EVALUATION OF DRAINAGE PIPE BY FIELD EXPERIMENTATION AND SUPPLEMENTAL LABORATORY EXPERIMENTATION

Interim Report No. 2

By

RICHARD W. KINCHEN
PAVEMENT RESEARCH ENGINEER

WILLIAM H. TEMPLE
ASSISTANT RESEARCH ENGINEER

HENRY W. LACINAK
CHEMICAL RESEARCH ENGINEER

AND

BRUCE J. GUEHO
PAVEMENT RESEARCH SPECIALIST

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SUMMARY

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

Perhaps the most common structure that these design engineers use is the drainage pipe--primarily concrete and metal. This study is investigating the durability properties of metal drainage pipe in Louisiana, where durability of such pipe is as important as strength because of harsh environs which promote corrosion.

Since 1973, eleven types of steel and aluminum test culverts have been installed at 11 test sites. Research personnel periodically inspect the full-scale culverts in the field and further evaluate field samples in the laboratory. Research personnel selected the test sites based on geographical location and on the pH and electrical resistivity values of the soil and effluent.

This interim report relates field and laboratory observations concerning the condition of the test pipes after four years of in-service exposure. It was found that the asbestos-bonded, asphalt-coated, galvanized steel pipe was performing better than the other ten types of culverts in resisting corrosion. All of the coatings on the various test culverts are showing signs of distress at the highly corrosive test sites.

INTRODUCTION

The State of Louisiana annually receives approximately 60 inches (152 cm.) of rainfall. The Louisiana Office of Highways' Road Design Engineer assigns a cross-slope and texture to his 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 (1)* and with stable bedding conditions can normally serve effectively for the life of a highway.

The Office 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. The purpose of this report is to relate preliminary findings in the study.

*Underlined numbers in parentheses refer to Bibliography.

SCOPE

In this study the evaluation of corrosion in 11 types of metal drainage pipe is limited to 11 field installations representing a cross section of soil and water conditions found in Louisiana. The types of corrugated culvert under evaluation include six which are presently authorized for use by Department specifications and five which are under evaluation as new products. The potential corrosiveness at the installation sites ranges from the highly corrosive environment found in brackish waters near the Gulf of Mexico to the fairly noncorrosive soils of North-central Louisiana. The indicators of corrosion potential are pH and electrical resistivity of both soil and effluent.

The evaluation is comprised of field observations, including a panel rating, and laboratory analyses of pipe samples taken in the field.

METHOD OF PROCEDURE

Site Selection

An earlier drainage pipe study (1) served to evaluate existing drainage structures in the seven general soils 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 normal soil conditions found in the northern, central, and southern sections of the state. The design was extended to include factors of high and low electrical resistivity (in ohm-centimeters) with correspondingly high pH.

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 the researchers selected to satisfy the requirements of the field experiment.

	Soil Resistivity, ohm-cm	
Soil pH	500-2000	Greater than 2000
5.0 - 6.0	Site No. 1	Site No. 4 Site No. 8
7.0 - 8.0	Site No. 2 Site No. 3	Site No. 5
8.0 - 9.0	Site No. 9 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) not shown in the factorial design 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.

Table 1 presents current characteristics of the soil and effluent at the 11 test sites. Figure 1 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.

In 1977 the researchers added a test site with soil exhibiting high corrosion potential to the field program. Soil at the site selected has an electrical resistivity value of 2017 ohm-cm. and a pH value of 4.3. A soil with these properties rarely occurs in Louisiana. However, the investigators consider that such an environment will add depth to the study and may aid in development of a rapid laboratory test to evaluate durability of drainage pipe.

Materials Tested

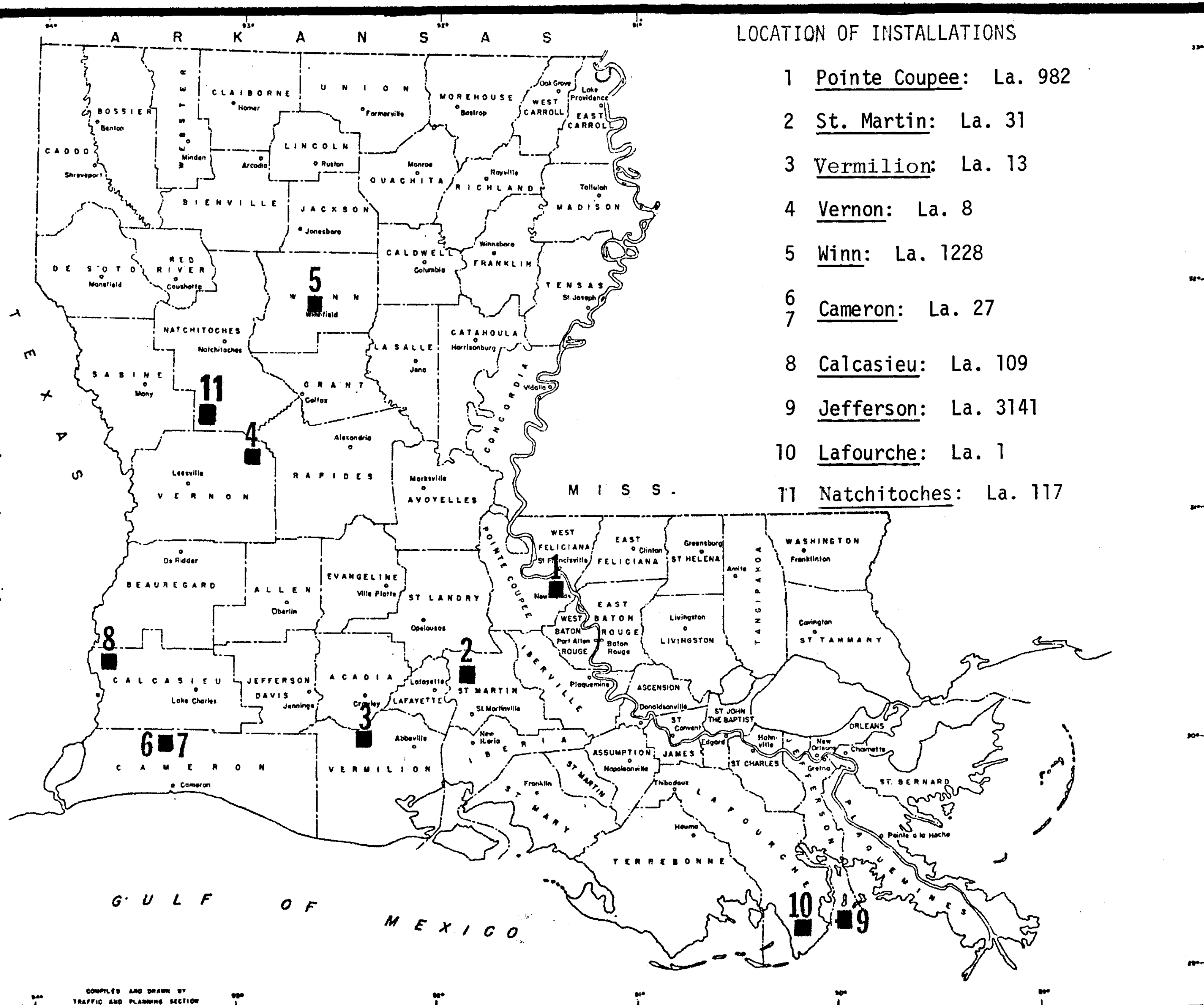
Eleven varieties of coated and uncoated galvanized steel and aluminum culvert were selected for evaluation. All sections of the corrugated

TABLE 1

SOIL AND EFFLUENT CHARACTERISTICS AT TEST SITES

Location Number	Soil			Effluent	
	Type	Electrical Resistivity, ohm-cm.	pH	Electrical Resistivity, ohm-cm.	pH
1	Clay	1,404	6.4	8,000	6.5
2	Silty Clay	1,208	7.6	3,400	7.1
3	Silty Clay	1,667	6.8	5,400	6.9
4	Silty Sand	12,750	5.9	20,000*	5.8*
5	Sand	5,050	7.3	28,000*	6.5*
6	Sandy Clay	275	8.4	300	7.3
7	Sandy Silt	208	8.3	200	7.3
8	Silty Clay	4,250	5.4	16,000	6.6
9	Sand	1,300	8.4	300	7.3
10	Silty Clay	150	8.3	200	7.1
11	Sandy Loam	2,017	4.3	4,400*	7.4*

*Water sample not available at this time.
Test results shown represent the 1976 sampling.



Location of Test Sites
FIGURE 1

culvert were 4 feet (1.2 m.) long and 18 inches (46 cm.) in diameter, with the exception of the aluminum plate arch, which is approximately 4.5 feet square (1.4 m. sq.). Six of these types of pipes are commonly known and are listed below:

1. Uncoated, 16-gauge (0.15 cm.) galvanized steel (AASHTO M36).
2. Asphalt-coated, 16-gauge (0.15 cm.) galvanized steel (AASHTO M190).
3. Asbestos-bonded, asphalt-coated, 14-gauge (0.19 cm.) galvanized steel (La. DOTD <u>Standard Specifications for Roads and Bridges</u>, Subsection 1007.03)
4. Uncoated, 16-gauge (0.15 cm.) aluminum pipe (AASHTO M196).
5. Asphalt-coated, 16-gauge (0.15 cm.) aluminum pipe (AASHTO M190, Type A).
6. Structural plate arch (AASHTO M196).

The remaining five types of pipes (new products) selected for evaluation are as follows:

1. Sixteen-gauge (0.15 cm.) galvanized steel with a 12-mil (0.31 mm.), U.S. Steel Nexon, coal-tar-based laminate applied to interior or exterior with a 0.3 mil (0.008 mm.), modified epoxy coating on the reverse side (AASHTO M246).
2. Sixteen-gauge (0.15 cm.) galvanized steel with a 20-mil, (0.51 mm.) U.S. Steel Nexon, coal-tar-based laminate applied to interior or exterior with a 0.3 mil (0.008 mm.), modified epoxy coating on the reverse side (AASHTO M246).
3. Sixteen-gauge galvanized steel with a 10-mil (0.25 mm.) interior and 3-mil (0.08 mm.) exterior, Inland Steel, polyethylene coating.
4. Sixteen-gauge (0.15 cm.) galvanized steel with a 12-mil (0.31 mm.) interior and 5-mil (0.13 mm.) exterior, Inland Steel, polyethylene coating.

5. Sixteen-gauge (0.15 cm.) galvanized steel pipe with 10-mil (0.25 mm.) interior and 3-mil (0.08 mm.) exterior, Wheeling Steel, polymeric coating (AASHTO M246).

Field Installation

During the month of August, 1973, research personnel, with the assistance of district maintenance forces, successfully installed 20 sections of culvert in each of the 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 incurred 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.

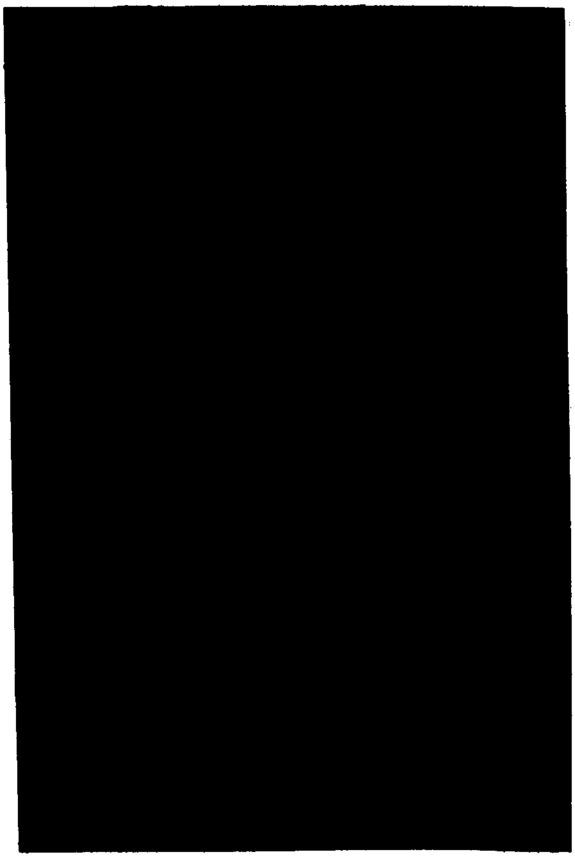
A "Grade-All" was used to remove all grass and debris from the ditches for approximately 200 feet (61 m.) to facilitate the installation. Next, the top two feet (0.6 m.) of in-place soil was removed and the pipes were lowered into the ditch by hand and spaced approximately six feet apart. The removed soil was then used to cover the individual pipe sections to provide a minimum cover of one foot (0.3 m.). A similar installation procedure was used at the two water sites.

At these two water locations the drainage pipes were installed along the side of drainage canals which parallel state highways running through the coastal marshes. The pipe sections were installed perpendicular to the roadway, half being covered with soil and half extending out into the brackish water. Two typical field installations can be observed in Figures 2 and 3. Soil and water samples were obtained at the time of installation and are now being taken annually to detect any changes in the potential corrosiveness at the test sites.

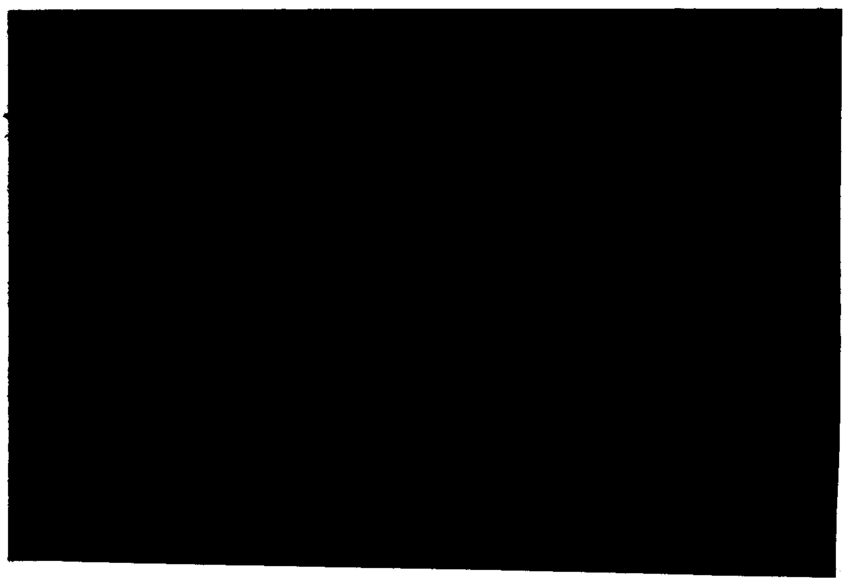
Using the above-described installation procedures, in 1975 research and maintenance personnel installed an eleventh type of test pipe at the ten test sites, one pair per site. And in 1977 the series of test culverts was installed at an eleventh test site with a highly acidic soil (Table 1). The test culverts at site number 11 have not been inspected subsequently and hence will not be discussed.

