EVALUATION OF DRAINAGE PIPE BY FIELD EXPERIMENTATION AND SUPPLEMENTAL LABORATORY EXPERIMENTATION

Interim Report No. 1

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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.

Research and maintenance personnel of the Office installed ten types of metal drainage pipes at each of ten locations in 1973. 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 two years of in-service exposure. It was found that the asbestos-bonded asphalt-coated galvanized steel pipe and the polyethylene-coated galvanized steel pipe are performing equally well and better than the other eight types of culverts in resisting corrosion. All of the coatings on the various test culverts are showing signs of failure 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 an electrolyte. 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 ten types of metal drainage pipe is limited to ten 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 four 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 in predicting 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 experiment 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 characteristics of the soil and effluent at the ten test sites. Figure 1 depicts 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 researchers plan to add a test site with soil exhibiting high corrosion potential to the field program. Soil at the site selected has an electrical resistivity value of 700 ohm-cm. and a pH value of 3.8. 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.

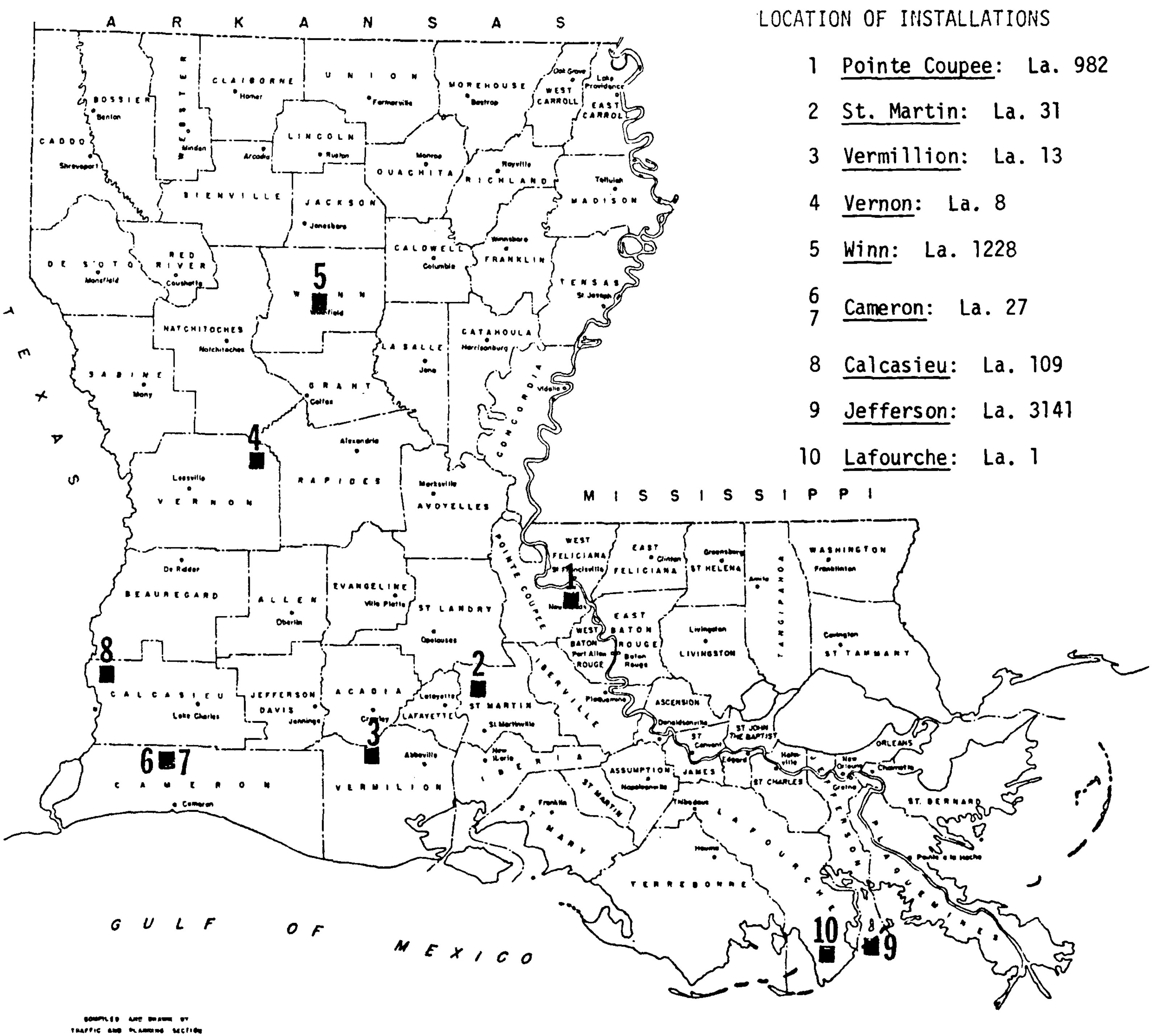
Materials Tested

Originally, ten varieties of coated and uncoated galvanized steel and aluminum culvert were selected for evaluation. All sections of the corrugated culvert were four 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 sq. m.). Six of these ten varieties of pipe are presently authorized for use by Office specifications, provided they conform to certain AASHTO requirements. These six

TABLE 1

SOIL AND EFFLUENT CHARACTERISTICS AT TEST SITES

Location Number	Soil: Type	Soil: Electrical Resistivity, ohm-cm.	Soil: pH	Effluent: Electrical Resistivity, ohm-cm.	Effluent: pH
1	Clay	1,022	6.4	13,000	6.3
2	Silty Clay	747	7.4	4,800	7.0
3	Silty Clay	1,201	7.0	5,133	6.9
4	Silty Sand	11,756	5.4	20,667	5.6
5	Sand	3,312	6.5	2,333	6.6
6	Sandy Clay	395	8.2	92	6.9
7	Sandy Silt	688	8.0	111	7.0
8	Silty Clay	3,291	5.6	15,667	7.0
9	Sand	781	8.4	275	7.8
10	Silty Clay	283	8.3	105	7.3



Location of Test Sites
FIGURE 1

pipes and the relevant AASHTO specifications are as follows:

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 (L.D.H. Standard Specifications for Roads and Bridges, Section 907.08).
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 M197).

The remaining four types of pipes (new products) originally 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.

An eleventh type of test pipe was recently selected for inclusion in this study. This was a 16-gauge (0.15 cm.) galvanized steel pipe with a 10-mil (0.25 mm.) interior and 3-mil (0.08 mm.) exterior Wheeling Steel polymeric coating (AASHTO M246). Since this product has not been inspected for field performance at this writing, it will not be discussed further in this report.

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 re-installation 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 being taken semi-annually to detect any changes in the potential corrosiveness at the test sites.

Typical Ditch Installation
(Location No. 3)
FIGURE 2

Typical Canal Installation
(Location No. 10)
FIGURE 3

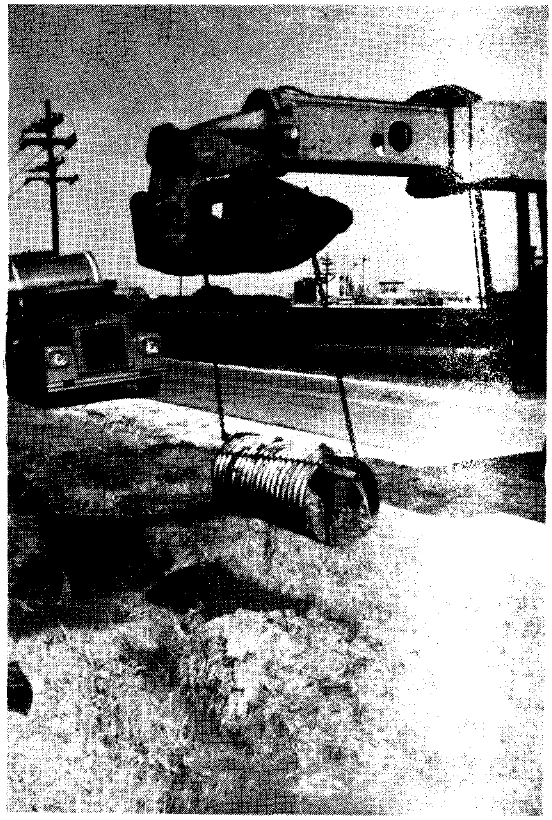
Field Inspection

During the months of October and November, 1975, the first field inspection was conducted, representing two 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.

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 process. On some of these pipes it is estimated that as much as 40% of the asphalt remained in the soil, thus indicating a loss of bond over the two-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 four highway engineering technicians visually rated the pipes using the evaluation form included in the Appendix. 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.



Drainage Pipe Remova
FIGURE 4

Cleaning Drainage Pi
FIGURE 5

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.

