# EVALUATION OF DRAINAGE PIPE BY FIELD EXPERIMENTATION AND SUPPLEMENTAL LABORATORY EXPERIMENTATION

Final Report

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Research Report No. 174

Research Project No. 72-1SS

Conducted by
LOUISIANA DEPARTMENT OF TRANSPORTATION
AND DEVELOPMENT
Research and Development Section
In Cooperation with
U. S. Department of Transportation
FEDERAL HIGHWAY ADMINISTRATION

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MARCH 1985

# SUMMARY

The Louisiana Department of Transportation and Development reacts to a major problem when it attempts to shape and control drainage patterns along its right-of-ways. The Department's design engineers meet this challenge through proper section design and appropriate application of drainage structures.

Perhaps the most common structure used by these design engineers is the drainage pipe--primarily concrete and metal. This study is an investigation of the durability properties of metal drainage pipe in Louisiana. Durability of such pipe is as important as design strength because of the environments which promote corrosion.

Beginning in August 1973, a series of pipe types of coated and uncoated galvanized steel and aluminum were installed in pairs at eleven various sites throughout Louisiana. Periodically, one each of the sixteen pairs of pipe types were evaluated to determine the corrosive effect of the eleven environments upon the test pipes. This fourth and final evaluation (report) relates the observations concerning the condition of the test pipes after a maximum of ten years of field exposure.

It was found that, generally, the 16-gauge asphalt coated aluminum, the 14-gauge asbestos bonded asphalt coated galvanized steel and the 16-gauge galvanized steel with a 12-mil interior and 5-mil exterior polyethylene coating were the test pipes with the most resistance to corrosion at the majority of the test sites. It was also found that although all of the coatings provided added resistance to corrosion, to some degree, the thicker coatings tested provided increased protection to the base metal. Based upon the results of this study, the adequacy of predicting pipe life by utilizing the minimum resistivity and pH of the environment for Louisiana conditions is also considered.

# METRIC CONVERSION FACTORS*

| To Convert from | To | Multiply by |
|---|---|---|
| | **Length** | |
| foot | meter (m) | 0.3048 |
| inch | millimeter (mm) | 25.4 |
| yard | meter (m) | 0.9144 |
| mile (statute) | kilometer (km) | 1.609 |
| | **Area** | |
| square foot | square meter ($m^2$) | 0.0929 |
| square inch | square centimeter ($cm^2$) | 6.451 |
| square yard | square meter ($m^2$) | 0.8361 |
| | **Volume (Capacity)** | |
| cubic foot | cubic meter ($m^3$) | 0.02832 |
| gallon (U.S. liquid)** | cubic meter ($m^3$) | 0.003785 |
| gallon (Can. liquid)** | cubic meter ($m^3$) | 0.004546 |
| ounce (U.S. liquid) | cubic centimeter ($cm^3$) | 29.57 |
| | **Mass** | |
| ounce-mass (avdp) | gram (g) | 28.35 |
| pound-mass (avdp) | kilogram (kg) | 0.4536 |
| ton (metric) | kilogram (kg) | 1000 |
| ton (short, 2000 lbs) | kilogram (kg) | 907.2 |
| | **Mass per Volume** | |
| pound-mass/cubic foot | kilogram/cubic meter ($kg/m^3$) | 16.02 |
| pound-mass/cubic yard | kilogram/cubic meter ($kg/m^3$) | 0.5933 |
| pound-mass/gallon (U.S.)** | kilogram/cubic meter ($kg/m^3$) | 119.8 |
| pound-mass/gallon (Can.)** | kilogram/cubic meter ($kg/m^3$) | 99.78 |
| | **Temperature** | |
| deg Celsius (C) | kelvin (K) | $t_K=(t_C+273.15)$ |
| deg Fahrenheit (F) | kelvin (K) | $t_K=(t_F+459.67)/1.8$ |
| deg Fahrenheit (F) | deg Celsius (C) | $t_C=(t_F-32)/1.8$ |

*The reference source for information on SI units and more exact conversion factors is "Metric Practice Guide" ASTM E 380.

**One U.S. gallon equals 0.8327 Canadian gallon.

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# INTRODUCTION

The state of Louisiana annually receives approximately 60 inches of rainfall. The Louisiana DOTD Road Design Engineer assigns a cross-slope and texture to the highways to rid them of this deluge of water. The Hydraulics Engineer often employs drainage pipe to remove the ensuing runoff from the highway right-of-way.

The Hydraulics Engineer can generally choose either reinforced concrete pipe or corrugated metal pipe in his designs. Concrete pipe is very durable and with stable bedding conditions can normally serve effectively for the life of a highway.

The Department also recognizes that metal pipe has its place in the field of hydraulics and maintains an interest in innovations in metal pipe. Metal pipe is relatively lightweight, an advantage that gains significance as the size of pipe increases. Metal pipe is relatively flexible, an advantage that could preclude failure under certain heavy loads. The major drawback with metal pipe is its tendency to corrode in the presence of moisture, oxygen, and salt. Additional information is needed on the rates at which galvanized steel and aluminum (with the various types of coatings recently introduced) will corrode.

The purpose of this study is to investigate the corrosion properties of metal drainage structures through a controlled field experiment and limited laboratory work.

## SCOPE

In this study the evaluation of corrosion in sixteen types of metal drainage pipe is limited to eleven field installations representing a cross section of soil and water conditions found in Louisiana. The types of corrugated culvert under evaluation include some pipes which are presently authorized for use by Department specifications and some pipes which are under evaluation as new products. The potential corrosiveness at the installation sites range from the highly corrosive environment found in brackish waters near the Gulf of Mexico to the fairly noncorrosive soils of north-central Louisiana. The assumed indicators of corrosion potential are pH and electrical resistivity of both soil and effluent.

The first three evaluations were comprised of field observations, including a panel rating, and laboratory analysis of pipe samples taken in the field. The final evaluation was comprised of a panel rating only.

## METHOD OF PROCEDURE

### Site Selection

An earlier drainage pipe study (1)* served to evaluate existing drainage structures in the seven general soil areas found in Louisiana. Resistivity and pH tests were conducted on soil samples from these areas to predict years-to-perforation of the culvert materials under evaluation. These test results, along with data from routine soils testing for preliminary subgrade surveys, provided the basis for selection of the sites used in the present study.

The following experimental design was developed to include soil conditions found in the northern, central and southern sections of the state.

A. Normal conditions for north and central Louisiana
   1. Resistivity > 2000 and pH 5.0-6.0
   2. Resistivity > 2000 and pH 7.0-8.0

B. Normal conditions for south Louisiana
   1. Resistivity 500-2000 and pH 5.0-6.0
   2. Resistivity 500-2000 and pH 7.0-8.0

C. Extreme soil conditions
   1. Areas of (high) resistivity > 2000 and pH 8.0-9.0
   2. Areas of (low) resistivity < 2000 and pH 8.0-9.0

The following factorial design indicates test sites that were originally selected to satisfy the requirements of the field experiment.

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*Underlined numbers in parentheses refer to Bibliography.

| | Minimum Soil Resistivity, ohm-cm | |
|---|---|---|
| Soil pH | Less Than 2000 | Greater Than 2000 |
| 5.0 - 6.0 | Site No. 1 | Site No. 4<br>Site No. 8 |
| 7.0 - 8.0 | Site No. 2<br>Site No. 3 | Site No. 5 |
| 8.0 - 9.0 | Site No. 9<br>Site No. 6 | |

A soil with pH ranging from 8.0-9.0 and electrical resistivity greater than 2000 ohm-cm could not be located. However, two additional sites (7 and 10) were selected to evaluate the pipes' performances in brackish water. These two sites are in drainage canals where the water exhibits electrical resistivity values less than 500 ohm-cm.

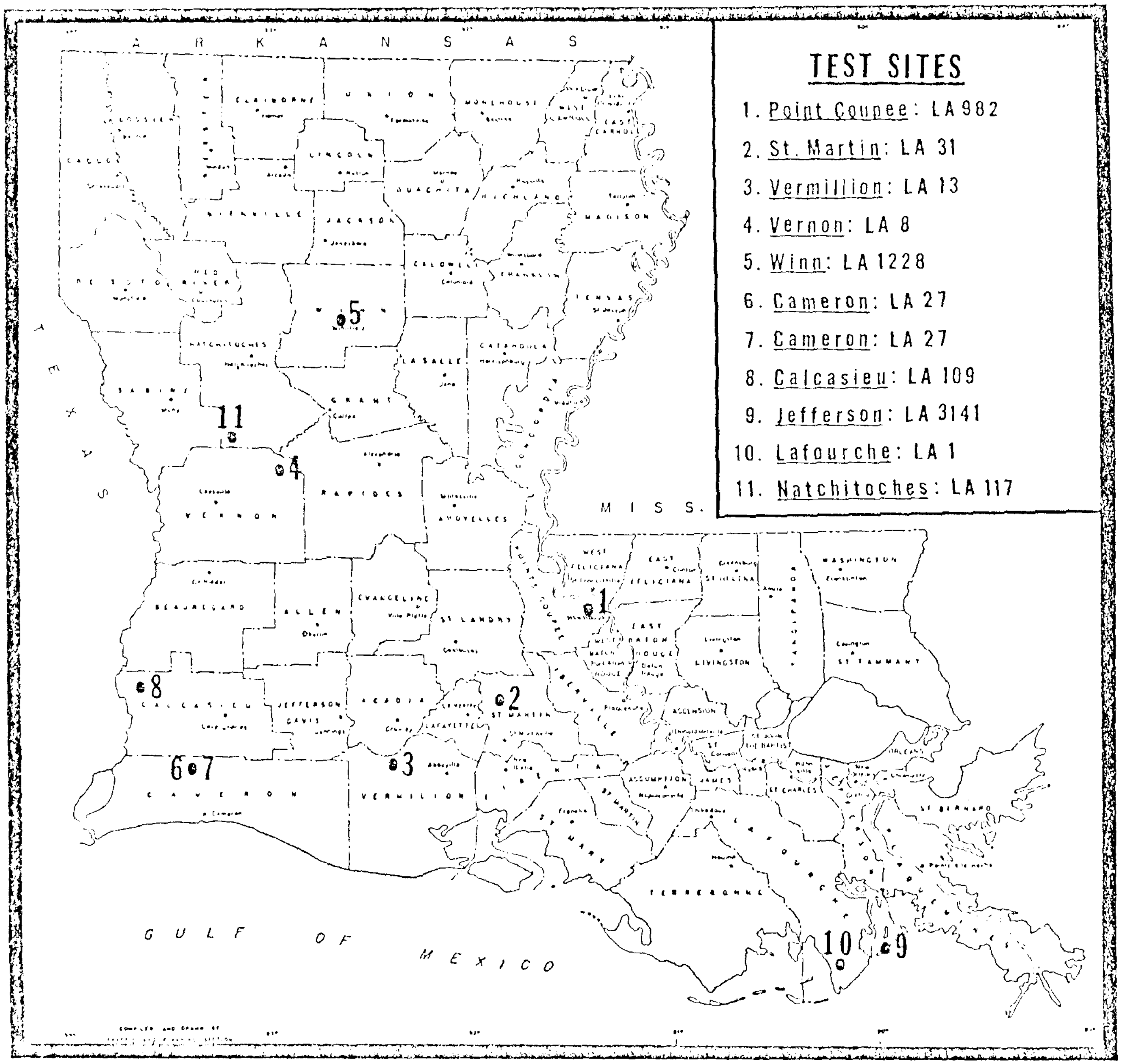
In 1977 test site No. 11 was added, with soil exhibiting high corrosion potential to the field program. Soil at the site selected has an electrical resistivity value of 2083 ohm-cm and a pH value of 4.9. A soil with these properties rarely occurs in Louisiana. However, the site was added to provide depth to the study and to aid in development of a field test to evaluate durability of drainage pipe.