Field Inspection

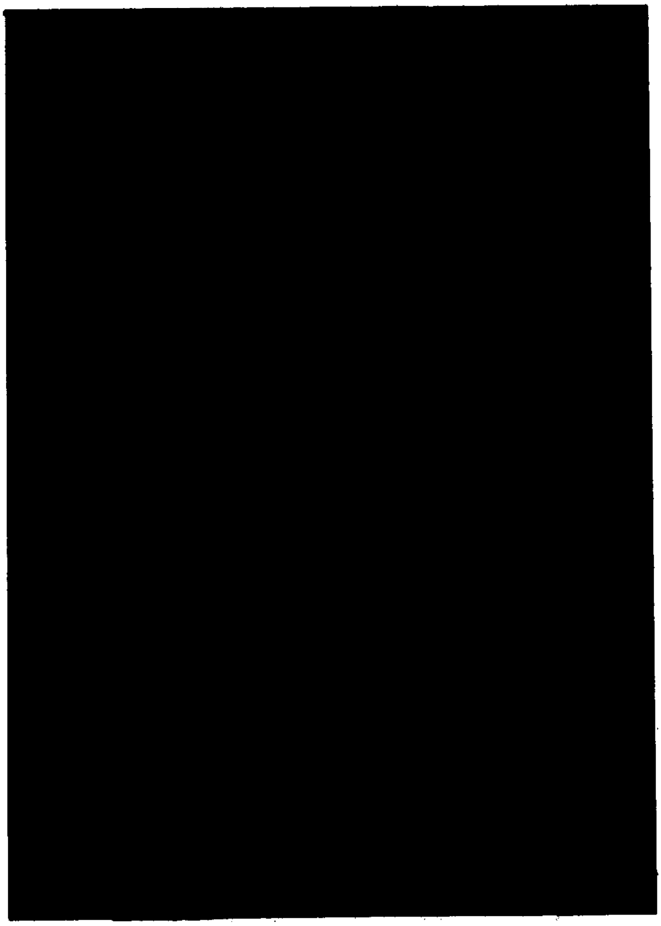
During the months of September and October, 1977, the second field inspection was conducted, representing four years of exposure. One of each type of pipe was removed for inspection, using a "Grade-All" and a padded, two-inch (5 cm.) pipe with a chain running through the center. After being hooked by chain to the "Grade-All" bucket, test culverts were slowly lifted and removed. The apparatus, illustrated in Figure 4, helped insure a relatively nondestructive removal by providing uniform support along the length of each culvert. Upon removal, the four-foot (1.2 m.) sections were washed clean, removing as much of the soil as possible without contributing to the removal of the coatings as shown in Figure 5. As was mentioned in Interim Report No. 1, the asphalt-coated galvanized steel and asphalt-coated aluminum sections were the only two types of culvert noticeably affected by the removal process and to a lesser extent by the washing



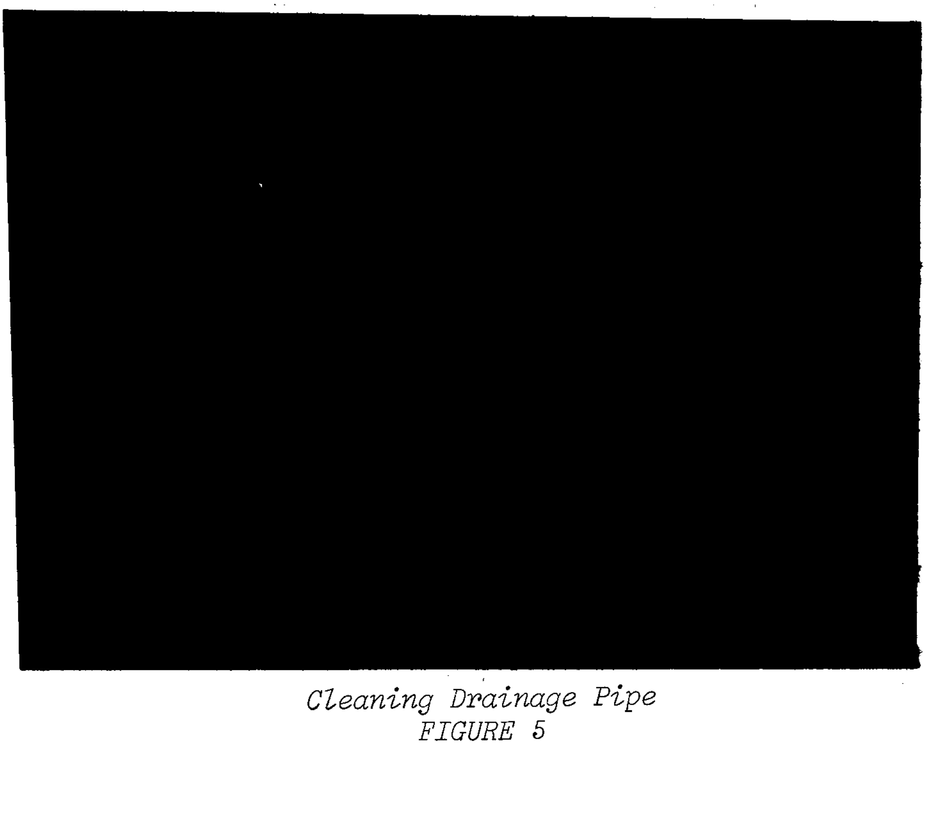
Typical Ditch Installation
(Location No. 3)
FIGURE 2



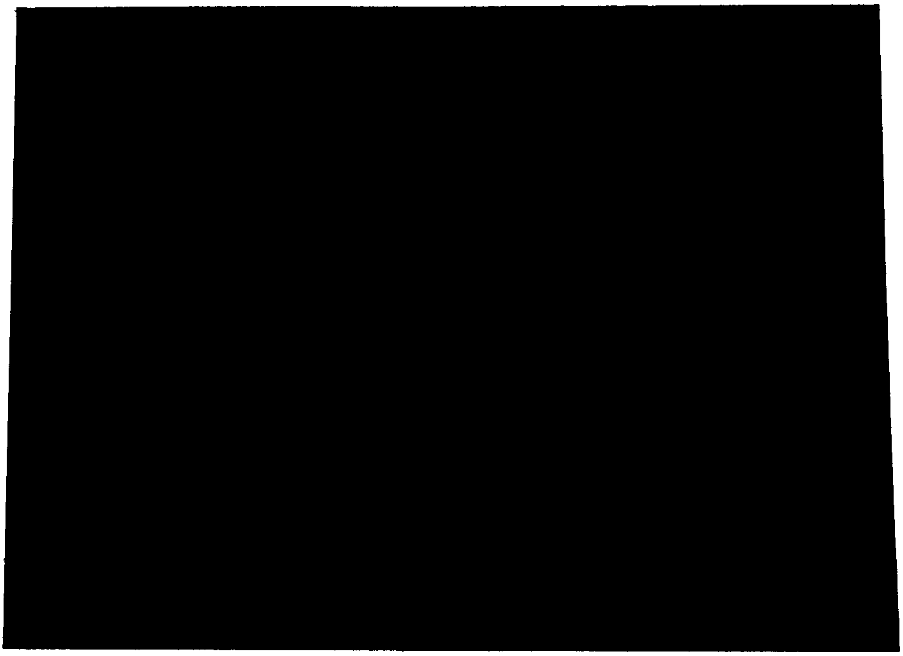
Typical Canal Installation
(Location No. 10)
FIGURE 3



Drainage Pipe Removal
FIGURE 4



Cleaning Drainage Pipe
FIGURE 5



Cutting Sample for Laboratory Testing
FIGURE 6

process. Some of the asphalt remained in the soil, thus indicating more loss of bond over the four-year period. Even if these pipes had not been disturbed, it is questionable whether or not the coatings could have prevented seepage of water onto the metal surfaces. The answer to this question may be resolved in the final inspection when the pipe samples left undisturbed for ten years are removed and evaluated.

After the pipes were cleaned, photographs were taken at several different angles to document the condition of each. Next, a panel consisting of two highway engineers and three highway engineering technicians visually rated the pipes using the evaluation form included in the Appexdix. 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 pipes were then sampled for laboratory analysis. The sampling shown in Figure 6 consisted of cutting a three-inch (8 cm.) band off the end of each section removed. To provide protection between yearly evaluations, a film of asphalt was brushed on the metal edges exposed during the cutting process. Upon completion of the field evaluation the pipes were returned to the ditch, oriented in their original positions, and covered with in-place soil.

Laboratory Analyses of Soil, Water, and Unexposed Culverts

Soil and water samples were initially collected from each installation site on a semi-annual basis. The investigators have changed to sampling annually, since the results from the semi-annual samples show 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 identified 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. Thickness and composition data are presented in the appendix 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 evaluations 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 the appendix. These results represent a starting point in attempting to correlate accelerated laboratory corrosion with field corrosion of culverts.

Laboratory Analyses of Field-Exposed Samples of Culvert

As related previously, the researchers sawed a circumferential sample 3 inches (8 cm.) wide from a given end of each culvert inspected in the field.

The culvert samples were brought to the Materials Laboratory and cut into short segments for easier handling. The samples were washed with soap and warm water in order to further remove soil.

The asphalt-coated samples were stripped of their coating by soaking in a bath of chlorothane. After this coating was removed, the samples were again washed with soap and warm water.

The aluminum culvert samples were cleaned of corrosion deposits in accordance with Section 5.2 of ASTM Designation G1. This cleaning enabled better examination of the depth of pitting and thickness loss.

Aluminum

The field samples of aluminum culvert were examined under a microscope for pitting and general thickness loss. The greatest depth of corrosion in each square inch of culvert sample was measured and recorded.

These maximum-depth-of-corrosion values were categorized into one of the following ranges:

0.0 - 0.2 mm
0.2 - 0.5 mm
0.5 - 0.8 mm
0.8 - 1.1 mm

The percentage of square-inch units of sample area associated with each maximum-depth category was multiplied by the average depth for the category. Summation of the products for the four categories yielded an average maximum thickness loss, in millimeters, for the sample.

Average maximum thickness loss was compared with original sample thickness in the following equation to provide a numerical rating from 0 to 5 for the aluminum culvert:

$$R_{Al} = 5 \left[\frac{T_{L1} + T_{L2}}{T_O} \right]$$

where,

R_{Al} = Rating for one wall of aluminum culvert sample

T_{L1} = Average maximum thickness loss of interior wall, millimeters

T_{L2} = Average maximum thickness loss of exterior wall, millimeters

T_O = Original thickness, millimeters (interior plus exterior walls)

This scheme of rating the aluminum culvert samples translates into the following scale:

Average Maximum Thickness Loss Per Square Inch (Expressed as Percentage of Original Wall Thickness)	Rating	
Negligible	0	Excellent
20%	1	Good
40%	2	Fair
60%	3	Poor
80%	4	Very Poor
100%	5	

This rating was applied to both the interior and the exterior wall of the culvert samples. An average of the ratings of both walls is reported as a final value. The scale of rating was developed to relate to the field panel ratings of 1 to 5 characterizing entire aluminum test culverts.

A problem in the measurement of thickness loss may develop if there are no areas of original surface to use as a reference point for measuring depth of corrosion. Measurements will also become more difficult if the corrosion for each given, localized area becomes less uniform.

Steel

The field samples of steel pipe culvert were examined to determine the percent of rusted surface area. The percentage values were used in the following equation to provide a rating of 0 to 5 for the steel culvert samples:

$$R_S = \frac{A_R}{20\%}$$

where,

R_S = Rating of field sample of steel culvert

A_R = Percent of square-inch sections of surface containing rust

This scheme of rating the steel pipe culvert samples translates into the following scale:

Percentage of Surface Area Containing Rust	Rating	
Negligible	0	Excellent
20%	1	Good
40%	2	Fair
60%	3	Poor
80%	4	Very Poor
100%	5	

This rating was given to both the interior and exterior walls of the culvert samples. An average of the ratings of both walls is reported as a final value. The scale of rating was developed to relate to the field panel ratings of 1 to 5 characterizing entire steel test pipes.

Coatings

The coatings, as field-exposed for two to four years, were examined to determine the percentage of surface area experiencing removal, blistering, and separation from the pipes (delamination). These percentages were used in the following equation to provide a rating of 0 to 5 for the coatings:

$$R_C = \frac{A_C}{20\%}$$

where,

R_C = Rating of field-exposed coating

A_C = Percentage of surface area which experienced coating failure

This scheme of rating the coatings translates into the following scale:

Percentage of Surface Area Which Experienced Coating Failure	Rating	
Negligible	0	
		Excellent
20%	1	
		Good
40%	2	
		Fair
60%	3	
		Poor
80%	4	
		Very Poor
100%	5	

The ratings for the coatings represent one wall or an average for the interior and the exterior walls, depending on whether or not the coating had been applied to both sides of the culvert.

A summary note would appear to be in order concerning the different rating schemes used for the aluminum and steel culverts. A rating of 5 for the aluminum culverts would indicate that the average maximum thickness loss per square inch is 100% of the original wall thickness. A rating of 5 for the steel pipes would indicate that every square inch of surface area contains rust. Ratings for all the culverts reflect the average condition of the interior and exterior walls. Perforation originating from either wall would be equally harmful.

The aluminum culverts are composed of a structural aluminum alloy core covered on both sides by an aluminum alloy cladding. The cladding is designed to oxidize in a lateral fashion and form a protective covering for the core. Hence, depth of corrosion per unit area was selected as the rating index for the aluminum culverts. Percentage of square-inch units of area containing rust was selected as the index of corrosion resistance for the steel pipes.

DISCUSSION OF RESULTS

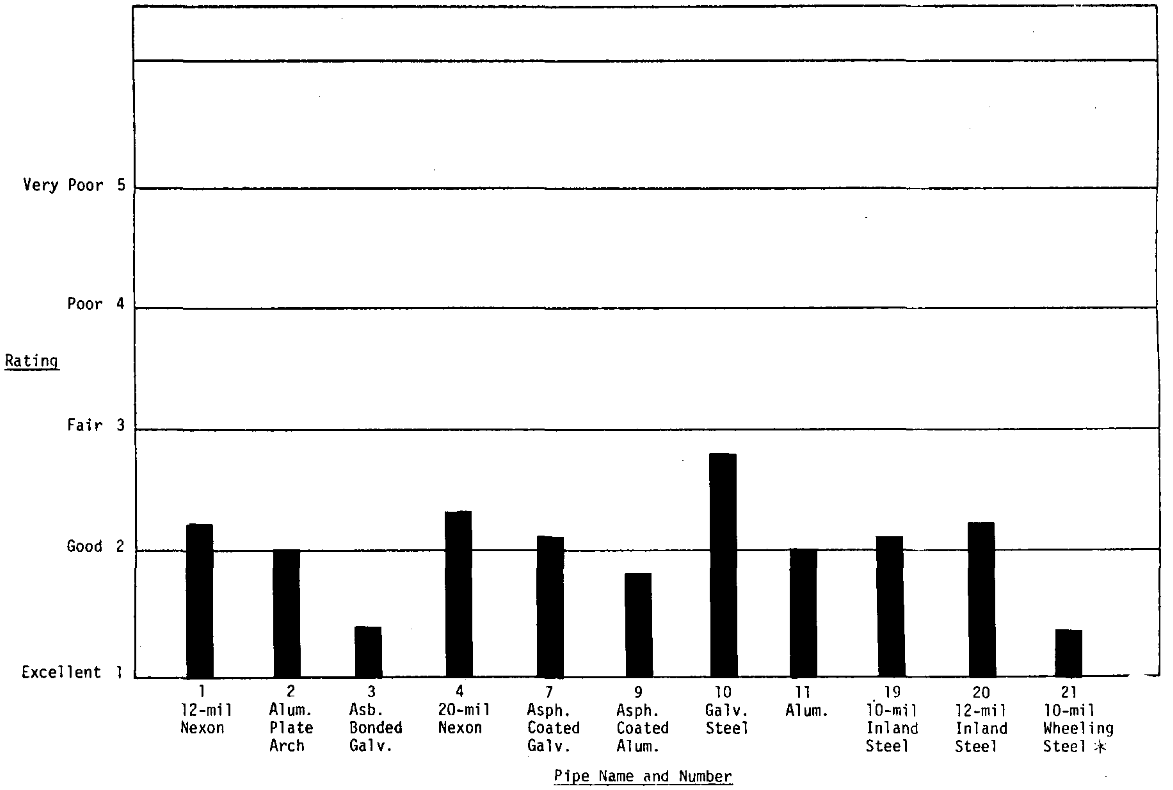
General Discussion

The culvert providing the best performance after four years of field exposure is the asbestos-bonded, asphalt-coated, galvanized steel pipe. The basis of field performance was the ability of the culverts to resist metallic corrosion. An index of corrosion resistance was assigned by a panel inspecting the entire culvert in the field and by an engineer examining a sample of the test culvert in the laboratory.