Cutting Sample for Laboratory Testing
FIGURE 6

Laboratory Analyses of Soil, Water, and Unexposed Culverts

Soil and water samples have been collected from each installation site on a semi-annual basis since the original 1973 installation. These samples have been tested for pH in accordance with LDH:TR 430-67 and for resistivity in accordance with LDH:TR 429-67. 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 LDH: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-coated, the asbestos-bonded, and the 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 (LDH: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 (LDH: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 three inches (eight 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 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:

$$R_{Al} = 5 \left[\frac{T_L}{T_{o/2}} \right]$$

where,

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

T_L = Average maximum thickness loss, millimeters

T_0 = 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 given 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 from 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 from 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 polymeric coatings, as field-exposed for two years, on four of the steel culverts were examined to determine the percentage of surface area experiencing blistering and separation from the pipes (delamination). These percentages were used in the following equation to provide a rating from 0 to 5 for the polymeric coatings:

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

where,

R_C = Rating of field-exposed polymeric coating

A_C = Percentage of surface area which experienced coating failure

This scheme of rating the polymeric 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 polymeric 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

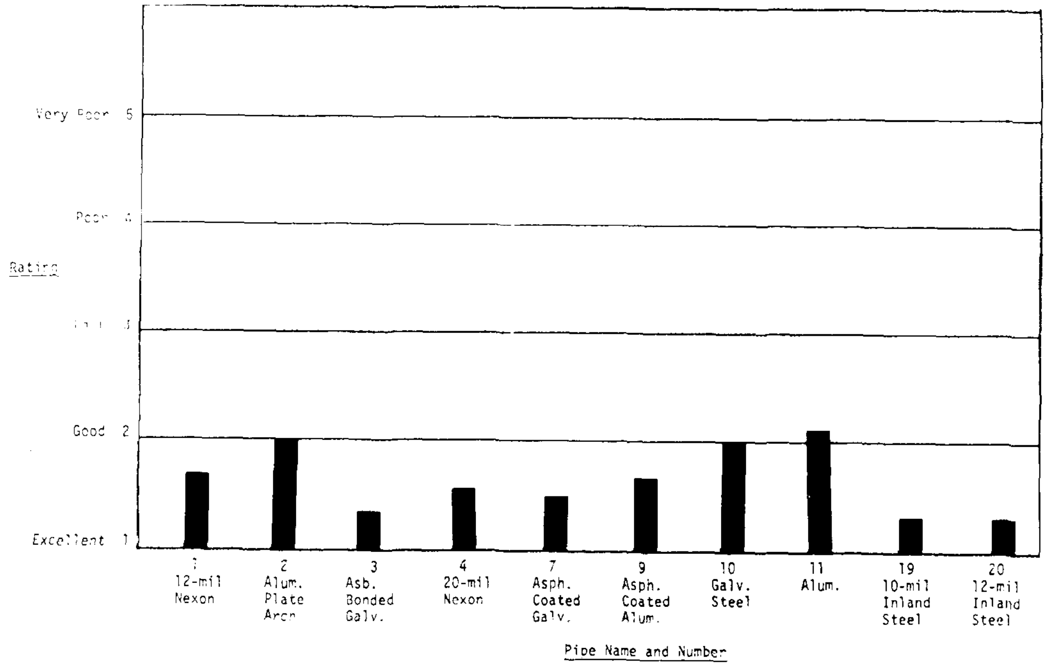
General Discussion

The types of culverts providing the best performance after two years of field exposure are the asbestos-bonded asphalt-coated galvanized steel pipe and the Inland Steel polyethylene-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.

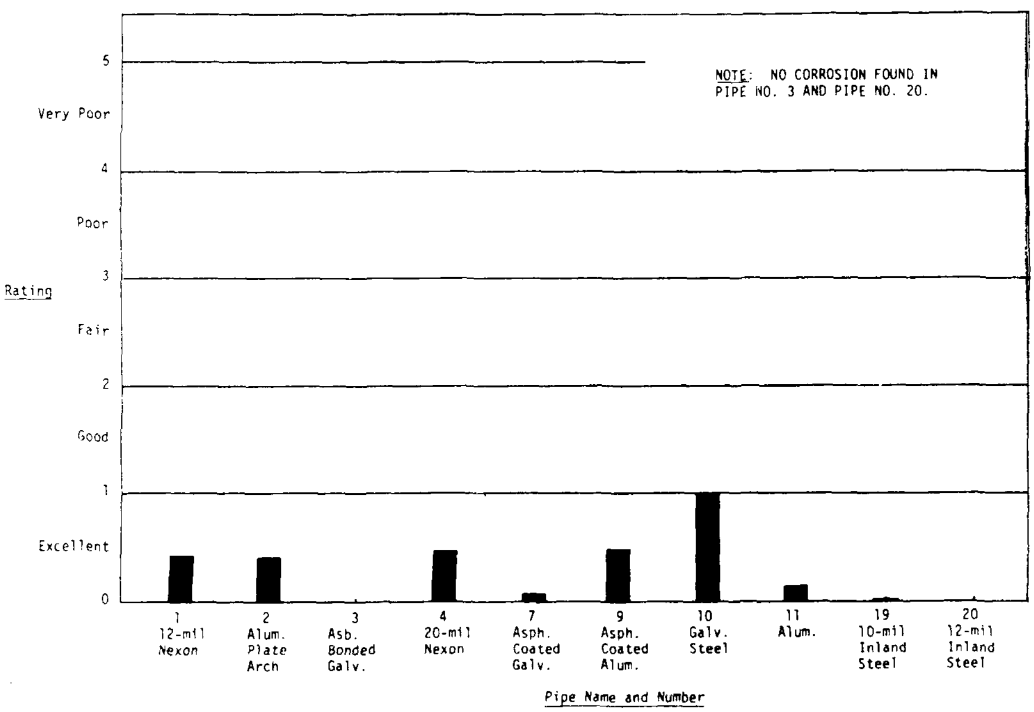
The field ratings are summarized in Figure 7. The ratings are the collective opinions of a panel of six highway engineering personnel who examined the culverts at the ten test locations and assigned a numerical rating ranging from one (excellent) to five (poor) to each culvert. Neither the two highway engineers nor the four engineering specialists comprising the panel are corrosion experts. However, the authors feel that the technical backgrounds of these individuals qualified them to identify tell-tale signs such as rust on steel and pitting on aluminum and to assign valid ratings to the test culverts.

The laboratory ratings are summarized in Figure 8. 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.

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 and blistering, particularly at the lateral extremities of the four-foot long culverts.



Average Panel Ratings at Ten Sites
FIGURE 7



Average Laboratory Ratings at Ten Sites
FIGURE 8

The aluminum culverts displayed two types of deterioration. Pitting of the surface was noticed on samples from some 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 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 of the interior walls of the test culverts was most extensive at the water line where concentrations of oxygen, water, and electrolytes such as 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 two years and that the exterior walls are corroding in a uniform manner. Corrosion attacks interior and exterior walls of culverts placed in the environments of Louisiana.

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 less than 300 ohm-cm. (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 9 relates the panel's ratings of this type of pipe at each of the ten test sites. Figure 10 relates the laboratory ratings of the samples taken from the test culverts at the time of the panel rating.

At four of the test sites (numbers 1, 2, 3, and 5), the galvanized steel pipes are performing very satisfactorily. At sites 4, 8, and 9 the panel noted small amounts of corrosion primarily on the outside walls of these test culverts. The galvanized steel test culverts at sites 6, 7, and 10 are corroding at fast rates and bear further discussion.

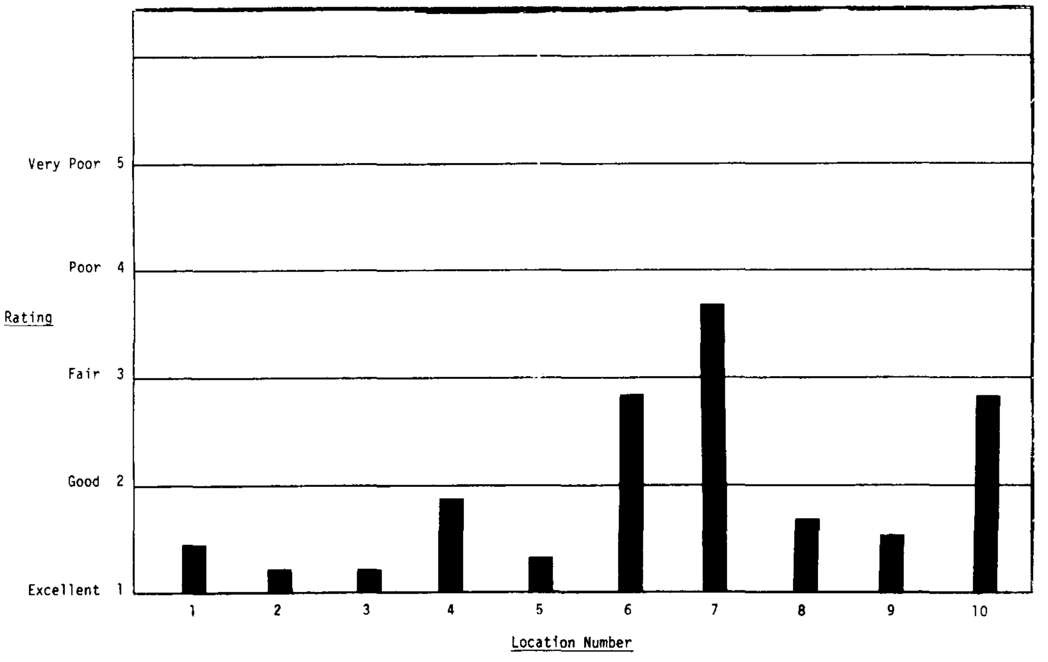
At site number 6, the soil and effluent both exhibit low electrical resistivity values of 395 and 92 ohm-cm., respectively. This conductive medium appears to be the cause for corrosion occurring inside and outside of the test pipe.

At site number 7, which is a canal, the soil and brackish water have low electrical resistivity values of 688 and 111 ohm-cm., respectively. The test pipe was extensively corroded.