Table 1 on page 5 presents average characteristics of the soil and effluent at the eleven test sites. Figure 1 on page 6 presents the locations of the test sites. Site number 6 is a ditch installation located directly across the road from the canal at site number 7. The pipes at site number 6 were accidentally destroyed during a utility relocation and are no longer available for study.

pH AND ELECTRICAL RESISTIVITY

| LOCATION NUMBER | LOCATION | SOIL TYPE | SOIL RESISTIVITY | SOIL pH | EFFLUENT RESISTIVITY | EFFLUENT pH |
|---|---|---|---|---|---|---|
| 01 | NEW ROADS | CLAY | 1,023 | 6.5 | 9,500 | 6.7 |
| 02 | BREAUX BRIDGE | SILTY CLAY | 881 | 7.6 | 5,175 | 7.3 |
| 03 | KAPLAN | SILTY CLAY | 1,593 | 6.7 | 5,200 | 5.8 |
| 04 | SIMPSON | SILTY CLAY | 11,169 | 5.5 | 18,333 | 6.2 |
| 05 | WINNFIELD | SAND | 3,720 | 6.7 | 3,375 | 6.9 |
| 06 | HACKBERRY | SANDY CLAY | 292 | 8.2 | 107 | 7.0 |
| 07 | HACKBERRY | SANDY SILT | 281 | 8.0 | 123 | 7.0 |
| 08 | STARKS | SILTY CLAY | 3,786 | 5.7 | 15,833 | 6.7 |
| 09 | GRAND ISLE | SAND | 365 | 8.4 | 300 | 7.7 |
| 10 | LEEVILLE | SILTY CLAY | 219 | 7.9 | 121 | 7.2 |
| 11 | KISATCHIE | SANDY LOAM | 2,083 | 4.9 | 4,400 | 7.4 |

TABLE 1




*Location of Test Sites*
*FIGURE 1*

Materials Tested

Originally there were ten varieties of coated and uncoated galvanized steel and aluminum culverts used for evaluation. During the course of the study several other types of pipes were installed at different times and locations. The types of pipes according to total field exposure time are listed below:

Ten Years Field Exposure
Sites 1 through 10

1. Uncoated, 16-gauge galvanized steel
2. Asphalt-coated, 16-gauge galvanized steel
3. Asbestos-bonded, asphalt-coated, 14-gauge galvanized steel
4. Uncoated, 16-gauge aluminum pipe, Alclad 3004
5. Asphalt-coated, 16-gauge aluminum pipe, Alclad 3004
6. 5052 structural aluminum plate arch
7. Sixteen-gauge galvanized steel with a 12-mil, U.S. steel "Nexon", coal-tar-based laminate applied to interior and 0.3-mil, modified epoxy coating on the reverse side
8. Sixteen-gauge galvanized steel with a 20-mil, U.S. Steel "Nexon", coal-tar-based laminate applied to interior or exterior with a 0.3-mil, modified epoxy coating on the reverse side
9. Sixteen-gauge galvanized steel with a 10-mil interior and 3-mil exterior, Inland Steel, polyethylene coating
10. Sixteen-gauge galvanized steel with a 12-mil interior and 5-mil exterior, Inland Steel Polyethylene coating

Eight Years Field Exposure
Sites 1 - 10

11. Sixteen-gauge galvanized steel pipe with 10-mil interior and 3-mil exterior, Wheeling Steel, polymeric coating

Six Years Field Exposure
Site 11

Pipes 1, 2, 3, 4, 6, and 11 were installed along with two additional types of pipes selected for evaluation. They are as follows:

12. Sixteen-gauge galvanized steel with a 10-mil, U.S. Steel "Nexon", coal-tar-based laminate applied to interior and exterior

13. Sixteen-gauge galvanized steel with an 8-mil interior and 4-mil exterior, Inland Steel, polyethylene coating

Four Years Field Exposure
Sites 4, 9, and 10

14. Sixteen-gauge steel with a 1.5-mil aluminum coating applied to the interior and exterior

Sites 4 and 10

15. Sixteen-gauge galvanized steel with a 10-mil interior and a 7-mil exterior epoxy coating

Sites 7, 9, and 10

16. Fourteen-gauge aluminum pipe Alclad 3004 with 10-mil interior and 5-mil exterior, polymeric coating

## Field Installation

During August, 1973, research personnel, with the assistance of district maintenance forces, successfully installed twenty sections of culvert in each of ten selected locations. Two sections of each type culvert were buried in all locations, one section to be removed periodically for evaluation and reinstallation, and the other to remain undisturbed for the duration of the ten-year study. Immediately prior to installation a survey of the condition of each pipe was conducted to make note of any possible damage to the various protective coatings which may have occurred while in transit or during the loading-unloading process. On the whole, damage of this nature was minor. Several of the coatings acquired minor scrapes where binding chains came into contact with the pipe exteriors. As the installation was conducted in the summer months, high temperatures caused the asphalt to soften. Some asphalt was, therefore, removed in handling. Conditions such as these were photographed before installation and have been taken into consideration to make the distinction between these and any actual signs of coating deterioration.

To facilitate the installation a "Gradall" was used to remove all grass and debris from the ditches for approximately 200 feet. Next, the top two feet of in-place soil were removed and the pipes were lowered into the ditch by hand, spaced approximately six feet apart. The removed soil was then used to cover the individual pipe sections to provide a minimum cover of one foot.

At the two water locations, the drainage pipes were installed along the side of drainage canals which parallel state highways within the coastal marshes. The pipe sections were installed perpendicular to the roadway, half covered with soil and half extending out into the brackish water. Soil and water samples were obtained at the time of installation and were taken annually to detect any changes in the potential corrosiveness at the test sites.

In 1975, using the above described installation procedures, research and maintenance personnel installed an eleventh type of test pipe at the original ten test sites, one pair per site. In 1977 a series of test culverts was installed at an eleventh test site with an acidic soil. In 1979 a series of four new pipe products was installed at various sites.

## Field Inspection

During the months of October and November 1983, the fourth and final field inspection was conducted representing a maximum of ten years of exposure. All of the pipes at each site were removed for inspection using a chain hooked to both ends of the pipe and to a "Gradall" bucket. The four-foot sections were then washed clean, removing as much of the soil as possible without contributing to the removal of the coatings.

After the pipes were cleaned, photographs were taken from several angles to document the condition of each. Next, a panel consisting of highway engineers and highway engineering technicians visually rated the pipes using the evaluation form, Figure 11 in Appendix B, page 51. The criteria for defining the condition of a pipe were as follows:

1. Excellent condition - if, under visual observation, there are no signs of deterioration
2. Good condition - if, under visual observation, there are very slight signs of deterioration and pitting

3. Fair condition - if, under visual observation, there are moderate signs of deterioration and pitting
4. Poor condition - if, under visual observation, there are extreme signs of deterioration and pitting
5. Very poor condition - if, under visual observation, there are signs of complete deterioration, and the pipe is no longer useful as a drainage tool

The fourth and final evaluation did not include pipe sampling as did the initial three evaluations. In most cases the laboratory rating did not correlate with the panel rating because, in many instances, field coupons submitted for lab evaluation did not include perforations or coating blisters which occurred on the test culverts. For this reason, the field panel ratings are considered more indicative of the overall performance.

Laboratory Analysis of Soil, Water and Unexposed Culverts

Soil and water samples were initially collected from each installation site on a semi-annual basis. Sampling frequency was later reduced to once a year since the results from the semi-annual samples showed very little change in the pH and resistivity. These samples have been tested for pH in accordance with La. DOTD:TR 430-67 and for resistivity in accordance with La. DOTD:TR 429-77. The two laboratory procedures require the use of a pH meter and a resistivity meter as the basis of measurement. The soil samples were classified by laboratory technicians in accordance with La. DOTD: TR 423-71.

Initially, the culvert testing program dealt with determination of the physical characteristics of the various metals and their protective coatings as manufactured. The amount of zinc coating, expressed in oz./ft.$^2$, was determined by measured weight loss as the zinc coating was dissolved in an acid solution. Thicknesses of the bituminous, asbestos, and various organic coatings were measured with a micrometer. The composition of steel and aluminum used in the culverts was determined by X-ray fluorescence, a process which provides a quantitative analysis of each element present in the metal alloys. Composition and thickness data are presented in Appendix A, pages 37 and 38 of this report.

The durability of the culvert materials as manufactured has been evaluated in the laboratory by two primary methods, the Salt Fog Exposure and the Weather-Ometer Exposure tests. The Salt Fog Exposure (La. DOTD:TR 1011-74) consists of a closed salt spray cabinet equipped with a cyclic temperature control. This test was originally designed to test zinc-rich paint systems. The Weather-Ometer Exposure (La. DOTD:TR 611-75) consists of a carbon arc Weather-Ometer with automatic humidity controls. The evaluation of Salt Fog and Weather-Ometer Exposure results are subjective and are normally reported as satisfactory or unsatisfactory for the specified number of hours exposed. Initial durability test results are presented in Appendix A, pages 39 and 40.

## DISCUSSION OF RESULTS

The average panel ratings given to each pipe at each site for this fourth and final evaluation are presented in Table 2, on page 14.