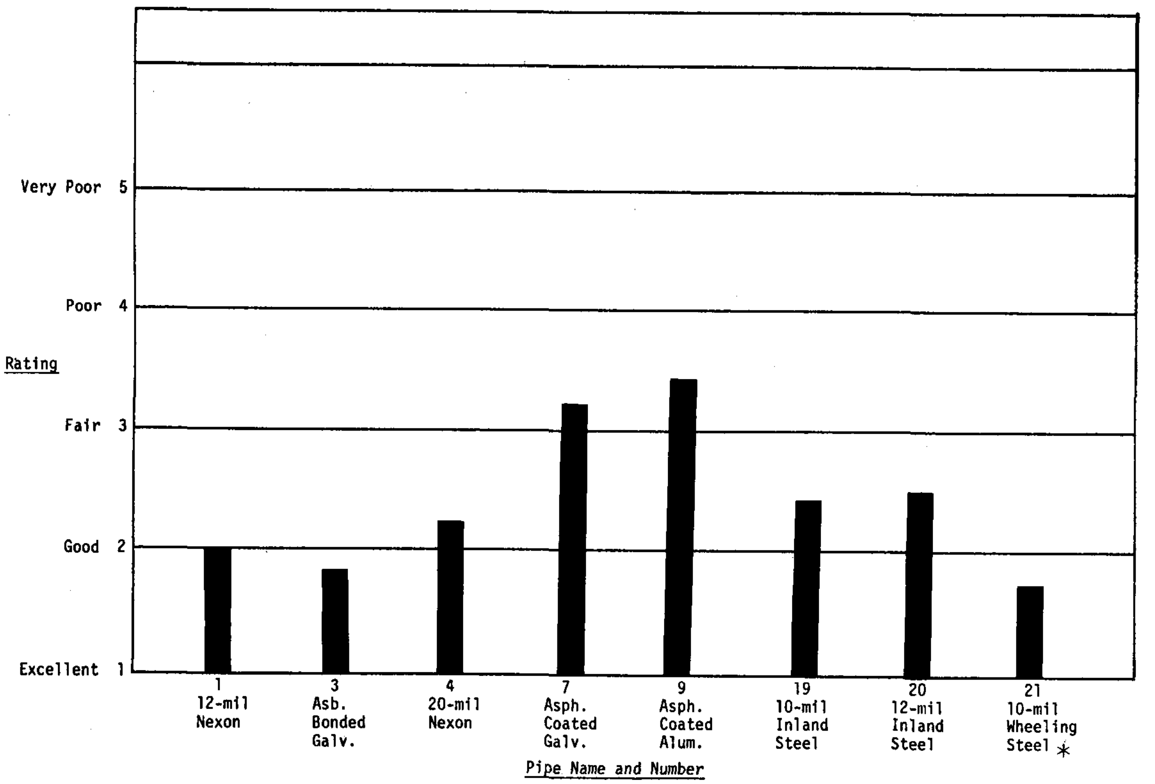
The field ratings of the test pipes and their individual coatings are summarized in Figures 7 & 8 respectively. The ratings are the collective opinions of a panel of five highway engineering employees who examined the culverts at the ten test locations and assigned a numerical rating ranging from one (excellent) to five (poor) to each culvert. Neither the two highway engineers nor the three engineering technicians comprising the panel are corrosion experts. However, the authors feel that the technical backgrounds of these individuals qualified them to identify signs of corrosion such as rust on steel and pitting on aluminum and to assign valid ratings to the test culverts.

The laboratory ratings are summarized in Figures 9 & 10. These ratings result from a chemical engineer examining each square-inch unit of area of samples from the test culverts in the laboratory and assigning a numerical rating ranging from zero (excellent) to five (poor) to each sample.

Field panel ratings of entire culverts and laboratory ratings of field samples complement each other. In several instances the field ratings reflect certain sections of test culverts exhibiting poor durability. The field samples did not include such failures and hence the laboratory ratings do not properly reveal the performance of the total test culvert. Examples of such failures are perforations of metal and

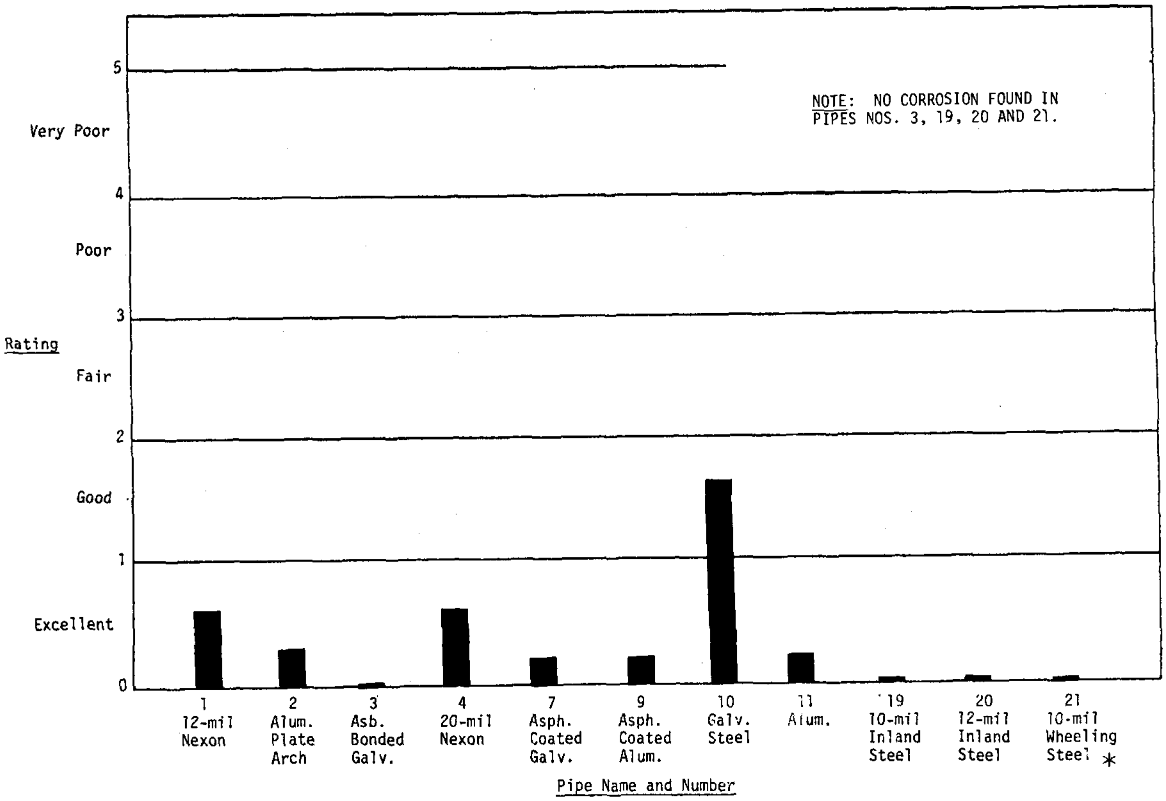


Average Panel Ratings of Pipes at Ten Sites
FIGURE 7

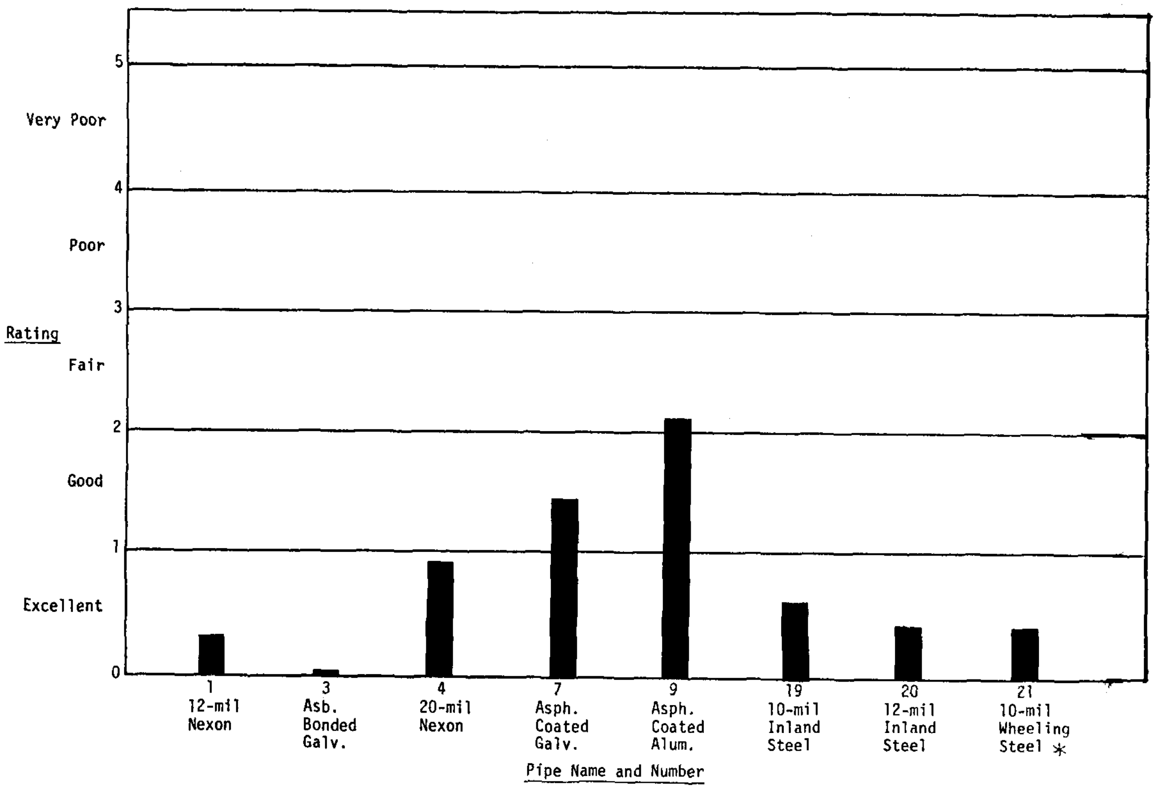


Average Panel Ratings of Coatings at Ten Sites
FIGURE 8

*2-YEAR RATINGS
FOR WHEELING STEEL CULVERTS
4-YEAR RATINGS FOR ALL OTHERS



Average Laboratory Ratings of Pipes at Ten Sites
FIGURE 9



Average Laboratory Ratings of Coatings at Ten Sites
FIGURE 10

*2 -YEAR RATINGS
FOR WHEELING STEEL CULVERTS
4-YEAR RATINGS FOR ALL OTHERS

blistering of coatings. By the same token, the laboratory engineer had the opportunity to examine the field samples under conditions much more controlled than in the field and with the aid of a microscope. Thus, the panel ratings and the laboratory engineer's ratings should be reviewed in combination.

The protective coatings applied to a number of the culverts experienced various types and degrees of failures. The asphalt coating applied directly to galvanized steel and aluminum culverts has cracked and separated from the metal significantly, leaving much of these culverts unprotected. The Inland Steel and U.S. Steel polymeric coatings exhibited separation from the steel, blistering and pitting, particularly at the lateral extremities of the four-foot long culverts.

The aluminum culverts displayed two types of deterioration. Pitting of the surface was noticed on samples from most test sites. The second type of deterioration was a uniform loss of thickness for a given local area of the culvert.

Pitting of the aluminum metal was primarily found in geographical areas where the culvert had been exposed to what appeared to be a growth of organisms. One reference (2) has related corrosion and resultant pitting of steel and iron to microorganisms. However, the authors are not aware of any source establishing a relationship between microorganisms and corrosion (with pitting) in aluminum. The researchers plan additional study of this possible relationship.

Corrosion attacks both interior and exterior walls of culverts placed in the environments of Louisiana. Corrosion of the interior walls of the test culverts was most extensive at the water line, where concentrations of oxygen, water, and salt could best cause the deterioration process. However, the exterior wall of samples from most sites had no such common area of corrosion concentration. The authors consider that the moisture in the soil surrounding the pipe reached somewhat of an equilibrium condition in four years and that the exterior walls are corroding in a uniform manner.

The culverts at sites 6, 7, 9, and 10 experienced the most corrosion. The uniquely dominant factor at these four sites is the low electrical resistivity of the effluent, each value being 300 ohm-cm. or less (Table 1, page 7). The effluents at these sites are neutral to slightly alkaline, reflecting the proximity of the salt water of the Gulf of Mexico.

A detailed review of panel and laboratory ratings for each type of test culvert follows this general discussion. Field and laboratory evaluation ratings compare reasonably well. The authors conclude that the panel assigned overly-harsh ratings to a number of culverts at site number 1, the first location visited for inspection.