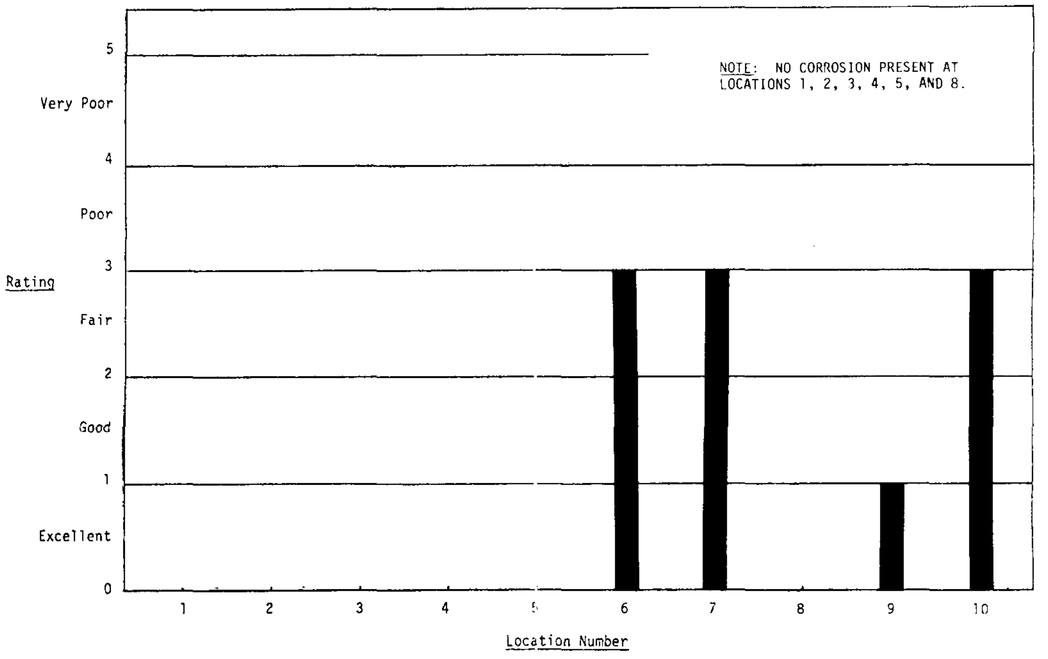
At site number 10, the pipes are resting in a canal of brackish water with an electrical resistivity of 105 ohm-cm. The silty clay soil also has a low electrical resistivity value of 283 ohm-cm. The galvanized steel pipe is deteriorating very heavily at this site. (All of the test pipes at site number 10 were encrusted with barnacles at the time of inspection.)

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 coat-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.



Panel Ratings of Galvanized Steel Culverts
FIGURE 9



Laboratory Ratings of Samples from
Galvanized Steel Test Culverts
FIGURE 10

Figure 11 relates the panel's evaluation of this pipe at each of the test sites. Figure 12 presents the laboratory ratings of the samples obtained from these test pipes at the time of the panel rating.

At sites 2, 3, 4, 5, 8, and 9, field and laboratory ratings were very favorable for these U. S. Nexon precoated culverts. However, the panel and the laboratory evaluation did note corrosion in progress at three sites, and these cases will be discussed further.

At site number 6 the soil and effluent have low electrical resistivity values of 395 and 92 ohm-cm., respectively. The test pipe has the coal-tar-based coating on the outside at this one site. Corrosion was noted on the inside of the pipe where the thin organic (0.3-mil modified epoxy) coating was generally removed.

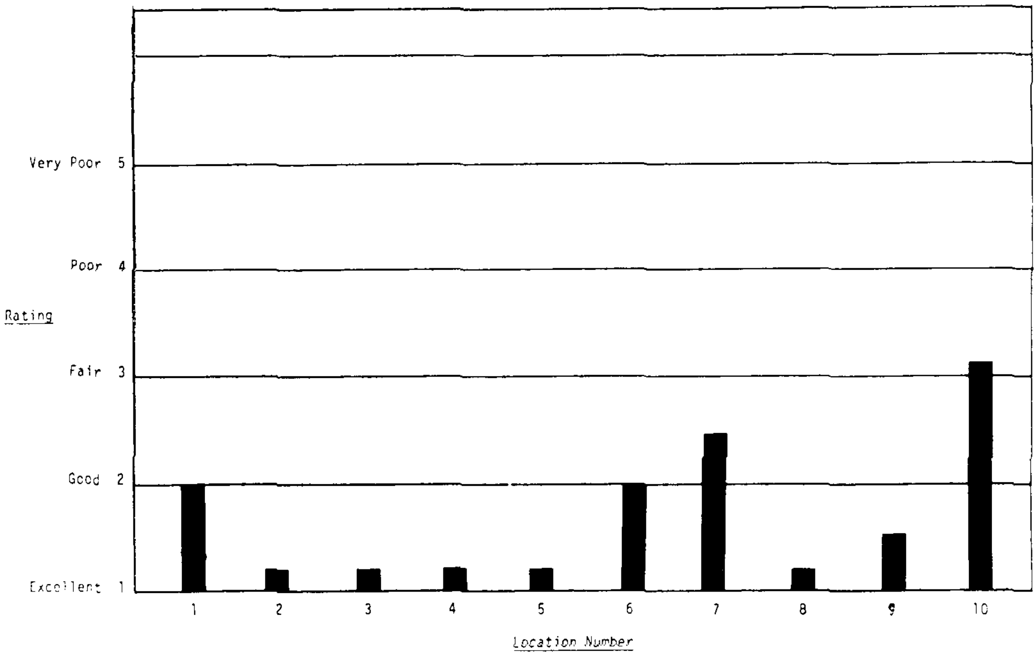
At site number 7 the pipe lies in brackish water with a low electrical resistivity of 111 ohm-cm. The metal comprising the pipe is corroding, as are rivets on the pipe. The 12-mil protective coating is blistering, peeling, and partially removed.

At site number 10 the pipe lies in brackish water with an electrical resistivity of 105 ohm-cm. The metal is corroding, the inside protective coating is peeling, and the outside thin organic coating is generally removed.

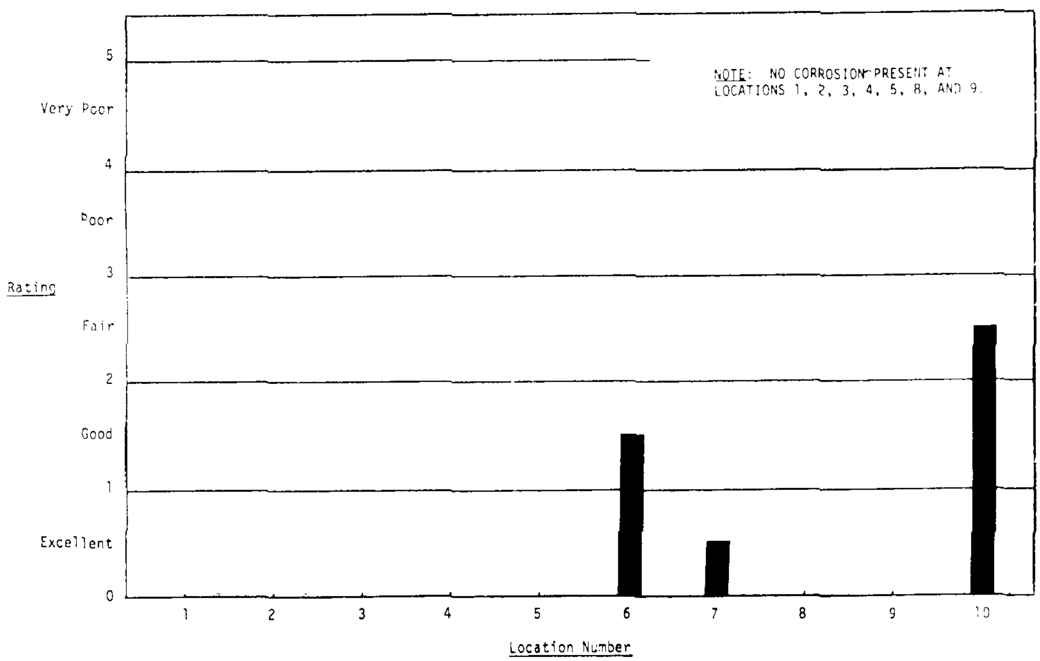
U. S. Steel Nexon Precoated Culvert Stock (Nominal 20-mil or 0.5-mm. Coating)

The thermo-plastic 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.

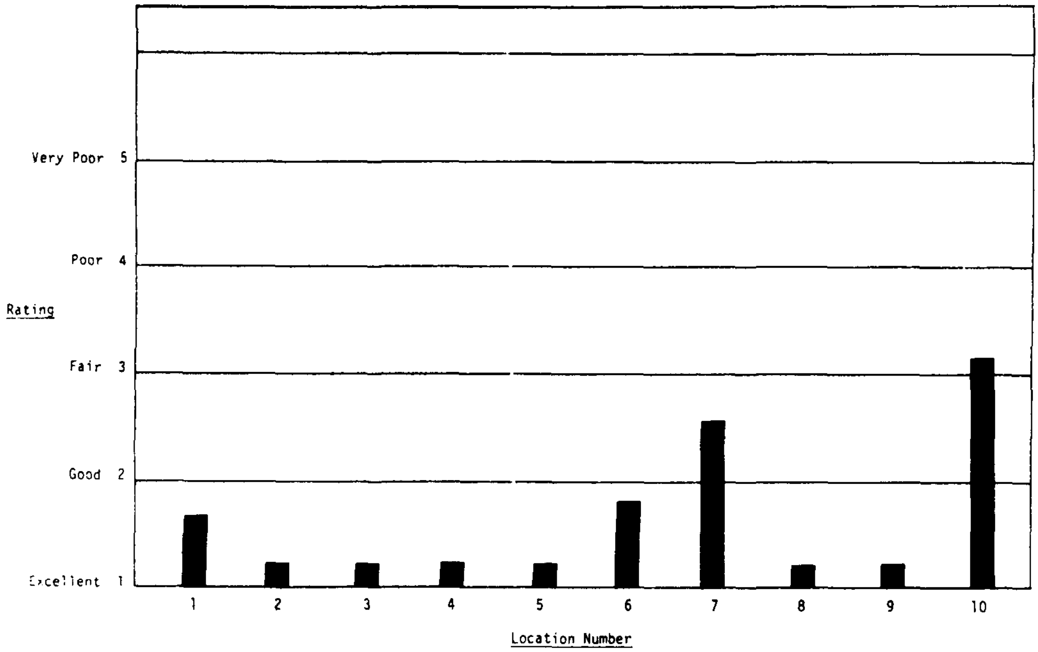
Figure 13 relates the panel ratings of this test pipe at each location. Figure 14 presents the laboratory ratings of the samples obtained from these test pipes at the time of the panel ratings.