The ratings reflect the collective opinions of a panel of Louisiana Department of Transportation and Development employees who examined the culverts and assigned a numerical rating ranging from one (excellent) to five (very poor). The panel felt that, due to improper handling and lack of protection, the ends of many of the pipes indicated excessive corrosion and distress. The panel members were therefore asked to provide their ratings without considering the condition of the pipe ends. This is a departure from previous evaluations in which the entire pipe was rated, but is believed to be a better representation of actual in-service conditions and performance.

To help in analyzing the data obtained during this study, the locations at which the pipes were installed were grouped into three categories, i.e., mildly corrosive, moderately corrosive and very corrosive. These groupings were based upon the environmental conditions at the sites represented by the minimum resistivity of the soil and effluent. The limits of each group were selected in an effort to categorize the corrosive effect of the minimum resistivity upon the galvanized steel base metal. This categorization placed sites 4, 5, and 8 into mildly corrosive environments, sites 1, 2, and 3 into moderately corrosive environments and sites 6, 7, 9, 10, and 11 into very corrosive environments.

A review of Table 2 will indicate that the ratings assigned to the uncoated galvanized steel pipe (pipe number 1) are not consistent with the expected performance based upon minimum

# TABLE 2

## PANEL RATING (FOURTH EVALUATION) FOR EACH PIPE AND EACH TEST SITE

| TYPE OF PIPE | AGE | SITES 1 | 2 | 3 | 4 | 5 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 UNCOATED GALVANIZED STEEL | 6 | | | | | | | | | | 1.5 |
| | 10 | 2.6 | 1.8 | 4.4 | 3.0 | 1.8 | 5.0 | 3.8 | 4.1 | 5.0 | |
| 02 ASPHALT COATED GALVANIZED STEEL | 6 | | | | | | | | | | 1.0 |
| | 10 | 1.5 | 1.0 | 3.0 | 1.8 | 1.4 | 5.0 | 2.9 | 3.0 | 5.0 | |
| 03 ASBESTOS-BONDED, ASPHALT-COATED GALVANIZED STEEL | 6 | | | | | | | | | | 1.0 |
| | 10 | 1.4 | 1.0 | 1.9 | 1.0 | 1.0 | 3.1 | 1.1 | 2.9 | 3.2 | |
| 04 UNCOATED ALUMINUM | 6 | | | | | | | | | | 1.6 |
| | 10 | 1.4 | 1.5 | 2.5 | 1.9 | 1.8 | 4.4 | 1.8 | 2.1 | 4.1 | |
| 05 ASPHALT COATED ALUMINUM | 6 | | | | | | | | | | |
| | 10 | 1.1 | 1.2 | 2.0 | 1.2 | 1.1 | 2.2 | 1.5 | 2.6 | 2.6 | |
| 06 STRUCTURAL ALUMINUM PLATE ARCH | 6 | | | | | | | | | | 2.5 |
| | 10 | 2.1 | 1.5 | 1.4 | 1.5 | 3.2 | 5.0 | 1.9 | 4.2 | 4.9 | |
| 07 12-MIL COAL-TAR-BASED POLYMER COATED GALVANIZED STEEL | 6 | | | | | | | | | | |
| | 10 | 1.6 | 1.4 | 2.6 | 2.1 | 2.2 | 5.0 | 2.6 | 3.5 | 5.0 | |
| 08 20-MIL COAL-TAR-BASED POLYMER COATED GALVANIZED STEEL | 6 | | | | | | | | | | |
| | 10 | 1.2 | 1.2 | 2.2 | 1.9 | 1.4 | 5.0 | 2.1 | 3.2 | 5.0 | |
| 09 10-MIL POLYETHYLENE COATED GALVANIZED STEEL | 6 | | | | | | | | | | |
| | 10 | 1.1 | 1.2 | 1.8 | 1.8 | 1.8 | 4.2 | 1.8 | 2.9 | 4.4 | |
| 10 12-MIL POLYETHYLENE COATED GALVANIZED STEEL | 6 | | | | | | | | | | |
| | 10 | 1.2 | 1.2 | 1.5 | 1.6 | 1.6 | 3.2 | 1.6 | 2.6 | 3.6 | |
| 11 10-MIL POLYMETRIC COATED GALVANIZED STEEL | 6 | | | | | | | | | | 1.0 |
| | 8 | 1.0 | 1.0 | 1.5 | 1.0 | | 2.8 | 1.5 | 2.5 | 3.2 | |
| 12 10-MIL COAL-TAR-BASED POLYMER COATED GALVANIZED STEEL | 6 | | | | | | | | | | 1.1 |
| 13 8-MIL POLYETHYLENE COATED GALVANIZED STEEL | 6 | | | | | | | | | | 1.6 |
| 14 ALUMINIZED STEEL | 4 | | | | 2.2 | | | | 2.8 | 3.6 | |
| 15 EPOXY COATED GALVANIZED STEEL | 4 | | | | 1.0 | | | | | 2.6 | |
| 16 10-MIL - PLASTIC COATED ALUMINUM | 4 | | | | | | 1.1 | | 1.1 | 2.1 | |

resistivities only, i.e., some galvanized steel pipes located at an assumed moderately corrosive site have a rating lower (better) than the same pipe at what was thought to be a mildly corrosive site. This is graphically illustrated in Figure 2 on page 16. Because of the inconsistencies outlined above, a different criteria of categorization or grouping of the eleven separate sites was established. This different grouping is based upon the combined effect of all environmental influences on corrosion of uncoated galvanized steel as indicated by the assigned rating. In other words, the relative condition of 10-year-old uncoated galvanized steel pipe was used to place the sites into categories of increasing corrosion potential. Figure 3 on page 17 presents a graph depicting the ratings of the uncoated galvanized steel when the sites are placed into the new categories. The limits of each category were established as follows:

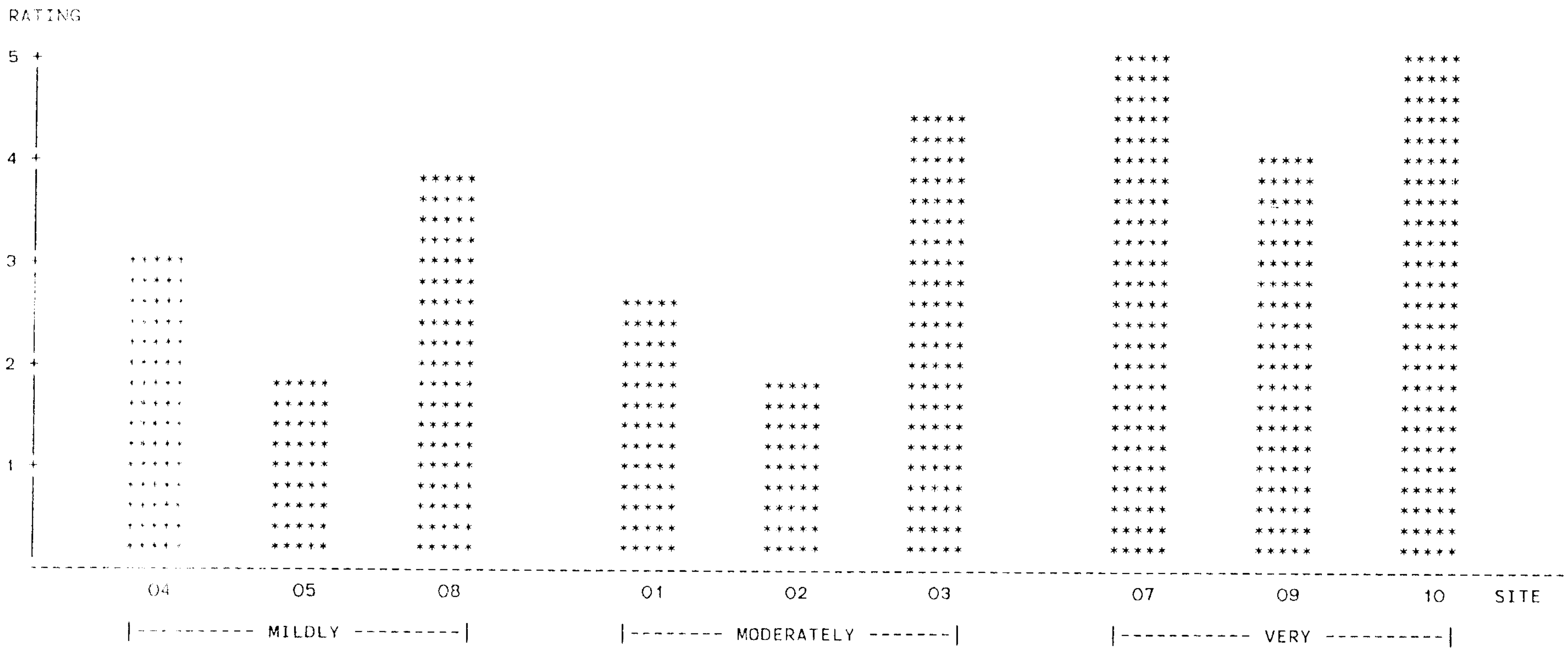
| Corrosive Condition | Uncoated G. S. Rating (10-yr.) |
|---|---|
| Mild | 1.0 - 3.4 |
| Moderate | 3.5 - 4.5 |
| Very | 4.6 - 5.0 |

These limits are based upon the previously outlined criteria established and used for the 1 to 5 rating scale, page 10.

Table 3 on page 18 presents the (fourth evaluation) rating of each pipe and each site grouped according to the above limits. Site 11 was placed under mildly corrosive conditions based upon the relatively good rating of the uncoated galvanized steel pipe after six years of exposure. The average rating of each pipe (10-year) within the three corrosive conditions are presented in Table 4 on page 19.

