anodes can be added easily | Generally not feasible in high resistivity areas because of limited current output |
| Little likelihood of stray current damage to other structures |  |

*Figure 6. Sacrificial-anode method for cathodic protection of culvert exterior surface.*

steel culverts (*13*). The magnesium sacrificial anodes have to date proven inadequate, possibly because of the large surface area of uncoated pipe to be protected and high soil resistivity.

At the new Dallas-Fort Worth International Airport, the underground drainage system includes 40 miles (64 km) of bituminous-coated galvanized steel pipe or pipe arch having diameters or widths of 1.5 to 22 ft (0.5 to 6.7 m). The system includes 344 corrosion test stations to monitor stray currents from other cathodically protected utility systems. Provisions have been made to install cathodic protection, if required in the future, on any of the drainage lines. Similar test stations have been installed in Florida at Tampa International Airport and the Kennedy Space Center.

There are many reasons why culverts rarely would need cathodic protection. It is much less expensive to apply suitable exterior protective coatings initially than to provide and periodically replace the required sacrificial anodes or to apply and monitor electrical potential and current supplied during the entire life of the facility (*53*). Also, protruding culvert end sections would not be protected. It should be remembered also that, in most drainage facilities, federal and state agencies report corrosion affecting the pipe interior surface rather than the pipe exterior, where it would be more practical to apply cathodic protection.

Drainage engineers should carefully analyze corrosion susceptibility of proposed metal culverts to be placed near and within the stray electric current field of existing cathodically protected utilities or structures. There may be situations in which cathodic protection can provide the only feasible means to protect such a drainage facility.

Detailed information on cathodic protection, including typical cost analyses for such systems as compared with other corrosion prevention measures, is given in Department of the Army Technical Manual 5-811-4, *Electrical Design, Corrosion Control,* August 1962, and publications of the National Association of Corrosion Engineers, Houston, Texas (*40*).

CHAPTER FIVE

# INSPECTION OF CULVERTS

## REASONS FOR INSPECTION

Culverts and pipelines of drainage systems require periodic inspection to detect corrosion-abrasion deterioration and other conditions affecting structural and hydraulic effectiveness. It is not within the scope of this synthesis to go into structural inspection details.

Another important reason for inspecting culverts is to evaluate performance of the various materials and corrosion-abrasion countermeasures in the specific natural environments encountered. Information on older culverts at or near a proposed site provides important points for any graphical or statistical correlation of the various environmental factors with service life. Evaluation of culvert materials that have been installed for shorter time spans yields less conclusive indications, because the short exposure time means that the protective layers and coatings are still relatively intact. Any failures or distress in newly installed culverts can, however, furnish highly significant information. It is important in these evaluations to determine the effectiveness of the materials used and to learn as much as is pertinent about the environment and electrolytes involved. These data assist in the design of economic drainage facilities in the future.

## SCHEDULING INSPECTIONS

In the less destructive environments, field inspections of a representative sample (about one-fourth) of the culvert sites may be conducted at intervals of ten years or more. Culverts in more aggressive environments should be examined at least every three years—more often if already heavily corroded or abraded. The Bureau of Reclamation has found it advantageous in preventing development of serious defects to inspect major structures (including pipelines) at two-year intervals (*6*). Some states inspect the more vulnerable areas of culverts, such as inverts, every three years and areas such as pipe outlets and selected soil-pipe exterior surface locations every six years.

Inspections should be made at locations in corrosion-abrasion-susceptible environments, such as where acid mine drainage, industrial and sanitary wastewaters, swamp and brackish waters, seawater, and sediment-laden runoff are present. Where different culvert materials have been used, with and without various protective treatments, inspection should include a representative number of culverts of each type. Careful field examination and tests should be made of culverts and storm drains near sources of possible stray direct current from utilities or cathodic protection systems.

Records of past field observations, where available, can provide guidance as to the desirable extent of coverage and frequency of inspection. Observations should be scheduled in seasons or at times when weather and flow or tide levels facilitate examination and sampling.

In addition to observations made at and near the exposed ends of culverts, internal inspections should be made where safety, pipe size, and flow conditions permit. Silt deposits, loosened coatings, scale, and rust should be removed where necessary to examine the pipe invert, which is particularly susceptible to corrosion-abrasion damage. In some cases, temporary damming and diversion of flow upstream from the culvert may be required for inspection. Coring or excavation to expose the soil-pipe interface may be required. Such a procedure may be necessary in highly acid, alkaline, sulfate, or chloride soils. This is usually first done away from traffic lanes, at or near the culvert ends where amount of cover over the pipe is normally less.

## PREPARATION FOR INSPECTIONS

Prior to field observations, office records should be examined to select and locate culverts to be investigated. Plans may indicate the exact location and age of these culverts. The local maintenance office should be contacted to determine whether or not the pipe has been extended or replaced. Inspectors should also look for any indications that the original culvert has been replaced. A program to mark all culverts with year of installation would be helpful in subsequent inspections.

## INSPECTION PERSONNEL

Inspection personnel should be trained in inspection techniques and in record keeping. Safety demands that no one enter culverts, manholes, or other underground drainage facilities unless another person is outside nearby and equipped to render emergency assistance if required. Experienced professional or technical personnel are required to make or at least supervise complex chemical or electrical tests unless a properly calibrated "black box" apparatus is used.

## INSPECTION EQUIPMENT

Depending on the type of inspection, equipment could include a short-handled, round-pointed shovel; geologist's pick; steel tape measure; sheet metal thickness gauge (micrometer); gauge for measuring depth of pits; penknife and small file for scraping scale; portable drill or hole saw for obtaining samples; kit for repairing sample holes; waterproof chalk; miner's lamp or flashlight; soil sample bags; one-quart (one-litre) plastic sample bottles; camera (preferably with color film and photoflood or flash attachment); and mirror. Field clothing often includes waterproof footwear or boots and, in extreme cases, wet suits. Portable ladders also may be required for entry into shallow manholes lacking built-in ladders or rungs. Most inspections also require portable soil-resistivity and pH meters. Also useful are compact field test kits for any other needed determinations of physical, chemical, or electrical parameters.

### Television Inspection

Television inspection services are available nationwide on a rental basis for observing and recording conditions within culverts and storm drains that are relatively inaccessible, unsafe, or not possible to inspect by other means. Access from ends or manholes allows for closed-circuit TV surveys safely and economically in all types and sizes of culverts and storm drains. These services have been extensively employed in examining and inspecting repair work in sanitary and storm sewer systems and also could prove useful in transportation drainage systems.

## INFORMATION REQUIRED

Where corrosion-abrasion problems are detected, the inspection should obtain or determine, if practicable, the following:

- History of installation and maintenance.
- Nature and analysis of the electrolyte.
- Rate of flow, velocity, and bedload conditions for low flow as well as flood conditions.
- Soil and water resistivity and pH.
- Location, extent, and type of corrosion and amount of material thickness lost due to corrosion.
- Preventive measures used and reasons for any deficiencies or failure.
- Samples of soil and water.
- Pipe material samples.
- Photographs, videotape, etc.

## PIPE RATING METHODS

Several state agencies and industry representatives making field inspections of culverts have developed evaluation methods with durability performance ratings. The numerical or qualitative ratings denote the inspector's estimate of degree of deterioration from time of installation to time of inspection. Because most ratings are based on visual examination, aided in some cases by tests (e.g., tapping the pipe with a geologist's pick and then measuring section loss at the "worst" locations), the findings normally are qualitative approximations. Although indications of service life can be deduced, the ratings do not necessarily represent the proportion of service life consumed or remaining.

Maine uses a six-class numerical rating system to indicate amount of deterioration (Table 5). Mississippi and several other states use a system wherein the investigator assigns a percentage rating designating the condition of a concrete or steel culvert (Table 6). The aluminum industry has developed a classification system for rating the condition of aluminum culverts based on visual inspection (Table 7). (It should be noted that the description of rating E in Table 7 should include unsound areas to completely deteriorated sections.)

Utah has an excellent method of determining pipe performance, including inspection, photographing, testing, and rating (*57*). During inspection, a form is filled out containing the following information: type of pipe; height of fill; slope of pipe and inlet channel; corrosion location, type, and degree; abrasion degree; general visual observations; and any additional pertinent remarks about the pipe's condition or its surroundings. A 4-in. (100-mm) core is drilled from the pipe, if possible at a location 12 ft (3.7 m) from the pipe end and 15 degrees up from the midpoint of the bottom. A soil sample is then taken from the soil side of the culvert and placed in a waterproof container for later laboratory analysis. If there is flow at the time, a water sample also is obtained. Photos are taken of the surrounding terrain as well as of the inside and soil sides of the pipe (when possible). The core hole is patched before leaving

TABLE 5

PIPE EVALUATION SCALE (MAINE) (*23*)

| Rating | Reinforced Concrete | Corrugated Steel |
|---|---|---|
| 0 | Approaching original condition. | Approaching original condition (Galvanizing intact). |
| 1 | Discoloration, slight spalling of mortar, no softening of concrete. | Superficial rust (no pitting). |
| 2 | Slight spalling of smaller aggregate, no softening. | Moderate rust (minor pitting). |
| 3 | Moderate spalling (loss of mortar and aggregate, minor amounts of softening). | Fairly heavy rust (moderate pitting, metal sound). |
| 4 | Extensive spalling of mortar and aggregate plus softening of concrete. | Heavy rust (deep pitting and some perforation). |
| 5 | Invert completely deteriorated. | Unsound areas (extensive perforation to completely deteriorated bottom). |

