TECHNICAL REPORT STANDARD PAGE

1. Report No. FHWA/LA-94/289	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Feasibility of Applying Cathodic Protection to Underground Culverts	5. Report Date January 1995 6. Performing Organization Code	
7. Author(s) J. D. Garber, Ph.D., P.E., J. H. Lin, Larry G. Smith, P.E.	8. Performing Organization Report No. 289	
9. Performing Organization Name and Address University of Southwestern Louisiana Chemical Engineering Department Lafayette, LA 70504	10. Work Unit No. 11. Contract or Grant No. 88-4P(B)	
12. Sponsoring Agency Name and Address Louisiana Transportation Research Center 4101 Gourrier Avenue Baton Rouge, LA 70808	13. Type of Report and Period Covered Final Report 1988 - 1994 14. Sponsoring Agency Code	

15. Supplementary Notes
Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

The Louisiana Department of Transportation and Development uses coated metal culverts throughout the state. Once placed, all coated metal culverts start to experience corrosion. The extent of corrosion taking place on these culverts range from slight to heavy depending upon many factors including the type and quality of the coating(s) and metal, time in service, construction/placement practice and the corrosiveness of the environment into which they are placed. This study was undertaken to assess the feasibility of applying cathodic protection both externally and internally to metal culverts to prevent corrosion from occurring.

The methodology employed ranged from a variety of laboratory tests to an actual field study. The laboratory tests were conducted: (1) to evaluate test methods in an effort to determine the best coating system to use in conjunction with cathodic protection and (2) to prove that internal cathodic protection using zinc anodes would work inside jointed metal culverts. The field work consisted of installing 10-foot (2, five foot joined) sections of eight different types of culverts with and without cathodic protection. Current and potential measurements were regularly made during this five-year field study.

The only laboratory test that was able to predict the best performing coating/metal system on steel was the 13-gallon water tank test using magnesium anodes. The more sophisticated tests, potentiostat and impedance, were unable to make good predictions.

The results of the field study proved that culverts can be protected from corrosion using cathodic protection. It has been found that the outside of the culvert required significantly more current for protection than the inside. The culvert requiring the least amount of current was the polymeric coated galvanized steel culvert. Subjective ratings indicate that the cathodically protected culverts out perform the unprotected culverts.

It is recommended that cathodic protection be applied to coated metal culvert systems requiring extended design life when placed in low resistivity environments.

17. Key Words culverts, metal culverts, corrosion, anodes, cathodic protection		18. Distribution Statement Unrestricted. This document is available to the public through the National Technical Information Service, Springfield, Virginia 21161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Classified	21. No. of Pages 46	22. Price

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FEASIBILITY OF APPLYING CATHODIC PROTECTION TO UNDERGROUND CULVERTS

FINAL REPORT

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LTRC REPORT NO. 289
LTRC RESEARCH PROJECT NO. 88-4P(B)

Conducted For
LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT
LOUISIANA TRANSPORTATION RESEARCH CENTER
in cooperation with
U.S. Department of Transportation
FEDERAL HIGHWAY ADMINISTRATION

January 1995

ACKNOWLEDGEMENT

We sincerely appreciate the contribution of the following people at the La. DOTD who made helpful suggestions during the project: Mr. Steven L. Cumbaa, Mr. William H. Temple, and Mr. Kirt Clement.

Also, a special thanks to Mr. Eugene Waguespack and Mr. Bill Fontenot of La. DOTD District 03 for providing the staff and equipment needed to bury the test culverts at the Pecan Island site in 1989 and remove them in 1994.

ABSTRACT

The Louisiana Department of Transportation and Development uses coated metal culverts throughout the state. Once placed, all coated metal culverts start to experience corrosion. The extent of corrosion taking place on these culverts range from slight to heavy depending upon many factors including the type and quality of the coating(s) and metal, time in service, construction/placement practice and the corrosiveness of the environment into which they are placed. This study was undertaken to assess the feasibility of applying cathodic protection both externally and internally to metal culverts to prevent corrosion from occurring.

The methodology employed ranged from a variety of laboratory tests to an actual field study. The laboratory tests were conducted: (1) to evaluate test methods in an effort to determine the best coating system to use in conjunction with cathodic protection and (2) to prove that internal cathodic protection using zinc anodes would work inside jointed metal culverts. The field work consisted of installing 10-foot (2, five foot joined) sections of eight different types of culverts with and without cathodic protection. Current and potential measurements were regularly made during this five-year study.

The only laboratory test that was able to predict the best performing coating/metal system on steel was the 13-gallon water tank test using magnesium anodes. The more sophisticated tests, potentiostat and impedance, were unable to make good predictions.

The results of the field study proved that culverts can be protected from corrosion using cathodic protection. It has been found that the outside of the culvert required significantly more current for protection than the inside. The culvert requiring the least amount of current was the polymeric coated galvanized steel culvert. Subjective ratings indicate that the cathodically protected culverts out perform the unprotected culverts.

It is recommended that cathodic protection be applied to coated metal culvert systems requiring extended design life when placed in low resistivity environments.

IMPLEMENTATION STATEMENT

The results of this five-year study have verified that coated metal culverts can be cathodically protected using internal and external zinc anodes. Life-cycle costs, the risk potential of failure, and the 50 to 70-year design life of these structures would dictate that the La. DOTD should consider cathodically protecting coated metal culverts whenever these culverts require a long design life and are placed in harsh (low resistivity) environments. Design, installation, and monitoring procedures can be developed should the Department wish to implement cathodic protection of metal culverts.

Cathodic protection may also be applied to existing culverts to extend their service life (at their existing condition) indefinitely. Retrofit cathodic protection systems will generally consume more anode material than equivalent new installations depending upon existing coating effectiveness and coating/metal condition. Condition survey, design, installation, and monitoring procedures could be developed should the Department wish to implement retrofit cathodic protection for existing metal culverts.

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INTRODUCTION

This study was undertaken to determine the feasibility of applying cathodic protection to metal drainage culverts. Field studies conducted previously by the Louisiana Department of Transportation (La. DOTD) (1) verified that most coated metal culverts experience severe corrosive attack in low resistivity soils after exposure times of ten years or less. The nature of the corrosion attack is, primarily, caused by oxygen in the soil and water. At the same time, La. DOTD is installing culverts with design life expectancies of 50 to 70 years. From the previously mentioned study, it is obvious that coatings alone will seldom provide the long term protection necessary and, therefore, an alternative system should be considered. Coated metal culverts in conjunction with cathodic protection appear to be a viable alternative.

The application of cathodic protection to the outside of pipes has been extensively studied and standards (2) have been established. One company in California, Farwest Corrosion Control Co., actually presents the design by which one can apply external cathodic protection to culverts. However, to completely protect the buried culvert from corrosion, cathodic protection must be installed internally as well as externally. It is the primary interest of this study to determine the current required to completely cathodically protect metal culverts having different types of coating. Another consideration is the practical aspect of providing internal cathodic protection to culverts with 24-inch or larger diameters.

A careful survey of the available literature on the application of cathodic protection to culverts has revealed that only external anodes have been applied. There has also not been any previous work done to determine the effectiveness of various coatings in culverts when cathodic protection is being used.

Researchers at Mobil Oil Company (3) have applied internal cathodic protection in cement-lined piping and have found that the larger diameter pipes gave the best current distribution. A zinc spool anode gave sufficient cathodic protection at a distance of more than 50 times the diameter of the pipe. Similar results were found by Groover and Peterson (4) who showed that low carbon steel pipes in stagnant sea water would be completely protected only when the diameters were larger than two inches. Cathodic protection was most effective in systems where there was a slow flow rate of corrosive fluid.