RATINGS FOR 16-GAUGE GALVANIZED STEEL PIPE

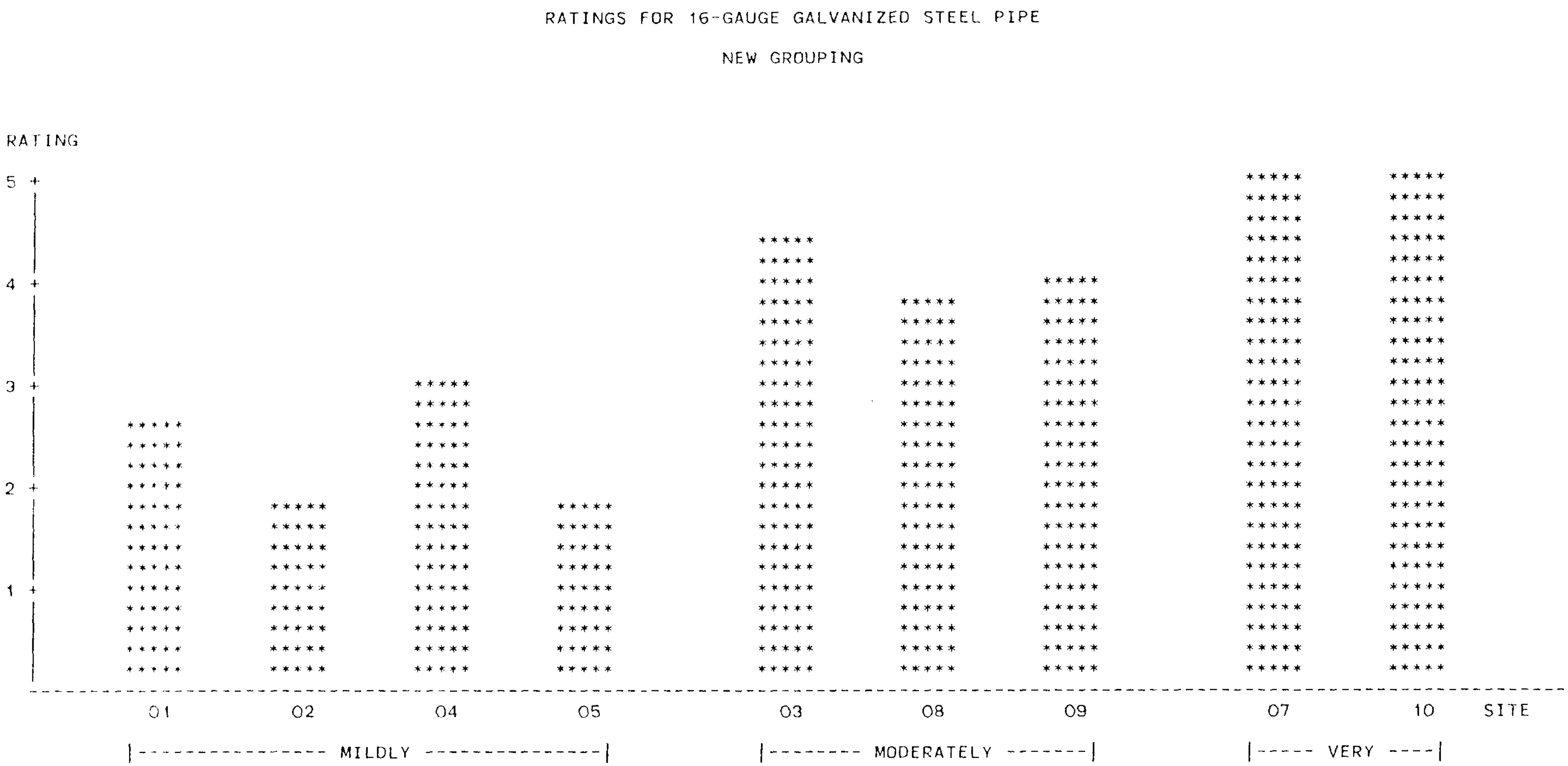
ORIGINAL GROUPING




Corrosive Conditions

(Based Upon Minimum Resistivity)

Figure 2




Corrosive Conditions

(Based Upon Ten-Year Performance)

Figure 3

# TABLE 3

## PANEL RATINGS (FOURTH EVALUATION) FOR EACH PIPE AND EACH TEST SITE GROUPED BY CORROSIVE CONDITIONS

| | | SITES BY CORROSIVENESS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MILDLY | | | | | MODERATELY | | | VERY | |
| TYPE OF PIPE | AGE | 1 | 2 | 4 | 5 | 11 | 3 | 8 | 9 | 7 | 10 |
| 01 UNCOATED GALVANIZED STEEL | 6 | | | | | 1.5 | | | | | |
| | 10 | 2.6 | 1.8 | 3.0 | 1.8 | | 4.4 | 3.8 | 4.1 | 5.0 | 5.0 |
| 02 ASPHALT COATED GALVANIZED STEEL | 6 | | | | | 1.0 | | | | | |
| | 10 | 1.5 | 1.0 | 1.8 | 1.4 | | 3.0 | 2.9 | 3.0 | 5.0 | 5.0 |
| 03 ASBESTOS-BONDED, ASPHALT-COATED GALVANIZED STEEL | 6 | | | | | 1.0 | | | | | |
| | 10 | 1.4 | 1.0 | 1.0 | 1.0 | | 1.9 | 1.1 | 2.9 | 3.1 | 3.2 |
| 04 UNCOATED ALUMINUM | 6 | | | | | 1.6 | | | | | |
| | 10 | 1.4 | 1.5 | 1.9 | 1.8 | | 2.5 | 1.8 | 2.1 | 4.4 | 4.1 |
| 05 ASPHALT COATED ALUMINUM | 6 | | | | | | | | | | |
| | 10 | 1.1 | 1.2 | 1.2 | 1.1 | | 2.0 | 1.5 | 2.6 | 2.2 | 2.6 |
| 06 STRUCTURAL ALUMINUM PLATE ARCH | 6 | | | | | 2.5 | | | | | |
| | 10 | 2.1 | 1.5 | 1.5 | 3.2 | | 1.4 | 1.9 | 4.2 | 5.0 | 4.9 |
| 07 12-MIL COAL-TAR-BASED POLYMER COATED GALVANIZED STEEL | 6 | | | | | | | | | | |
| | 10 | 1.6 | 1.4 | 2.1 | 2.2 | | 2.6 | 2.6 | 3.5 | 5.0 | 5.0 |
| 08 20-MIL COAL-TAR-BASED POLYMER COATED GALVANIZED STEEL | 6 | | | | | | | | | | |
| | 10 | 1.2 | 1.2 | 1.9 | 1.4 | | 2.2 | 2.1 | 3.2 | 5.0 | 5.0 |
| 09 10-MIL POLYETHYLENE COATED GALVANIZED STEEL | 6 | | | | | | | | | | |
| | 10 | 1.1 | 1.2 | 1.8 | 1.8 | | 1.8 | 1.8 | 2.9 | 4.2 | 4.4 |
| 10 12-MIL POLYETHYLENE COATED GALVANIZED STEEL | 6 | | | | | | | | | | |
| | 10 | 1.2 | 1.2 | 1.6 | 1.6 | | 1.5 | 1.6 | 2.6 | 3.2 | 3.6 |
| 11 10-MIL POLYMETRIC COATED GALVANIZED STEEL | 6 | | | | | 1.0 | | | | | |
| | 8 | 1.0 | 1.0 | 1.0 | | | 1.5 | 1.5 | 2.5 | 2.8 | 3.2 |
| 12 10-MIL COAL-TAR-BASED POLYMER COATED GALVANIZED STEEL | 6 | | | | | 1.1 | | | | | |
| 13 8-MIL POLYETHYLENE COATED GALVANIZED STEEL | 6 | | | | | 1.6 | | | | | |
| 14 ALUMINIZED STEEL | 4 | | | 2.2 | | | | | 2.8 | | 3.6 |
| 15 EPOXY COATED GALVANIZED STEEL | 4 | | | 1.0 | | | | | | | 2.6 |
| 16 10-MIL - PLASTIC COATED ALUMINUM | 4 | | | | | | | | 1.1 | 1.1 | 2.1 |

AVERAGE 10 YEAR RATING BY ENVIRONMENTAL CONDITION

ENVIRONMENTAL CONDITION=MILDLY CORROSIVE

| PIPE NUMBER AND DESCRIPTION | AVERAGE RATING |
|---|---|
| 03 - ASBESTOS-BONDED, ASPHALT-COATED GALVANIZED STEEL | 1.1 |
| 05 - ASPHALT COATED ALUMINUM | 1.1 |
| 10 - 12-MIL POLYETHYLENE COATED GALVANIZED STEEL | 1.4 |
| 02 - ASPHALT COATED GALVANIZED STEEL | 1.4 |
| 08 - 20-MIL COAL-TAR-BASED POLYMER COATED GALVANIZED STEEL | 1.4 |
| 09 - 10-MIL POLYETHYLENE COATED GALVANIZED STEEL | 1.5 |
| 04 - UNCOATED ALUMINUM | 1.6 |
| 07 - 12-MIL COAL-TAR-BASED POLYMER COATED GALVANIZED STEEL | 1.8 |
| 06 - STRUCTURAL ALUMINUM PLATE ARCH | 2.1 |
| 01 - UNCOATED GALVANIZED STEEL | 2.3 |

ENVIRONMENTAL CONDITION=MODERATELY CORROSIVE

| PIPE NUMBER AND DESCRIPTION | AVERAGE RATING |
|---|---|
| 10 - 12-MIL POLYETHYLENE COATED GALVANIZED STEEL | 1.9 |
| 03 - ASBESTOS-BONDED, ASPHALT-COATED GALVANIZED STEEL | 2.0 |
| 05 - ASPHALT COATED ALUMINUM | 2.0 |
| 04 - UNCOATED ALUMINUM | 2.1 |
| 09 - 10-MIL POLYETHYLENE COATED GALVANIZED STEEL | 2.2 |
| 06 - STRUCTURAL ALUMINUM PLATE ARCH | 2.5 |
| 08 - 20-MIL COAL-TAR-BASED POLYMER COATED GALVANIZED STEEL | 2.5 |
| 07 - 12-MIL COAL-TAR-BASED POLYMER COATED GALVANIZED STEEL | 2.9 |
| 02 - ASPHALT COATED GALVANIZED STEEL | 3.0 |
| 01 - UNCOATED GALVANIZED STEEL | 4.1 |

ENVIRONMENTAL CONDITION=VERY CORROSIVE

| PIPE NUMBER AND DESCRIPTION | AVERAGE RATING |
|---|---|
| 05 - ASPHALT COATED ALUMINUM | 2.4 |
| 03 - ASBESTOS-BONDED, ASPHALT-COATED GALVANIZED STEEL | 3.1 |
| 10 - 12-MIL POLYETHYLENE COATED GALVANIZED STEEL | 3.4 |
| 04 - UNCOATED ALUMINUM | 4.2 |
| 09 - 10-MIL POLYETHYLENE COATED GALVANIZED STEEL | 4.3 |
| 01 - UNCOATED GALVANIZED STEEL | 5.0 |
| 02 - ASPHALT COATED GALVANIZED STEEL | 5.0 |
| 06 - STRUCTURAL ALUMINUM PLATE ARCH | 5.0 |
| 07 - 12-MIL COAL-TAR-BASED POLYMER COATED GALVANIZED STEEL | 5.0 |
| 08 - 20-MIL COAL-TAR-BASED POLYMER COATED GALVANIZED STEEL | 5.0 |

TABLE 4

Figures 4, 5, and 6 on pages 21 through 23 depict the average (10-year) ratings under the three environmental conditions. Based upon the average (10-year) ratings within the three corrosive environments the following are indicated:

Mildly Corrosive Environments

The asbestos bonded asphalt coated galvanized steel and the asphalt coated aluminum pipes are the best performing pipes tested, with an average rating of 1.1. The 10-year average rating for all pipes ranges from a best of 1.1 to the worst of 2.3. This indicates that all pipes tested performed very well under these mild environmental conditions.