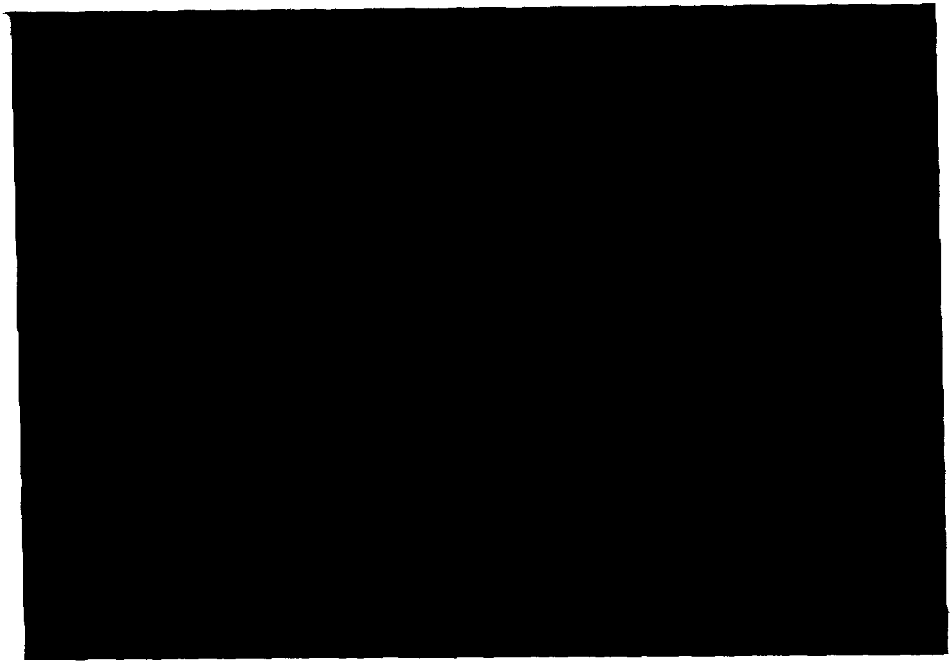
Evaluation of Individual Types of Culverts

Galvanized Steel

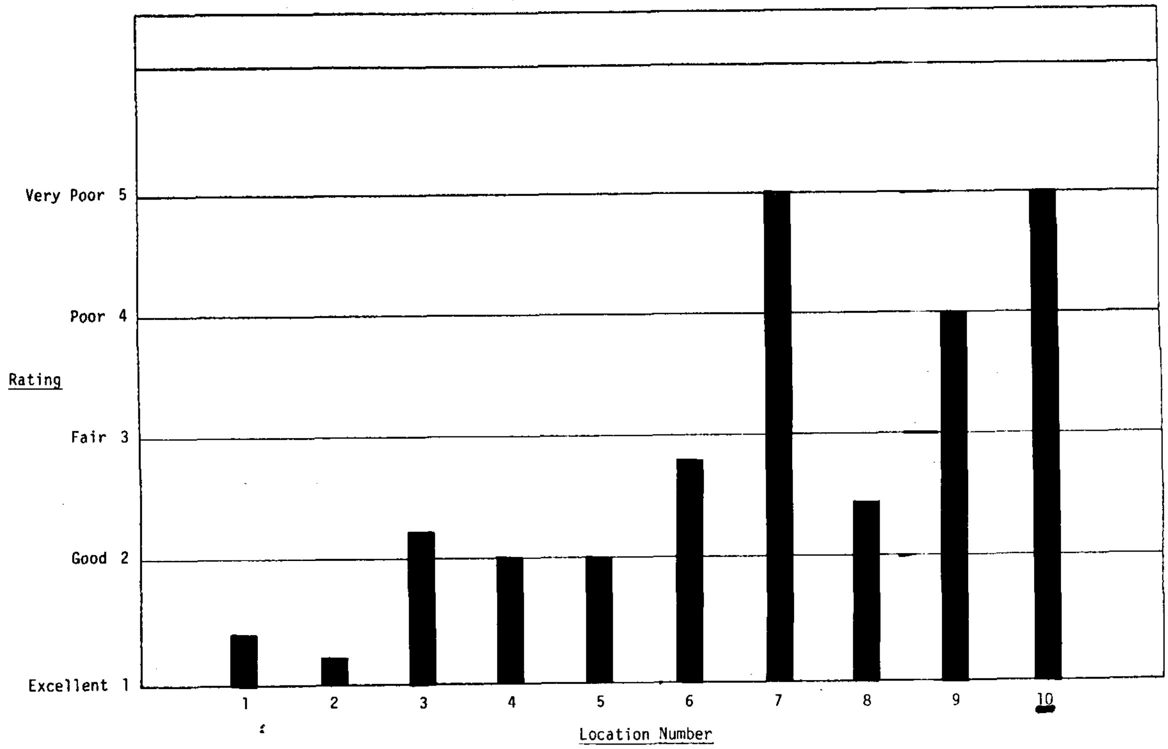
Figure 12 relates the panel's ratings of this type of pipe at each of the ten test sites. Figure 13 relates the laboratory ratings of the samples taken from the test culverts at the time of the panel rating.

At two of the test sites (number 1 and 2), the galvanized steel pipes are performing very satisfactorily. At sites 3, 4, 5, 6 and 8 the panel noted corrosion spots, rusty rivets, and minor pitting.

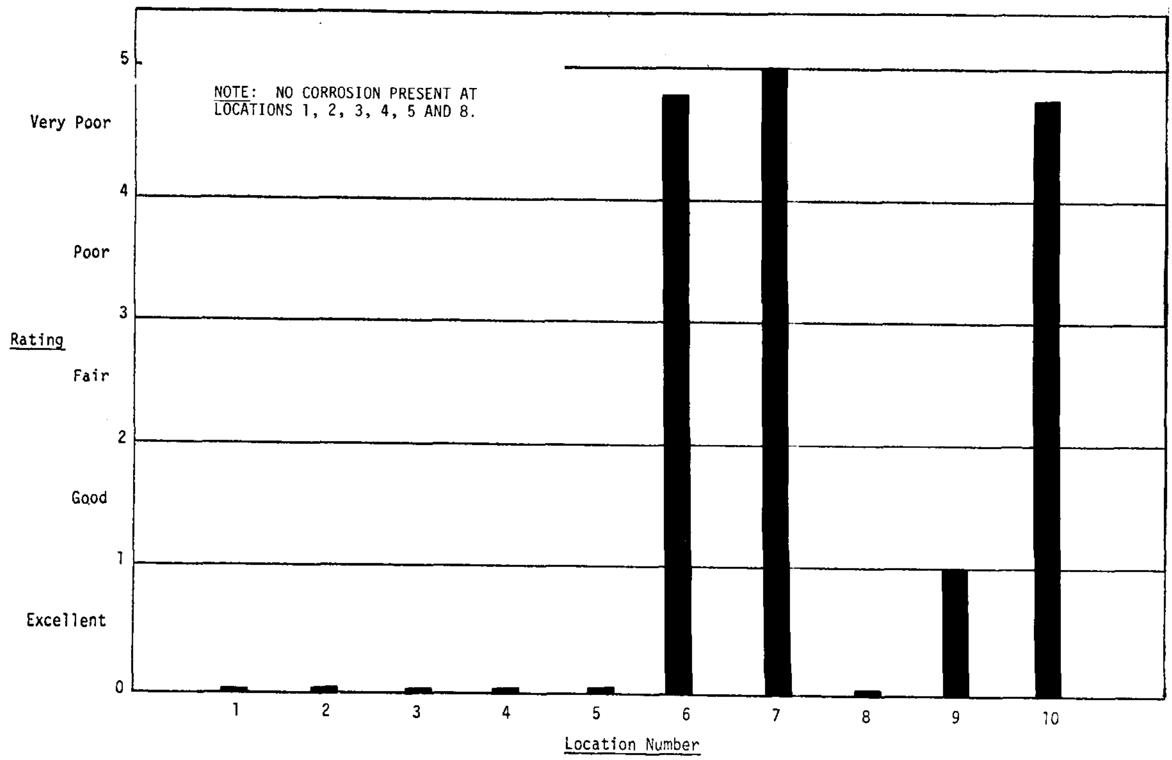
At sites 7, 9 and 10 the soil and effluent both exhibit low electrical resistivity values of less than 1300 ohm-cm. The galvanized steel pipe was completely rusted at these locations (see figure 11 for condition of test pipe at site number 7).



Photograph of Galvanized Steel Culvert at Site No. 7
after Four Years
FIGURE 11



Panel Ratings of Galvanized Steel Culverts
FIGURE 12



Laboratory Ratings of Samples from Galvanized Steel Test Culverts
FIGURE 13

U. S. Steel Nexon Precoated Culvert Stock (Nominal 12-mil or 0.3-mm. Coating)

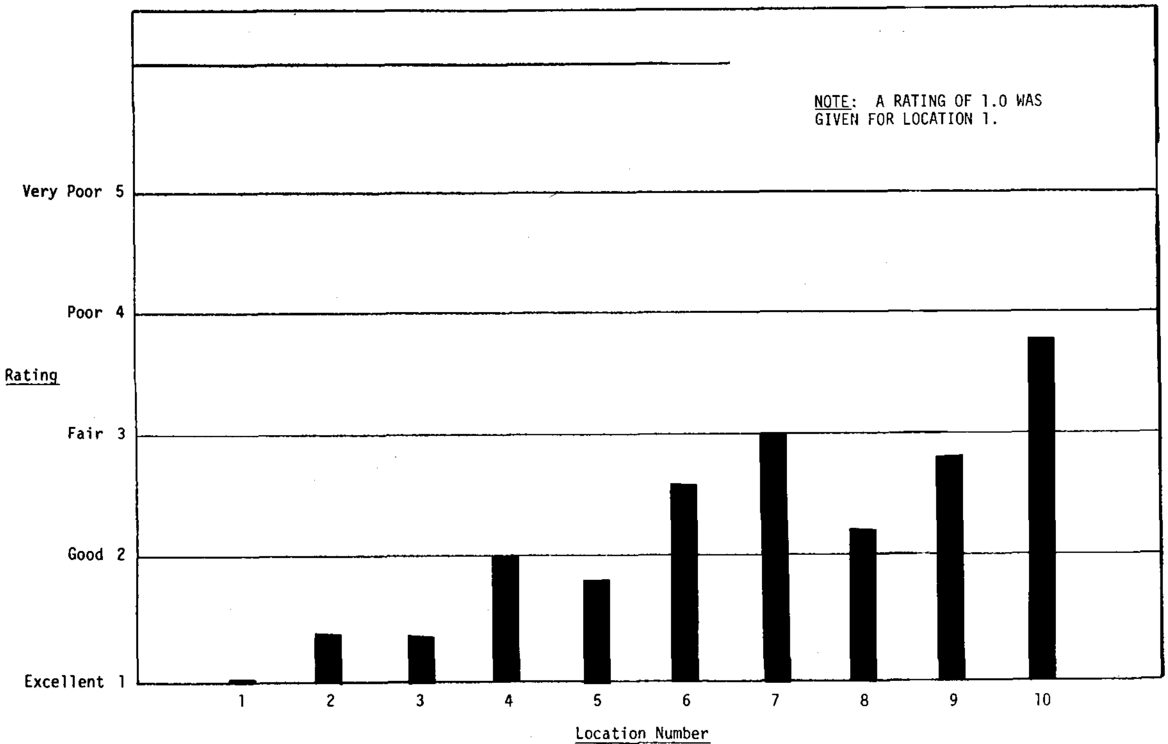
This galvanized steel pipe can be ordered from the fabricator with the thermoplastic, coal-tar-based laminate on either the inside or the outside. A 0.3 mil (0.008 mm.) organic coating is also applied to the reverse side. All of the U. S. Steel Nexon test pipes originally had the 12-mil coating on the interior except those placed at site number 6.

Figure 14 relates the panel's evaluation of this pipe at each of the test sites. Figure 15 presents the laboratory ratings of the samples obtained from these test pipes at the time of the panel rating.

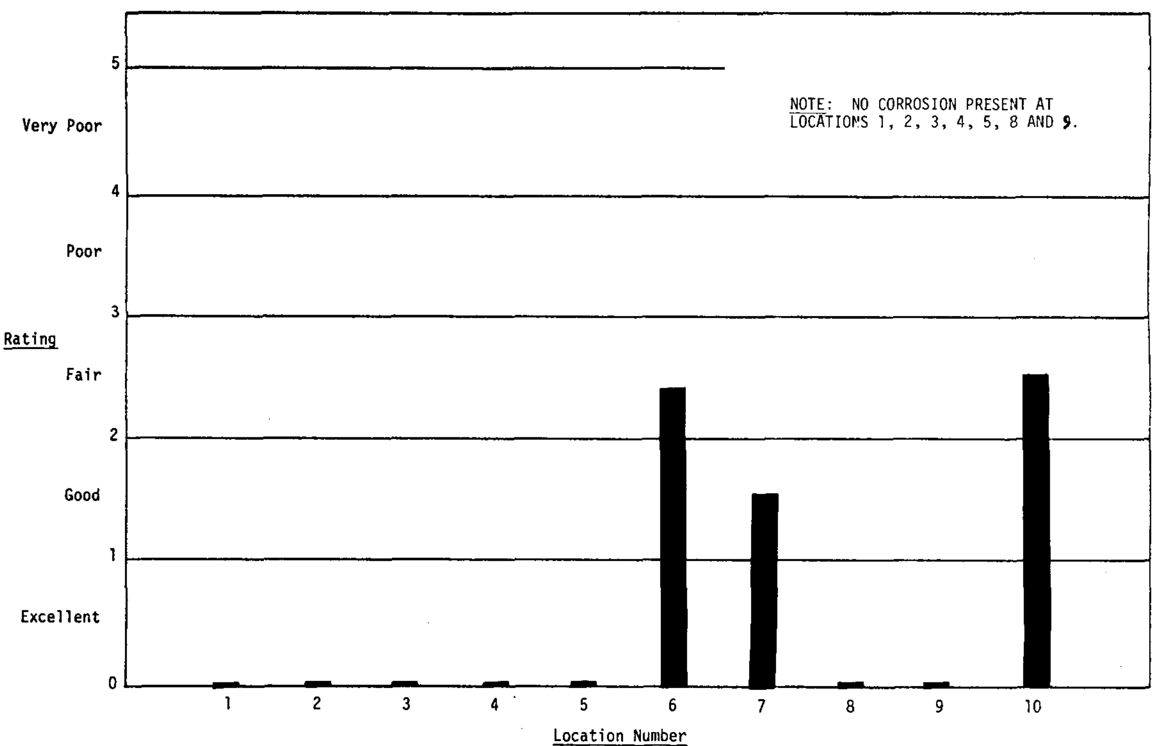
At sites 1, 2, and 3 the field ratings were very favorable for these U. S. Steel Nexon precoated culverts. The test pipes at sites, 4, 5, 6, and 8, showed minor pitting and rust on the inside, plus some corrosion of the rivets. The test culvert at site number 5 also showed some separation of the inside coating.

At site 7 the pipe lies in brackish water with a low electrical resistivity of 200 ohm-cm. The metal comprising the pipe is corroding. The 12-mil protective coating is pitted, separated and partially removed.

At site number 9 the raters noted some corrosion along with thickness loss. The effluent at this location has an electrical resistivity of 300 ohm-cm.



Panel Ratings of U. S. Steel Nexon Precoated Culverts (12-mil Coating)
FIGURE 14



Laboratory Ratings of Samples from U. S. Steel Nexon Test Culverts (12-mil Coating)
FIGURE 15

At site number 10 the pipe lies in brackish water with a low electrical resistivity of 200 ohm-cm. The outside coating is partially removed, the inside protective coating is separating from the pipe, and the metal is corroding.