MacKay and Grace (5) designed a zinc anode assembly and tested it inside tanker pipelines containing stagnant sea water. The anode used inside a 14-inch steel pipe produced a current density of 14.5 ma/m^2 and provided cathodic protection over a length of 520 pipe diameters.

A paper by Simpson and Robinson (6) examined which coatings on steel pipes work best in conjunction with cathodic protection. It was found that the worst blistering occurred at the highest protective potentials. The best coatings proved to be epoxy and coal tar epoxy systems. These coating systems showed no deterioration after four years of exposure.

The above papers represent the limited amount of literature that is available on the application of internal anodes to corroding systems. It is clear that this project can provide information that is very important to a better understanding of applying cathodic protection to metal culvert systems that have different types of coatings.

OBJECTIVES

The objectives of this study include:

1) To develop and evaluate laboratory and bench scale tests in an effort to evaluate various coating systems for use in conjunction with cathodic protection.

2) To verify in the laboratory that cathodic protection can be applied internally to joined sections of metal culverts before going to the field.

3) To evaluate the performance of eight different types of coated culverts in the field when installed with and without anodes. Installation is to be in a harsh (corrosive) environment.

4) To monitor the potentials and current requirements of the field-installed culverts as a function of time to obtain design data for later field installations.

SCOPE

The scope of this project included a laboratory evaluation and single site field installation and evaluation of eight protected and unprotected coated metal systems. The laboratory work and the field installation are documented in the interim report. This phase of the project addresses the field monitoring of the culverts, the subjective evaluation of the effectiveness of cathodic protection in reducing corrosion at this site during the period of evaluation and the establishment of preliminary cathodic protection design parameters.

Eight coated metal culvert systems are examined in this project, representing most of the culvert types from which the La. DOTD can currently choose. It is anticipated that other types of coated metal culverts may enter the market place in the future. For this reason, laboratory test methods were developed and evaluated in an effort to identify a laboratory screening tool which may help in coating evaluation and the cathodic protection design process.

DISCUSSION OF RESULTS

In the interim report No. FHWA/LA-91/238, three (3) different areas of this study were completed and reported. They were:

(1) Evaluation of various culverts in the laboratory to estimate which coated metal culvert system should respond best to cathodic protection.

(2) Proving in the laboratory that it is possible to apply cathodic protection inside the joined sections of metal culverts.

(3) The actual installation of the cathodically protected and unprotected culverts in the field.

This final report documents the data obtained during the five year period of field exposure and the subjective evaluation of the effectiveness of cathodic protection from a visual examination. Preliminary cathodic protection design parameters are established and the economics related to cathodic protection of coated metal culverts are discussed.

<u>Field Removal of Culverts</u>

On June 2, 1994, approximately five (5) years after being buried, the sixteen (16) ten-foot culverts (2 five-foot culverts connected together) were removed by La. DOTD from the field test site on La. 3147 in Pecan Island just south of the Fresh Water Bayou pontoon bridge. Site 1, closest to the pontoon bridge, contained the cathodically protected culverts. The cathodically protected culvert systems consisted of a 1.4" x 1.4" x 60" zinc anode installed on the inside and outside of each culvert. Site 2 approximately 200 yards south of site 1, contained eight (8) duplicate 10-foot sections of un-protected culverts. The coated metal culvert systems installed at these 2 locations are as listed below:

Culvert ID.	Culvert Type
A	Polymeric Coated Cold-Rolled Steel
B	Polymeric Coated Aluminized Type II Steel
C	Polymeric Coated Aluminized Type I Steel
D	Polymeric Coated Galvanized Steel (Supplier 2)
E	Polymeric Coated Galvanized Steel (Supplier 1)

TABLE 10

VISUAL RATING OF COATING

Type Culvert	Unprotected	Protected	Difference
Polymeric Coated Cold-Rolled Steel	2.4	2.6	-.2
Polymeric Coated Aluminized Type II Steel	4.1	2.0	2.1
Polymeric Coated Aluminized Type I Steel	3.6	2.1	1.5
Polymeric Coated Galvanized Steel (Supplier 2)	2.1	1.8	0.3
Polymeric Coated Galvanized Steel (Supplier 1)	2.0	1.9	0.1
Bituminous Coated Galvanized Steel	3.8	3.3	0.5
Galvanized Steel	3.8	3.1	0.7
Fiber-Bonded Bituminous Coated Galvanized Steel	2.9	2.5	0.4
Average	3.1	2.4	+0.7

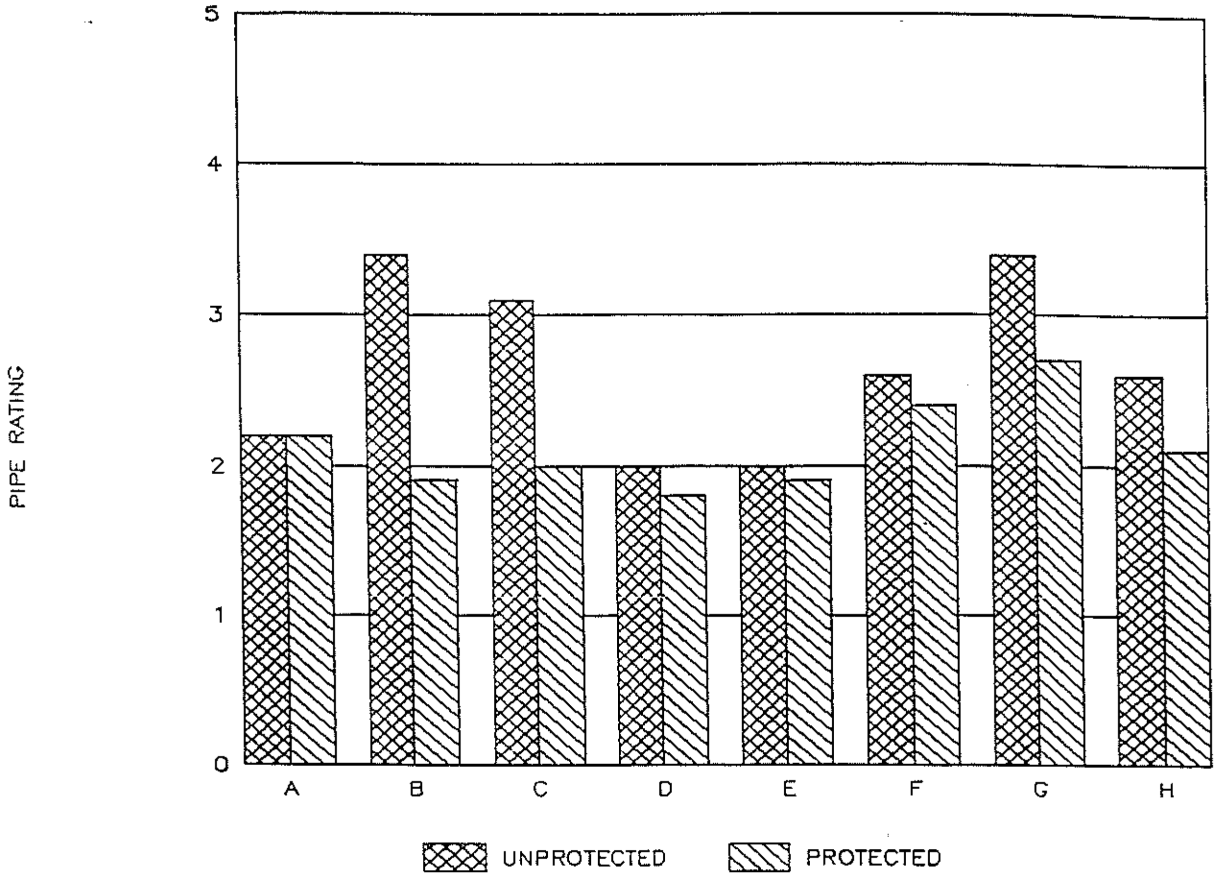


Figure 8. Visual rating of pipe after completion of field study.