TABLE 6

CULVERT MATERIAL CONDITION RATING CHART (MISSISSIPPI) (*17*)

| Rating (Percent ) | Reinforced Concrete | Corrugated Steel |
|---|---|---|
| 90 | No weathering or disintegration and no softening from acid, alkali, or other causes. | Spelter entirely intact. |
| 75 | Some weathering or spalling and disintegration. Slight erosion of invert. | Spelter just gone and thin rust beginning to form in places, no abrasion and no pitting. |
| 50 | Decided disintegration or erosion in invert. General weathering and spalling. Softening due to alkali or acid. | Complete loss of spelter and considerable loss of metal in invert. Pitting and some abrasion. |
| 30 | Decided disintegration throughout pipe. Considerable weathering and spalling. Softening due to alkali or acid. | Decided pitting and abrasion. Heavy loss of metal in invert. |
| 10 | Extreme disintegration and spalling. Material very soft due to acid or alkali. | Metal corroded and abraded through invert in small spots. Very heavy rust and deep pitting generally over invert. |
| 0 | Disintegration through pipe. Reinforcing exposed. | Entire invert gone. |

TABLE 7

RATING CLASSIFICATIONS FOR ALUMINUM CULVERT INSPECTIONS (ALUMINUM INDUSTRY) (*32*)

| Rating | Appearance Description | Description of Corrosion |
|---|---|---|
| A | Excellent | No observed corrosion or significant metal surface staining. |
| B | Very good | Superficial corrosion in the form of occasional pits confined to surface and/or cladding. Pits no more than 5 percent of surface; or<br>Extensive surface staining, gray cast in alkaline exposures to orange cast in organic acid exposures. |
| B/C | Good | Significant corrosion confined to cladding. Pit frequency unlimited except that less than 50 percent of the surface is etched on the worst square foot observed. Usually evidence of corrosion build-up in pits. Staining may accompany attack but will be incidental to the over-all effect. |
| C | Fair | Attack covering more than 50 percent of the surface on the worst square foot observed with corrosion limited to cladding. Will give appearance of etched surface. Occasional pit may appear to penetrate into core. |
| D | Poor | Attack but not perforation of the core alloy, generally accompanied by extensive surface corrosion. |
| E | Very poor | Perforation of the metal. |

the site. Cores, cleaned of loose debris, are examined by three persons, each of whom assigns a tentative pipe rating on a scale from 10 (excellent) to 0 (failure). Core thickness, an average of five random-location measurements to the nearest 0.001 in. (0.025 mm), and weight are determined. The core samples are then stripped of coatings and measured and weighed again. Tentative pipe rating evaluations are reviewed as a result of visual observations of the core samples. Final pipe ratings are assigned to each specimen after reviewing the field notes, photos, tentative ratings, core observations, and measurements. These pipe ratings, designating the relative degree of corrosion, are used for numerical analysis of pipe durability performance.

There are many variations of rating systems in use, but basically the same indexes of corrosion and abrasion are employed. Maryland, in a statewide survey of performance of bituminous coatings on corrugated steel pipe, assigned ratings corresponding to the inspector's opinion of the average amounts of coating loss (1 = 10 percent lost, 10 = 100 percent lost) (*26*).

Instead of arbitrarily assigning a qualitative rating, it is always better to measure the thickness of the remaining metal; depth and extent of pitting; or area and condition of protective coating, cladding, or treatments. Complete and accurate recording of data facilitates laboratory analysis and evaluation.

## INSPECTION RECORDS

Standard forms or notebooks for recording field data should be used. Such notebooks or forms have been developed by several state agencies. Instructions for use of these forms commonly include description of the rating system for numerically classifying the condition of the pipe and/or its protective material. A typical steel culvert pipe inspection report form, as used by Washington (*7*), is included in Appendix C. Where detailed data are required for a comprehensive analysis, more complete forms are used. For example, California has a two-page tabular form (Form T 620) with four pages of accompanying instructions to the inspector (*4*).

When precision is required, it is customary to review the results of field tests as a guide in selection of samples to be tested more accurately in the laboratory. All pertinent observations and measurements should be recorded when made. Such information should not be entrusted to memory.

CHAPTER SIX

# MAINTENANCE AND REPAIR OF CULVERTS

## PURPOSE

Maintenance and repair are required so that culvert and storm-drain facilities can continue to meet hydraulic and structural requirements of the drainage facility economically for the remainder of their programmed life.

## ROUTINE MAINTENANCE

Routine maintenance involves removing major obstructions (such as boulders, logs, construction debris, ice jams, underbrush, and refuse) that cause or threaten blockage, flow diversion, or damage to the transportation facility, the culvert, or its appurtenant structures. In some cases, clearing or alignment of approach and exit waterways, drainage channels, and their overbank floodways also may be warranted. Abnormal accumulations of deposited sediment and other material may require flushing or other removal techniques. Equipment should be handled with caution to prevent damage to the pipe and its coatings, linings, or pavement. Ends of culverts, regardless of type of material, are particularly vulnerable to damage by maintenance equipment.

## MAJOR MAINTENANCE AND REPAIR

Extensive measures beyond the scope of routine maintenance are of a curative or restorative nature for culverts and pipes that have experienced corrosion-abrasion damage. They are undertaken at relatively infrequent intervals in aggressive environments and rarely in normal environments, assuming that the original design and material selection were adequate. Changes in land and water use may, however, upset the existing corrosion-abrasion defenses and necessitate corrective procedures. Because there are a wide variety of corrosion-abrasion causes and combinations thereof, there are also a broad assortment of repair techniques. These should be carefully analyzed from standpoints of practicality, compatibility with the existing installation, prospective performance, and economics. The precepts for selecting corrosion-preventive schemes are few and the possible choices numerous. Specialists seldom agree even in less controversial situations, and solutions often are, in reality, compromises. The principal means for extending the useful life of existing culverts and storm drains are described in the following paragraphs.

### Metal Culvert Maintenance

Corroded or abraded areas of metal culverts normally are not repaired unless extensively perforated, structurally weakened, or missing sections of the invert (see Fig. 1). In locations with seasonally or continually high water table and fine-grained noncohesive soils, however, early remedial action is required to prevent detrimental infiltration, loss of backfill, structural damage, and pipe blockage. Among possible repair techniques to be considered for metal pipe are the following:

1. Detached, loosened, or badly checked coatings can be removed; metal surfaces can be cleaned; and new coatings can be applied (usually of the bituminous or epoxy type). To ensure observance of safety and health precautions, experienced personnel should be employed in applying these coatings with proper forced-draft ventilation. Zinc dust paint can be brush- or spray-applied to bare metal areas where spelter is gone. A new technique under experimental development consists of injecting a compressed gas (such as nitrogen) as a carrier for a polymer. The polymer can be deposited to cover the pipe interior including any corroded or eroded areas. Such deposits provide a protective lining about ⅒ in. (2.5 mm) thick.
2. Major leaks that threaten structural support, particularly where soil and water may infiltrate, can be remedied by welding, plugging, or grouting. In lines with diameters greater than 24 in. (610 mm), repairs can be made internally by use of expanding metal bands or steel tunnel liner plates.
3. Missing portions of an invert can be replaced by welding in metal plate or sheet. Concreting in portions of invert to replace damaged or missing sections, particularly at pipe ends, is common practice.
4. Internal centrifugally applied cement-mortar grout can be used. In a 1954 study in California, a centrifugally applied mortar (1 part sand to 1 part cement, with 10 to 15 percent pozzolan added) in ½-in. (13-mm) increments to a thickness of 1 in. (25 mm) or more was applied to line several deteriorated metal culverts (*45*). Costs were less than for replacing culverts when depth of cover was 9 ft (3 m) or more. Grouting, unlike culvert replacement, does not entail traffic disruption.
5. In extreme cases where replacement is not feasible, a smaller pipe can be inserted within a badly corroded culvert, sacrificing some hydraulic capacity in return for added service life. Consideration should be given to sealing the space between the two pipes.
6. Cathodic protection, as discussed in Chapter Four, can be used to protect costly drainage installations from corrosion. The cost analysis for such systems should include consideration of use of sacrificial anodes or the continuous application of low-voltage current.

### Concrete Culvert Maintenance

Abraded or deteriorated areas should be repaired before structures are materially weakened. Need for early maintenance is also indicated by the exposure of steel reinforcement due to abrasion, spalling, cracking, or other defects (see Fig. 1). Corrosion-abrasion can roughen interior surfaces, particularly the invert, and, in extremely aggressive environments, expose the steel reinforcement. Among possible repair techniques to be considered for concrete culverts and storm drains are the following:

1. Worn and abraded concrete surfaces can be restored by overlay or grouting techniques, including (a) centrifugally sprayed cement-mortar grout as outlined in item 4 of the previous section for metal culverts, (b) use of epoxy cement, or (c) troweling grout mixture into cracks or over small areas. In extremely aggressive conditions, thickening the wall internally can extend service life. Thick coatings usually are reinforced with wire mesh.

The subject of restoration of deteriorated concrete is covered in detail in Chapter 7 of "Durability of Concrete in Service" (*14*). That report emphasizes that the most important requirement in the repair of concrete under all conditions is that all deteriorated or defective concrete be removed. "One of the most common errors in repair procedures is a reluctance to remove all unsound and semisound concrete. Any questionable or semisound concrete must be ruthlessly removed until there is no doubt that the quality of the remaining concrete is satisfactory."

2. Where corrosive influences are the dominant cause of deterioration (as in acid waters), clay or plastic liners can be inserted. Clay liner plates, although impervious to acid damage, require acid-resistant mortar and careful hand placement, a procedure that Kentucky has found more costly than providing an added thickness of sacrificial concrete.