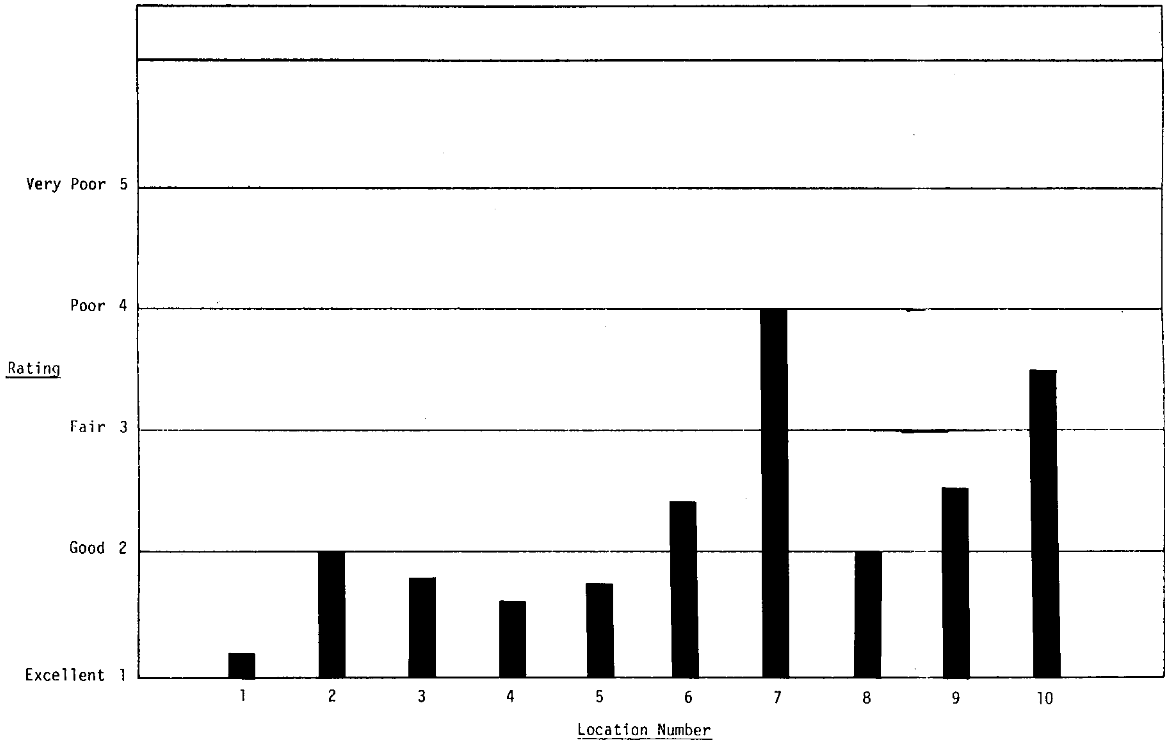
U. S. Steel Nexon Precoated Culvert Stock (Nominal 20-mil or 0.5-mm. Coating)

The thermoplastic, coal-tar-based laminate can be ordered on the interior or on the exterior of this galvanized steel pipe. A 0.3-mil, (0.008-mm.) organic coating is applied to the reverse side. All of the U. S. Steel test pipes originally had the 20-mil coating on the inside except the ones at site number 6.

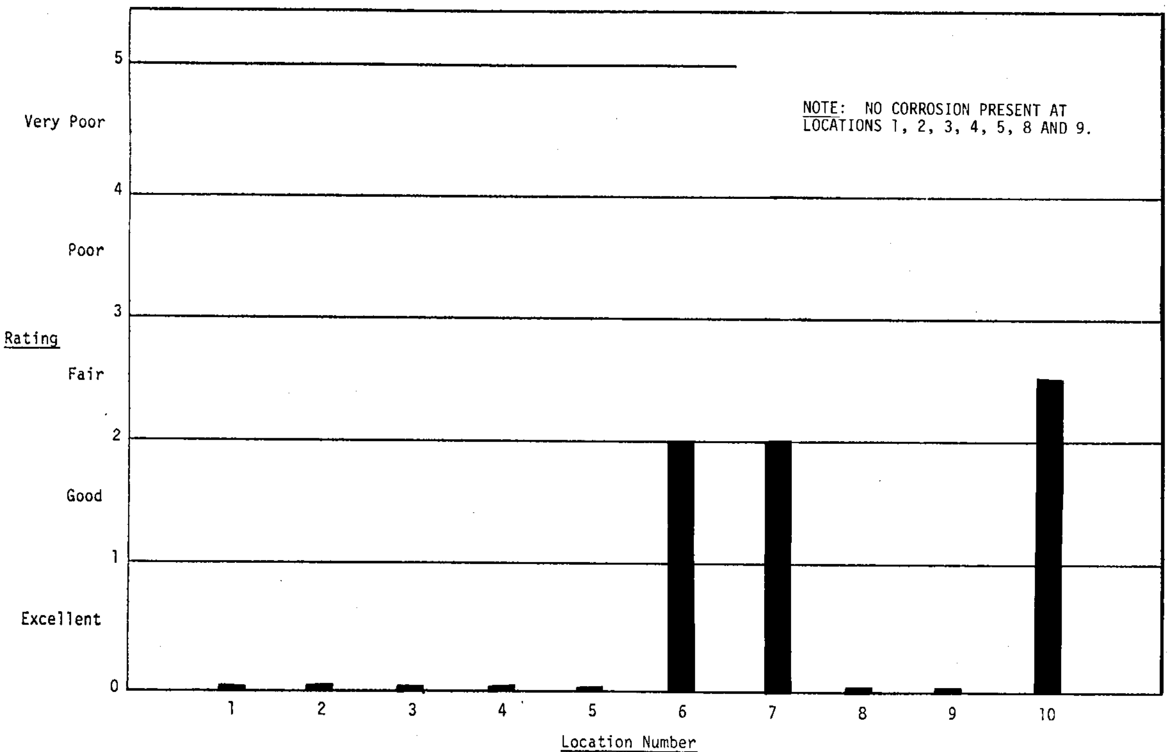
Figure 16 relates the panel ratings of this test pipe at each location. Figure 17 presents the laboratory ratings of the samples obtained from these test pipes at the time of the panel ratings.

At sites 1, 4, 8, and 9 the rivets were corroding. At sites 2, 3, 5, 7, 8, 9, and 10 the panel observed separation of the inside coating from the pipe. At sites 4, 5, 7, and 8 there are signs of pitting on the inside and outside of the pipe.

At site number 6 (20-mils outside coating) corrosion was noted on the inside thin coating. At site number 7 it was noted that the pipe was rusting and perforated at one edge. At site number 10 the pipe's outside coating is practically all removed.



Panel Ratings of U. S. Steel Nexon Precoated Culverts (20-mil Coating)
FIGURE 16



Laboratory Ratings of Samples from U. S. Steel Nexon Test Culverts (20-mil Coating)
FIGURE 17

Inland Steel Precoated Culvert Stock (Nominal 10-mil or 0.2-mm. Inside Coating/3-mil or 0.08-mm. Outside Coating)

Figure 18 relates the panel ratings and Figure 19 presents the laboratory ratings of the resistance to corrosion exhibited by this pipe after four years in the field.

The panel noted that rivets exposed on the exterior of this pipe are corroding at all sites except number 5. The panel was also concerned about the durability of the coating in environments where both soil and effluent have low electrical resistivity values. Typical deterioration at these sites included blistering, pitting, and separation of both inside and outside coatings.

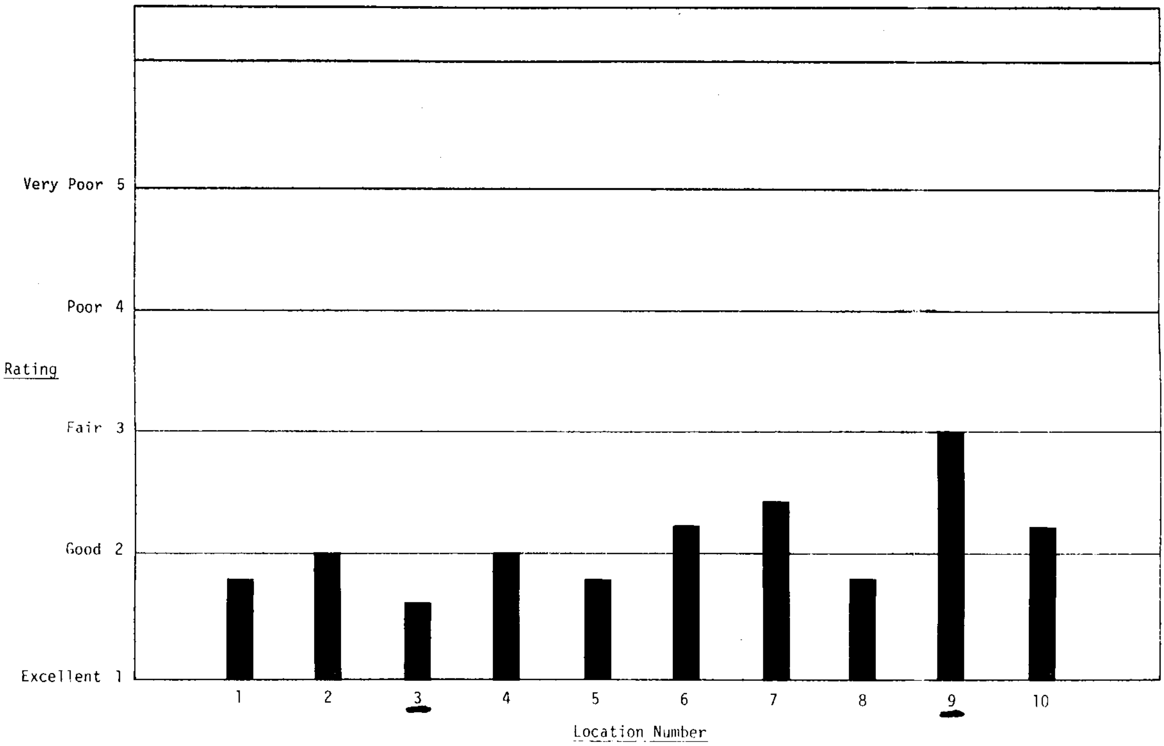
Inland Steel Precoated Culvert Stock (Nominal 12-mil or 0.3-mm. Inside Coating/5-mil or 0.1-mm. Outside Coating)

Figure 20 relates the panel ratings and Figure 21 presents the laboratory ratings of the resistance to corrosion exhibited by this pipe after four years in the field.

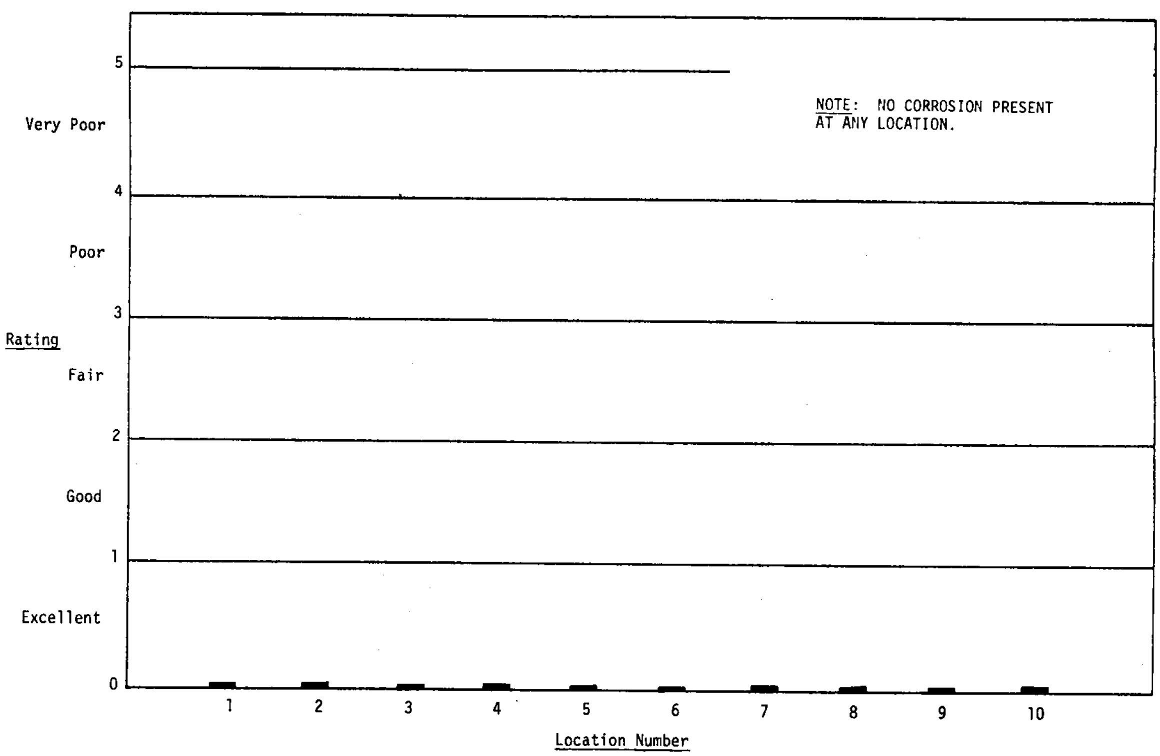
At all sites except number 5 the rivets exposed on the exterior are corroding, and at six of the ten sites the pipe seams are rusty.

At site number 6 the soil and effluent have low electrical resistivity values of 275 and 300 ohm-cm., respectively. Complete perforation of the pipe was noted at this site.

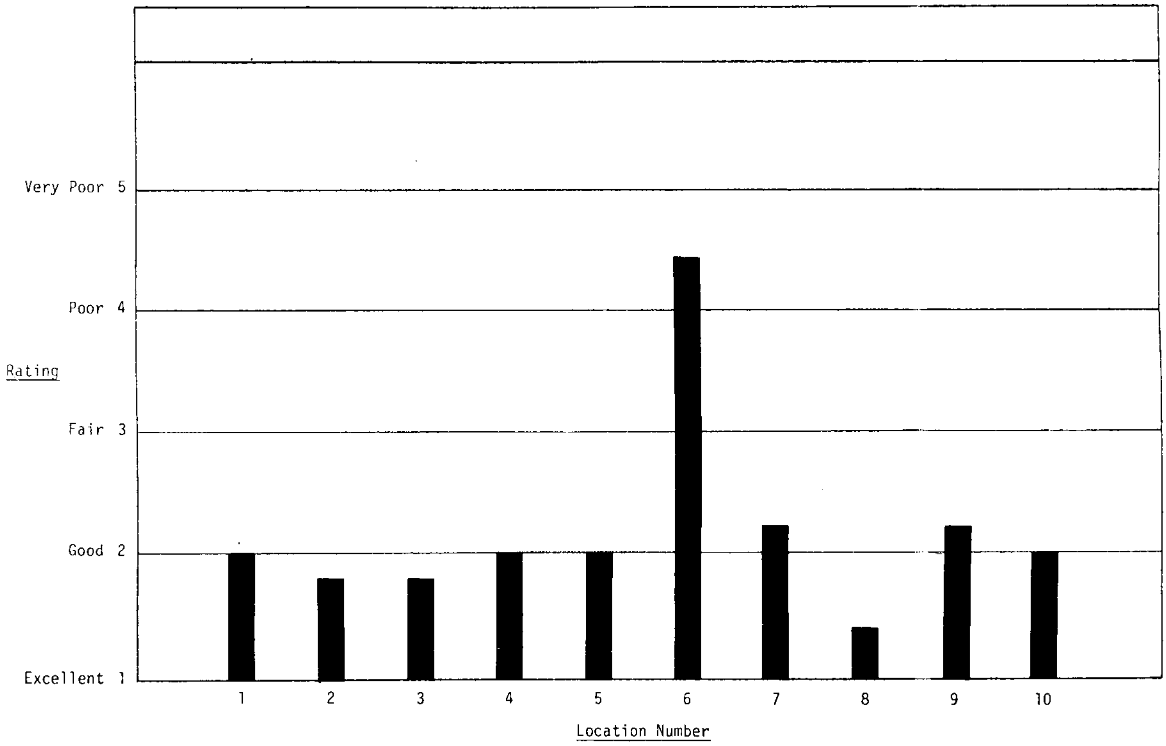
The typical deterioration at sites 6, 7, 9, and 10 (salt-water environments) included pitting, blistering and separation of both the inside and outside coatings.