TABLE 9

VISUAL RATING OF PIPE

Type Culvert	Unprotected	Protected	Difference
Polymeric Coated Cold-Rolled Steel	2.2	2.2	0
Polymeric Coated Aluminized Type II Steel	3.4	1.9	1.5
Polymeric Coated Aluminized Type I Steel	3.1	2.0	1.1
Polymeric Coated Galvanized Steel (Supplier 2)	2.0	1.8	0.2
Polymeric Coated Galvanized Steel (Supplier 1)	2.0	1.9	0.1
Bituminous Coated Galvanized Steel	2.6	2.4	0.2
Galvanized Steel	3.4	2.7	0.7
Fiber-Bonded Bituminous Coated Galvanized Steel	2.6	2.1	0.5
Average	2.7	2.1	0.6

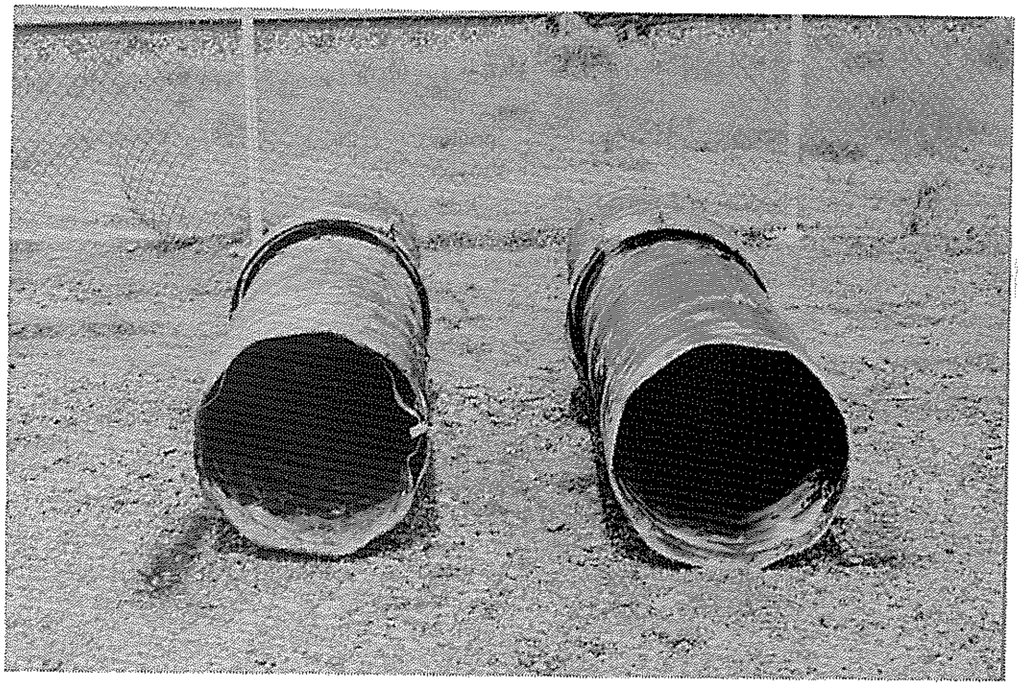


Figure 7. Unprotected (left) and cathodically protected (right) polymeric coated aluminized Type II steel culvert.

TABLE 2

INTERNAL POTENTIAL READINGS
(AVERAGE OF LAST TWO MEASUREMENTS)

Culvert	Protected Potential, Volts	Unprotected Potential, Volts	Difference Volts
Polymeric Coated Cold-Rolled Steel	-1.029	-0.551	0.478
Polymeric Coated Aluminized Type II Steel	-1.033	-0.621	0.413
Polymeric Coated Aluminized Type I Steel	-1.024	-0.623	0.401
Polymeric Coated Galvanized Steel (Supplier 2)	-1.031	-0.614	0.417
Polymeric Coated Galvanized Steel (Supplier 1)	-1.028	-0.695	0.334
Bituminous Coated Galvanized Steel	-1.024	-0.927	0.097

TABLE 3

EXTERNAL POTENTIAL READINGS
(AVERAGE OF LAST TWO MEASUREMENTS)

Culvert	Protected Potential, Volts	Unprotected Potential, Volts	Difference Volts
Polymeric Coated Cold-Rolled Steel	-1.004	-0.555	0.490
Polymeric Coated Aluminized Type II Steel	-1.046	-0.623	0.423
Polymeric Coated Aluminized Type I Steel	-1.043	-0.627	0.416
Polymeric Coated Galvanized Steel (Supplier 2)	-1.037	-0.619	0.418
Polymeric Coated Galvanized Steel (Supplier 1)	-1.038	-0.697	0.342
Bituminous Coated Galvanized Steel	-1.038	-0.879	0.159
Galvanized Steel	-1.006	-0.775	0.231

TABLE 4

INTERNAL AND EXTERNAL CURRENT READINGS (AVERAGE OF LAST TWO MEASUREMENTS)

Culvert	Outside Current ma	Inside Current ma	Total Current ma
Polymeric Coated Cold-Rolled Steel	54	18	72
Polymeric Coated Aluminized Type II Steel	43	27	70
Polymeric Coated Aluminized Type I Steel	44	39	83
Polymeric Coated Galvanized Steel (Supplier 2)	32	21	53
Polymeric Coated Galvanized Steel (Supplier 1)	47	40	87
Bituminous Coated Galvanized Steel	39	32	71
Galvanized Steel	79	61	140

TABLE 5

FIVE (5) YEAR AVERAGE CURRENT VALUES OF CULVERTS

Culvert	Outside Current ma	Inside Current ma	Total Current ma
Polymeric Coated Cold-Rolled Steel	72	18	90
Polymeric Coated Aluminized Type II Steel	58	20	78
Polymeric Coated Aluminized Type I Steel	39	20	59
Polymeric Coated Galvanized Steel (Supplier 2)	24	13	37
Polymeric Coated Galvanized Steel (Supplier 1)	35	22	57
Bituminous Coated Galvanized Steel	40	18	58
Galvanized Steel	61	29	90

Over the five-year test period, the two polymeric coated galvanized steel culverts required the lowest amount of total current. The polymeric coated cold-rolled steel and the galvanized steel required the most current. However, during the most recent time period, Table 4 shows that at the five-year mark, the fiber-bonded bituminous coated galvanized steel is requiring slightly less current than the polymeric coated galvanized steel from (Supplier 2).

Based on the current measurements, it was possible to calculate the approximate weight loss of the internal zinc anodes using the fact that zinc looses 25 pounds/amp-yr. The calculated values over the five-year life are presented in Table 6. The values ranged from 1.6 pound loss for the polymeric coated galvanized steel (Supplier 2) to a high of 3.6 pounds for galvanized steel. Before weighing, each anode had to be descaled, since there was calcium carbonate scale on all the anodes. The final weights were then subtracted from the initial weights and the results are presented in Table 6.

The measured anodes weight loss ranged from 1 to 3.5 pounds and on the average were within 1/2 pound of the calculated values.

Using this same approach, it was possible to calculate the weight loss of the external anodes which could not be recovered after the test was completed. Table 7 shows that these values ranged from 2.9 to 9.0 pounds of zinc loss for the polymeric coated galvanized steel (Supplier 2) and the polymeric coated cold rolled steel, respectively.