3. The method being developed for applying a polymer coating internally using a compressed gas as a carrier (as described for metal pipe maintenance) may prove to be suitable for lining concrete or asbestos-cement pipe.

4. Where damaged sections are localized, steel tunnel liner plate may be inserted to provide added structural support.

5. As in severely distressed metal pipe, insertion of a smaller pipe is a measure to be used as a last resort when pipe replacement is not practical. In most cases, the annular space between the old and new pipes is filled with grout.

### REPLACEMENT OF CULVERTS

When culvert replacement is necessary because of premature failure or deterioration, the causes of failure should be determined. The replacement pipe should be one that has the most economical service life, considering size, structural and hydraulic requirements, and availability. First consideration should be given to the commonly used drainage materials (steel, aluminum, and concrete) and their coatings and then, if necessary, to vitrified clay, stainless steel, cast iron, and plastic.

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CHAPTER SEVEN

# SERVICE LIFE ESTIMATION

The rate of deterioration of underground drainage materials depends on the environment in which they are installed. The environment consists of many factors pertaining to the soil, water, and atmosphere. Studies have revealed that certain relationships that seem to correlate in one place may not in another. Consequently, designers have adopted various field and laboratory test methods of varying complexity and accuracy for determining the rates of deterioration in a given environmental situation. Methods used have ranged from referring to a state or local map showing a specific index of corrosion susceptibility to detailed field sampling and complex laboratory testing.

### WHAT IS FAILURE?

There is no widely agreed-upon definition for failure of a culvert or storm drain, short of collapse. The criterion for water pipe that a wall penetrated by a corrosion pit constitutes failure is not applicable to culverts or storm drains except under abnormal soil conditions. Obviously, deterioration constitutes failure when a weakened structure collapses or threatens embankment stability. A pipe whose invert has corroded or abraded or a pipe that is severely pitted and perforated still may be capable of supporting its backfill and cover; however, it constitutes a poor risk and warrants prompt repair or replacement.

One way of defining the service life of a culvert is by the number of years of relatively maintenance-free performance. Although a culvert may have reached its service life, there may be many more years until failure. However, the level of maintenance required after reaching service life may be such that replacement is justified well before failure occurs.

Generally, designers are looking for relatively maintenance-free culvert performance for at least 25 years in secondary road facilities and for 40 years or more in primary highway, urban transit, or rail facilities. A longer service life requirement is also justified for hard-to-place culverts in key urban locations or under high fills, particularly in small longer conduits with limited internal accessibility. Frequently, a durability safety factor as large as 2 is also used to assure that the structure will definitely serve its required life span. Errors in judgment have been on the safe side, according to industry and the engineering and scientific professions. This adds directly to the cost, however.

As experience is accumulated, the accuracy in predicting service life improves. Allowances should be made for progressive changes in culvert materials and in methods of installation, inspection, and maintenance. As new materials enter the culvert inventory, estimates of their service life are established. Such a situation occurred in 1960, when aluminum alloy pipe first entered the highway drainage market. Although aluminum was not a new material, the application was new and industry and prospective users had to estimate its service life under various conditions. Similar efforts are now under way for pipe products made of plastics, new alloys, and other materials.

Service life of culvert and pipeline materials in various environments has been evaluated in several studies. The methods used in these studies involve four different approaches to the problem: (a) field performance surveys, (b) field prototype tests, (c) laboratory tests, and (d) analytical methods. However, when extrapolating data to other areas, it must be kept in mind that these methods were developed for environments in specific geographic areas.

## FIELD PERFORMANCE SURVEYS

One of the earliest studies, reported in 1931 by Crum (*10*), includes a statistical analysis of service characteristics of different kinds of culverts based on field surveys by others of more than 3000 culverts in California, Georgia, Tennessee, Texas, and Virginia. This was one of the first efforts at defining and classifying recognizable stages in the progressive deterioration of corrugated metal culverts due to corrosion-abrasion processes. Rigid culverts of concrete, clay, and cast iron, although subject to wearing away, are reported as generally retired from service through collapse as a structure. Material deterioration may or may not contribute to the final result (*10*).

For metal pipe, measurement of depth of pitting or of thickness remaining to determine how much of the total thickness has been lost is a common practice. By extrapolation of the time remaining to perforation, service life of a certain material under the specific environmental conditions can then be estimated. Romanoff found that corrosion does not continue at a constant rate but that a gradual retardation in rate generally occurs, so that straight-line extrapolation of service life provides a measure of conservatism in design (*43*). However, culverts have not been studied specifically in this manner.

## FIELD PROTOTYPE TESTS

Field corrosion or abrasion susceptibility can be ascertained by installing similar lengths and sizes of pipe of different materials in tandem so that the same amounts and concentrations of corrosive or abrasive fluids flow successively through all specimens. Field tests are usually conducted in locations selected to obtain the effects of an aggressive, accelerated environment. These tests, depending on the vagaries of climate, may require an unreasonably long time to reveal the effects of normal seasonal cycles. However, results from such tests in the natural environment have the greatest credibility. The best results are based on laboratory tests combined with controlled field observations and conducted to the maximum practical degree with the same soil and water environment and climatic exposure.

## LABORATORY TEST METHODS

Laboratory tests are useful in evaluating the comparative service life qualities of different materials or the relative effects of various corrodents. Samples of different metals, alloys, or coatings can be immersed for long exposures under controlled conditions in various concentrations of reagents expected to be found in the soils or waters at the drainage site. Such chemical reactions often can be accelerated by an increase in the temperature or concentration. It should be realized, however, that corrosion of some materials proceeds at a greater rate in diluted than in concentrated solutions. Similarly, there are laboratory methods for accelerated testing of pipe sections and coatings to determine their relative resistance to various abrasive bedloads (sand, gravel, crushed stone, or mixtures) in water at various temperatures and velocities. Freeze-thaw cycling tests of coatings are also important in evaluating brittleness, susceptibility to chipping when cold, spalling, maintenance of bond, and other changes. Specialists in corrosion control also urge caution in evaluating laboratory results, because such tests do not reproduce the effects of soil and water electrolytes or of bacterial action in the fields.

## ANALYTICAL METHODS

A few of the analytical methods used by state agencies for selection of certain drainage materials and prediction of their service life are outlined in the following sections.

### California Method for Estimating Service Life of Steel Culverts

Following a 1959 study of performance of 7000 corrugated steel culverts in northern California, researchers noted that these data, with supplementary information from other parts of the state, showed that of the several factors examined, those most influencing the corrosion rate were the hydrogen ion concentration (pH) and the electrical resistivity of the soils and waters (*5*). A relatively simple test method was developed, which can be completed in about five minutes for water and not more than ten minutes for soils (*46*). Detailed procedures for this test method are given in Appendix B.

Louisiana (*1*) and Idaho (*15*) have found this method suitable in their environments in connection with other parameters; Oklahoma finds that this method applies only to its panhandle region and two other small areas. Based on field observations of service life of pipe in Louisiana, an excellent correlation coefficient (0.95) was obtained using the California Test Method. A number of other investigators, although agreeing that these two parameters are good indicators of corrosion potential, conclude that California's method yields conservative results for their geographical areas (*37*). The states of Washington (*7*), Utah (*41*), Kansas (*56*), and New York (*20*) and an Australian government researcher (*25*) did not obtain the desired degree of association of their data using the California method of relating corrosivity of metal culverts to soil and water pH and resistivity. Environmental and geological factors not evident from the several corrosion indexes reported may account for the differences encountered by the various investigators. In Utah's alkaline soils, all pipe materials corrode faster in higher pH when resistivity and soluble salt content remain constant. In addition to pH and resistivity, Utah uses the soluble salt content as a necessary parameter (*57*).

It should be pointed out that methods of this type indicate average service life and that service life of individual culverts may deviate markedly from such an average because of the numerous factors involved. Observations of existing culverts in the area should be made.

### California Method for Estimating Time to Corrosion of Concrete Structures

The California method for estimating the service life of reinforced concrete bridge substructures is based on the combined evaluation of three factors: (a) pH, (b) sulfate-ion ($SO_4^{--}$) concentration, and (c) chloride-ion ($Cl^-$) concentration in the soil and/or water environment. This test method (Calif. 532-A) also can be used for reinforced concrete culverts of known water-cement ratio and for thickness of concrete cover over the reinforcing steel, but it has not been investigated for precast concrete pipe. The estimated time to corrosion is shown in convenient nomographic form.

### New York Method Based on Average Annual Metal Loss

New York completed a statewide survey of performance of about 800 uncoated, coated, and coated and paved galvanized steel culverts with up to 35 years' service (*20*). In these field observations, *estimates* were made of the percent of the original thickness lost and were prorated based on the area affected to derive average metal loss for the entire culvert. A statistical analysis was made to determine the relationship, if any, between culvert performance (metal loss) and environmental factors, including pH and electrical resistivity of the soil and water, land use, topography, stream velocity, sediment load, and effect of bituminous coatings. No meaningful correlation was evident. It should be pointed out that the data were related to narrow pH and resistivity variations and may not be applicable to different environments. Curves were plotted of the percent of culverts (probability) equaling or exceeding rates of metal loss. Curves for uncoated, coated, and coated and paved galvanized steel culverts were plotted. More recent data (contained in an unpublished report by New York) based on actually measured metal loss indicate that these curves are low. The revised curves indicate that the number of culverts with metal loss rates greater than 2 mils/year (.05 mm/year) is higher than the original curves suggested but still in the range of 1 mil to 5 mil/year (.03 mm to .13 mm/year) experienced by others.