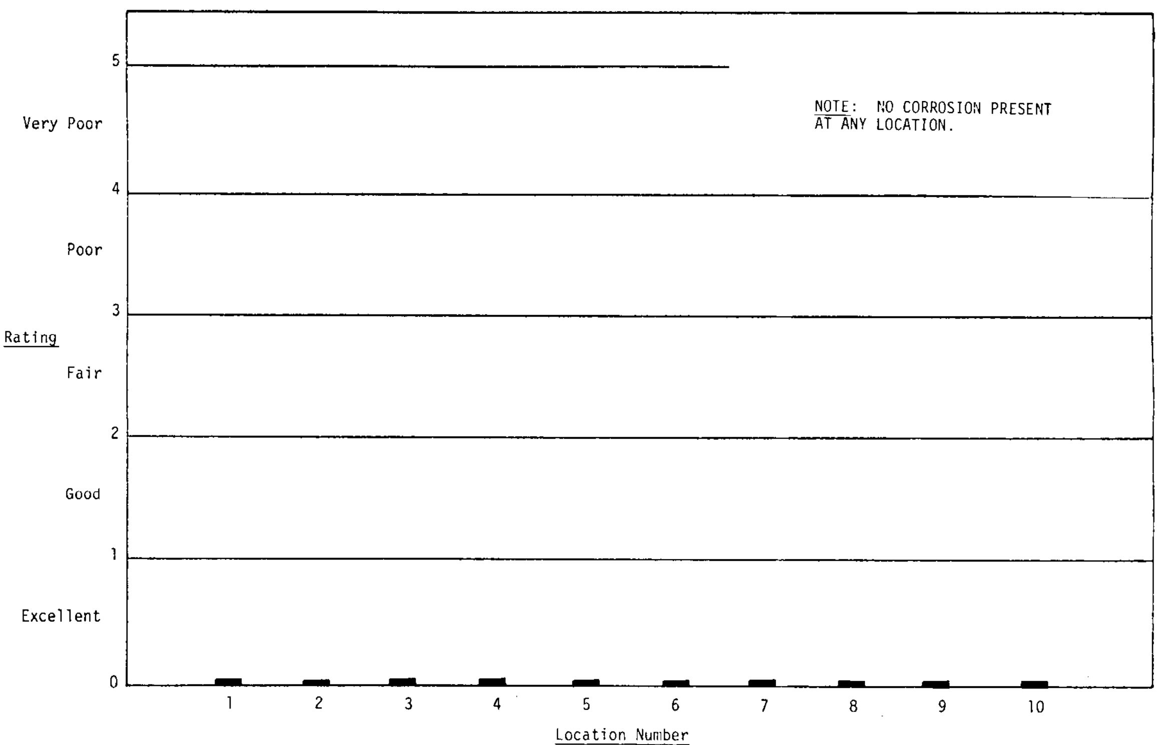
Panel Ratings of Inland Steel Polyethylene-Coated Culverts (10-mil / 3-mil Coatings)
FIGURE 18



Laboratory Ratings of Samples from Inland Steel Test Culverts (10-mil / 3-mil Coatings)
FIGURE 19



Panel Ratings of Inland Steel Polyethylene-Coated Culverts (12-mil / 5-mil Coatings)
FIGURE 20



Laboratory Ratings of Samples from Inland Steel Test Culverts (12-mil / 5-mil Coatings)
FIGURE 21

Wheeling Steel Precoated Culvert Stock (Nominal 10-mil or 0.25-mm. Inside Coating/3-mil or 0.08-mm. Outside Coating)

This type of test pipe is resisting corrosion very well after only two years in the variety of environments. The pipe's performance can best be described in Figures 22 and 23.

At sites 6, 7, 9, and 10 the soil and effluent have low electrical resistivity values. Typical deterioration at these sites included blistering and separation of inside and outside coatings.

Asbestos-Bonded Asphalt-Coated Galvanized Steel Pipe

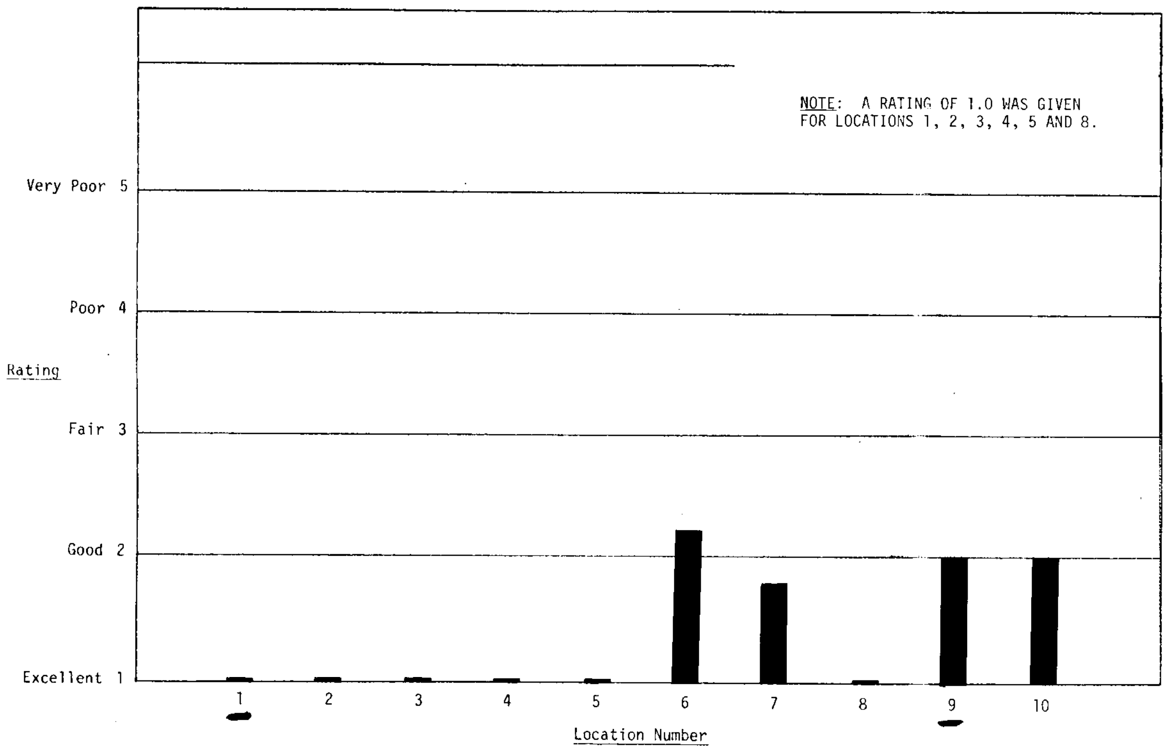
Figures 24 and 25 relate that this type of test pipe is consistently performing very well in regard to corrosion resistance after four years in the field.

At site number 10 the panel noted minor asphalt removal and edge corrosion. However, at 200 mils (5.1-mm.), this is the thickest coating under evaluation (Table 4 in appendix), and it is doing an excellent job of protecting the galvanized steel from corrosion.

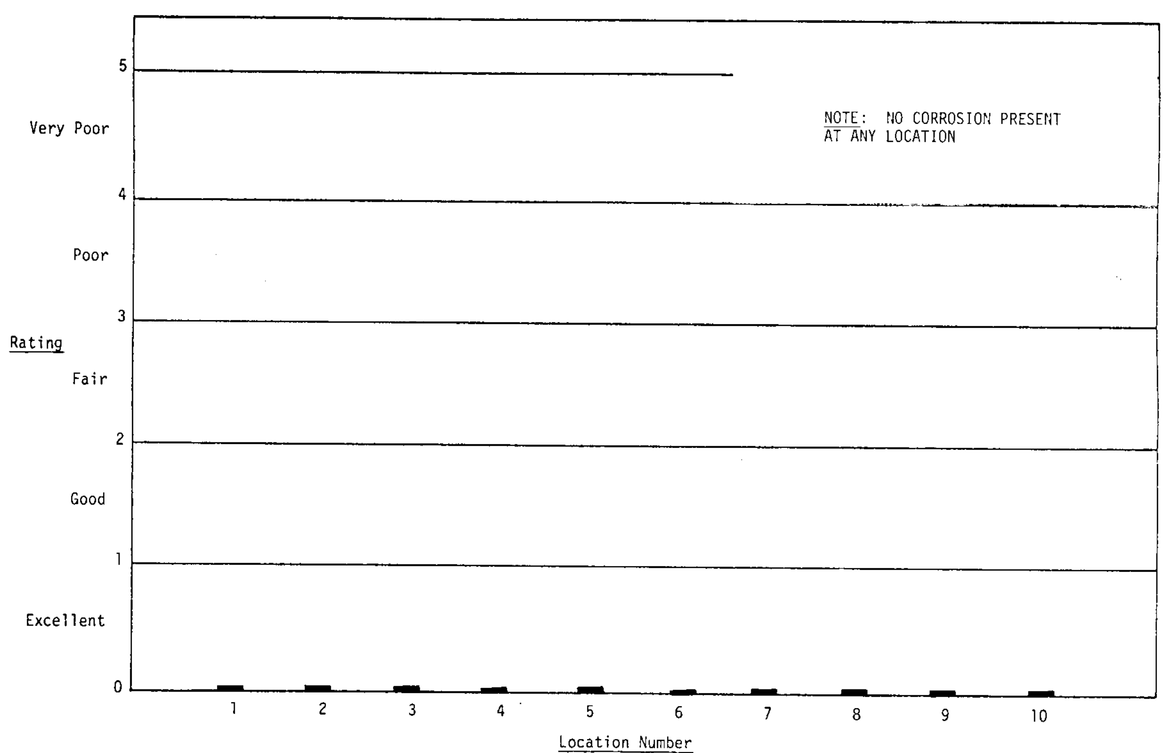
Asphalt-Coated Galvanized Steel Pipe

Figures 26 and 27 relate that after four years of field exposure, this type of pipe has resisted corrosion very well at most sites. However, the panel did note some corrosion at sites 7, 9, and 10.

At sites 7 and 10 the panel reported a heavy removal of coating, as well as rust and perforations. At site number 9 the test pipe had minor removal of coating, with very little rust at uncoated spots.

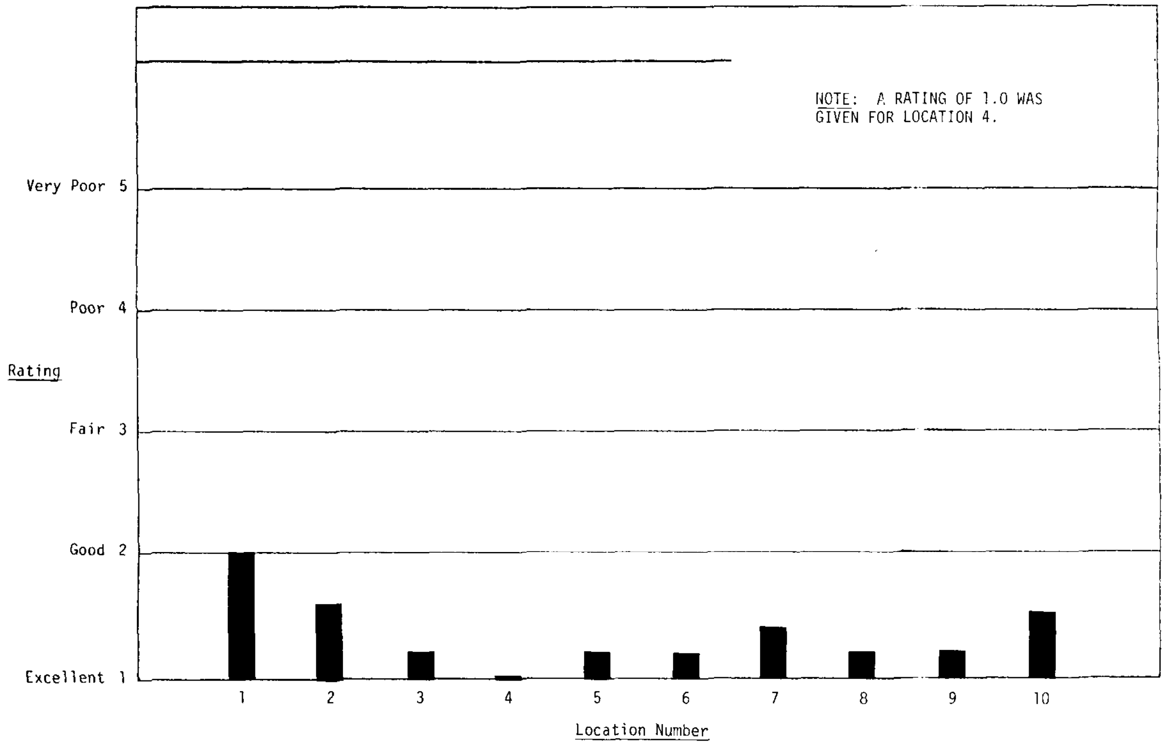


*Panel Ratings of Wheeling Steel Precoated Culverts (10-mil / 3-mil Coatings)**
FIGURE 22