From the results in Table 6 and 7, it is possible to obtain the total zinc loss. Table 8 shows the tabulated data for total zinc loss and reveals that the polymeric coated galvanized steel culverts had to the lowest anode loss and the galvanized steel culverts having the highest anode loss. Although the polymeric coated cold rolled steel culvert requires 10.5 pounds of zinc, it should

TABLE 6

INTERNAL ZINC ANODE WEIGHT LOSS DURING FIVE-YEAR STUDY, LBS.

Culvert	Average Current ma	Calculated Weight Loss	Measured Weight Loss
Polymeric Coated Cold-Rolled Steel	18.2	2.28	1.5
Polymeric Coated Aluminized Type II Steel	19.6	2.45	1.5
Polymeric Coated Aluminized Type I Steel	19.9	2.48	1.0
Polymeric Coated Galvanized Steel (Supplier 2)	12.8	1.59	1.5
Polymeric Coated Galvanized Steel (Supplier 1)	22.0	2.75	2.0
Bituminous Coated Galvanized Steel	17.8	2.23	3.0
Galvanized Steel	28.5	3.56	3.5
Fiber-Bonded Bituminous Coated Galvanized Steel	14.2	1.78	1.0
Average		2.39	1.9

TABLE 7

EXTERNAL ZINC ANODE CALCULATED WEIGHT LOSS DURING FIVE-YEAR STUDY

Culvert	Average Current ma	Calculated Weight Loss lbs.
Polymeric Coated Cold-Rolled Steel	71.7	8.96
Polymeric Coated Aluminized Type II Steel	57.6	7.20
Polymeric Coated Aluminized Type I Steel	38.6	4.82
Polymeric Coated Galvanized Steel (Supplier 2)	23.5	2.94
Polymeric Coated Galvanized Steel (Supplier 1)	34.7	4.34
Bituminous Coated Galvanized Steel	40.3	5.04
Galvanized Steel	60.7	7.58
Fiber-Bonded Bituminous Coated Galvanized Steel	55.0	6.88

TABLE 8

TOTAL ZINC WEIGHT LOSS DURING FIVE-YEAR STUDY, LBS.

Culvert	Internal Weight Loss	External Weight Loss	Total Weight Loss
Polymeric Coated Cold-Rolled Steel	1.5	9.0	10.5
Polymeric Coated Aluminized Type II Steel	1.5	7.2	8.7
Polymeric Coated Aluminized Type I Steel	1.0	4.8	5.8
Polymeric Coated Galvanized Steel (Supplier 2)	1.5	2.9	4.4
Polymeric Coated Galvanized Steel (Supplier 1)	2.0	4.3	6.3
Bituminous Coated Galvanized Steel	3.0	5.0	8.0
Galvanized Steel	3.5	7.6	11.1
Fiber-Bonded Bituminous Coated Galvanized Steel	1.0	6.9	7.9

Visual Examination of Culverts

After the culverts were removed from the field, they were transported to the DOTD district 03 office in Lafayette. The eight sets of ten foot culverts were placed side by side, unprotected next to protected. Figure 7 shows this arrangement for the polymeric aluminized Type II steel culvert with the unprotected culvert on the left. The bolts on the bands were cut so that any corrosion under the band could be exposed.

The culverts were subjectively rated, by 14 individuals, within 2-weeks of their removal using a rating system with 1 being excellent and 5 being poor. Decimals were allowed to help in this discrimination. This rating description sheet used is given in Appendix A. The ratings were then averaged, and the results for the unprotected and protected culverts were tabulated and graphed.

Table 9 shows the average values of the subjective visual rating of the degree of corrosion occurring in the metal of the 8 coating/culvert combination. A rating of 1 represents the case of the metal in excellent condition while a rating of 5 represents extremely poor metal condition. In every case except for the polymeric coated cold rolled steel, the cathodically protected pipes were judged to be in better condition than the unprotected ones. The polymeric coated aluminized Type II steel culvert showed the highest difference (1.5 units) between the unprotected and protected culvert. The average difference was found to be 0.6 units. Figure 8 shows a bar graph representation of these results.

Table 10 gives the average values of the visual rating for the coatings on various culverts. A rating of 1 represents a coating in excellent condition while a rating of 5 represents a coating that is no longer of value. The subjective rating of the coating indicated that the cathodically protected culvert coatings averaged 0.7 units better than the unprotected culverts. The

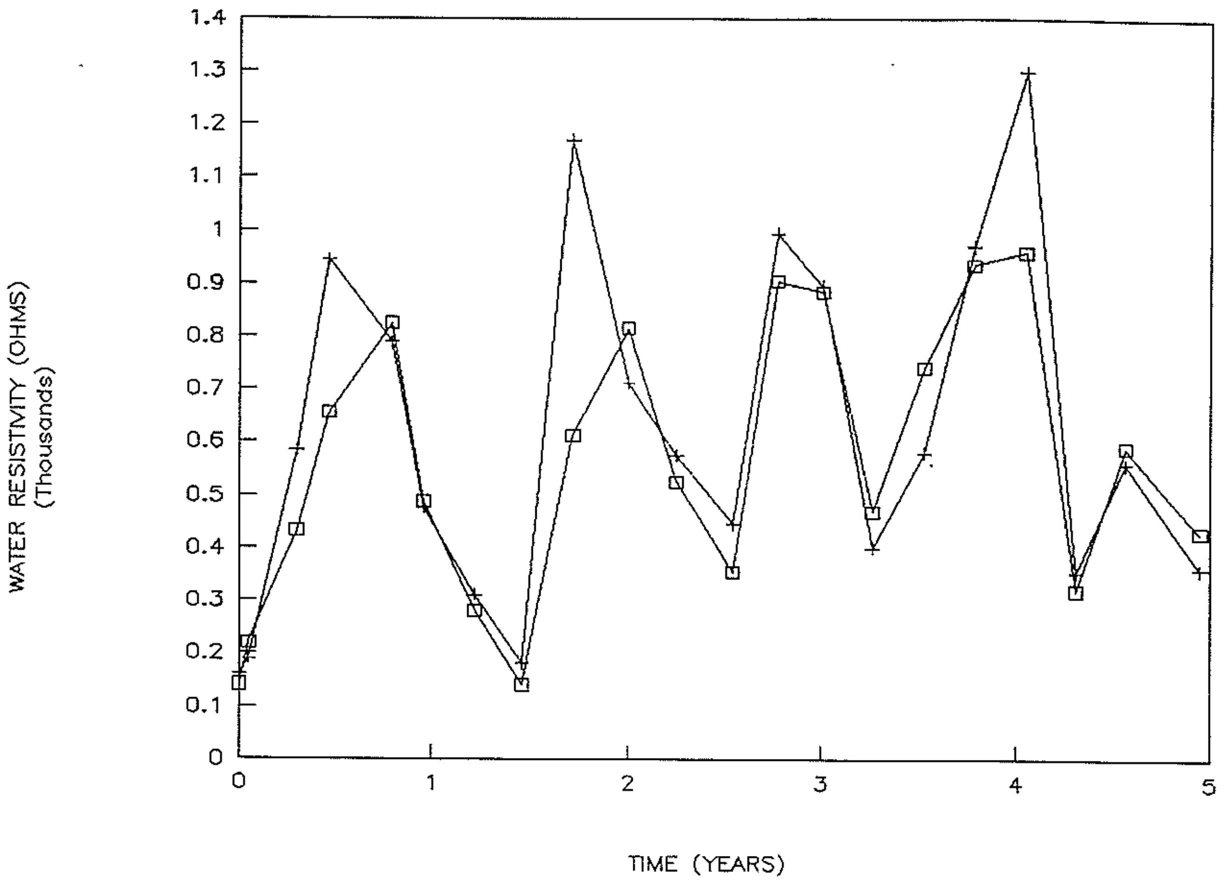


Figure 6. Water resistivity versus time for the protected (□) and unprotected (+) sites.