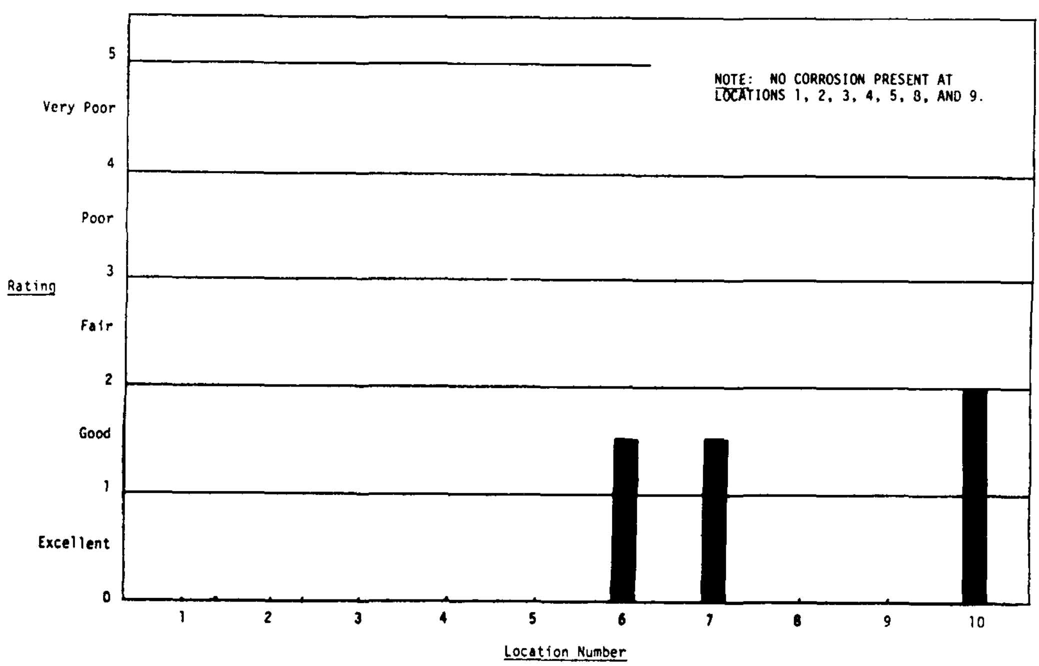
Panel Ratings of U. S. Steel Nexon Precoated Culverts (12-mil Coating)
FIGURE 11



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



Panel Ratings of U. S. Steel Nexon Precoated Culverts (20-mil Coating)
FIGURE 13



Laboratory Ratings of Samples from U. S. Steel Nexon Test Culverts (20-mil Coating)
FIGURE 14

At sites 2, 3, 4, 5, 8, and 9, the panel and laboratory ratings of the resistance to corrosion of this type of pipe were almost excellent. At sites 2, 5, 8, and 9, the panel did observe that the protective coating was separating from the pipe. The panel and the laboratory evaluation noted corrosion of the galvanized steel at three sites and these cases will be discussed further.

At site number 6 the electrical resistivities of the soil and effluent are low values of 395 and 92, respectively. The protective coating is on the outside of this test pipe, and corrosion is occurring inside the pipe.

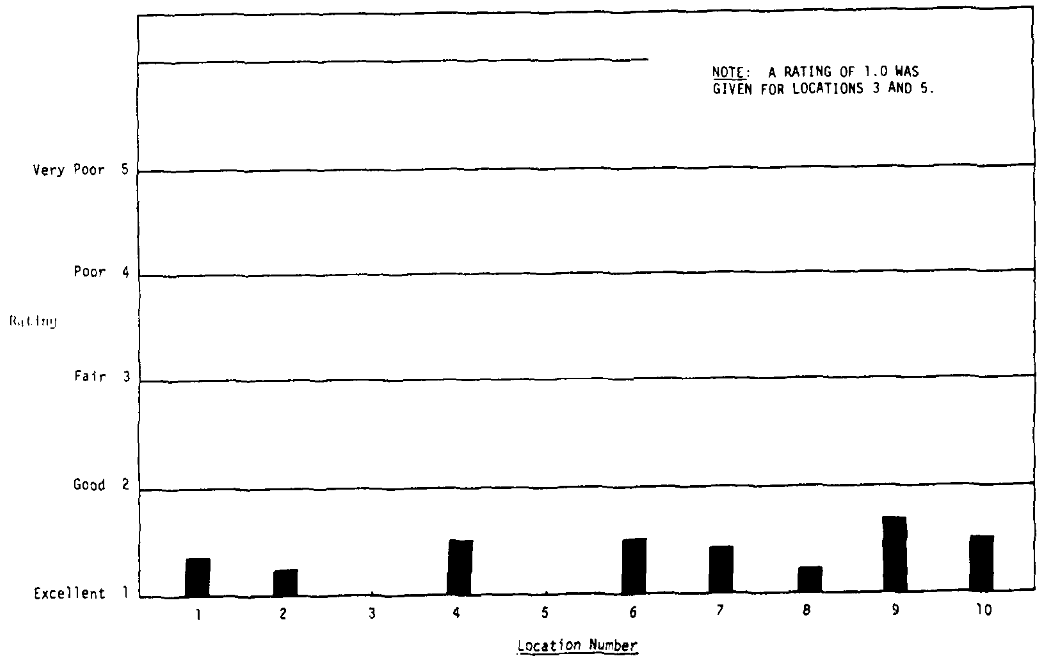
At site number 7 the pipe lies in a canal of brackish water having low electrical resistivity (111 ohm-cm.). The pipe is corroding in spots, and the rivets are corroding severely. The inside protective coating is separating from the pipe at one end.

At site number 10 the pipe is located in a canal with water having low electrical resistivity of 105 ohm-cm. The pipe is corroding, and the coating is peeling.

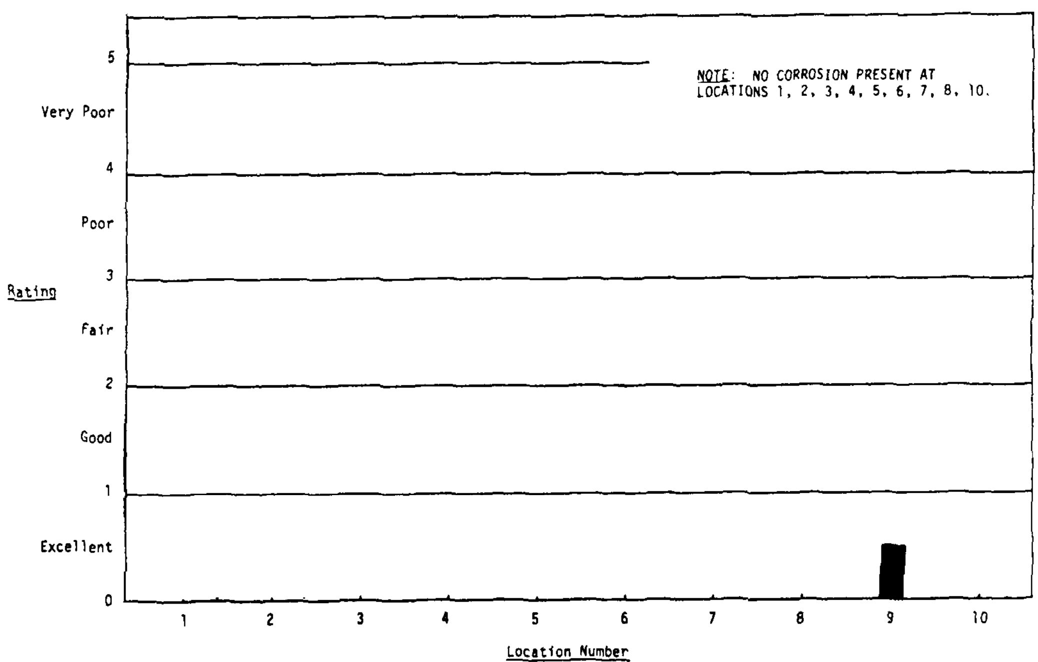
Inland Steel Precoated Culvert Stock (Nominal 10-mil or 0.2-mm. Inside Coating / 3-mil or 0.08-mm. Outside Coating)

Figure 15 relates the panel ratings and Figure 16 presents the laboratory ratings of the resistance to corrosion exhibited by this pipe after two years in the field. The polyethylene coatings have thus far functioned very well in protecting the galvanized steel of this pipe from corrosion.

The panel did note that rivets exposed on the exterior of this pipe are corroding at six of the ten sites. The panel was also concerned about the durability of the coating in environments where both soil and effluent have low electrical resistivity values. At sites numbers 6, 7, and 9, the panel and the engineer in the laboratory both noted that the polyethylene coating was blistering and peeling.



Panel Ratings of Inland Steel Polyethylene-Coated Culverts (10-mil/3-mil Coatings)
FIGURE 15



Laboratory Ratings of Samples from Inland Steel Test Culverts (10-mil/3-mil Coatings)
FIGURE 16

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

Figures 17 and 18 relate that this type of test pipe is resisting corrosion very well after two years in the variety of environments.

The panel did observe that the rivets on the test pipes at six of the sites had corroded. The panel and the laboratory evaluation both noted that the polyethylene coating was blistering and peeling at sites 6, 7, and 9.

Table 2 is a summary of the laboratory ratings of the polymeric coatings on the field-exposed samples of this study. These ratings range from zero (excellent) to five (poor) and reflect the percentage of square-inch units of area of polymeric coating experiencing failure.