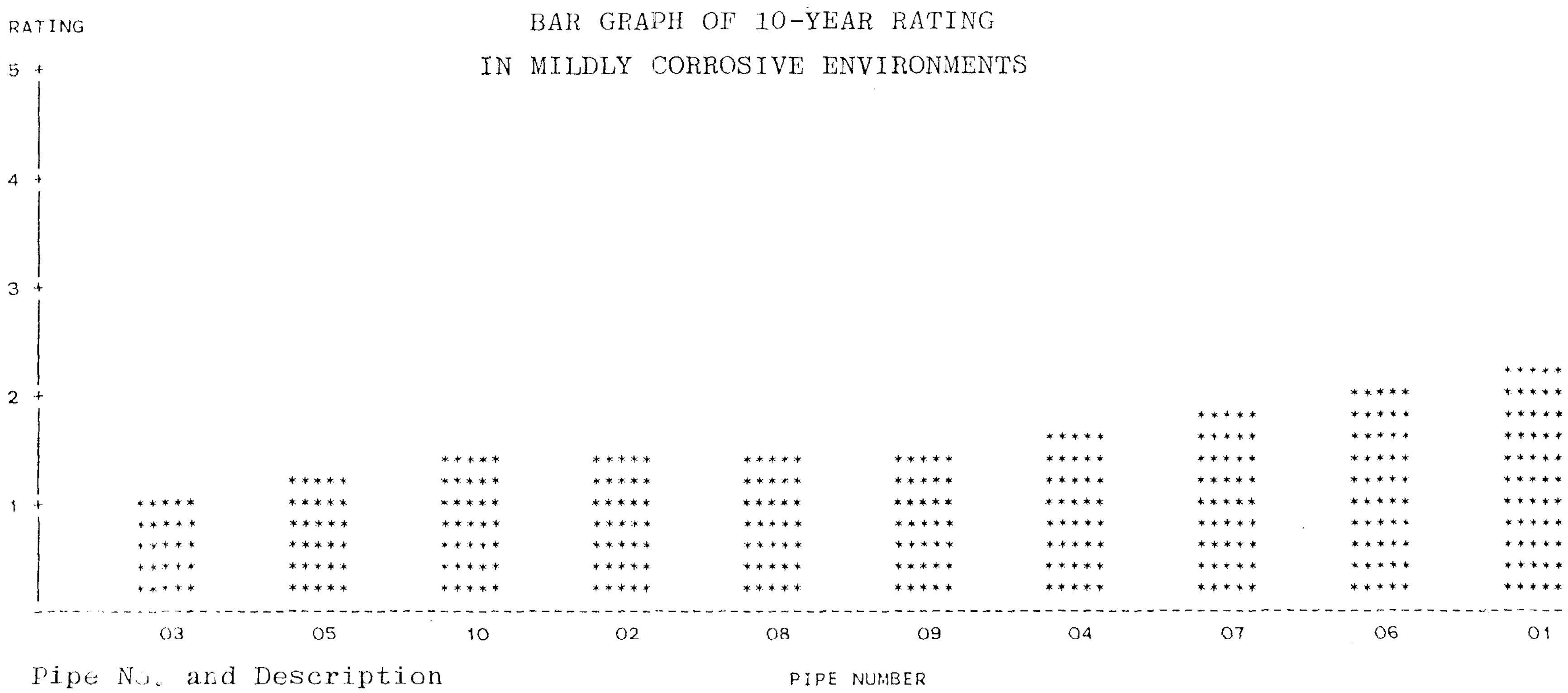
Moderately Corrosive Environments

The asphalt coated aluminum, 12-mil polyethylene coated galvanized steel and the asbestos bonded asphalt coated galvanized steel are among the best performing pipes evaluated with a 10-year average ratings of 1.9 and 2.0. All pipes with the exception of the uncoated galvanized steel performed reasonably well in these moderately corrosive environments.

Very Corrosive Environments

The asphalt coated aluminum (rating of 2.4), asbestos bonded asphalt coated galvanized steel (rating of 3.1) and the 12-mil polyethylene coated galvanized steel (rating of 3.4) are the best performing pipes in the very corrosive environments; these pipes stand out in their ability to resist corrosion under the very harsh conditions, and have some additional life remaining. The other pipes tested are at, or near, their end of life.

The only pipe with a maximum of eight years field exposure as of this final evaluation is the 10-mil polymeric coated

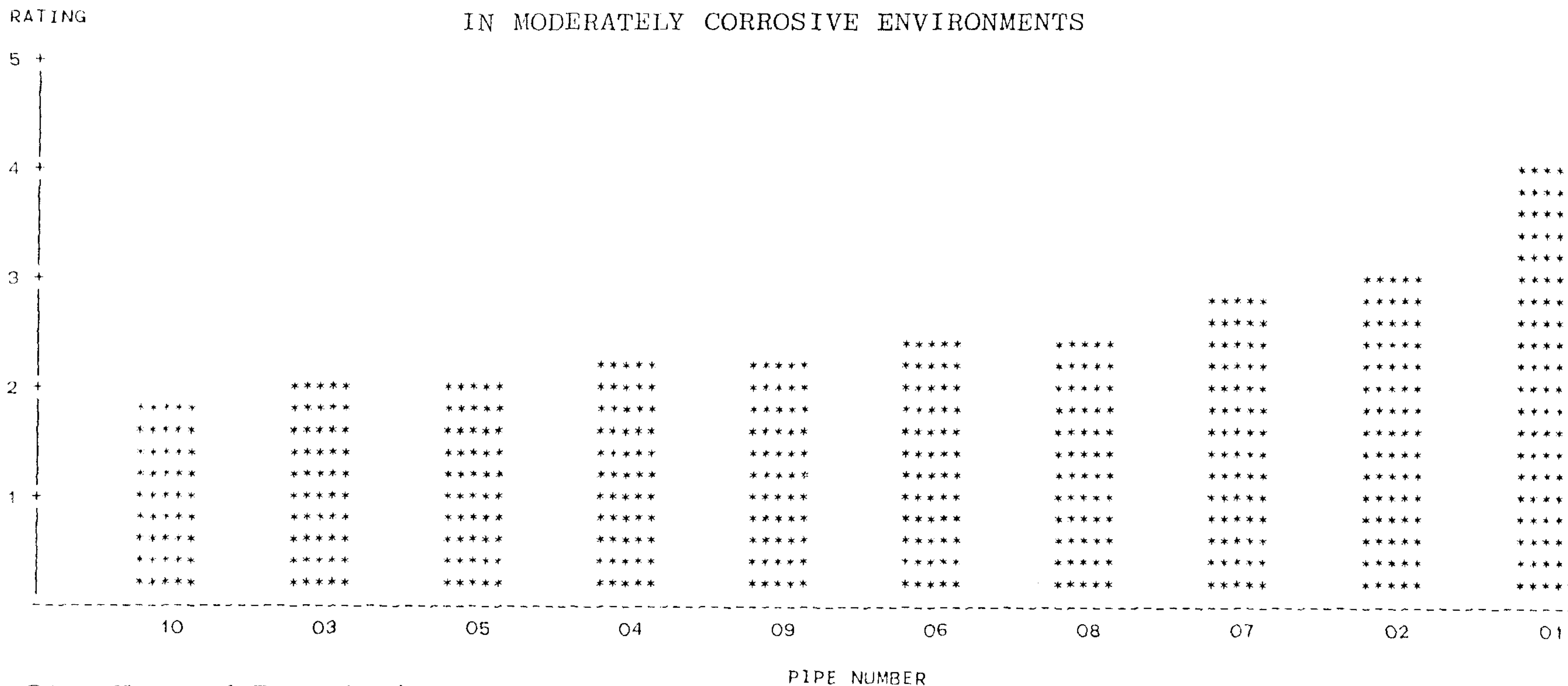



Pipe No. and Description

01 UNCOATED GALVANIZED STEEL
02 ASPHALT COATED GALVANIZED STEEL
03 ASBESTOS-BONDED, ASPHALT-COATED GALVANIZED STEEL
04 UNCOATED ALUMINUM
05 ASPHALT COATED ALUMINUM
06 STRUCTURAL ALUMINUM PLATE ARCH
07 12-MIL COAL-TAR-BASED POLYMER COATED GALVANIZED STEEL
08 20-MIL COAL-TAR-BASED POLYMER COATED GALVANIZED STEEL
09 10-MIL POLYETHYLENE COATED GALVANIZED STEEL
10 12-MIL POLYETHYLENE COATED GALVANIZED STEEL