The results of the electrochemical laboratory tests and a description of the field installation of the culverts were presented in Interim Report No. FHWA/LA-91/238 along with initial field measurements of current requirements and potential during the first two years of exposure.

The electrochemical laboratory evaluation included Potentiostat, AC Impedance, and current draw and weight loss measurements from coupon samples placed in an aerated salt solution within a 13 gallon water tank. These tests were conducted and evaluated in an effort to develop a coating/metal effectiveness measure for use in future evaluations of other coating/metal combinations. The results of the Potentiostat and AC Impedance electrochemical laboratory tests were inconsistent and inconclusive when compared to the subjective performance ratings. The 13 gallon tank test as described in the interim report provided rankings consistent with the subjective performance ratings.

Full scale laboratory tank tests were also conducted to determine the feasibility of applying internal cathodic protection for jointed culverts sections, prior to installation in the field. The full scale laboratory tank tests indicated that internal protection of jointed sections of metal culvert was feasible.

In this final report, all of the field results obtained after installation of the culverts are presented. The condition of the various coatings on the culverts after five years of exposure to this harsh environment is also reported. Based upon the current requirements and anode consumption rates for the test culverts during the five-year period, estimates of anode consumption and associated costs to protect metal culverts for extended periods of time can be calculated.

Site pH, Resistivity and Chloride Content

At the time of installation, the water was found to have a pH and chloride content of 7.7 pH and

TABLE 1

RESISTANCE READING AT THE FIELD TEST SITES
(Ω-Cm)

		Site 1 (Protected)		Site 2 (Unprotected)	
Date	Day	Soil	Water	Soil	Water
6/13/89	0		140		160
6/30/89	17		220		190
9/30/89	109	428	432	370	585
11/30/89	170		655		945
3/30/90	290		825		790
5/30/90	351		488		475
8/31/90	444		280		310
11/31/90	535		140		180
2/28/91	625		613		1170
6/13/91	730		815		712
9/13/91	822		525		575
12/26/91	926		355		445
3/20/92	1011		905		995
6/13/92	1096		885		895
9/14/92	1189		470		400
12/21/92	1287		740		580
3/23/93	1379		935		970
6/30/93	1478		960		1300
10/8/93	1573		320		355

unprotected site. Figure 6 shows a plot of this water resistivity data versus time for both the protected and unprotected sites. These results show a cyclic pattern and a slightly upward trend toward higher resistivity during the five-year period. The reason for this fluctuation is unknown but may be related to seasonal rainfall variations. Based upon the above data, it is evident that the two sites were of comparable corrosiveness.

Culvert Potential (Voltage) and Current Measurements

The potential or voltage of any metal in water or soil can indicate if the metal is being protected or is corroding. In this study, a copper-copper sulfate reference electrode was used to determine if the culverts were below the -0.850 Volt potential necessary to prevent the steel beneath the coating from corroding. The average open circuit potential (not connected) of the zinc anode used in the study was -1.093 V versus the copper-copper sulfate reference electrode.

Measurements of the potential of the protected and unprotected culverts were made on both the inside and outside each time the site was visited.

Table 2 and 3 show the average internal and external potential readings obtained during the last two visits. The larger this potential difference, the more the structure is being protected. From this information, the polymeric cold-rolled steel appears to have experienced the greatest potential shift while the bituminous galvanized steel received the least amount of potential shift. A -0.30 volt shift in potential is considered adequate to provide cathodic protection.

The cost of this protection is directly related to the current requirement. This is because the zinc anode is consumed at a rate of 25 pounds/amp-year. Table 4 gives the average internal and external current readings for the last two visits, and Table 5 gives average current values both inside and outside for the five-year duration.

Figure 4. Each culvert is sprayed inside and outside with water.

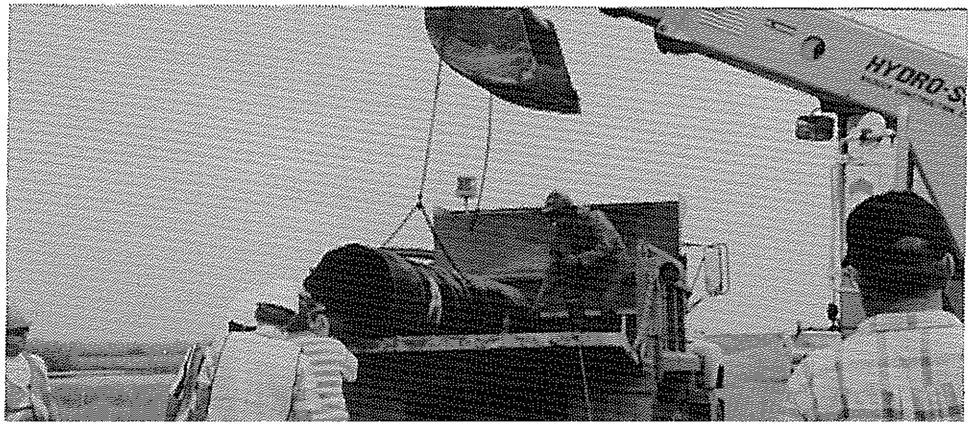


Figure 4. Each culvert is sprayed inside and outside with water.

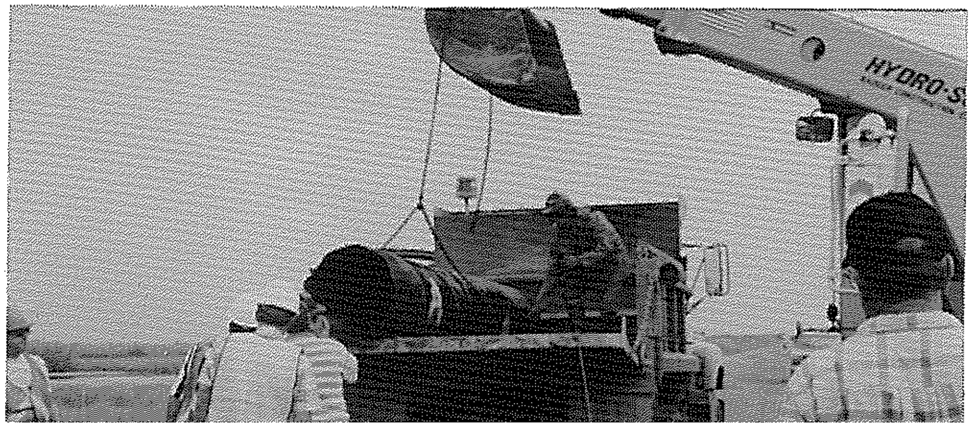
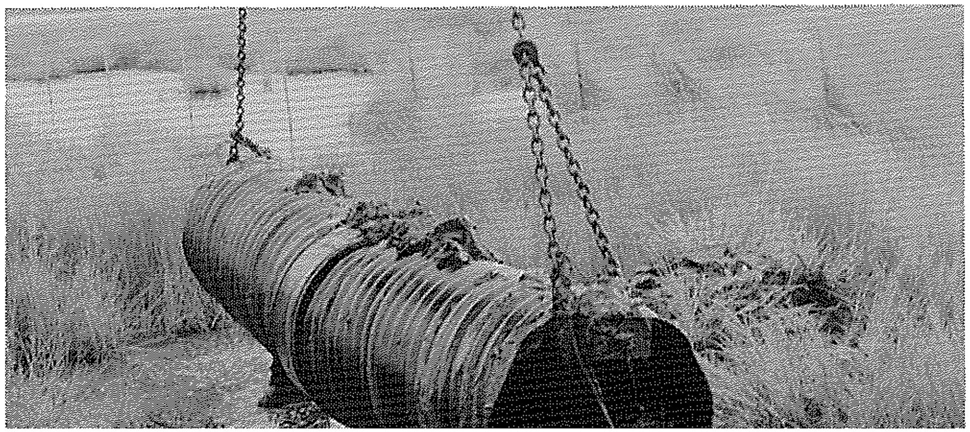


Figure 2. The excavator is seen lifting a culvert.