Asbestos-Bonded Asphalt-Coated Galvanized Steel Pipe

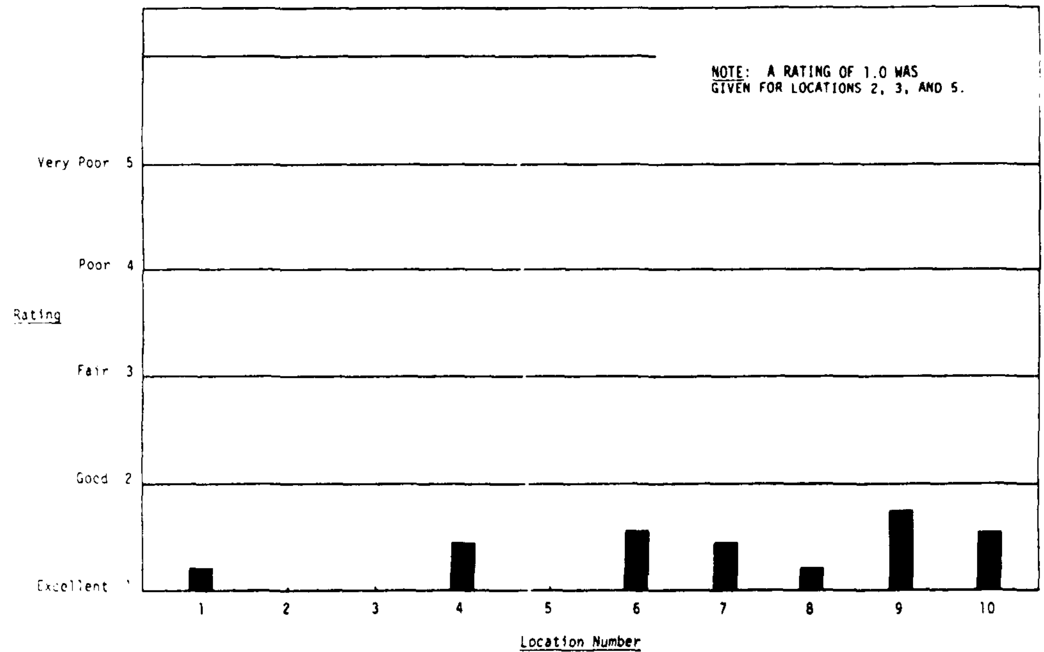
Figures 19 and 20 relate that this type of test pipe is consistently performing very well in regard to corrosion resistance.

The panel did note that the asphalt-asbestos coating was cracking, primarily in an alligator pattern. 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 in protecting the galvanized steel from corrosion.

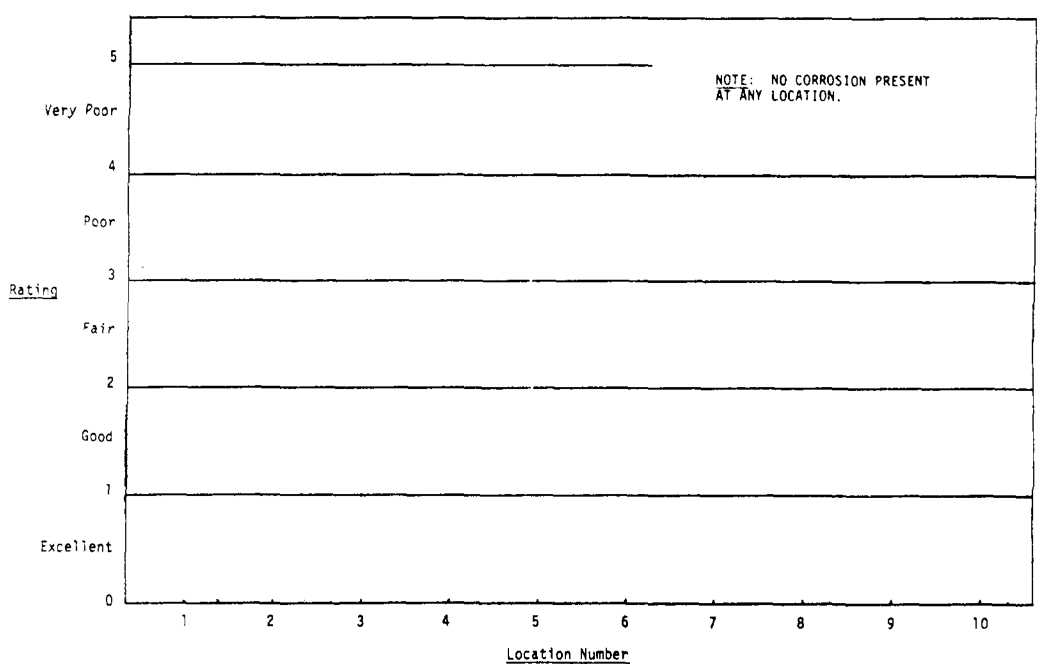
Asphalt-Coated Galvanized Steel Pipe

Figures 21 and 22 relate that this type of pipe has resisted corrosion quite well at most sites after two years of field exposure. However, the panel and the laboratory evaluation noted corrosion in progress at sites numbers 7 and 10.

The panel reported that the asphalt coating was generally experiencing cracking and partial removal on the interior and exterior. At two of the sites, the panel reported that the outside coating was coming off as the surrounding soil was removed for the inspection.



Panel Ratings of Inland Steel Polyethylene-Coated Culverts (12-mil/5-mil Coatings)
FIGURE 17

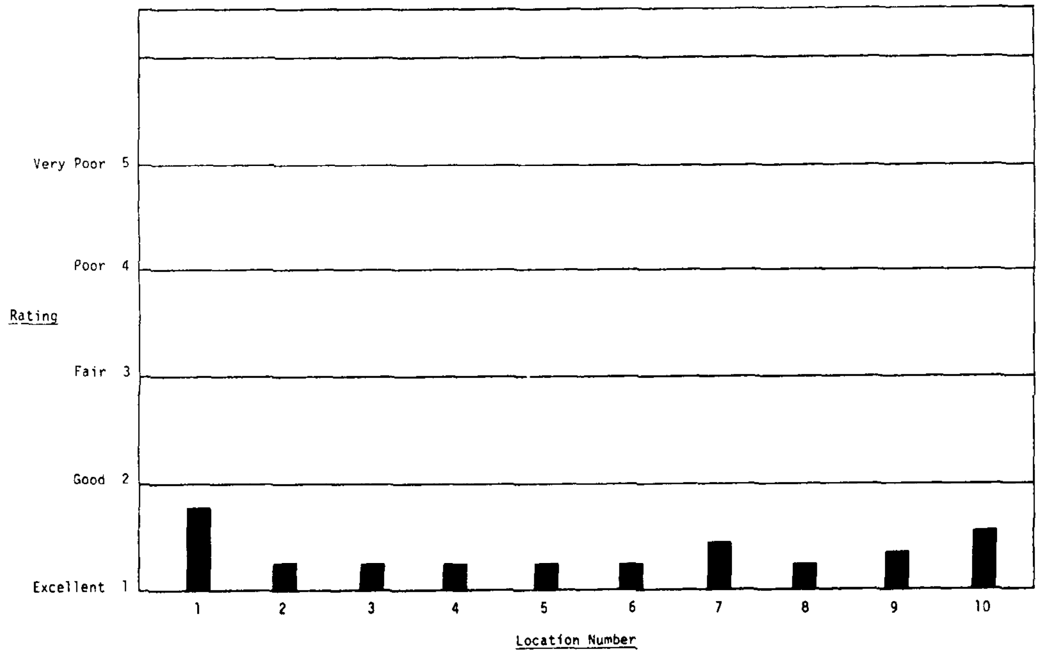


Laboratory Ratings of Samples from Inland Steel Test Culverts (12-mil/5-mil Coatings)
FIGURE 18