Figure 4

## BAR GRAPH OF 10-YEAR RATINGS
## IN MODERATELY CORROSIVE ENVIRONMENTS

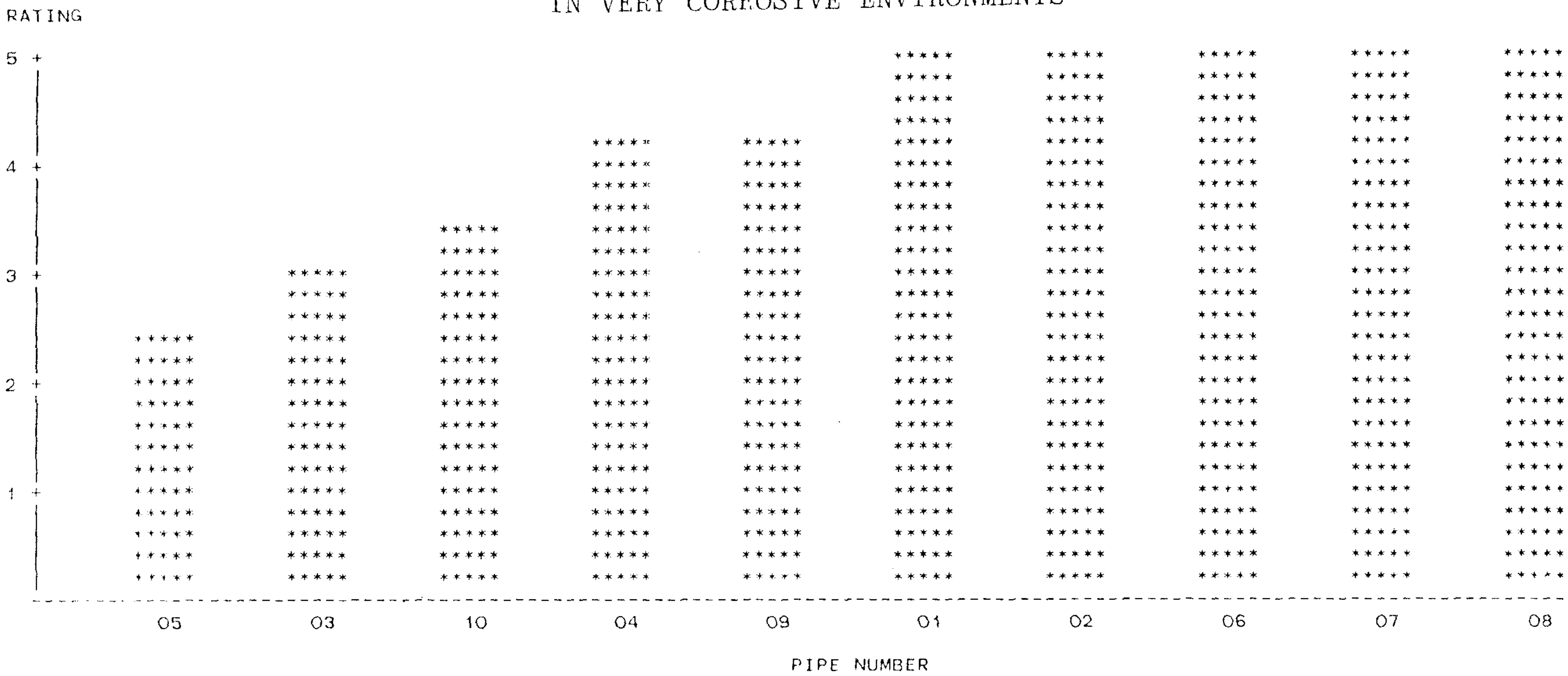



Pipe No. and Description

01 UNCOATED GALVANIZED STEEL
02 ASPHALT COATED GALVANIZED STEEL
03 ASBESTOS-BONDED, ASPHALT-COATED GALVANIZED STEEL
04 UNCOATED ALUMINUM
05 ASPHALT COATED ALUMINUM
06 STRUCTURAL ALUMINUM PLATE ARCH
07 12-MIL COAL-TAR-BASED POLYMER COATED GALVANIZED STEEL
08 20-MIL COAL-TAR-BASED POLYMER COATED GALVANIZED STEEL
09 10-MIL POLYETHYLENE COATED GALVANIZED STEEL
10 12-MIL POLYETHYLENE COATED GALVANIZED STEEL

Figure 5

## BAR GRAPH OF 10-YEAR RATINGS
## IN VERY CORROSIVE ENVIRONMENTS




Pipe Number and Description

01 UNCOATED GALVANIZED STEEL
02 ASPHALT COATED GALVANIZED STEEL
03 ASBESTOS-BONDED, ASPHALT-COATED GALVANIZED STEEL
04 UNCOATED ALUMINUM
05 ASPHALT COATED ALUMINUM
06 STRUCTURAL ALUMINUM PLATE ARCH
07 12 MIL COAL-TAR-BASED POLYMER COATED GALVANIZED STEEL
08 20-MIL COAL-TAR-BASED POLYMER COATED GALVANIZED STEEL
09 10-MIL POLYETHYLENE COATED GALVANIZED STEEL
10 12-MIL POLYETHYLENE COATED GALVANIZED STEEL

Figure 6

galvanized steel. This pipe performed well in the mild and moderately corrosive environments and had an average rating of 3.0 in the highly corrosive environments.

Eight pipe types which were installed at site 11 (mild environment) had a maximum of six years field exposure as of this final evaluation. The pipes that performed the best at this site, with a rating of 1.0 after six years, are the asphalt coated galvanized steel, the asbestos-bonded asphalt coated galvanized steel and the 10-mil polymeric coated galvanized steel.

Three pipe types had a maximum of four years field exposure as of this final evaluation. The 10-mil plastic coated aluminum was the pipe with the best performance in all three environments.

Table 5 on page 25 is a list of sites at which 16-gauge uncoated galvanized steel pipes have perforated and/or reached a rating of 5.0, and the corresponding number of years elapsed to reach this end condition. Also included in this table is the pipes' expected life (years to perforation) as predicted by the California Chart (2) for the existing site conditions. The California Chart relates expected years to perforation vs. minimum resistivity and pH of the site environment. As can be seen in Table 5 and illustrated in figure 7, page 27, the California Chart overestimates the anticipated life of 16-gauge uncoated galvanized steel at those sites where perforation or failure has occurred during this study. The chart does, however, seem to provide predicted life relative to the available range of pH and resistivities when sites are grouped by performance of galvanized steel as indicated in Table 6, page 26. It is impossible to accurately estimate or predict pipe life in all the various environments based upon the ratings obtained during this study because of the non-linearity of the 1 to 5 rating scale. For example, a rating of 3.0 (mid-point of the rating scale) does not necessarily indicate that one-half of the life or usefulness of the

ACTUAL VS. PREDICTED LIFE FOR
16-GAUGE GALVANIZED STEEL

| Site Locations Where 16-Gauge Galvanized Steel Perforated | Actual Age To Perforation | Predicted Years To Perforation (By California Chart) | | |
|---|---|---|---|---|
| | | By Soil | By Effluent | Combined |
| 3 | 6-10 years | 21 years | 23 years | 22 years |
| 7 | 2- 4 years | 19 years | 6 years | 12.5 years |
| 8 | 6-10 years | 20 years | 38 years | 29 years |
| 9 | 6-10 years | 29 years | 19 years | 24 years |
| 10 | 2- 4 years | 17 years | 12 years | 14.5 years |

TABLE 5

## TABLE 6

### PREDICTED YEARS TO PERFORATION - ALL SITES

| | SITE #'S | | YEARS TO PERFORATION* |
|---|---|---|---|
| | 1 | | 15.0 |
| Mildly | 2 | | 30.0 |
| Corrosive | 4 | | 27.0 |
| | 5 | | 27.0 |
| | | Average | (25.0) |
| | 3 | | 21.0 |
| Moderately | 8 | | 20.0 |
| Corrosive | 9 | | 19.0 |
| | | Average | (20.0) |
| | 7 | | 6.0 |
| Very Corrosive | 10 | | 12.0 |
| | | Average | ( 9.0) |

*Predicted years to perforation for uncoated, 16-gauge galvanized steel pipe - utilizing the California Chart and worst case, environmental condition.

16-GAUGE GALVANIZED STEEL AFTER
10 YEARS OF EXPOSURE AT SITE NO. 7

Figure 7

pipe is gone. All pipes tested would require field exposure times of such length that the pipes reach a rating of 5.0 prior to any accurate determination of pipe life or additional life due to the various pipe coatings.

Three general types of coatings were used to protect the base metal of some of the (10-year) test pipes. Based upon the results of the ratings of coated and uncoated pipes, all coatings provided some degree of additional life by reducing corrosion of the base metal. The three coatings fall into the following categories:

1. Asphalt
2. Asbestos Bonded With Asphalt Coating
3. Polymeric

The asphalt coatings tended to be removed during handling and tended to be removed or cracked from exposure to the environment; Figure 8, page 29. In harsh environments, rust stains appearing in the asbestos indicates corrosion of the base metal; Figure 9, page 30. The polymers tended to blister in harsh environments and tended to peel (separate from the base) in moderate and harsh environments, Figure 10, page 31. The thicker polymeric coatings appeared to protect the base metal better than the thin coatings.

A detailed review of the performance of each test pipe may be found in Appendix B, page 41.

ASPHALT COATING CRACKED

AND REMOVED

CORROSION BETWEEN ASBESTOS
AND BASE METAL - SITE NO. 10

Figure 9

# POLYMERIC COATINGS - BLISTERS AND PEELING IN HARSH ENVIRONMENTS

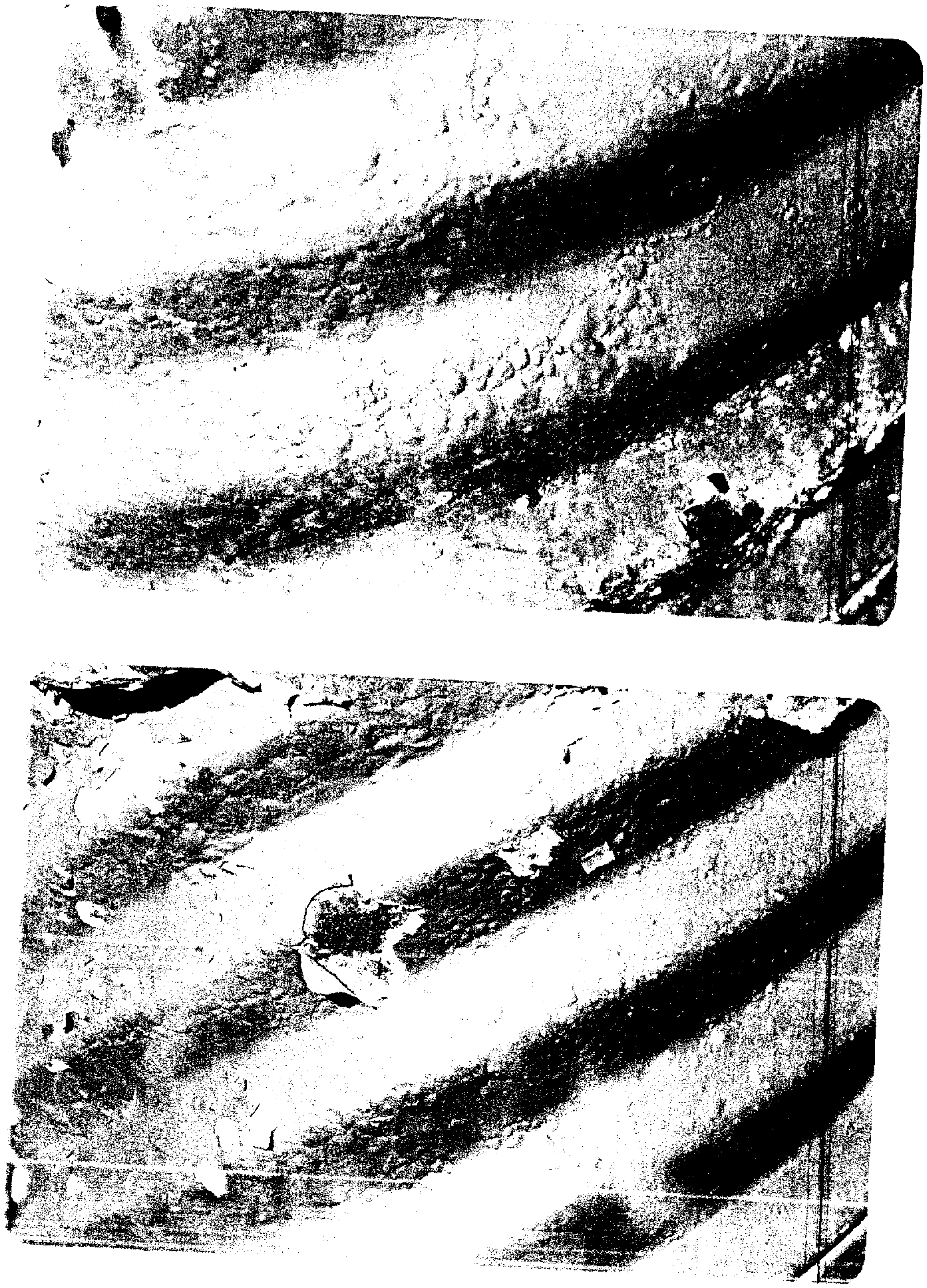


Figure 10

## CONCLUSIONS

Ten years of field exposure have provided much information concerning the in-service performance of the various types of test culverts. The following conclusions have been reached at this time:

1. The pipe types providing the best overall performance after ten years of exposure to the various environments are the 16-gauge asphalt coated aluminum, the 14-gauge asbestos bonded asphalt coated galvanized steel and the 16-gauge 12-mil polyethylene coated galvanized steel.

2. Under the environmental conditions (moderately and very corrosive) encountered during this study, the California Chart overestimates predicted pipe life. The chart does, however, combine pH and resistivities to correctly predict life in a relative sense for the mildly, moderately, and very corrosive environments.

3. All coatings provided some degree of protection to the pipe base metal. The thicker polymeric coatings provided more protection against corrosion than the thinner polymeric coatings.

## RECOMMENDATIONS

The following recommendations are based upon the data obtained and the visual observations made during this ten-year evaluation of the various pipes exposed to mild, moderate and very corrosive environmental conditions:

1. The Department's procedure for determining coating and gauge requirements for metal pipe, EDSM II.2.1.6, is generally supported by the results of this ten-year study. However, where failures of 16-gauge uncoated galvanized steel pipe were documented, life predictions using the "years to perforation" chart in the EDSM (California Chart) exceed actual time to perforation of the culverts. It is therefore recommended that the ability of the chart to accurately predict corrosion rates in a variety of Louisiana conditions be evaluated.

2. The relative difference (as given in EDSM II.2.1.6) in added life attributable to bituminous coating versus that provided by the polyethylene coatings should be evaluated.

3. Consideration should be given to allow aluminum pipe to be bituminous coated, provided the problems previously experienced with bonding of the coating can be resolved.

## BIBLIOGRAPHY

1. Azar, D. G. <u>Drainage Pipe Study</u>. Louisiana Department of Highways Report No. 57, 1971.

2. Engineering Directives and Standards Manual, No. II.2.1.6, Figure 1, Louisiana Department of Transportation and Development, Office of Highways, November 4, 1983.

# APPENDIX A

# LABORATORY ANALYSIS OF TEST PIPE

ANALYSIS OF METAL PIPE BY X-RAY FLUORESCENCE

TABLE 7

| Test Culverts | Elements | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Zn | Cu | Ni | Ti | Ca | K | Mn | Mg | Si |
| Galvanized | tr | 0.215 | tr | tr* | | | | | 0.8 |
| A.C.G.P. | tr | 0.20 | tr | tr* | | | | | 1.21 |
| A.B.A.C.P. | tr | 0.215 | tr | tr* | | | | | 1.98 |
| "Nexon" (12-mils) | tr | 0.215 | tr | tr* | tr | tr | 0.36 | | 1.82 |
| "Nexon" (20-mils) | tr | 0.25 | tr | tr* | | | 0.4 | | 1.48 |
| Inland (12/5-mils) | tr | 0.195 | tr | tr* | | | | | 1.2 |
| Inland (10/3-mils) | 0.065 | 0.175 | tr | tr* | | | 0.06 | | 0.96 |
| Wheeling (10/3-mils) | tr | 0.26 | <0.04 | tr | | | 0.4 | | 0.18 |
| A.C.A.P. | high, ≅1% | 0.04 | | | | | | <0.1 | |
| Aluminum Pipe | high, ≅1% | 0.035 | | | | | | 0.1 | |
| Aluminum Arch | 0.045 | 0.075 | | | | | | 2.5 | |

NOTE: All values recorded are percent of material present.
A.C.G.P. - Asphalt-coated, galvanized steel pipe
A.B.A.C.G.P. - Asbestos-bonded asphalt-coated galvanized steel pipe
A.C.A.P. - Asphalt-coated aluminum pipe

tr = Trace, <0.01%
tr* = Trace, Extremely small, <0.001%
Ca & K = Amount unknown due to lack of standard; may be <0.1%

PIPE AND COATING THICKNESSES, AS MEASURED

TABLE 8

| Type of Pipe | Gauge | Zinc Coating oz./ft.$^2$ | Asphalt Coating oz./ft.$^2$(mils) | Other Coating mils |
|---|---|---|---|---|
| Galvanized Pipe | 16 | 2.40 | --- | --- |
| A.C.G.P. | 16 | 3.03 | 3.03 (52) | --- |
| A.B.A.C.G.P. | 14 | 2.39 | 13.30 (58) | --- |
| U.S.S. | 16 | 2.77 | --- | 16 (12*) |
| U.S.S. | 16 | 2.70 | --- | 12 (20*) |
| Inland Steel | 16 | 2.52 | --- | Interior 10 (10*)<br>Exterior 3 ( 3*) |
| Inland Steel | 16 | 2.38 | --- | Interior 10 (12*)<br>Exterior 5 ( 5*) |
| Aluminum Pipe | 16 | --- | --- | --- |
| A.C.A.P. | 16 | --- | 2.55 (50) | --- |
| Aluminum Plate | 12 | --- | --- | --- |
| Wheeling Steel | 16 | 2.64 | --- | Interior 10 (10*)<br>Exterior 3 ( 3*) |
| Epoxy Coated Steel | 16 | 2.00 | --- | Interior 10<br>Exterior 7 |
| Plastic Coated Aluminum | 14 | --- | --- | Interior 8<br>Exterior 5 |
| Aluminized Steel | 16 | --- | --- | Interior 1.5<br>Exterior 1.5 |

* Nominal total thickness of "other coating."

Note: A.C.G.P. - Asphalt-coated, galvanized steel pipe
A.B.A.C.G.P. - Asbestos-bonded, asphalt-coated, galvanized steel pipe
A.C.A.P. - Asphalt-coated, aluminum pipe

U.S.S. "Nexon" 10/10 and Inland Steel 8/4 (pipes #12 and #13) not measured.

CONDITION OF SAMPLES AFTER ONE MONTH
IN SALT FOG CHAMBER

TABLE 9

| | Sample Type | Sample Condition |
|---|---|---|
| 1. | Galvanized Steel | Completely Corroded |
| 2. | A.C.G.P. | Slight Blistering Near Scribe and Edges |
| 3. | A.B.A.C.G.P. | No Significant Effects |
| 4. | "Nexon" (12-mils) | Blistering Near Scribe and Edges |
| 5. | "Nexon" (20-mils) | Blistering Near Scribe and Edges |
| 6. | Inland (10/3-mils) | Blistering Near Scribe and Edges |
| 7. | Inland (12/5-mils) | Blistering Near Scribe and Edges |
| 8. | Aluminum Pipe | Cladding Pitted |
| 9. | A.C.A.P. | Very Slight Blistering Along the Edge |
| 10. | Aluminum Plate | Cladding Pitted |
| 11. | Wheeling (10/3-mils) | Blistering Along Surface |

Note: A.C.G.P. = Asphalt-coated, galvanized steel pipe
A.B.A.C.G.P. = Asbestos-bonded, asphalt-coated, galvanized steel pipe
A.C.A.P. = Asphalt-coated, aluminum pipe

CONDITION OF SAMPLES AFTER 1500 HOURS
IN WEATHER-OMETER

TABLE 10

| | Sample Type | Sample Condition |
|---|---|---|
| 1. | Galvanized Steel | No Significant Effects |
| 2. | A.C.G.P. | Asphalt Coating Cracked to Metal |
| 3. | A.B.A.C.G.P. | Asphalt Coating Cracked, Not to Metal |
| 4. | "Nexon" (12-mils) | No Significant Effect, Slight Discoloration |
| 5. | "Nexon" (20-mils) | No Significant Effect, Slight Discoloration |
| 6. | Inland (10/3-mils) | Complete Delamination of Coating |
| 7. | Inland (12/5-mils) | Complete Delamination of Coating |
| 8. | Aluminum Pipe | No Significant Effects |
| 9. | A.C.A.P. | Asphalt Coating Cracked to Metal |
| 10. | Aluminum Plate | No Significant Effects |
| 11. | Wheeling Steel (10/3-mils) | No Significant Effects |

Note: A.C.G.P. = Asphalt-coated, galvanized steel pipe
A.B.A.C.G.P. = Asbestos-bonded, asphalt-coated, galvanized steel pipe
A.C.A.P. = Asphalt-coated, aluminum pipe

# APPENDIX B

## EVALUATION OF INDIVIDUAL TYPES OF CULVERTS AND FIELD EVALUATION FORM

## Evaluation of Individual Types of Culverts

Eleven sites chosen for installation were divided into three categories in terms of their corrosiveness as follows:

a. Site 1, 2, 4, 5 and 11 are considered to be mildly corrosive.

b. Site 3, 8, and 9 are considered to be corrosive.

c. Site 7 and 10 are considered to be very corrosive.

The following is a general description of the condition of each pipe at each site.