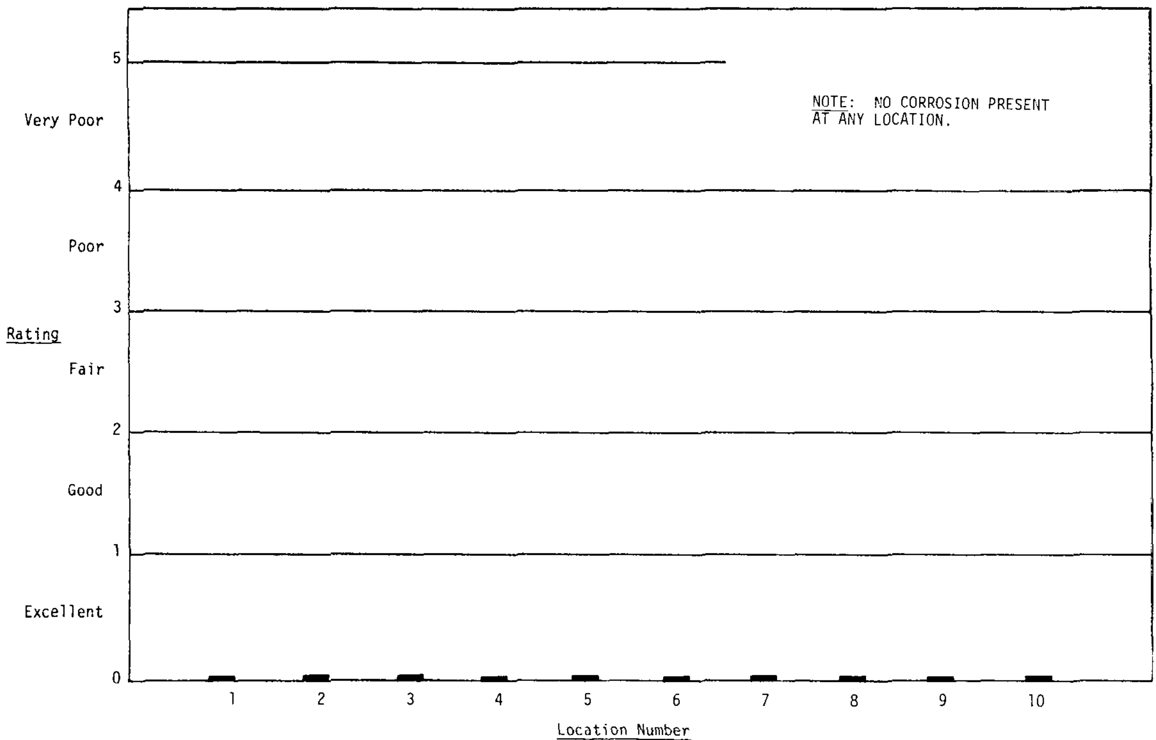


*Laboratory Ratings of Samples From Wheeling Steel Test Culverts (10-mil / 3-mil Coatings)**
FIGURE 23

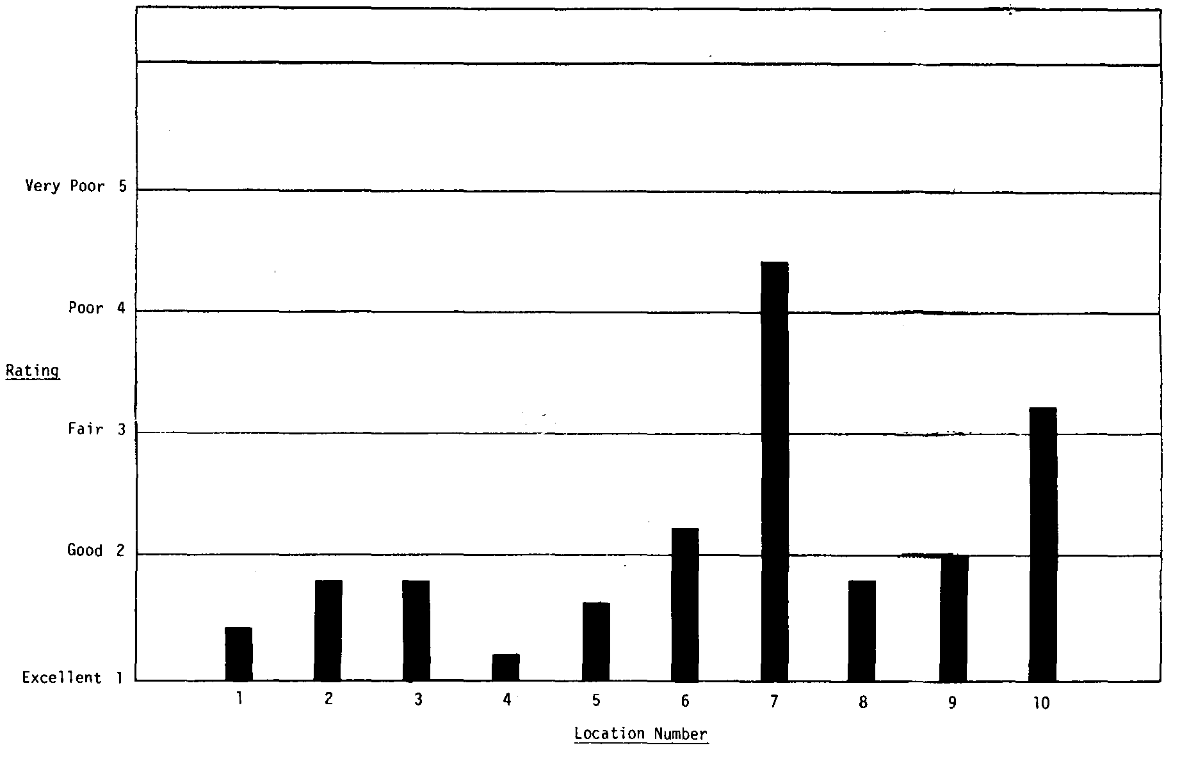
*AFTER 2 YEARS



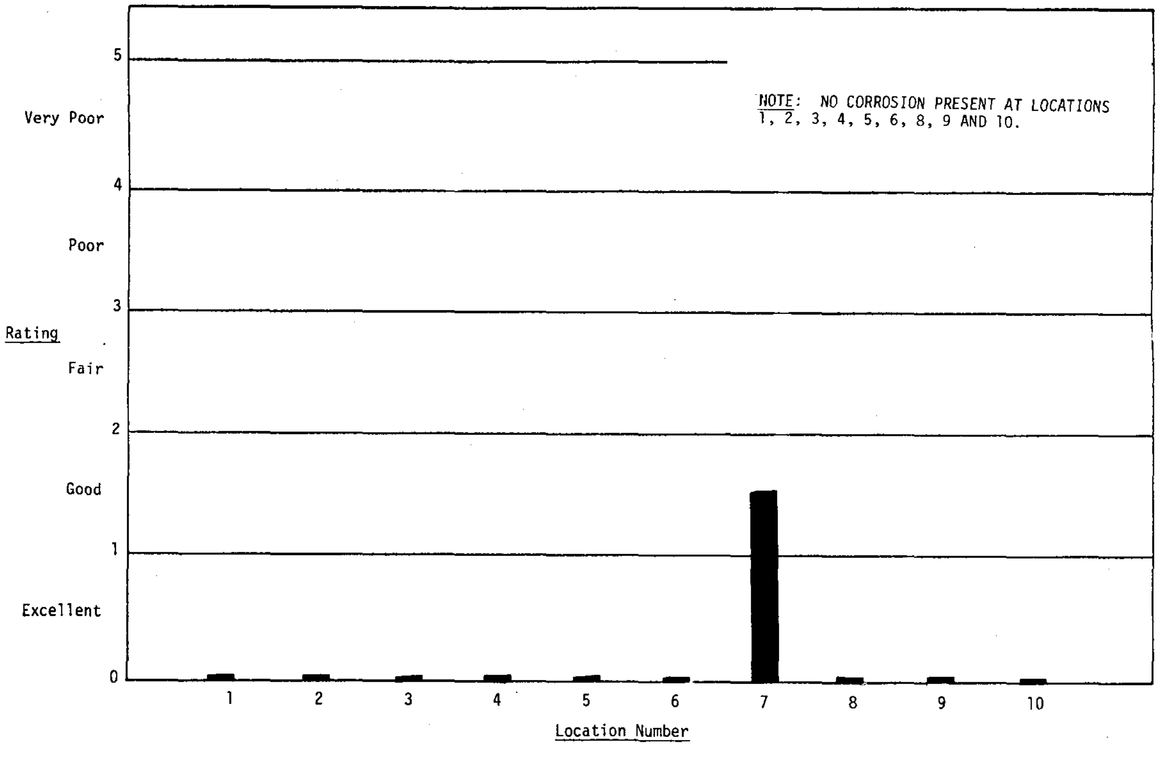
Panel Ratings of Asbestos-Bonded Asphalt-Coated Galvanized Steel Culverts
FIGURE 24



Laboratory Ratings of Samples from Asbestos-Bonded Asphalt-Coated Galvanized Steel Test Culverts
FIGURE 25



Panel Ratings of Asphalt-Coated Galvanized Steel Culverts
FIGURE 26



Laboratory Ratings of Samples from Asphalt-Coated Galvanized Steel Test Culverts
FIGURE 27

Corrugated Aluminum Pipe

The supplier advised that in order to minimize corrosion of aluminum culvert the following conditions should be met: (1) soil and water pH should range between 4.0 and 9.0, (2) soil and water should have electrical resistivity values greater than 500 ohm-cm., unless the effluent is seawater and the surrounding soil is clean granular material, and (3) no dissimilar metals should be in contact with the aluminum.

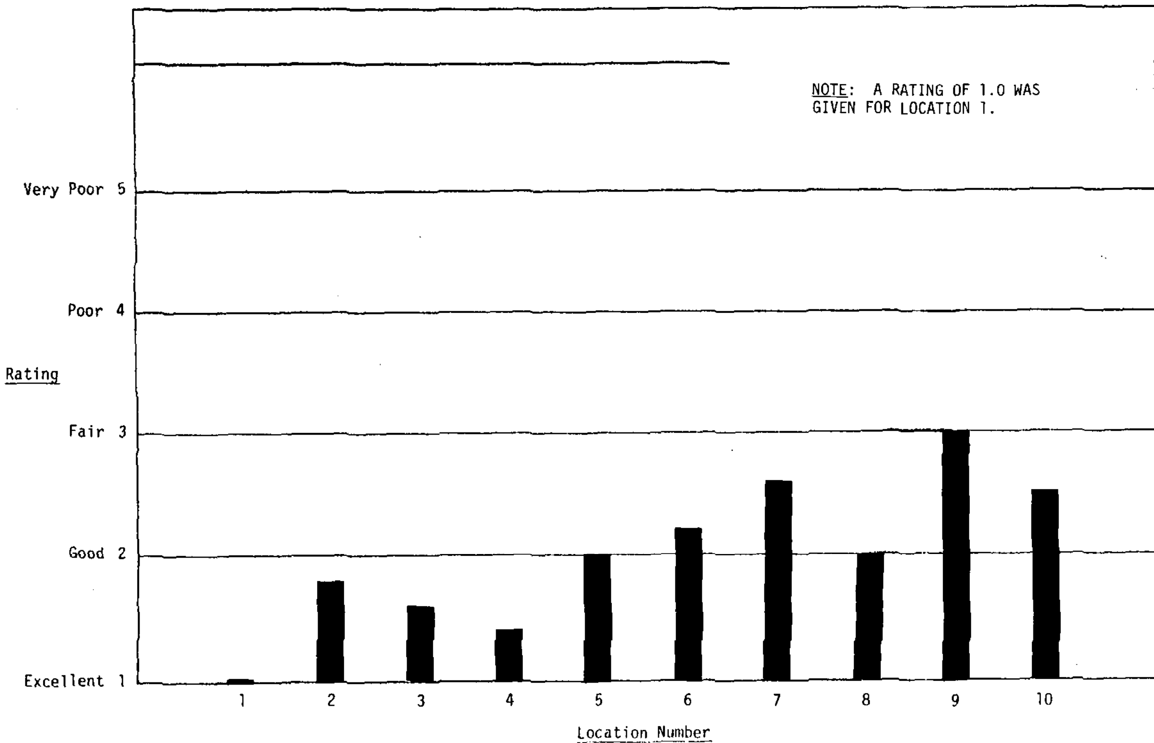
At most of the sites which met the above pH and resistivity criteria, the aluminum pipes have performed very well in resisting corrosion. After 2 years of field exposure, the aluminum pipes exhibited staining, pitting, or localized thickness loss at sites where the soil and/or the effluent possessed electrical resistivity values near or below the threshold of 500 ohm-cm.(6).

After 4 years of field exposure the test pipes at site numbers 1, 2, 3, and 4 are exhibiting the best resistance to corrosion. Test pipes at the other six sites are experiencing pitting and/or thickness loss.

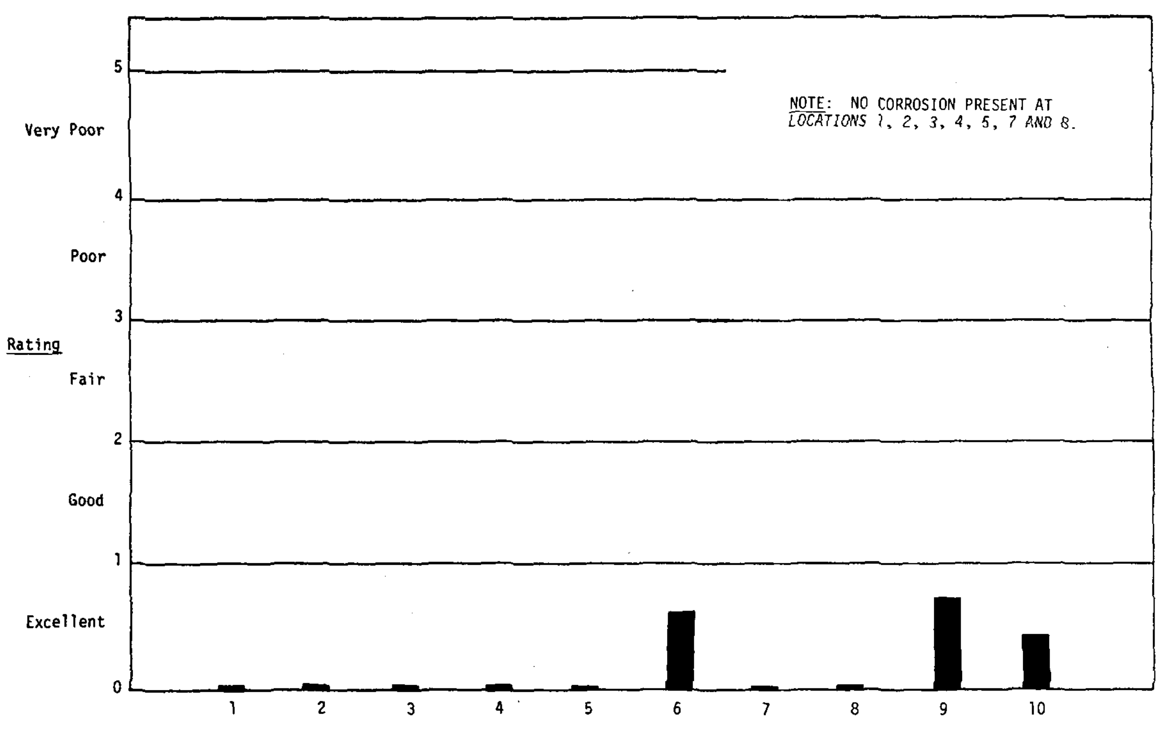
The field and laboratory ratings after 4 years are presented in Figures 28 and 29.