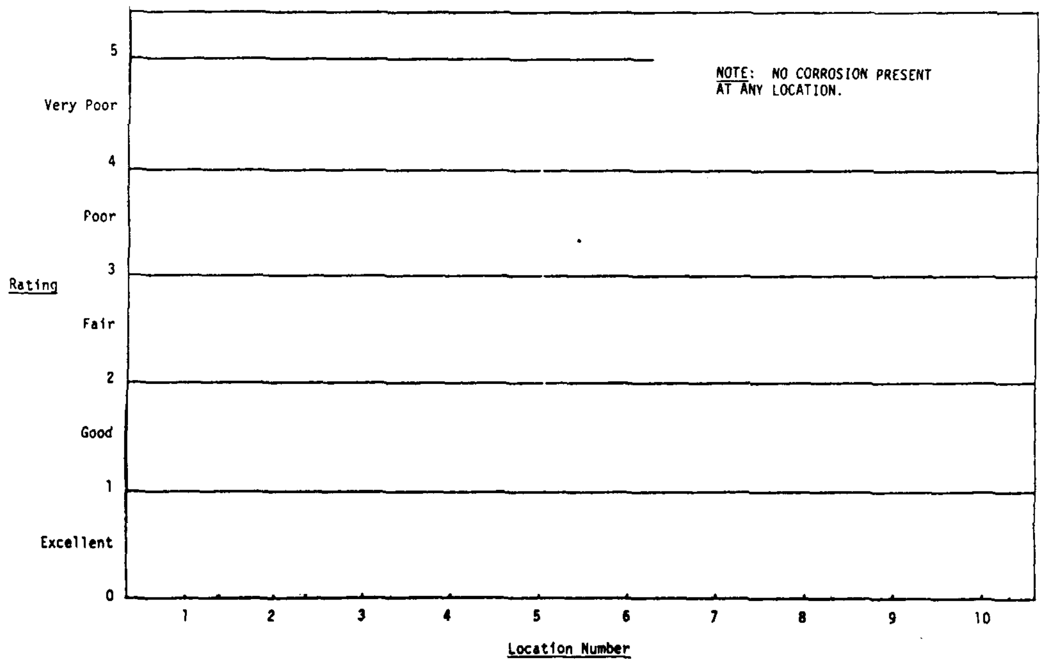
TABLE 2

LABORATORY RATINGS OF POLYMERIC COATINGS

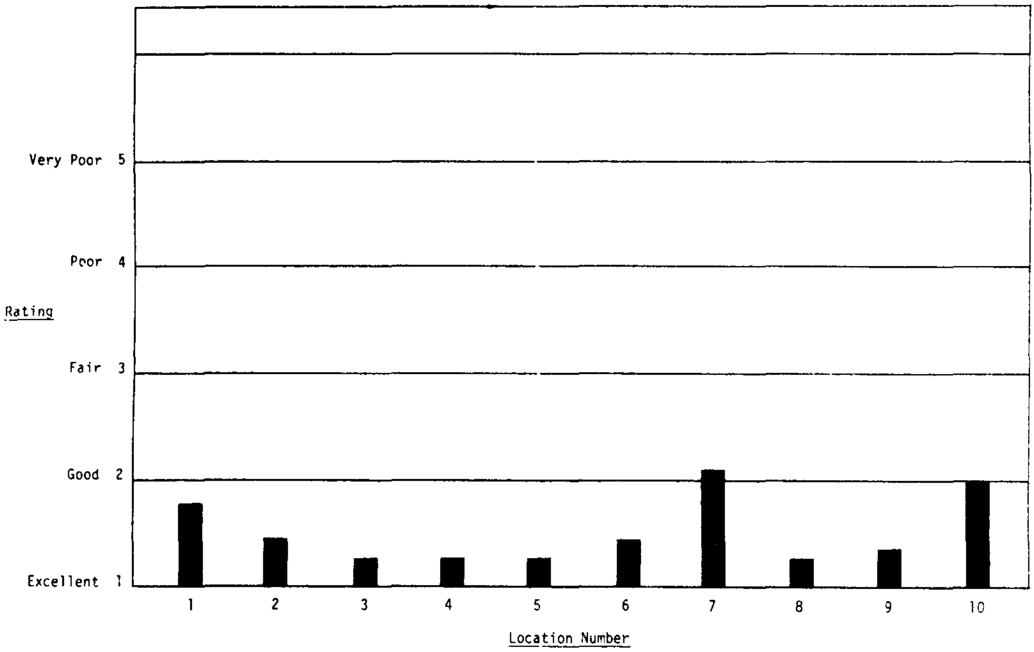
	Test Site Number									
	1	2	3	4	5	6	7	8	9	10
U. S. Steel Polymeric Coated Galvanized Culvert (12 mils)	0	0	0	0	0	0.5	1.0	0	1.0	1.5
U. S. Steel Polymeric Coated Galvanized Culvert (20 mils)	0	0.5	0.5	0	0	0.5	3.5	0.5	3.0	3.5
Inland Steel Polymeric Coated Galvanized Culvert (10/3 mils)	0	0	0	0	0	2.3	2.3	0	2.0	2.0
Inland Steel Polymeric Coated Galvanized Culvert (12/5 mils)	0	0	0	0	0	2.0	1.5	0	1.3	2.3



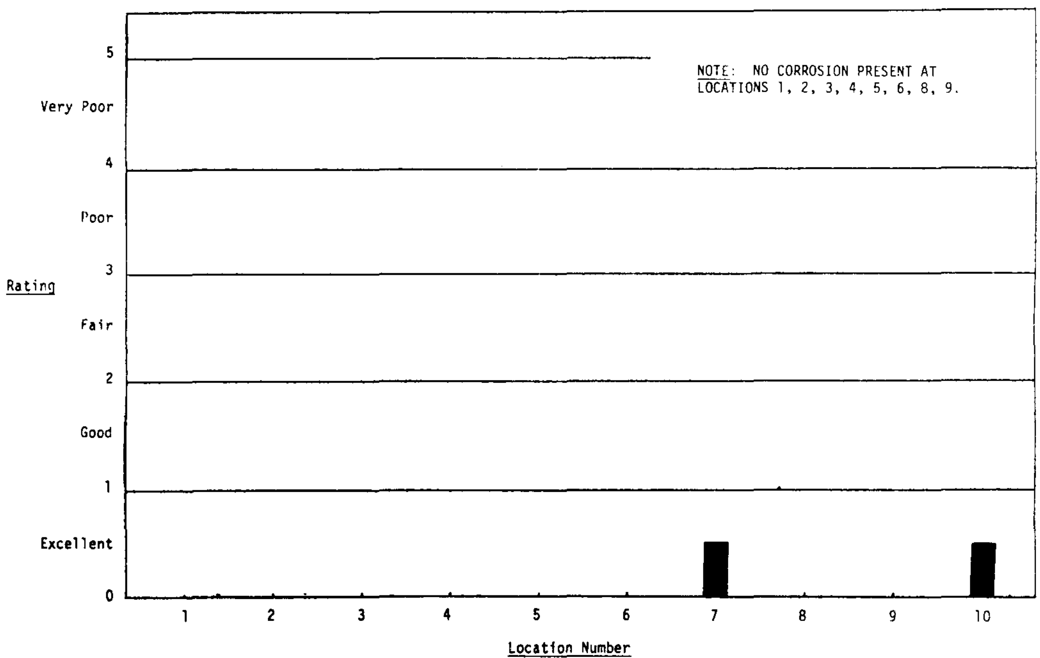
Panel Ratings of Asbestos-Bonded Asphalt-Coated Galvanized Steel Culverts
FIGURE 19



Laboratory Ratings of Samples from Asbestos-Bonded Aspahlt-Coated Galvanized Steel Test Culverts
FIGURE 20



Panel Ratings of Asphalt-Coated Galvanized Steel Culverts
FIGURE 21



Laboratory Ratings of Samples from Asphalt-Coated Galvanized Steel Test Culverts
FIGURE 22

Corrugated Aluminum Pipe

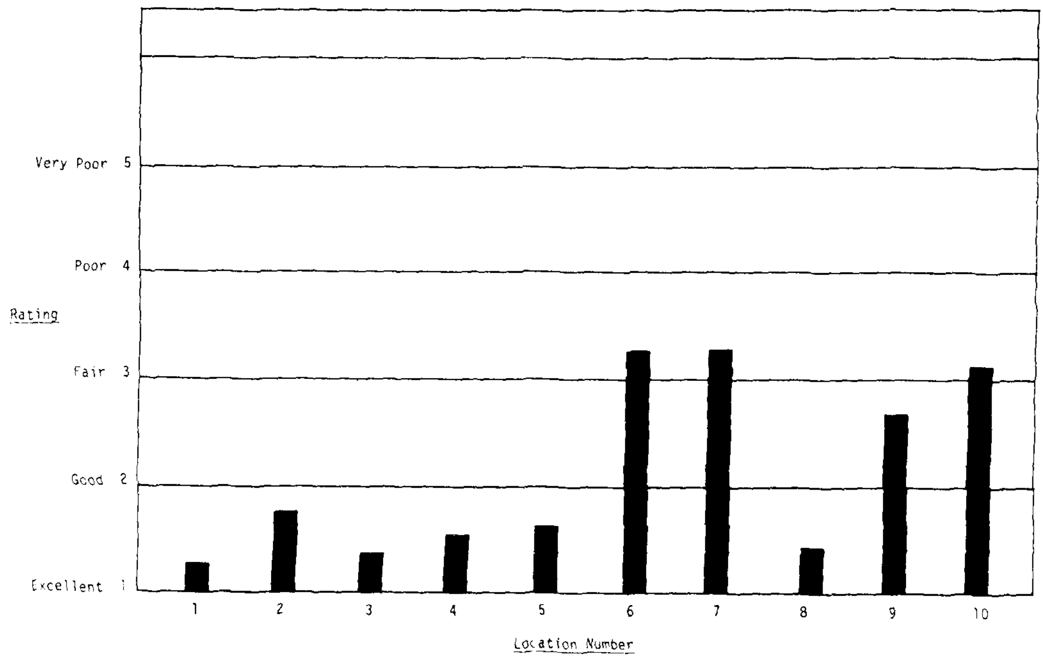
The supplier advised that in order to minimize corrosion of aluminum culvert the following conditions should be met: (1) soil and water pH should range between 4.0 and 9.0, (2) soil and water should have electrical resistivity values greater than 500 ohm-cm., unless the effluent is seawater and the surrounding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

At sites which met the above pH and resistivity criteria, the aluminum pipe performed very well in resisting corrosion. At sites where the soil and/or effluent exhibited electrical resistivity values near or below the threshold value of 500 ohm-cm., the aluminum pipe exhibited staining, pitting or localized thickness loss after the two years of field exposure.