F	Bituminous Coated Galvanized Steel
G	Un-Coated Galvanized Steel
H	Fiber-Bonded Bituminous Coated Galvanized Steel

The removal of the sixteen (16) culverts was accomplished in one day by using equipment and men from Louisiana DOTD. Figure 1 shows the soil being removed from the top of a test culvert. Once the soil on top of the buried culvert was removed a twelve-foot 4" x 6" beam was passed through the culvert. Figure 2 shows the chains attached to both ends of the beam and the culvert being lifted by the excavator (Grade-All). Figure 3 shows the culvert being removed from the ground and that there was a considerable amount of sediment inside this culvert. This sediment was removed by dumping and spraying the inside and outside with water, Figure 4. After wash up was completed, each culvert was visually observed, tagged and then placed on a DOTD truck for transport to the District 03 Headquarters in Lafayette, Figure 5.

TABLE 11

OVERALL VISUAL RATING

Type Culvert	Unprotected	Protected	Difference
Polymeric Coated Cold-Rolled Steel	2.4	2.4	0
Polymeric Coated Aluminized Type II Steel	3.8	2.0	1.8
Polymeric Coated Aluminized Type I Steel	3.4	2.0	1.4
Polymeric Coated Galvanized Steel (Supplier 2)	2.1	1.8	0.3
Polymeric Coated Galvanized Steel (Supplier 1)	2.1	1.9	0.2
Bituminous Coated Galvanized Steel	3.2	2.8	0.4
Galvanized Steel	3.6	2.8	0.8
Fiber-Bonded Bituminous Coated Galvanized Steel	2.7	2.2	0.5
Average	2.9	2.2	0.7

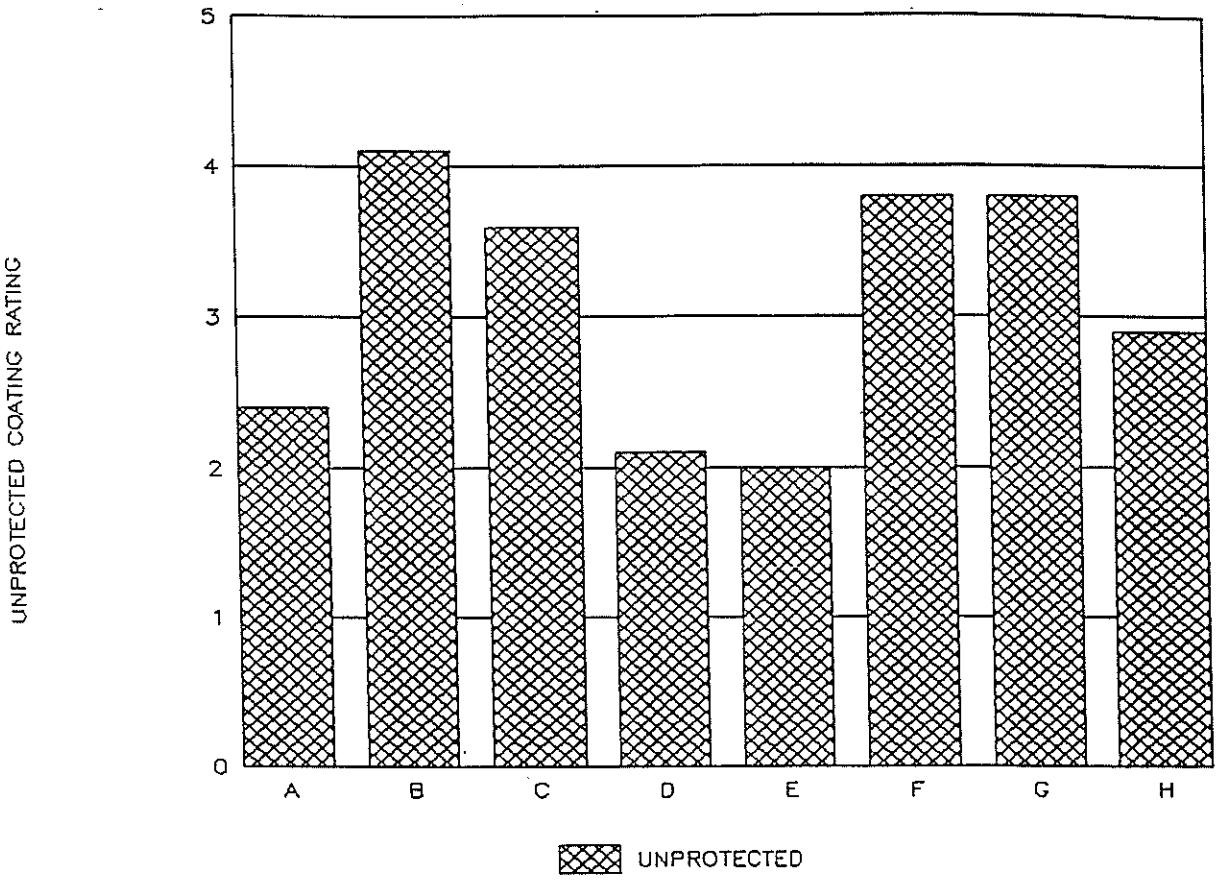


Figure 10. Visual rating of the coatings of the unprotected culverts.

An indication of coating quality can be obtained by looking at only the unprotected culvert coating ratings. Based upon these results, it is possible to rank the coatings on the culverts for the 8 materials tested for five-years in this corrosive environment. The polymeric coated galvanized steel culvert (Supplier 1) rated the best with a value of 2.0 while the polymeric aluminized Type II steel culvert was worst with a rating of 4.1. A bar graph of these results clearly show this rating. Figure 10.

Table 11 gives the overall visual subjective ratings of the coated metal culverts. A rating of 1 represents a culvert in excellent overall condition while a rating of 5 represents a culvert in extremely poor overall condition. This table shows that the average overall condition was 0.7 units better for the protected culverts than the unprotected ones. The polymeric coated aluminized Type II steel obtained the worst overall rating and the polymeric coated galvanized steel culvert (Supplier 1) obtained the best rating. Figure 11 shows a bar graph of these results.

It should be noted that on every one of the unprotected culverts, there was notable corrosion on the bolts in the connection bands. The protected culverts did not shown any corrosion on these bolts. Since the condition of the bands is critical to the integrity of the culverts, it is clear that only cathodic protection will be able to provide long term life to the culverts in this project.

Design Factor and Economics

The results presented so far in this report show that applying cathodic protection to culverts works. The culverts that were cathodically protected were subjectively judged to be in better condition than those that were unprotected after only five years of exposure. It is believed that the difference between the protected and unprotected metal culverts would become increasingly more pronounced for increased periods of exposure.