Recently the New Jersey Department of Transportation, after reviewing available design methods, decided to adopt for its use the original New York curves as the most suitable for metal culvert service life determination in its area (*42*).

The probability curves can be used to evaluate the potential performance of a culvert once the metal gauge (or thickness) based on structural adequacy has been determined as follows:

1. Assign a metal-loss probability value commensurate with the intended use of the culvert, and select the corresponding design rate from the probability curves. In the examples in the New York report, 15 percent is used for secondary highways and 5 percent for an Interstate highway with a low risk factor. New Jersey suggests a 5 or 10 percent risk factor for a culvert under a deep fill or a heavily traveled pavement and a risk factor of 34 to 50 percent (66 or 50 percent confidence level) for an easily replaced driveway pipe or culvert under shallow earth cover.
2. Compute estimated total metal loss as the product of design rate and design life.
3. Establish the thickness required to provide the minimum safety factor acceptable at the end of the design life. A safety factor of 1.0 is suggested.
4. If the sum of items 2 and 3 equals or is less than the thickness of the pipe selected, the design is acceptable.
5. If the sum of items 2 and 3 is greater than the thickness of the pipe selected, a deficiency of metal is indicated and a greater thickness is required.

This approach was not implemented in New York, primarily because it was felt that a more standardized, simpler procedure was needed that would result in more uniform design. As a result, an interim method based on a durability rating was developed. In this method an attempt was made to determine if an aggressive environment existed, thus requiring coating and invert paving (*9*). To do this, a zoned map of New York was created based on the basic soil types, field measurements of water hardness, and field performance of culverts included in the earlier statewide survey (*20*) and other test culverts. Each of the five zones was thought to represent areas of differing corrosiveness. More recent field-measurement data do not substantiate the assumption that the five zones are indeed different.

### Utah Pipe Material Selection Criteria

The objectives of research and field studies by the Utah State Department of Highways on pipe corrosion and protective coatings (*57*) were:

- To identify testing procedures that are pertinent for pipe selection and to set levels to assure optimum performance of various culvert materials and coatings in Utah's water and soil conditions.

- To evaluate and if necessary update Utah's pipe selection chart.
- To determine the effects of turbidity and abrasion on the culvert materials.
- To determine the extent to which total soluble salts affect culvert performance and the relative corrosive potential contributed by each type of soluble salt.
- To formalize (in the standard tests manual) the field testing and evaluation procedures for soil resistivity.

Utah's procedure is to obtain soil samples from proposed culvert locations. These are tested for resistivity, pH, and soluble salt and sulfate content. Water samples are tested for pH and soluble salt content and, in certain areas, for sulfates and organic matter. Charts are then used to estimate the expected life of various pipe materials (see Appendix D). Additional consideration is given to the actual service life of existing comparable materials in the area. Recommended design life is 40 years on Interstate highways and 30 years on other facilities.

The guidelines and criteria are based on environmental conditions that are most prevalent in Utah soils; extreme care should be exercised when extrapolating the findings beyond the limits within which they were developed. The Utah selection criteria may not correlate with field experience when (a) resistivity is less than 150 ohm-cm, (b) soil pH is less than 7.0 or more than 9.6, (c) soluble salts are less than 0.8 percent or more than 10 percent, (d) sulfate content is more than 0.5 percent, or (e) there are continuous flows with an abrasive bedload.

CHAPTER EIGHT

# GUIDELINES FOR DURABILITY

## GENERAL GUIDELINES

Decisions on location and design of culverts and other drainage facilities are made primarily on the basis of such considerations as topography, rights-of-way, roadway geometrics, geology, and hydraulic and structural requirements. However, there is often sufficient flexibility and need to take into account and accommodate the following corrosion-abrasion control guidelines, which are generally accepted by drainage and corrosion engineers.

### Site Investigation

(a) Field investigators, when making preliminary site studies, also can obtain basic soil and water information (including bedload information) and samples for laboratory evaluations of culvert durability. They can also inspect and evaluate existing culverts in the area. This assists the design engineer in selection of culvert materials and in determination of the need for corrosion-abrasion preventive measures to meet service life requirements.

(b) Consideration should be given to possible future changes in land and water use during the anticipated service life of the culvert. Changes that could affect corrosion-abrasion rates include urbanization, industrialization, mining, shift from forest to agricultural use, establishment of feedlots or barnyards, stream diversions or damming, site stripping or defoliation for development, establishment of sanitary landfills, and disposal or storage of refuse or sludge on the watershed.

### Design

(a) The inclusion of at least two suitable pipe materials as contractors' options or alternate bid items, provided analyses show that approximately equal service can be expected, is often advantageous to the using agency. Although this necessitates additional effort, the specification of competitive materials frequently offers a savings. Conversely, agencies also can specify a single material if it is considered superior to alternate materials.

(b) Culvert materials should not be selected solely on the basis of the type of highway pavement material involved.

(c) Galvanic couples, such as the placing of an aluminum pipe extension in contact with a steel pipe, should be avoided.

(d) The potential for bedload should be evaluated.

(e) At sites subject to severe abrasion, velocity-reducing expedients should be used where practical. Protective devices, such as rails, also could be used.

(f) Because the height of fill is greater over the midportion of a culvert than at the ends, greater settlement occurs along the midsection of the culvert. This may result in continuous ponding inside the pipe, a situation conducive to corrosion. Provision of camber in the pipe to compensate for the expected settlement minimizes this problem.

(g) Use of clean sand, crushed stone, or gravel should be considered for culvert bedding and backfill where in-situ soils might be corrosive. Where permeable bedding and backfill materials are used, consideration should be given to prevention of seepage or piping pathways, such as through the use of seepage collars. Corrosion testing of backfill materials is important.

(h) Irrespective of hydraulic requirements, a minimum culvert size may be necessary to facilitate cleaning, maintenance, inspection, and so forth. The minimum size may vary, depending on location, length of pipe, height of fill, cost of replacement, and traffic considerations.

### Construction and Maintenance

(a) Deposits of materials causing corrosion must be removed from drainage trenches, bedding, or backfill. Abandoned iron or steel pipe, fence posts, or copper wire could be detrimental if in contact with an aluminum culvert. Similarly, contact of copper with steel should be avoided. Care should be taken in selecting backfill material to avoid corrosive materials.

(b) Struts or tie-wires sometimes placed in flexible culverts to limit distortion during construction should be removed to prevent obstructions that accumulate debris and cause ponding inside pipe.

(c) Obstructions within culverts or accumulations downstream that back up water should be cleared.

(d) Access for personnel and equipment should be provided to permit periodic cleaning of debris and maintenance of the culvert.

## SELECTION POLICY

Although selection of an anticorrosion-abrasion system is based on technical and theoretical factors, the final decision on the type of pipe material and any required protective measures also depends on economic considerations. The consequences of pipe deterioration or failure must be weighed against the cost of repair or replacement, the importance of the drainage structure, and, in turn, its impact on the transportation facility being served. In some cases failure of the culvert would have only negligible or slight impact on the facility but the repair or replacement cost would be great. In general, the best policy is always to provide a criterion of durability design for all culvert installations (for example, 25 years on secondary roads and 40 years on primary roads or important structures). If this is not done, maintenance, repair, and replacement of a large number of culverts can be quite costly. Durability design should be as commonly applied as hydraulic considerations are.

## SELECTION PROCEDURE

1. *Hydrologic and Hydraulic Considerations.* Determine the number, cross-section area, and other details of culverts and storm drains required to accommodate the design discharge.

2. *Structural Considerations.* Indicate the culvert or pipe-strength classification or wall or sheet thickness required for the specific conditions, such as type of soil, bedding, backfill, depth of cover, and loading.

3. *Availability and Suitability.* The specific site may limit the types and sizes acceptable. This includes consideration of transportation, accessibility, compatibility with existing drainage facilities, equipment for installation, and environmental and aesthetic suitability.

4. *Durability.* Using accepted principles and guidelines and assuming (for the purposes of this report) that at least two materials have "survived" the previously described procedures, the materials under consideration should be examined next from the important standpoint of corrosion-abrasion durability. It should be kept in mind that no one material may satisfy every environmental condition; thus the maintenance aspects and the relative difficulties of the various materials should be an integral part of culvert selection.

The most useful information concerning durability and service life is that obtained, if available, from appraisal of the performance of similar pipe materials exposed to the same or very similar environmental conditions. Then, based on the experience of the design agency, one or more of the agency's preferred methods can be used for selection of the suitable culvert material (Fig. 7). Some agencies have established durability test methods that can be used for selection of pipe materials and estimation of service life.

## RESEARCH AND RECOMMENDATIONS

- The apparent poor correlation among corrosion indicators indicates that the collection of additional data on existing culverts and coatings and the continuation of research in this area are desirable.
- Transportation agencies with similar environmental conditions should work together to develop improved pipe material selection criteria.
- Coatings and treatments have been developed for protection of culvert pipes. Research is needed to determine the effectiveness of these coatings and treatments, the specific applicability of each, and their economic value.
- A culvert located under a deep fill or under a highway with high traffic volumes can not be easily replaced. Research into methods and materials that can be used to salvage in-place culverts would be highly desirable.
- There should be a continuing search to identify culvert materials that are resistant to corrosion and abrasion under a wide range of conditions and that possess the strength needed to meet structural requirements.
- A few state transportation agencies have corrosion en-

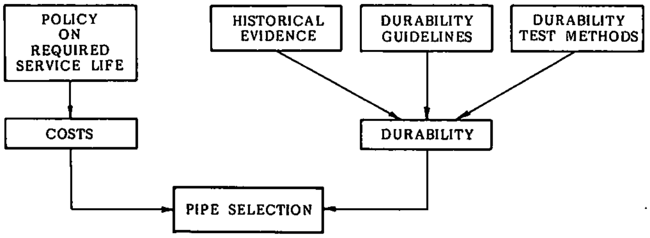

*Figure 7. Drainage pipe selection.*

gineers or specialists on their staffs. Others could benefit from the addition of such specialists, not only to analyze potential or actual corrosion of culverts, but also to assess corrosion of other facilities, such as bridge decks and lighting systems. Development of in-house expertise through training programs is a secondary means of enhancing capability.