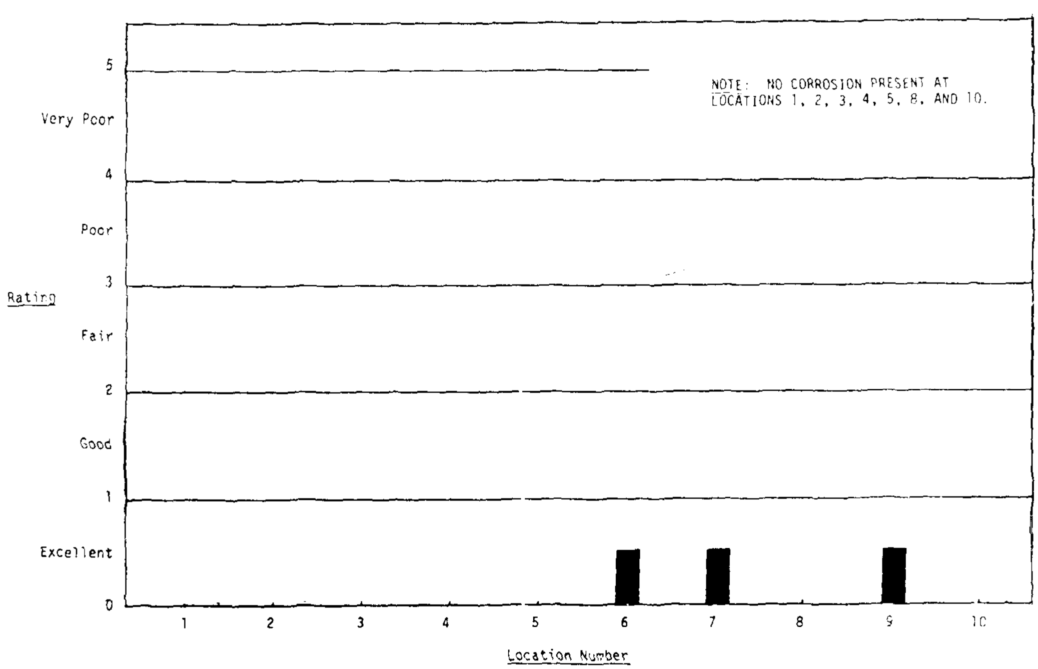
The panel noted extensive oxidation on the aluminum pipes at the brackish water sites (numbers 6, 7, 9, and 10). Laboratory evaluation of the samples taken from the ends of the test culverts at sites 6, 7, and 9 indicated an average maximum thickness loss per square inch of 10% of the original thickness (rating 0.5). Such an average maximum thickness loss would indicate total penetration of the cladding and probably a portion of the core alloy at some spots on the sample. The field and laboratory ratings are presented as Figures 23 and 24, respectively.

Asphalt-Coated Corrugated Aluminum Pipe

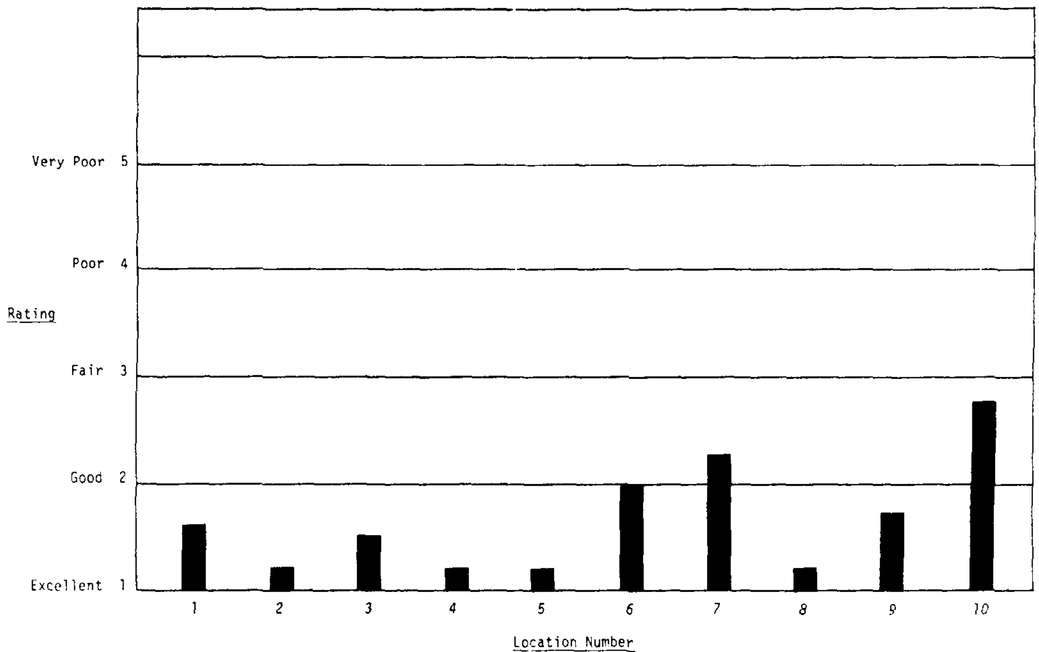
The panel's ratings for this type of test pipe are shown in Figure 25. The panel commented that the asphalt coating was extensively removed from these test pipes. The group made special note of the oxidation manifested on the aluminum at sites 3, 6, 7, 9, and 10. Laboratory evaluation revealed that the stains on these pipes at sites 6, 7, 9, and 10 are more than just signs of oxidized cladding, and reported thickness loss penetrating the core alloy at these four sites. For example, the rating of 1.0 at site 7, as shown in Figure 26, indicates an average maximum thickness loss per square inch of 20% of the original thickness.



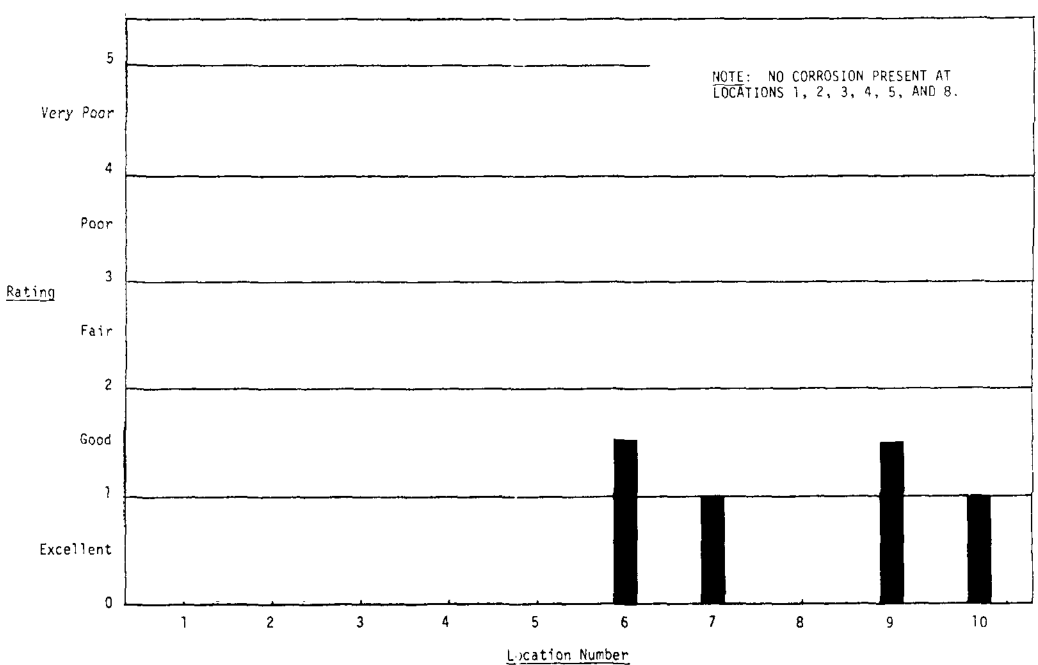
Panel Ratings of Corrugated Aluminum Pipe
FIGURE 23



Laboratory Ratings of Samples from
Corrugated Aluminum Test Pipes
FIGURE 24



Panel Ratings of Asphalt-Coated Corrugated Aluminum Pipe
FIGURE 25

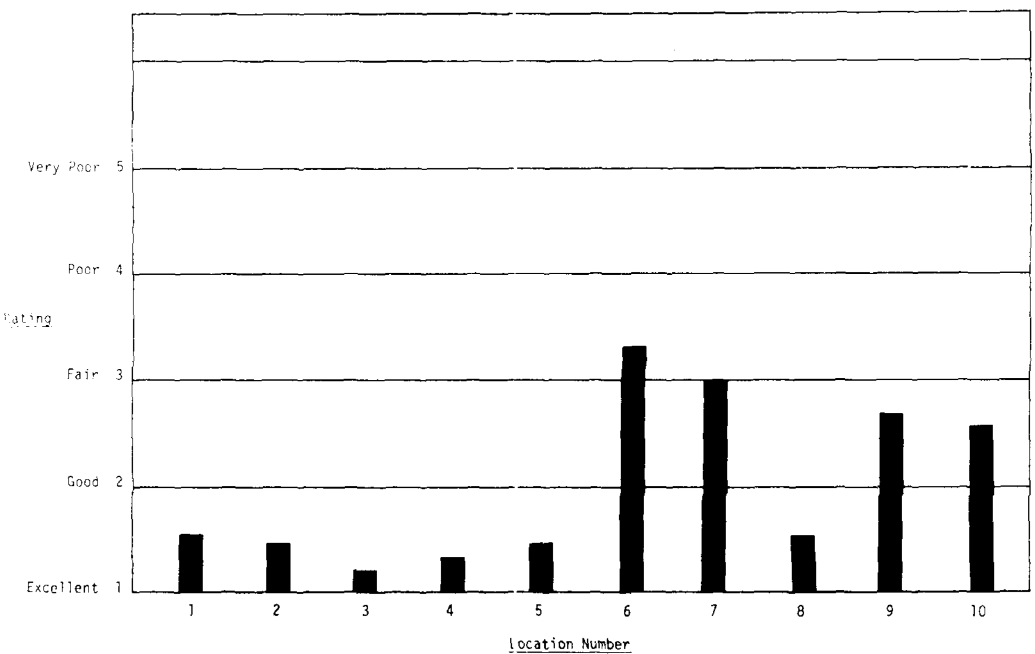


Laboratory Ratings of Samples from Asphalt-Coated Corrugated Aluminum Test Pipes
FIGURE 26