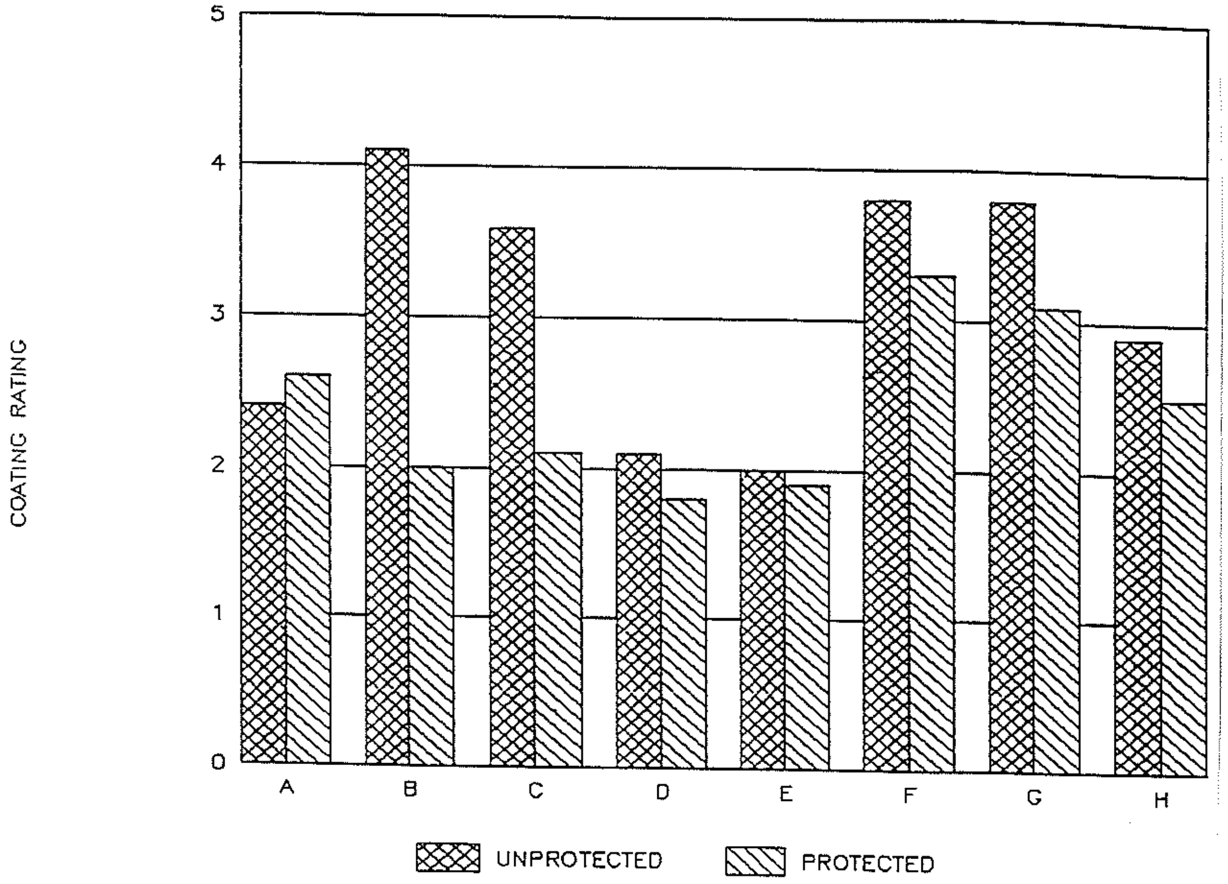


Figure 9. Visual rating of coating on culvert after completion of field study.

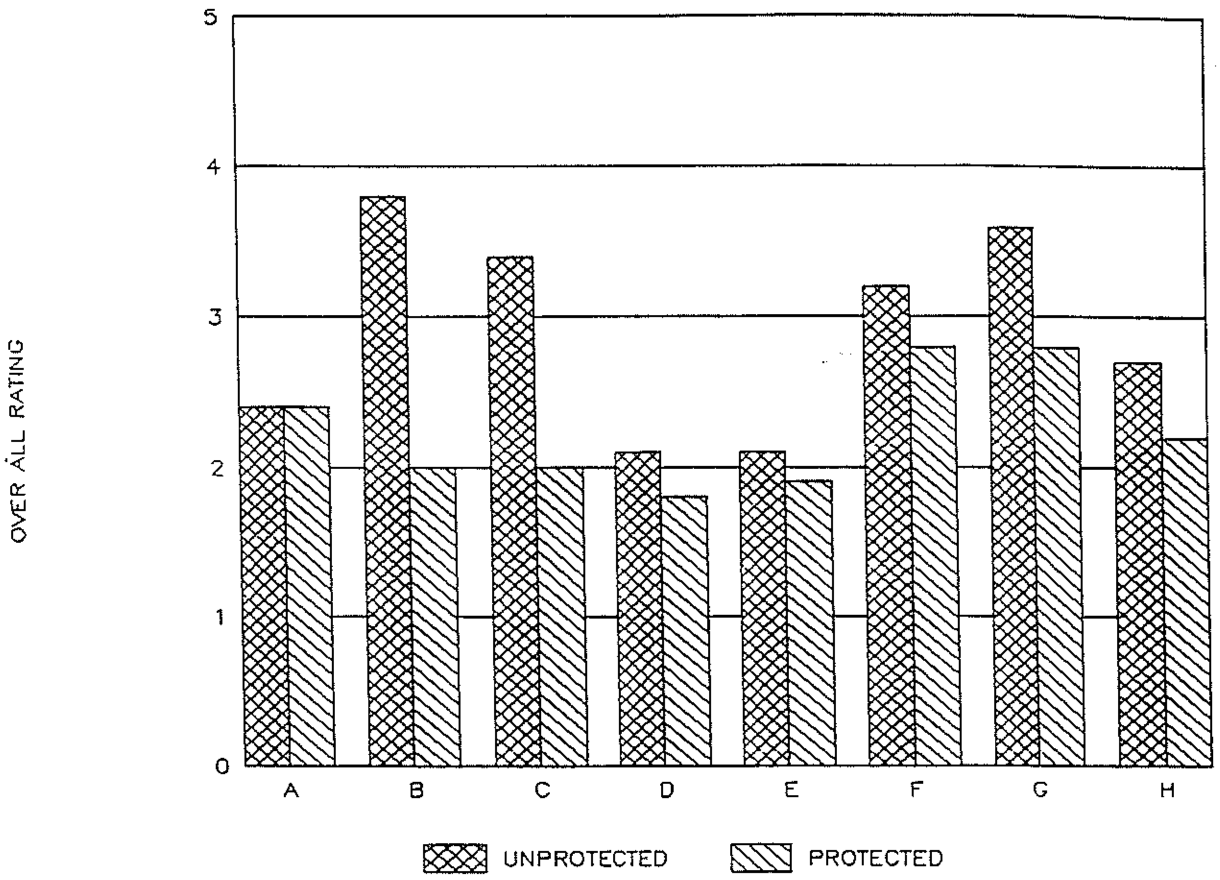


Figure 11. Visual rating of overall culvert condition after completion of field study.

galvanized steel culvert would consume 198 lbs. of zinc in 75 years and still be in very good condition. The current cost of zinc anode material is approximately $1.75/lb. which translates into a total cost of $346. One estimate of the materials cost of installing a culvert in the Pecan Island area is $85/foot and the culverts in that area have historically lasted for 25 years. The cost of replacing one 30 foot culvert would be $2550. Based on three replacements in 75 years, it can be seen that cathodic protection is an extremely cost effective method of protecting steel culverts.