- At present, only a few transportation agencies are engaged in any major research on pipe durability. There are some who believe that a more intensive research effort is desirable; however, there is some question as to how to organize the research. One approach might be a major study with nationwide support by all transportation agencies. A second approach would combine the efforts and funding of transportation agencies having common problems. Individual agencies should continue to document conditions at new pipe installations and to perform in-depth examinations when existing pipes are removed or replaced.

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# APPENDIX A

## SELECTED BIBLIOGRAPHY

1. AZAR, D. G., "Drainage Pipe Study." *Research Rep. No. 57,* Louisiana Dept. of Hwys. (May 1971).
2. BAUMAN, E. W., and LEWIS, D. W., "Five-Year Field Corrosion Study of Steel Pipe to Determine Effects of Backfill Materials." *Hwy. Res. Record No. 140* (1966) pp. 1–8.
3. BEARG, E. A., ET AL., "Durability Design Method for Galvanized Steel Pipe in Nebraska." Armco Steel Corp. (1966–67).
4. BEATON, J. L., and STRATFULL, R. F., "Corrosion of Corrugated Metal Culverts in California." *HRB Bull. 223* (1959) pp. 1–13.
5. BEATON, J. L., and STRATFULL, R. F., "Field Test for Estimating Service Life of Corrugated Metal Pipe Culverts." *Proc., HRB,* Vol. 41 (1962) pp. 255–272.
6. BELLPORT, B. P., "Combatting Sulfate Attack on Concrete on Bureau of Reclamation Project." U.S. Bureau of Reclamation, presented at symposium sponsored by Div. of Bldg. Res., Natl. Res. Council of Canada & ACI, Toronto (Apr. 7, 1967) 24 pp.
7. BERG, V. E., "A Culvert Material Performance Evaluation in the State of Washington." *Res. Proj. No. HPR-1-2,* Washington State Hwy. Comm. (Apr. 1965) 44 pp.
8. BRASUNAS, A. deS., ET AL., "NACE Basic Corrosion Course." Natl. Assn. of Corrosion Eng., Houston (Apr. 1971).
9. BUTLER, B. E., "Structural Design Practice of Pipe Culverts." *Hwy. Res. Record No. 413* (1972) pp. 57–66.
10. CRUM, R. W., "Report on Culvert Investigation." *Proc., HRB,* Vol. II, Part I (1932) pp. 338–363.
11. "Culvert Performance at Test Sites in Colorado (1962–1968)." *Res. Rep. No. 68-8,* Colorado Div. of Hwys. (Aug. 1968) 15 pp.
12. CURTICE, D. K., and FUNNELL, J. E., "Comparative Study of Coatings on Corrugated Metal Culvert Pipe." Southwest Research Institute, San Antonio (Mar. 1971) 50 pp.
13. DANA, J. S., "Corrosion of Highway Metal Structures and Cathodic Protection." *Final Rep.,* Arizona Hwy. Dept. (Nov. 1973) 60 pp.
14. "Durability of Concrete in Service." *Proc., ACI,* Vol. 59, No. 12, ACI (Dec. 1962) pp. 1771–1820.
15. "Durability of Metal Pipe Culverts." Idaho Dept. of Hwys., Res. Proj. No. 16 (Apr. 1965).
16. ELLIS, J. T., "Corrosion Performance of Aluminum Culverts." Second progress rep., *Res. Rep. R-679,* Michigan Dept. of State Hwys. (Dec. 1968) 25 pp.; final progress rep., *Res. Rep. R-976* (Nov. 1975) 22 pp.
17. EUBANK, D., and THOMAS, H. D., "1964 Pipe Evaluation Study Supplement." Mississippi State Hwy. Dept. (1964) 14 pp.
18. HAVENS, J. H., "Considerations Regarding Type of Culverts; Pennyrile (Pennyroyal) Parkway." Kentucky Dept. of Hwys. (June 1966).
19. HAVENS, J. H., "Durability of Culvert Pipe." Kentucky Dept. of Hwys. (Aug. 1968) 13 pp.
20. HAVILAND, J. E., ET AL., "Durability of Corrugated Metal Culverts." *Hwy. Res. Record No. 242* (1968) pp. 41–66. (Also published by New York State DOT as *Res. Rep. 66-5,* Nov. 1, 1967.)
21. HAYES, C. J., "A Study of the Durability of Corrugated Steel Culverts in Oklahoma." Oklahoma Dept. of Hwys. (1971) 39 pp.
22. HYDE, L. W., ET AL., "Detrimental Effects of Natural Soil and Water Elements on Drainage Pipe Structures in Alabama." Geological Survey of Alabama for Alabama Hwy. Dept. (Aug. 1969).
23. JACOBS, K. M., "Culvert Life Study." *Tech. Paper 74-1,* Maine DOT (Jan. 1974) 24 pp.
24. JACOBS, K. M., "Zinc Content of Streams With Cor-

rugated Metal Pipes." *Tech. Paper 74-2,* Maine DOT (Jan. 1974) 11 pp.

25. JAMES, L. M., "Unexpected Corrosion of Galvanized Corrugated Metal Culverts." *Proc., Australian Road Res. Board,* Vol. 4, Part 2, Paper No. 437 (1968) 6 pp.
26. KALB, M., "Statewide Survey of Bituminous-Coated Only, and Bituminous-Coated and Paved Corrugated Metal Pipe." Final rep., Maryland State Roads Comm. (Apr. 1971).
27. KILL, D. L., "Serviceability of Corrugated Metal Culverts." Investigation No. 116, final rep., Minnesota Dept. of Hwys. (1969) 22 pp.
28. KOEPF, A. H., "The Mechanisms of Abrasion of Aluminum Alloy Culvert, Related Field Experiences, and a Method to Predict Culvert Performance." *Hwy. Res. Record No. 262* (1969) pp. 44–55.
29. KRIZEK, R. J., ET AL., "Structural Analysis and Design of Pipe Culverts." *NCHRP Report 116* (1971) 155 pp.
30. LINDBERG, R. I., "Method of Estimating Corrosion of Highway Culverts by Means of Polarization Curves." *Hwy. Res. Record No. 204* (1967) pp. 1–10.
31. LOWE, T. A., and KOEPF, A. H., "Corrosion Performance of Aluminum Culvert." *Hwy. Res. Record No. 56* (1964) pp. 98–115.
32. LOWE, T. A., ET AL., "Corrosion Evaluation of Aluminum Culvert Based on Field Performance." *Hwy. Res. Record No. 262* (1969) pp. 56–68.
33. MALCOM, W. J., "Durability Design Method for Galvanized Steel Pipe in Iowa." Corrugated Metal Pipe Assn. of Iowa & Nebraska (Spring 1968) 24 pp.
34. MCKEEL, W. T., JR., "Comparative Study of Aluminum and Steel Culverts." *Culvert Studies Rep. No. 3,* Virginia Hwy. Res. Council (Feb. 1965).
35. MCKEEL, W. T., JR., "A Comparative Study of Aluminum and Steel Culverts." *Culvert Studies Progress Rep. No. 4,* Virginia Hwy. Res. Council (May 1971).
36. MEACHAM, D. G., "Culvert Durability Study: An Interim Report." Ohio DOT (Dec. 1972) 14 pp.
37. "Nebraska Soil Resistivity and pH Investigation as Related to Metal Culvert Life." Nebraska Dept. of Roads (Apr. 1969).
38. NORDLIN, E. F., and STRATFULL, R. F., "A Preliminary Study of Aluminum as a Culvert Material." *Hwy. Res. Record No. 95* (1965) pp. 1–70.
39. OLIVER, J. C., and PALMORE, R. D., "Iso-pH Maps Identify Areas Detrimental to Drainage Structure Performance Life." *Hwy. Res. Record No. 56* (1964) pp. 116–123.
40. PEABODY, A. W., "Control of Pipeline Corrosion." Natl. Assn. of Corrosion Eng., Houston (Dec. 1967).
41. PETERSON, D. E., "Evaluation of Aluminum Alloy Pipe for Use in Utah's Highways." Utah State Hwy. Dept. (June 1973) 43 pp.
42. RAY, D., and CROTEAU, J., "Corrosion of Corrugated Metal Pipe." Final rep., New Jersey DOT, unpublished (Feb. 1974) 30 pp.
43. ROMANOFF, M., "Underground Corrosion." *Circ. 579,* Natl. Bur. of Standards, U.S. Govt. Printing Ofc., Washington, D.C. (Apr. 1957) 227 pp.
44. SCHWERDTFEGER, W. J., "Soil Resistivity as Related to Underground Corrosion and Cathodic Protection." *Hwy. Res. Record No. 110* (1966) pp. 20–21.
45. STRATFULL, R. F., "Report on the Experimental Placing of a Cement Mortar Coating in Corrugated Metal Culverts in District 1." California Div. of Hwys. memo., unpublished (May 1954) 14 pp.
46. STRATFULL, R. F., "A New Test for Estimating Soil Corrosivity Based on Investigation of Metal Highway Culverts." *Corrosion,* Vol. 17, No. 10 (Oct. 1961).
47. STRATFULL, R. F., "Highway Corrosion Problems, Metal Culverts and Reinforced Concrete Bridges." Western Region Conf. Natl. Assn. of Corrosion Eng. (Oct. 1962) 20 pp.
48. STRATFULL, R. F., "Field Method of Detecting Corrosive Soil Conditions." *Proc., 15th Ann. Street and Hwy. Conf.,* ITTE and Univ. Extension, Univ. of California at Los Angeles (Jan. 1963).
49. SWAN, J. D., "Steel Products for Culvert Applications." Paper presented at 51st Ann. Meet. of HRB, unpublished (Jan. 1972).
50. "Symposium on Effects of Aggressive Fluids on Concrete." *Hwy. Res. Record No. 113,* 6 reps. (1966) 117 pp.
51. UHLIG, H. H., *Corrosion and Corrosion Control: An Introduction to Corrosion Science and Engineering,* 2nd ed., Wiley (June 1971) 419 pp.
52. WELBORN, J. Y., and OLSEN, R. E., "Report on Inspection of Bituminous Coated and Uncoated Galvanized Metal Culvert Pipe." Bur. of Pub. Roads, Ofc. of Res. & Dev. (Oct. 1964) 11 pp. + tables.
53. WILSON, C. L., and OATES, J. A., *Corrosion and the Maintenance Engineer,* 2nd ed., Hart (1968) 196 pp.
54. WOODS, H., "Durability of Concrete Construction." *Monograph No. 4, ACI* (1968) 187 pp.
55. WORLEY, H. E., "Effectiveness of Bituminous Coatings on Corrugated Metal Pipe." State Hwy. Comm. of Kansas (1970) 9 pp.
56. WORLEY, H. E., and CRUMPTON, C. F., "Corrosion and Service Life of Corrugated Metal Pipe in Kansas." *Hwy. Res. Record No. 412* (1972) pp. 35–40.
57. WELCH, B. H., "Pipe Corrosion and Protective Coatings." Utah State Hwy. Dept. (Nov. 1974) 72 pp. (Also published in *Transp. Res. Record 604,* 1976, pp. 20–24.)
58. HARRIS, J. O., "Microbiological Studies Reveal Significant Factors in Oil and Gas Pipeline Back-Filled Ditches." Kansas Agric. Exper. Sta. (1963) 47 pp.