Pipe No. 1 Uncoated, 16-gauge galvanized steel

| Site No. | Yrs. of Exposure | Condition |
|---|---|---|
| 1 | 10 | Minor Rusting |
| 2 | 10 | Very Good Condition |
| 3 | 10 | Heavy Rusting/Perforations |
| 4 | 10 | Moderate Rusting |
| 5 | 10 | Minor Rusting |
| 7 | 10 | Rusted Out |
| 8 | 10 | Heavy Rusting/Perforations |
| 9 | 10 | Heavy Rusting/Perforations |
| 10 | 10 | Rusted Out |
| 11 | 6 | Very Good Condition |

Pipe No. 2 Asphalt-coated, 16-gauge galvanized steel

| Site No. | Yrs. of Exposure | Condition |
|---|---|---|
| 1 | 10 | Asphalt Coating Almost Completely Removed - pipe in very good condition |
| 2 | 10 | Same as Site No. 1 |
| 3 | 10 | Asphalt Coating Almost Completely Removed - pipe is heavily rusted |
| 4 | 10 | Asphalt Coating Almost Completely Removed - pipe is moderately rusted |
| 5 | 10 | Same as Site 1 and 2 |

| Site No. | Yrs. of Exposure | Condition |
|---|---|---|
| 7 | 10 | Asphalt Almost Completely Removed - pipe is rusted out |
| 8 | 10 | Same as Site No. 3 |
| 9 | 10 | Same as Site No. 3 |
| 10 | 10 | Same as Site No. 7 |
| 11 | 6 | Asphalt Coating is Cracked - pipe is in very good condition |

Pipe No. 3 Asbestos-bonded, asphalt-coated, 14-gauge galvanized steel

| Site No. | Yrs. of Exposure | Condition |
|---|---|---|
| 1 | 10 | Asphalt Coating is Almost Completely Removed - very minor rusting |
| 2 | 10 | Asphalt Coating Moderate Removal - pipe in very good condition |
| 3 | 10 | Asphalt Coating is Almost Completely Removed - minor rusting |
| 4 | 10 | Asphalt Coating is Cracked - pipe is in very good condition |
| 5 | 10 | Some Removal of Asphalt Coating - pipe in very good condition |
| 7 | 10 | Asphalt Coating Almost Completely Removed - heavy rusting - almost perforated |
| 8 | 10 | Asphalt Coating is Almost Completely Removed - minor rusting |
| 9 | 10 | Asphalt Coating is Almost Completely Removed - moderate rusting |
| 10 | 10 | Same as Site No. 7 |
| 11 | 6 | Pipe and Coating in Very Good Condition |

Pipe No. 4 Uncoated, 16-gauge aluminum pipe, Alclad 3004

| Site No. | Yrs. of Exposure | Condition |
|---|---|---|
| 1 | 10 | Very Good Condition |
| 2 | 10 | Good Condition |
| 3 | 10 | Minor Thickness Loss |
| 4 | 10 | Minor Pitting and Thickness Loss |
| 5 | 10 | Minor Thickness Loss |
| 7 | 10 | Perforated |
| 8 | 10 | Minor Thickness Loss |
| 9 | 10 | Minor Thickness Loss |
| 10 | 10 | Perforated |
| 11 | 6 | Minor Thickness Loss |

Pipe No. 5 Asphalt-coated, 16-gauge aluminum pipe, Alclad 3004

| Site No. | Yrs. of Exposure | Condition |
|---|---|---|
| 1 | 10 | Some Asphalt Coating Removed - pipe in very good condition |
| 2 | 10 | Same as Above |
| 3 | 10 | Asphalt Coating Almost Completely Removed - some weight loss |
| 4 | 10 | Same as Site No. 1 Above |
| 5 | 10 | Same as Site No. 1 Above |
| 7 | 10 | Same as Site No. 3 Above |
| 8 | 10 | Some Asphalt Coating Removed - minor weight loss |
| 9 | 10 | Same as Site No. 3 Above |
| 10 | 10 | Same as Site No. 3 Above |

Pipe No. 6 5052 Structural aluminum plate arch

| Site No. | Yrs. of Exposure | Condition |
|---|---|---|
| 1 | 10 | Minor Pitting and Thickness Loss |
| 2 | 10 | Same as Site No. 1 Above |
| 3 | 10 | Same as Site No. 1 Above |

| Site No. | Yrs. of Experience | Condition |
|---|---|---|
| 4 | 10 | Same as Site No. 1 Above |
| 5 | 10 | Heavy Pitting and Thickness Loss |
| 7 | 10 | Perforated |
| 8 | 10 | Same as Site No. 1 Above |
| 9 | 10 | Perforated |
| 10 | 10 | Perforated |
| 11 | 6 | Moderate Pitting and Thickness Loss |

Pipe No. 7 Sixteen-gauge galvanized steel with a 12-mil, U.S. Steel, coal-tar-based laminate applied to interior and 0.3 mil, modified epoxy coating on the reverse side

| Site No. | Yrs. of Exposure | Condition |
|---|---|---|
| 1 | 10 | Pipe in Very Good Condition - Inside Coating in Good Condition - minor outside coating loss |
| 2 | 10 | Same as Site No. 1 Above |
| 3 | 10 | Pipe and Inside Coating in Good Condition - moderate outside coating loss |
| 4 | 10 | Same as Site No. 3 Above |
| 5 | 10 | Same as Site No. 3 Above |
| 7 | 10 | Pipe is Rusted Out |
| 8 | 10 | Same as Site No. 3 Above |
| 9 | 10 | Heavy Rusting - moderate inside coating loss - moderate to heavy outside coating loss |
| 10 | 10 | Pipe is Rusted Out |

Pipe No. 8 Sixteen-gauge galvanized steel with a 20-mil, U.S. Steel, coal-tar-based laminate applied to interior with a 0.3-mil modified epoxy coating on the reverse side

| Site No. | Yrs. of Exposure | Condition |
|---|---|---|
| 1 | 10 | Pipe and Coatings in Very Good Condition |
| 2 | 10 | Same as Site No. 1 Above |
| 3 | 10 | Pipe is in Good Condition - inside coating is peeling - outside coating loss moderate |
| 4 | 10 | Pipe is in Good Condition - inside coating is in good condition - slight coating loss |
| 5 | 10 | Pipe is in Good Condition - inside coating is peeling - outside coating loss is slight |
| 7 | 10 | Pipe is Rusted Out |
| 8 | 10 | Same as Site No. 3 Above |
| 9 | 10 | Pipe is Heavily Rusted - inside coating is peeling - outside coating loss is heavy |
| 10 | 10 | Pipe is Rusted Out |

Pipe No. 9 Sixteen-gauge galvanized steel with a 10-mil interior and 3.0-mil exterior, Inland Steel, polyethylene coating

| Site No. | Yrs. of Exposure | Condition |
|---|---|---|
| 1 | 10 | Pipe and Coatings in Very Good Condition |
| 2 | 10 | Same as Site No. 1 Above |
| 3 | 10 | Minor Rusting of Pipe/Blistering of Outside Coating |
| 4 | 10 | Same as Site No. 3 Above |
| 5 | 10 | Same as Site No. 3 Above |
| 7 | 10 | Pipe is Rusted Out |
| 8 | 10 | Same as Site No. 3 Above |
| 9 | 10 | Moderate to Heavy Rusting of Pipe/Blistering of Outside Coating |
| 10 | 10 | Pipe is Rusted Out |

Pipe No. 10 Sixteen-gauge galvanized steel with a 12-mil interior and 5-mil exterior, Inland Steel Polyethylene coating

| Site No. | Yrs. of Exposure | Condition |
|---|---|---|
| 1 | 10 | Pipe is in Very Good Condition - inside coating is peeling |
| 2 | 10 | Pipe and Coatings in Very Good Condition |
| 3 | 10 | Minor Rusting of Pipe/Blistering of Outside Coating |
| 4 | 10 | Same as Site No. 3 Above |
| 5 | 10 | Same as Site No. 3 Above |
| 7 | 10 | Heavy Rusting of Pipe/Blistering of Outside Coating - inside coating is peeling |
| 8 | 10 | Same as Site No. 3 Above |
| 9 | 10 | Moderate Rusting of Pipe/Blistering of Outside Coating |
| 10 | 10 | Same as Site No. 7 Above |

Pipe No. 11 Sixteen-gauge galvanized steel pipe with 10-mil interior and 3-mil exterior, Wheeling Steel, polymeric coating

| Site No. | Yrs. of Exposure | Condition |
|---|---|---|
| 1 | 8 | Pipe and Coating in Very Good Condition |
| 2 | 8 | Same as Site No. 1 Above |
| 3 | 8 | Minor Rusting of Pipe/Blistering of Outside Coating - inside coating starting to peel |
| 4 | 8 | Very Minor Rusting of Pipe/Blistering of Outside Coating |
| 7 | 8 | Moderate to Heavy Rusting of Pipe/Blistering of Outside Coating |
| 8 | 8 | Same as Site No. 4 Above |

| Site No. | Yrs. of Exposure | Condition |
|---|---|---|
| 9 | 8 | Same as Site No. 7 Above |
| 10 | 8 | Heavy Rusting of Pipe/Blistering of Outside Coating |
| 11 | 6 | Same as Site No. 1 Above |

Pipe No. 12 Sixteen-gauge galvanized steel with a 10-mil U.S. Steel, coal-tar-based laminate applied to interior and exterior

| Site No. | Yrs. of Exposure | Condition |
|---|---|---|
| 11 | 6 | Pipe and Inside Coatings in Very Good Condition - outside coating is peeling |

Pipe No. 13 Sixteen-gauge galvanized steel with an 8-mil interior and 4-mil exterior, Inland Steel, poly-ethylene coating

| Site No. | Yrs. of Exposure | Condition |
|---|---|---|
| 11 | 6 | Pipe and Outside Coating is in Good Condition - inside coating is pitted |

Pipe No. 14 Sixteen-gauge steel with a 1.5-mil aluminum coating applied to the interior and exterior

| Site No. | Yrs. of Exposure | Condition |
|---|---|---|
| 4 | 4 | Minor Rusting of Pipe |
| 9 | 4 | Moderate Rusting of Pipe |
| 10 | 4 | Heavy Rusting of Pipe |

Pipe No. 15 Sixteen gauge galvanized steel with a 10-mil epoxy coating on the interior and a 7-mil epoxy coating on the exterior

| Site No. | Yrs. of Exposure | Condition |
|---|---|---|
| 4 | 4 | Pipe and Coating in Very Good Condition |
| 10 | 4 | Moderate to Heavy Rusting of Pipe-Blistering of Outside Coating |

Pipe No. 16 14-Gauge, Alclad 3004, Aluminum pipe with 10-mil interior and 5-mil exterior, polymeric coating

| | | |
|---|---|---|
| 7 | 4 | Pipe and Coating in Very Good Condition |
| 9 | 4 | Pipe in Very Good Condition Coating Starting to Peel |
| 10 | 4 | Pipe in Good Condition Coating is Peeling |