Asphalt-Coated Corrugated Aluminum Pipe

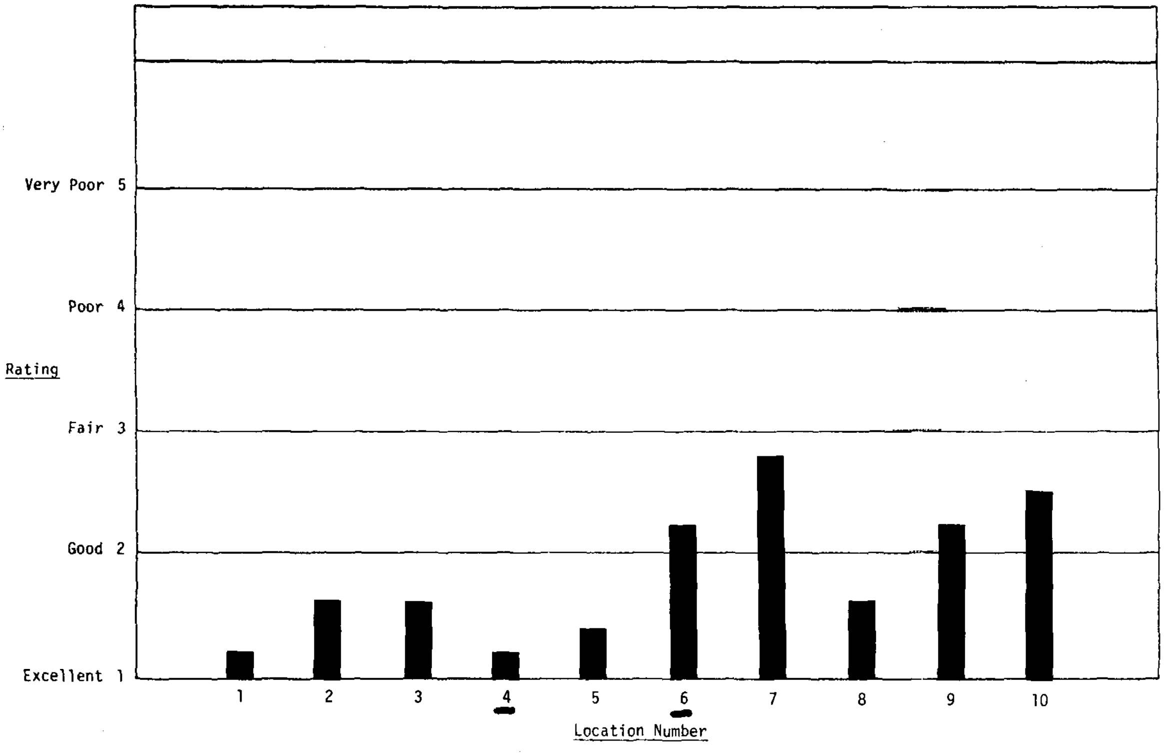
The panel and laboratory ratings for this type of test pipe are shown in Figures 30 and 31. The panel commented that the asphalt coating was extensively removed from these test pipes. The panel made note of pitting and thickness loss at sites 6, 7, 9, and 10.



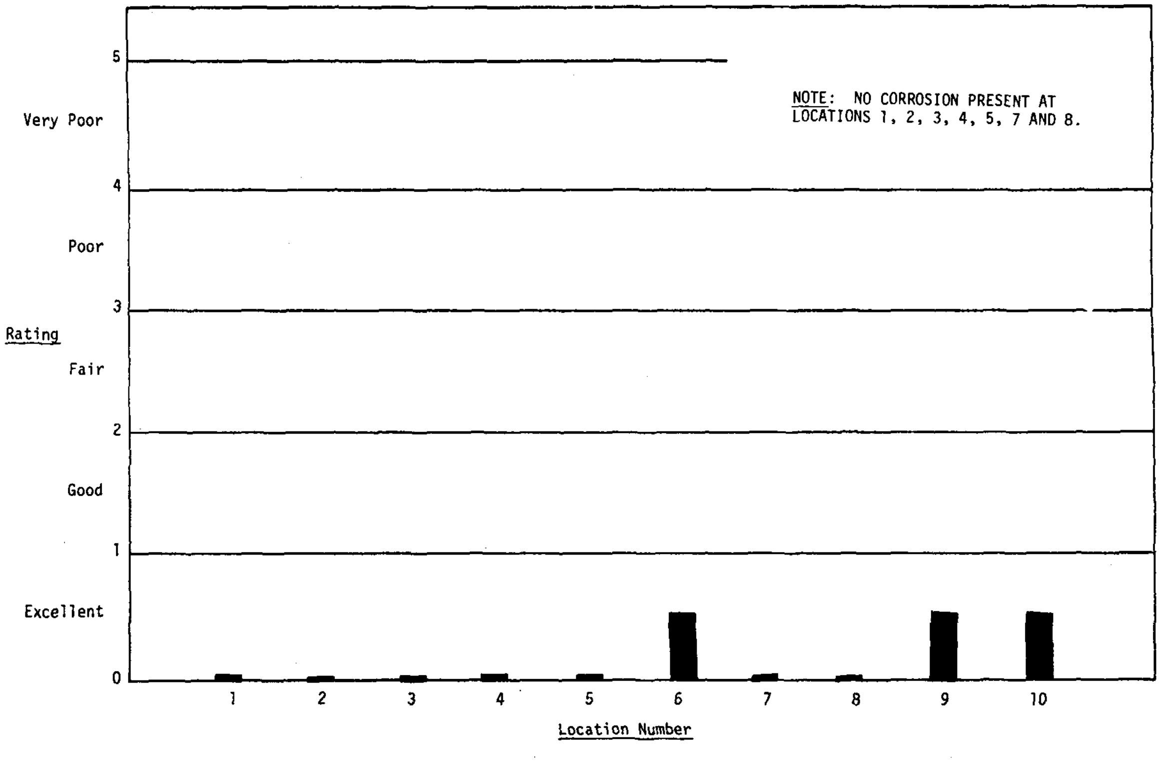
Panel Ratings of Corrugated Aluminum Pipe
FIGURE 28



Laboratory Ratings of Samples from Corrugated Aluminum Test Pipes
FIGURE 29



Panel Ratings of Asphalt-Coated Corrugated Aluminum Pipe
FIGURE 30

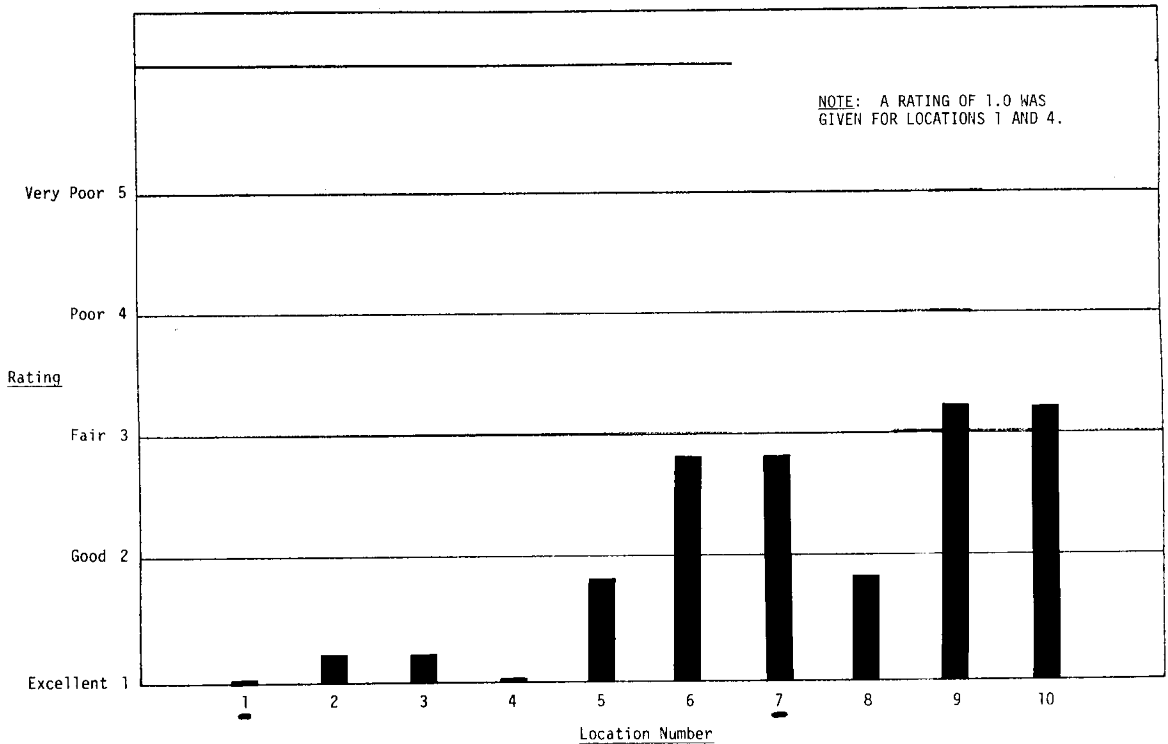


Laboratory Ratings of Samples from Asphalt-Coated Corrugated Aluminum Test Pipes
FIGURE 31

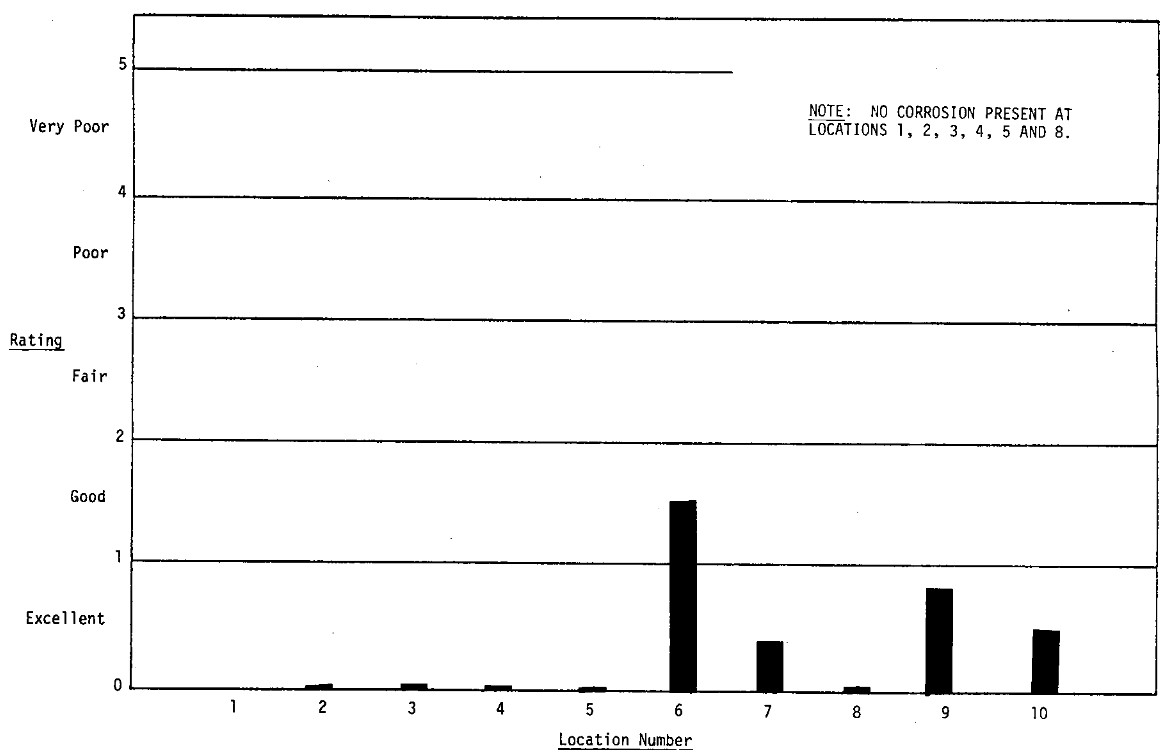
Aluminum Plate Arch

The panel noted that oxidation of this type of culvert was noticeable at all ten sites. Figures 32 and 33 relate that those aluminum plate arches at sites 6, 7, 9, and 10 were in the worst condition. Those at sites 6, 7, 9, and 10 had severe pitting and thickness loss. At site number 7 perforation of the metal was also observed. These four sites are located near the Gulf of Mexico and the electrical resistivity values of soil and effluent are low.

The other six sites had very minor deterioration of the metal.



Panel Ratings of Aluminum Plate Arch
FIGURE 32



Laboratory Ratings of Samples from Aluminum Test Plate Arch
FIGURE 33

CONCLUSIONS

Four years of field exposure have provided much information concerning the performance of the various test culverts. However, additional inspections are planned to obtain more information regarding the durability of these culverts. The following conclusions have been reached at this time:

1. The type of culvert providing the best resistance to corrosion after four years of field exposure is the asbestos-bonded, asphalt-coated, galvanized steel pipe. This is the concensus of a panel which inspected the test culverts in the field and of an engineer who examined field samples of the test culverts in the laboratory.

2. A number of the test culverts have corroded significantly after four years of field exposure in harsh environments. Five of the individual test culverts have already experienced complete perforation. These five are a galvanized steel culvert, an aluminum plate arch, an asphalt-coated, galvanized steel culvert, a 20-mil, U.S. Steel-coated, galvanized steel culvert, and a 12-mil, Inland Steel-coated, galvanized steel culvert.

3. The galvanized steel and aluminum culverts are experiencing the greatest amounts of corrosion at sites 6, 7, 9, and 10. The electrical resistivity of the effluent at these four locations is 300 ohm-cm. and less.

4. The coated pipes are also showing weaknesses at the four test sites mentioned above. The coatings are separating and subjecting the pipes to corrosion.

BIBLIOGRAPHY

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

2. Perry, John H., editor. Chemical Engineers' Handbook. 4th edition, section 23, New York: McGraw-Hill Book Company, 1963.

3. Lowe, T. A., et al. Corrosion Evaluation of Aluminum Culvert Based on Field Performance. Highway Research Record 262. Washington: Highway Research Board, National Academy of Sciences, 1969, pp. 56-68.

4. Speller, F. N. Corrosion--Causes and Prevention. New York: McGraw-Hill Book Company, 1951.

5. Peabody, A. W. Control of Pipeline Corrosion. Houston, Texas: National Association of Corrosion Engineers, 1967.

6. Kinchen, R. W., et al. Evaluation of Drainage Pipe by Field Experimentation and Supplemental Laboratory Experimentation, Interim Report No. 1. Louisiana Department of Transportation and Development Report No. 101, 1977.

APPENDIX

Date: ______________________ Evaluation No.: ______________________

Location No.: ______________________ Evaluated By: ______________________

Pipe No.	Condition of Pipe					Condition of Coating							
	Excellent	Good	Fair	Poor	Very Poor	Blistering		Removed		Other		Good	
						I	O	I	O	I	O	I	O

(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.

Type of Fluid Flowing: ______________________

Other Comments: ______________________

____

O = Outside Coating ______________________
I = Inside Coating ______________________

Sample Field Evaluation Form
FIGURE

TABLE 2

ANALYSIS OF METAL PIPE BY X-RAY FLUORESCENCE

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 standards; may be <0.1%

TABLE 3

PIPE AND COATING THICKNESSES, AS MEASURED

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 (102)	---
A.B.A.C.G.P.	14	2.39	13.30 (200)	---
U.S.S. Nexon	16	2.77	---	16 (12*)
U.S.S. Nexon	16	2.70	---	12 (20*)
Inland Steel	16	2.52	---	Interior 10 (10*) Exterior 3 (3*)
Inland Steel	16	2.38	---	Interior 10 (12*) 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*) Exterior 3 (3*)

*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

TABLE 4

CONDITION OF SAMPLES AFTER ONE MONTH
IN SALT FOG CHAMBER

	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

TABLE 5

CONDITION OF SAMPLES AFTER 1500 HOURS
IN WEATHER-OMETER

	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