# APPENDIX B

## CALIFORNIA METHOD FOR ESTIMATING SERVICE LIFE OF METAL CULVERTS (Note that "metal" in this method is steel)

State of California
Department of Public Works
Division of Highways

**MATERIALS AND RESEARCH DEPARTMENT**

Test Method No. Calif. 643-C
October 2, 1972
(5 pages)

## METHOD FOR ESTIMATING THE SERVICE LIFE OF METAL CULVERTS

## GENERAL SCOPE

Two environmental factors are combined for estimating the service life of metal culverts. These environmental factors are the hydrogen-ion concentration (pH) and the electrical resistivity of the site and backfill materials.

The hydrogen-ion concentration (pH) of the soils and waters indicates the degree of acidity or alkalinity, while the resistivity measurements indicate the relative quantity of soluble salts.

Using these values, the probable service life of a metal culvert in a given location is estimated by means of the Chart shown on Figure II.

This information, combined with observations of existing culverts, if any, provides a basis for (1) estimating the service life of galvanized metal culverts and (2) estimating the additional life that would be obtained by coating the culverts to reduce the corrosion rate.

This test method is divided into the following parts:

I. Method of Field Resistivity Survey and Sampling for Corrosion Tests.
II. Preliminary Field Method of Determining pH of Water Samples.
III. Method of Determining pH of Soils.
IV. Laboratory Method of Determining Minimum Resistivity.
V. Estimating Service Life of Metal Culverts from Test Data.

### PART I. METHOD OF FIELD RESISTIVITY SURVEY AND SAMPLING FOR CORROSION TESTS

#### Scope

The field resistivity test is an indication of the soluble salts in the soil or water, and is used primarily as a guide for selecting samples that will be further tested in the laboratory to obtain data for estimating the service life of culverts. The natural soil in each channel or culvert location and the structural backfill material are tested by a portable earth resistivity meter, and samples are selected on the basis of these tests.

#### Procedure

**A. Apparatus**

1. Portable earth resistivity meter, suitable for rapid in-place determinations of soil resistivity.
2. Field probe.
3. Steel starting rod, for making hole (in hard ground) for inserting probe.
4. Sledge hammer (4 lbs.)

**B. Materials**

Distilled, de-ionized or other clean waters that measure greater than 20,000 ohm-cm.

**C. Recording Data**

Record test data in a field notebook for use in selecting samples and also for use as needed in analyzing laboratory test data.

**D. Test Procedure**

1. In the channel of a proposed culvert site, insert the field probe into the soil for a depth of between 6" and 12" and measure resistivity. Remove the field probe and pour about 2 ounces of clean water into the hole.
2. Re-insert the probe, while twisting to mix the water and soil, then measure the resistivity. Follow manufacturer's instructions for correct use of meter.
3. Withdraw the field probe and add an additional 2 ounces of clean water.
4. Re-insert the probe and again measure the resistivity of the soil.
5. Record the lowest of the readings as the field resistivity of the soil.

**E. Selection of Soil Samples for Laboratory Tests**

1. Make sufficient resistivity determinations at various locations in the channel or culvert site area to represent adequately the entire area.
2. If the resistivity is reasonably uniform within the limits of the project, three soil samples from different locations will be sufficient. If, however, some locations show resistivities that differ significantly from the average of the determinations for the area being surveyed, additional soil samples should be taken to represent these locations—particularly those with resistivities significantly below the average.
   a. For example, if the soil resistivities throughout the surveyed area are all at or near an average value of 2000 ohm-cm, three samples will be enough. If any of the locations tested have resistivities markedly below this average, for example 800 ohm-cm, then these "hot spots" should definitely be represented by additional samples. Scattered locations of higher resistivity, for example 3000 ohm-cm or more, do not necessarily require additional samples.
   b. Judgment must be exercised both in the field testing and sampling and in evaluating the laboratory tests.
   c. In all cases, do not take less than 3 samples.

**F. Precautions**

In field testing and sampling, follow very carefully the test method instructions and also the manufacturer's instructions for use of meters.

#### Notes

If the minimum resistivity of a soil is determined to be less than 1000 ohm-cm in the laboratory, a representative sample weighing 2 to 5 lbs. which passes the No. 8 sieve will be needed for a sulfate ($SO_4$) analysis. This should be taken into account in field sampling and is to be used for evaluating the effect of the environment on the stability of normal concrete.

## PART II. PRELIMINARY FIELD METHOD OF DETERMINING pH OF WATER SAMPLES

### Scope

This method is suitable for use in the field or laboratory for determining the pH of water samples.

### Procedure

**A. Apparatus and Materials**

1. 2 oz. or larger wide-mouth container, e.g. glass jar, beaker, or dry wax paper cup.
2. pH meter, suitable for either field or laboratory testing.
3. pH standard solution of pH 7.

**B. Recording Data**

Record test data in a field notebook.

**C. Method of Sampling**

1. Dip the wide-mouth container into the water to be tested. Swirl to rinse and pour out contents to avoid contamination from container.
2. Dip into the water again for obtaining a sample.
3. Pour off any film which is on the surface of the sample before testing.

**D. Standardizing pH Meter**

Follow the instructions provided with the type of pH meter being used.

**E. Use of pH Meter to Determine pH of Water**

Follow the instructions provided with the type of pH meter being used.

**F. Precautions**

Follow the manufacturer's instructions for use of the meter and observe the usual precautions for making chemical tests.

### Notes

pH readings may be taken at any period other than flood flow. All waters which have a pH of less than 6 should be sampled for further analysis, in one quart bottles.

## PART III. METHOD OF DETERMINING pH OF SOILS

### Scope

This method is suitable for use in determining the pH of soil samples.

### Procedure

**A. Apparatus and Materials**

1. Paper cups, 2 oz. wax coated type.
2. Teaspoon or small metal scoop.
3. Wash bottle containing distilled water.
4. pH meter suitable for field or laboratory testing.
5. pH Standard solution of pH 7.

**B. Recording Data**

Record data in a field notebook or on Form T-619.

**C. Preparation of Test Specimens**

1. Place 2 rounded teaspoonsful of the soil to be tested into a 2-oz. paper cup.
2. Add about 2 teaspoonsful of distilled water to the sample in the cup.
3. Disperse soil in water by stirring. The specimen is now ready for testing.

**D. Standardization of pH Meter**

Follow the instructions provided with the pH meter.

**E. Use of pH Meter to Determine pH of Soil**

Follow the instructions provided with the pH meter.

**F. Precautions**

Carefully follow the above procedure and the manufacturer's instructions.

If the pH reading is unstable when the electrode is immersed in the soil slurry, leave the electrode immersed until the pH reading has stabilized. In some cases this waiting period for the stabilization of the pH reading may take 5 minutes.

## PART IV. LABORATORY METHOD OF DETERMINING MINIMUM RESISTIVITY

### Scope

This method covers the procedure for determining the minimum resistivity of soil or water samples selected as indicated in PART I. These resistivity values are used in estimating culvert life as described in PART V.

### Procedure

**A. Apparatus**

1. Resistivity meter suitable for laboratory testing.
2. Soil box calibrated for use with resistivity meter. See Figure I for details.
3. No. 8 Sieve.
4. Round tin pans. 12" diameter and 2" deep.
5. 200° F. oven.
6. One balance, 5 Kg. capacity, accurate to 10 g.