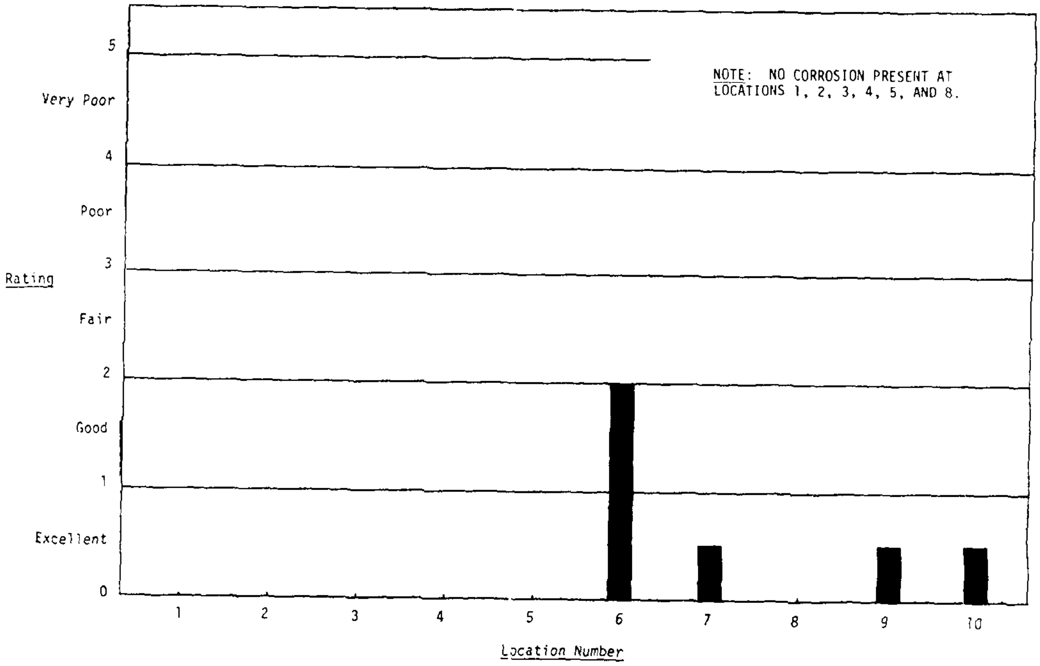
Aluminum Plate Arch

The panel noted that oxidation of this type of culvert was noticeable at all ten sites. Figures 27 and 28 relate that those aluminum plate arches at sites 6, 7, 9, and 10 were in the worst condition. These four sites are near the Gulf of Mexico and the electrical resistivity values of soil and effluent are low.

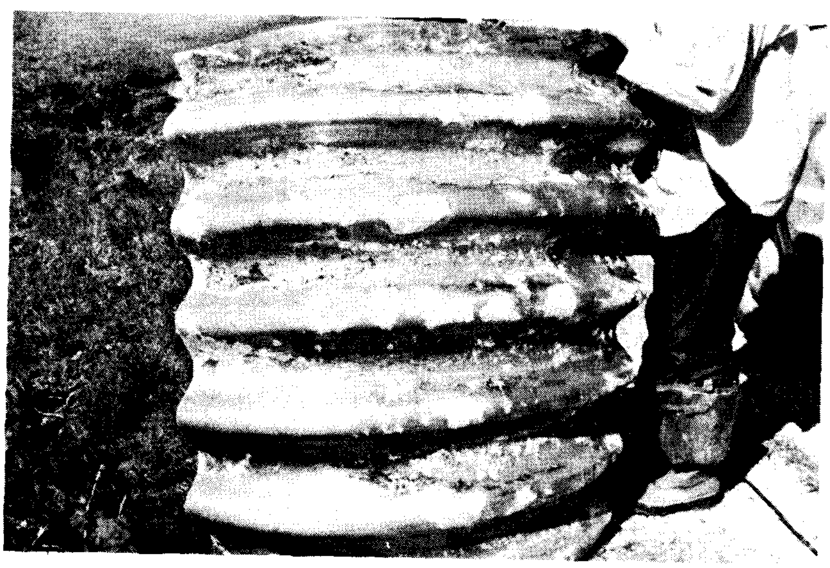
Figure 29 is a photograph of the aluminum plate arch at site 9 after two years of field exposure. Figures 30 and 31 demonstrate the two types of deterioration occurring in the aluminum culverts--pitting and general thickness loss.



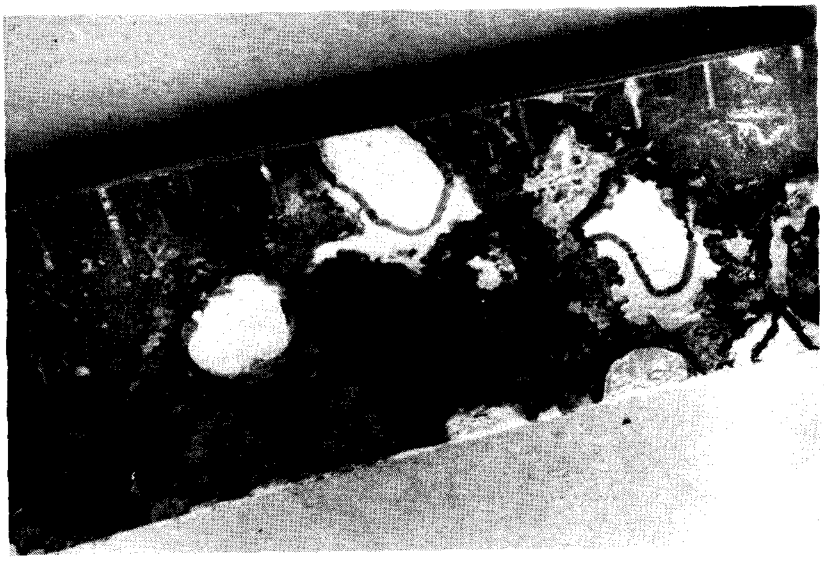
Panel Ratings of Aluminum Plate Arch
FIGURE 27



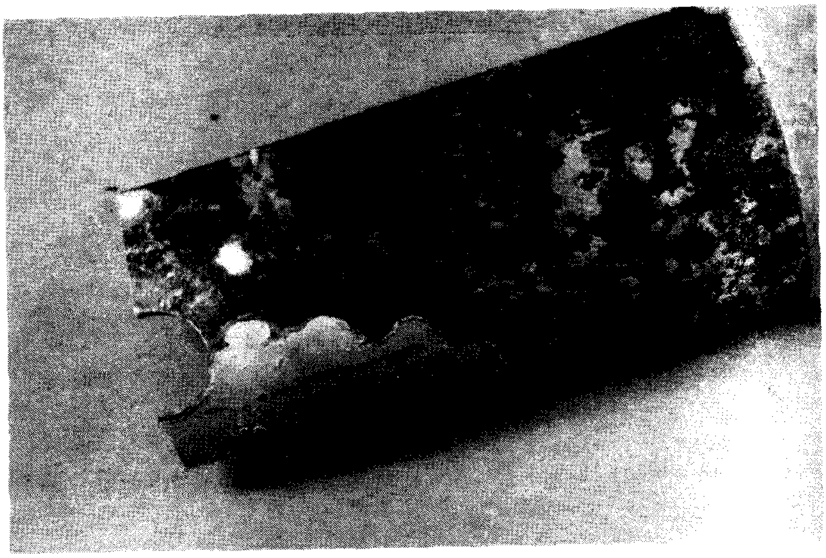
Laboratory Ratings of Samples from Aluminum Test Plate Arch
FIGURE 28



Photograph of Aluminum Plate Arch at Site No. 9 after Two Years
FIGURE 29



Pitting of Aluminum Plate
FIGURE 30



General Thickness Loss of Aluminum Plate
FIGURE 31

CONCLUSIONS

1. The types of culverts providing the best resistance to corrosion after two years of field exposure are the asbestos-bonded asphalt-coated galvanized steel pipe and the galvanized steel pipe coated on exterior and interior with polyethylene. This is the concensus of a panel who inspected the test culverts in the field and of an engineer who examined samples of the test culverts in the laboratory.

2. All of the coated and uncoated galvanized steel and aluminum pipes under evaluation are exhibiting various degrees of resistance to corrosion after two years in the field. In none of the test culverts has the metal experienced complete perforation.

3. Electrical resistivity of the effluent is the primary factor controlling corrosion of the galvanized steel and aluminum culverts. The test pipes are experiencing the greatest amounts of corrosion at those four test sites where the electrical resistivity of the effluent is less than 300 ohm-cm.

4. Coatings are providing significant protection to the galvanized steel test pipes located in severely corrosive environments. Unfortunately, these same environments are providing the severest tests of durability for the coatings. Coating failures now in evidence may allow an increase in the rate of corrosion of the parent metal culverts at these sites.

5. Two years of field exposure have provided a limited basis to compare performances of the various test culverts. Future inspections could provide more information regarding the durability of these culverts. Such inspections are planned.

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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 32

TABLE 3

ANALYSIS OF METAL PIPE BY X-RAY FLUORESCENCE

Steels:	Galvanized	A.C.G.P.	A.B.A.C.P.	Nexon (12-mils)	Nexon (20-mils)	Inland (12/5-mils)	Inland (10/3-mils)
Sample:	#5	#7	#6	#1	#2	#4	#8
Element							
Zn	tr	tr	tr	tr	tr	tr	0.065
Cu	0.215	0.20	0.215	0.215	0.25	0.195	0.175
Ni	tr	tr	tr	tr	tr	tr	tr
Ti	tr*	tr*	tr*	tr*	tr*	tr*	tr*
Ca				tr			
K				tr			
Mn				0.36	0.4		0.06
Si	0.8	1.21	1.98	1.82	1.48	1.2	0.96

tr = trace, $<$ 0.01%

tr* = trace, extremely small, $<$ 0.001%

Ca & K - amount unknown due to lack of standards; may be $<$ 0.1%

Aluminum Alloys:	A.C.A.P.	Aluminum Pipe	Aluminum Plate
Sample:	#3	#9	#10
Element			
Cu	0.04	0.035	0.075
Zn	high, ~ 1%	High, ~ 1%	0.045
Mg	$<$ 0.1	0.1	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

TABLE 4

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	---	---	---

*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 5

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

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 6

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

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