To assist in designing such a cathodic protection system, it is good to have some design factors such as the current required per square foot of area to be protected. Since current readings have fluctuated over the five-year period, but have largely stabilized during the past year, it was decided to use the average of the last two current readings (Table 4) to establish a design factor. The corrugated culverts used in this study were 2 feet in diameter and 10 feet long which gives an inside and outside surface area of 62.8 ft^{2}. An area factor to correct for the Type A corrugation is 1.073. This increases the area, inside and outside, to 67.4 ft.^{2}. The galvanized steel culvert is used in this calculation since it does not have any coating to reduce the exposed area. Since the resistivity of the soil was lower than the water by about 25%, it is no surprise that the outside current 79 ma is about 25% higher than the inside current of 61 ma. Based on this current data, the current density for the soil side is 79 ma/67 ft.^{2} or 1.2 ma/ft.^{2} and the water side is 0.9 ma/ft.^{2}. These values agree with general design data in practice which calls for 1 to 3 ma/ft.^{2} for steel in soil and water. These values are a little low because of the remaining zinc on the galvanized culvert.

As would be expected, the coated culverts should show a reduction in current requirement since the surface area exposed to the environment is reduced. Table 4 verifies this fact. The inside and outside currents were greater for the galvanized steel culvert than the others by a factor of

Since zinc anodes are being used for protection, the galvanized coating on the culverts will eventually be removed which will lead to more coating disbondment and greater current requirements. The cold-rolled steel does not have any zinc and therefore, in the long term, should not experience any further coating failure. For that reason, it appears to be a good long term material to use under these conditions.

CONCLUSIONS

- All culverts in the field have successfully responded to both internal and external cathodic protection. The measured potentials indicate that the protected culverts never approached the -0.85V value required for corrosion of steel.

- Even though the resistivity of the water at the protected site varied from 140 to 960 Ω-cm, the zinc anodes were able to protect the culverts. The resistivity of the water at this site appeared to undergo seasonal cycles.

- The field study showed that a culvert disconnected from the anode can be readily identified. After reconnection to the anode, the potential and current values returned to normal almost immediately.

- The unprotected culverts in the field were losing the protection they were receiving from their galvanized or aluminized coatings, and they were experiencing corrosion. This is verified since the potentials were always more positive than the -0.85V potential value.

- After removal from the field, a visual inspection of the unprotected culverts showed that the polymeric coated galvanized culverts looked the best. The polymeric coated aluminized Type II steel culvert was judged to be in the worst condition.

- The subjective rating of the metal condition showed an average of 0.6 unit positive difference between the unprotected and protected while the rating of the coating showed a positive difference of 0.7 units. Overall, the rating difference was found to be a positive 0.7 units. For this very short five year period, this difference can be considered

- During the five-year study, the polymeric coated galvanized steel culverts required less total current than any other culvert under evaluation.

- The last two current readings made on the culverts showed that the fiber-bonded bituminous galvanized steel was beginning to out-perform the polymeric coated galvanized steel (Supplier 2).

- The uncoated galvanized steel culvert was requiring 1.2 ma/ft^2 on the soil side and 0.9 ma/ft^2 on the water side. These design factors are in line with general field information. Most of the coated steel culverts were at least 50% effective at reducing the current as compared to uncoated galvanized steel requirement during this five year period.

- All coated culverts can be economically protected by cathodic protection. The total anode consumption (inside and outside) showed that the 2 foot diameter by 10 foot long polymeric coated galvanized steel culvert (Supplier 2) required only 4.4 lbs. of anode material over a five-year period for protection. Scaling up to a 24 inch diameter, 30 foot long culvert for a 75-year period would consume only 198 lbs. of zinc. at an anode cost of approximately $400.00.

- It was noted that the bolts holding the bands together on the unprotected culverts were experiencing corrosion which would eventually destroy the integrity of the culvert. On the protected culverts, the bolts were in excellent condition.

- The polymeric coated cold rolled steel may eventually out-perform all the culverts since it does not have any zinc to lose which leads to coating disbondment and higher current requirements.

- Based on total current requirements, recent current measurements, and projected trends, the culverts recommended for cathodic protection are: polymeric coated cold-rolled steel, fiber-bonded bituminous coated galvanized steel, and polymeric coated galvanized steel.

- A 13 gallon water tank test, which was described in the interim report, measured the current applied by a magnesium anode to protect the various culvert materials. The test appears to be the best available laboratory method. This 14-day test correctly predicted that the polymeric coated galvanized steel and fiber-bonded bituminous steel culverts would respond best to cathodic protection. The field results now verify this fact.

RECOMMENDATIONS

Based on the positive nature of this feasibility study, it is recommended that the LaDOTD consider utilizing cathodic protection on metal culverts whenever these culverts are placed in harsh environments and have extended design lives. This recommendation becomes increasingly important for large structures under major highways in areas with resistivities less than 1500 ohm-cm. If implementation is not feasible at this time, then consideration should be given to providing the electrical connectivity between jointed culvert for new installations such that retrofit at a later date is made easier.

It is also recommended that consideration be given to identifying several projects in several parishes south of I-10 under which large metal culverts exist. The culverts on these projects should be identified as to age, diameter, length, coating type, culvert condition, soil and water pH, and resistivity. Based upon the results of the survey, retrofit cathodic protection systems could be designed and installed at the culvert locations on three or four of the projects in an effort to gain needed additional information and experience relative to retrofit design, installation, and performance.

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APPENDIX A

TABULATION OF THE INTERNAL AND EXTERNAL POTENTIAL OF THE PROTECTED AND UNPROTECTED CULVERTS VERSUS TIME

DRAINAGE CULVERT VISUAL EVALUATION

CULVERT TYPES

POLY COATED COLD ROLLED, NON GALVANIZED STEEL
POLY COATED ALUMINIZED STEEL, TYPE II
POLY COATED ALUMINIZED STEEL, TYPE I
POLY COATED GALVANIZED STEEL, (SUPPLIER 2)
POLY COATED GALVANIZED STEEL, (SUPPLIER 1)
BIT COATED GALVANIZED STEEL
UNCOATED GALVANIZED STEEL
ARAMID FIBER BONDED, BIT COATED GALVANIZED STEEL

RATING SCALE

EXCELLENT........GOOD........POOR........VERY POOR........BAD

1 ....2 ....3 ....4 5

<u>RATINGS</u>		<u>VISUAL OBSERVATION</u>
1	<u>PIPE</u>:	NO SIGNS OF PITTING OR CORROSION, METAL IN EXCELLENT CONDITION
	<u>COATING</u>:	NO SIGNS OF BLISTERING OR DELAMINATION, COATING IN EXCELLENT CONDITION
	<u>OVERALL</u>:	PIPE IN EXCELLENT OVERALL CONDITION
2	<u>PIPE</u>:	MODERATE SIGNS OF PITTING OR CORROSION, METAL IN GOOD CONDITION
	<u>COATING</u>:	MODERATE SIGNS OF BLISTERING OR DELAMINATION, COATING IN GOOD CONDITION
	<u>OVERALL</u>:	PIPE IN GOOD OVERALL CONDITION
3	<u>PIPE</u>:	HEAVY SIGNS OF PITTING OR CORROSION, METAL IN POOR CONDITION
	<u>COATING</u>:	HEAVY SIGNS OF BLISTERING OR DELAMINATION, COATING IN POOR CONDITION
	<u>OVERALL</u>:	PIPE IN POOR OVERALL CONDITION
4	<u>PIPE</u>:	VERY HEAVY SIGNS OF PITTING OR CORROSION, METAL IN VERY POOR CONDITION

DRAINAGE CULVERT VISUAL RATING

PIPE	RATING OF PIPE 1 - 5	RATING OF COATING 1 - 5	OVERALL RATING 1 - 5
1-1			
1-2			
1-3			
1-4			
1-5			
1-6			
1-7			
1-8			
2-1			
2-2			
2-3			
2-4			
2-5			
2-6			
2-7			
2-8			

RATING SCALE

EXCELLENT........GOOD........POOR........VERY POOR........BAD

1 ....2 ....3 ....4.................5

USE DECIMALS WHEN APPROPRIATE

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