**B. Materials**

Distilled or de-ionized water.

**C. Recording Data**

Record data on Form T-619 or in notebook.

**D. Preparation of Soil Samples**

After thorough mixing of sample, screen it through a No. 8 sieve. If the sample is too moist to be sieved, it may be dried and crushed. Do not crush rocks. Only the natural material that passes the No. 8 sieve is to be used for the test.

**E. Measuring the Resistivity of Soil Sample**

1. Quarter or split out about 1300 grams of the passing No. 8 material.

2. If the sample was dried, add about 150 grams of distilled water to the 1300 grams of soil and thoroughly mix.

3. After the soil sample is thoroughly mixed, place and compact it (moderate compaction with the fingers is sufficient) in the soil box.

4. Measure the resistivity of the soil in accordance with the instructions furnished with the meter.

5. Remove the soil from the soil box and add about 100 additional grams of distilled water and again thoroughly mix.

6. Again place and compact the soil in the soil box and measure its resistivity.

7. Repeat this procedure once more.

8. If the resistivity of the soil has not followed a trend of high resistivity, low resistivity, and then an increase in resistivity for the preceding additions of distilled water, continue to add water in about 50 gram increments to the soil; mixing, placing, compacting, and measuring resistivity for each increment, until the minimum resistivity is obtained.

9. If the sample was not dried, begin the test procedure by adding 50 grams of water in lieu of 150 grams specified above in 1. Continue to add 50 gram increments of water followed by mixing, placing, compacting, and measuring until a minimum value of resistivity is measured.

10. Record the test value that is the minimum value of soil resistivity at any moisture content.

### F. Measuring the Resistivity of a Water Sample

1. Thoroughly clean the soil box of all soil particles and rinse the soil box a minimum of three times with distilled or de-ionized water.

2. Fill the soil box with distilled water and measure its resistivity.

3. If the distilled water in the soil box measures infinite resistivity, empty the soil box of distilled water, fill with the test water, measure its resistivity, then record the measured value.

4. If the distilled water in the soil box did not measure infinite resistivity, continue to rinse the box with distilled or de-ionized water until the box is thoroughly clean, which is indicated by an infinite resistivity measurement.

### G. Recording Data

Record data in notebook or on Form T-619.

### H. Precautions

Follow the above instructions very carefully.

## PART V. ESTIMATING SERVICE LIFE OF METAL CULVERTS FROM TEST DATA

### Procedure

### A. Calculations

Using the minimum resistivity and the pH values of the soils or waters, obtained as described in Parts II, III, and IV of this test method, determine the estimated service life (years to perforation) from the Chart shown on Figure II.

### Reporting

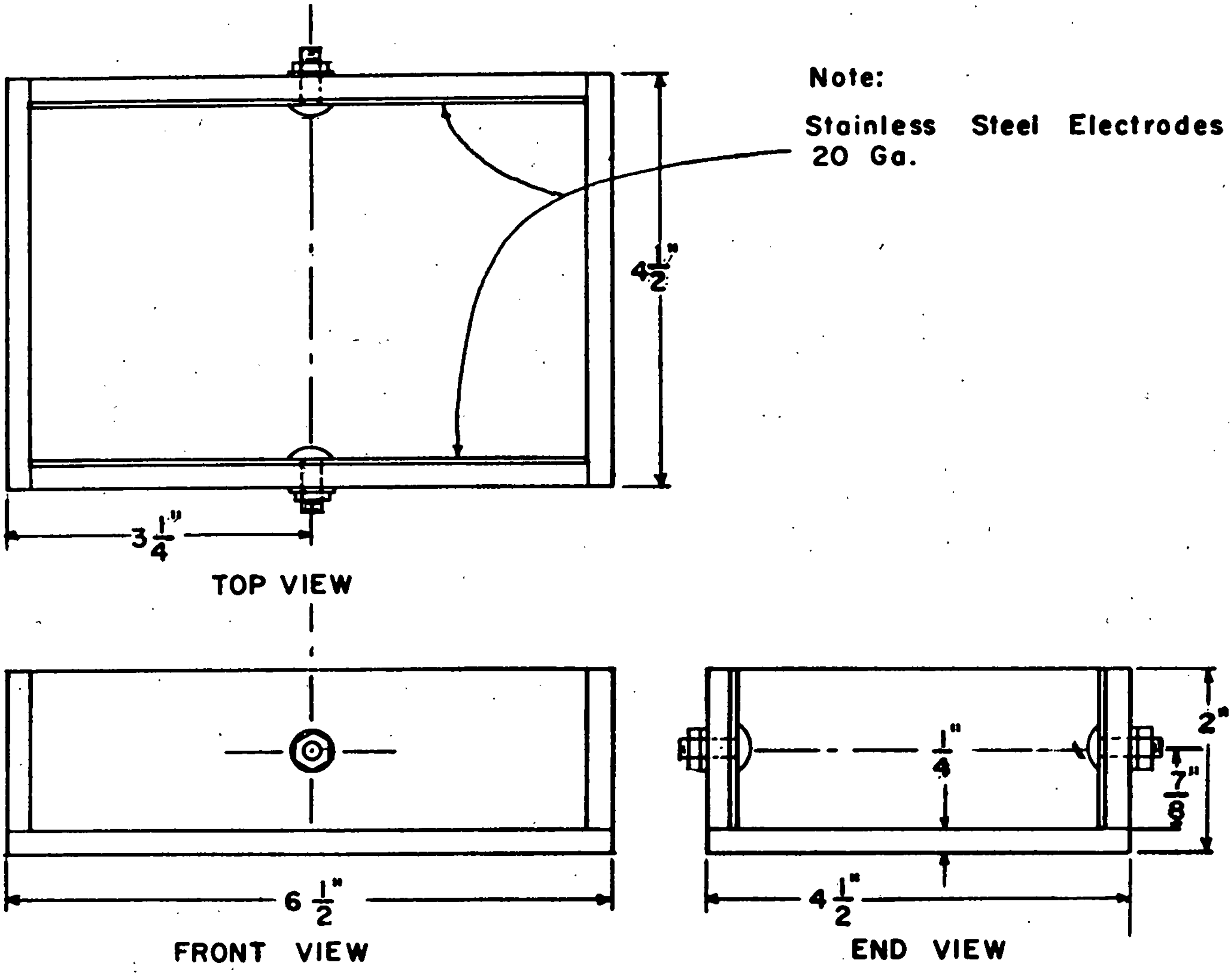
District reports which include evaluation of data obtained from tests and observations of existing culverts, as well as test data, shall be made and the results noted in the District Materials Report.

### REFERENCE

A California Method

1. Field Test for Estimating Service Life of Corrugated Metal Culverts, by J. L. Beaton and R. F. Stratfull. Proc. Highway Research Board Vol. 41, P. 255, 1962.
2. Field Method of Detecting Corrosive Soil Conditions. By R. F. Stratfull. Proc. 15th Calif. Street and Highway Conference, held at U.C.L.A., Jan. 24-26, 1963, I.T.T.E. P. 158.

End of Text on Calif. 643-C



**Material — $\frac{1}{4}''$ Plastic**

Bottom — 1 Pc. $6\frac{1}{2}'' \times 4\frac{1}{2}'' \times \frac{1}{4}''$

Ends — 2 Pcs. $4\frac{1}{2}'' \times 1\frac{3}{4}'' \times \frac{1}{4}''$

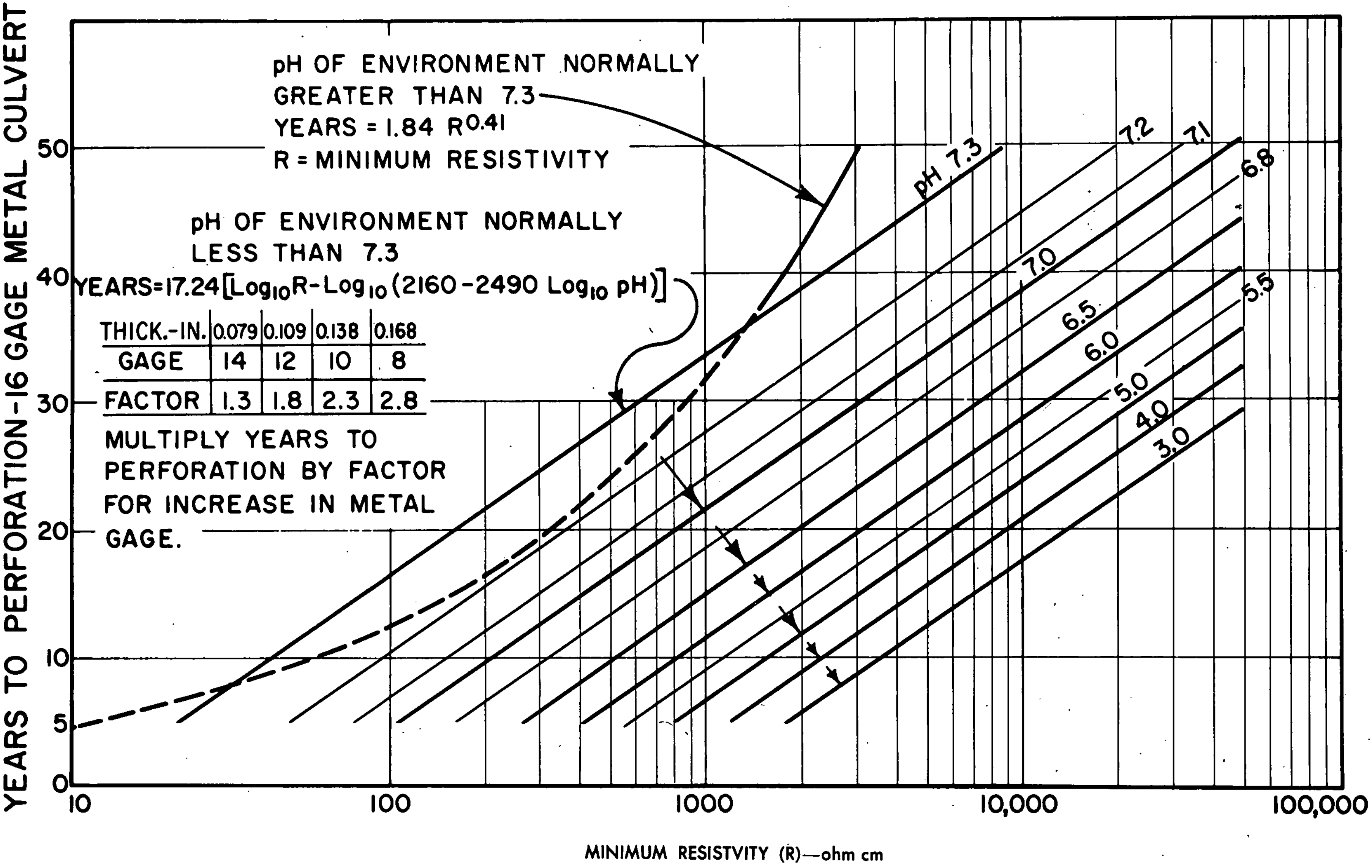
Sides — 2 Pcs. $6'' \times 1\frac{3}{4}'' \times \frac{1}{4}''$

Electrodes — 2 Pcs. 20 Ga. Stainless Steel $6'' \times 1\frac{3}{4}''$

2 Ea. No. 8-32 $\times \frac{3}{4}''$ Round Head Stainless Steel Machine Screw With Rubber Washer & Stainless Steel Washer & Nut.

FIGURE I
SOIL BOX FOR LABORATORY RESISTIVITY DETERMINATION

# CHART FOR ESTIMATING YEARS TO PERFORATION OF METAL CULVERTS



pH OF ENVIRONMENT NORMALLY GREATER THAN 7.3

$\text{YEARS} = 1.84\ R^{0.41}$

R = MINIMUM RESISTIVITY

pH OF ENVIRONMENT NORMALLY LESS THAN 7.3

$\text{YEARS} = 17.24[\text{Log}_{10} R - \text{Log}_{10}(2160 - 2490\ \text{Log}_{10}\ \text{pH})]$

| THICK.-IN. | 0.079 | 0.109 | 0.138 | 0.168 |
|---|---|---|---|---|
| GAGE | 14 | 12 | 10 | 8 |
| FACTOR | 1.3 | 1.8 | 2.3 | 2.8 |

MULTIPLY YEARS TO PERFORATION BY FACTOR FOR INCREASE IN METAL GAGE.

FIGURE II

# APPENDIX C

## WASHINGTON INSPECTION REPORT FORM

### CULVERT PIPE
### INSPECTION REPORT

ROAD NAME ____________________ COUNTY ____________ SAMPLE NO. ______

PROJECT OR ROAD NO. ____________________ Station ____________________

Type of Installation ____________ (X = Cross Pipe), Metal Thickness ____________ Gauge ____________

Diameter ________ Inches Material: CIP ____________ Concrete ____________

Length ________ Feet Coated: Yes ____________ No ____________

Height of Fill ________ Feet Paved Invert: Yes ____________ No ____________

Headwalls: Yes ______ No ______ Hydraulic Adequacy: Adequate ___ Inadequate ___ Explain.

Date Placed ____________ Present Age: ____________________

Type of Backfill Material ________________________________

Alignment and Slope: Straight ___ Some Distortion _____ Badly Distorted _____ Failed ______

Condition at Joints: Tight ______ Separated _____ Badly Separated ______ Dislocated ______

General Condition of Pipe: Good _____ Adequate _____ Fair ____ Poor ____ Failed ______

RATING OF PIPE (Circle One)

| Description: | Numerical Rating: | |
|---|---|---|
| Spelter Like New | 95 | ____________________ |
| Spelter Dull | 92-5 | ____________________ |
| Spelter Very Dull | 90-0 | ____________________ |
| Pin-Point Rust Spots | 87-5 | ____________________ |
| Spelter Entirely Gone | 85.0 | ____________________ |
| Light Rust Film | 80.0 | ____________________ |
| Shallow Pitting | 70.0 | ____________________ |
| Scaley Rust or Pits not halfway through metal | 60 | ____________________ |
| Heavy Rust or Pits halfway through metal | 45 | ____________________ |
| Heavy Rust or Pits three-quarters through metal | 30 | ____________________ |
| Few Holes through metal | 15.0 | ____________________ |
| Large Areas of metal gone | 0.0 | ____________________ |

SOIL SAMPLES

Taken: Yes _____ No _____

pH = ____________

r = ____________

WATER SAMPLE

Taken: Yes _____ No _____

pH = ____________

r = ____________

DATE: ____________________

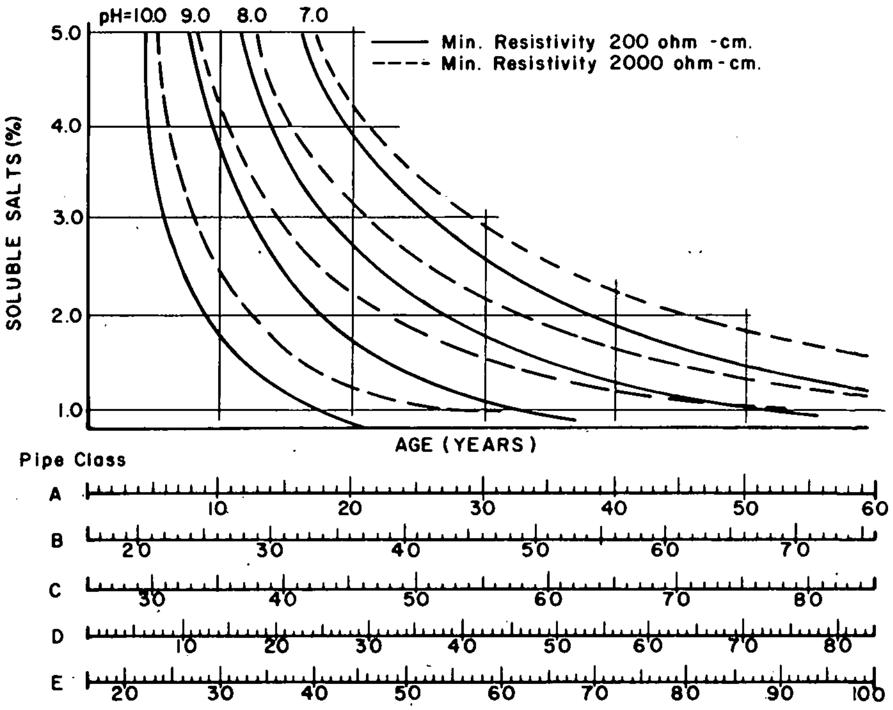
Years to Perforation: ____________

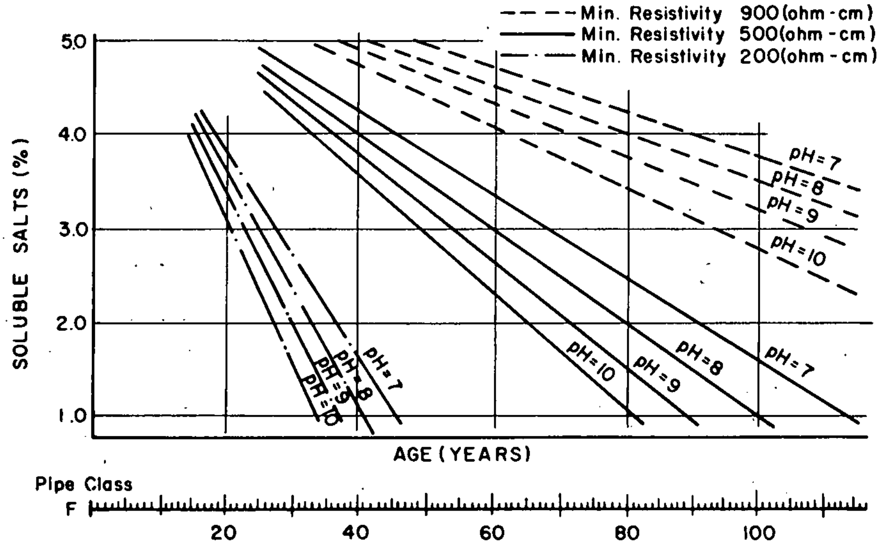
INSPECTOR: ____________________

Calif. Test Method ____________

# APPENDIX D

## UTAH PIPE MATERIAL SELECTION CRITERIA





$SO_4 < 0.5$ % use Type - II Cement

$SO_4 \geq 0.5$ % use Type - V Cement

Pipe Class A = Plain corrugated steel

Pipe Class B = Bituminous-coated corrugated steel pipe, aluminum alloy pipe, galvalume pipe, pitch-resin adhesive-coated corrugated steel pipe (coated on exterior side only)

Pipe Class C = Asbestos-bonded bituminous-coated corrugated steel pipe, pitch-resin adhesive-coated corrugated steel pipe (coated on both sides)

Pipe Class D = Plain corrugated steel structural-plate pipe

Pipe Class E = Bituminous-coated corrugated steel structural-plate pipe, aluminum alloy structural-plate pipe

Pipe Class F = Portland cement concrete pipe

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