Cathodic Protection of Culverts
Field Application and Expert System

PB2000-103352

Final Report

by

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LTRC REPORT NO. LA-99 / 324
LTRC RESEARCH PROJECT NO. 97-1IMP

Conducted For
LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT
LOUISIANA TRANSPORTATION RESEARCH CENTER

June 1999

TECHNICAL REPORT STANDARD PAGE

1. Report No. LA-99 / 324	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle **Cathodic Protection of Culverts – Field Application and Expert System**	5. Report Date **June 1999** 6. Performing Organization Code	
7. Author(s) **J.D. Garber, Ph.D., P.E.** **Larry G. Smith, P.E.**	8. Performing Organization Report No.324	
9. Performing Organization Name and Address **University of Southwestern Louisiana** **Chemical Engineering Department** **Lafayette, LA 70504**	10. Work Unit No. **LTRC Project Number: 97 – 1IMP** 11. Contract or Grant No. **State Project Number: 736-99-0435**	
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** **Period Covered: Jan 1997 – June 1999** 14. Sponsoring Agency Code	

15. Supplementary Notes

16. Abstract

Coated metal culverts are used throughout the state of Louisiana. These culverts are susceptible to both internal and external corrosion once they are placed in the ground. It is simply a matter of time before all of the culverts in the state corrode through and failure occurs. An earlier study illustrated that applying cathodic protection might be an economically feasible method of protecting these culverts from both external and internal corrosion.

The implementation of cathodic protection to a culvert system already in existence was performed at the 122-mile marker of I-49. Three ten-foot diameter parallel culverts, which were 360 feet long each, were retrofitted for cathodic protection and monitored for 2 years. The installation cost was $25,863 and was achieved in 5 working days. Cathodic protection is working very well externally, but due to excessive internal coating damage, internal cathodic protection could not be achieved.

Application of cathodic protection to a much smaller, new culvert system was achieved in 1 day on Highway 757 in Eunice, Louisiana at a cost of $3,495. This culvert was 4 feet in diameter and 60 feet long. After 1 year of monitoring, cathodic protection is working well both internally and externally in this new culvert system.

The information obtained from these two installations provided sufficient data to develop a computer expert system. This windows based program provides the user with economics of installing a cathodic protection system on any metal culvert system in the state of Louisiana given information on the culvert, its expected life and the various environmental parameters.

A technical manual gives the details of the calculation procedure used and a "User's Manual" gives information on how to use the program.

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

ABSTRACT

Coated metal culverts are used throughout the state of Louisiana. These culverts are susceptible to both internal and external corrosion once they are placed in the ground. It is simply a matter of time before all of the culverts in the state corrode through and failure occurs. An earlier study illustrated that applying cathodic protection might be an economically feasible method of protecting these culverts from both external and internal corrosion.

The implementation of cathodic protection to a culvert system already in existence was performed at the 122-mile marker of I-49. Three ten-foot diameter parallel culverts, which were 360 feet long each, were retrofitted for cathodic protection and monitored for two years. The installation cost was $25,863 and was achieved in five working days. Cathodic protection is working very well externally, but due to excessive internal coating damage, internal cathodic protection could not be achieved.

Application of cathodic protection to a much smaller, more recent culvert system was achieved in one day on Highway 757 in Eunice a cost of $3,495. This culvert was four feet in diameter and 60 feet long. After one year of monitoring, cathodic protection is working well both internally and externally in this new culvert system.

The information obtained from these two installations provided sufficient data to develop a computer expert system. This windows based program provides the user with economics of installing a cathodic protection system on any metal culvert system in the state given information on the culvert, its expected life, and the various environmental parameters.

A technical manual gives the details of the calculation procedure used and a "User's Manual" gives information on how to use the program. Also given with the model is the generic procedure for anode installation on new and existing culvert systems.

ACKNOWLEDGEMENT

We sincerely appreciate the contributions of the people at the DOTD who made helpful suggestions during the project: Mr. Neil Bennett, Mr. Bill Fontenot, Mr. William H. Temple, Dr. Babak Naghavi, Mr. Kirt Clement, Mr. Walid Alaywan, and Mr. Art Rogers.

Special thanks to Mr. Neil Bennett of Natchitoches and Mr. Shannon Fontenot of Eunice who were both helpful in providing the staff and equipment needed to apply cathodic protection to a retrofit culvert and new culvert system.

IMPLEMENTATION STATEMENT

The results of this three-year study have clearly shown that cathodic protection can be applied to both new and retrofit culverts. Since all metal culverts in the field will eventually corrode and collapse, it is recommended that cathodic protection be applied in cases where replacement would be more costly than applying cathodic protection. The new culvert system installation showed corrosion protection internally as well as on the exterior. However, on the retrofit system, cathodic protection worked externally but excessive internal coating damage made it ineffective on the interior. It is believed that in some cases only external cathodic protection may be sufficient protection for culverts that remain dry most of the time.

The expert system developed from the data obtained in these field studies provides the economics needed to decide if cathodic protection should be applied to a new or retrofit system. This system will be made available to the DOTD Hydraulics Section for developing alternates to concrete pipe in situations where the metal pipes have been excluded because of low pH and resistivity values.

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INTRODUCTION

Louisiana uses metal culverts though out the state for drainage purposes. Concrete culverts are also used, but the large concrete culverts are generally more expensive; also, the foundation has to be able to bear their weight. In contrast, metal culverts are less expensive concrete and the soil is typically suitable to bear their weight. However, the use of steel culverts creates a new problem - corrosion.

Until now, no attempts have been made to apply any corrosion mitigation method to these metal culverts. They are simply replaced after failure occurs. To protect these buried culverts completely, both internal and external cathodic protection should be employed. A sacrificial anode system using magnesium or zinc anodes could be used depending on the environment. In soils with resistivities of between 100-550 ohm-cm, a zinc anode is preferred. Between 550 to 10,000 ohm-cm, magnesium anodes are used and above 10,000 ohm-cm, the system is impractical to use.

Soils are known to vary considerably in their corrosivity. A study by Stratfull on over 70,000 culverts in California produced a good correlation between the first penetration of a metal culvert and the soil pH and its minimum resistivity *[2]*. This chart was later developed into an average culvert life chart in which it was estimated that 25 percent of metal loss in a culvert was a good average service life *[3]*. Azar performed a comparison of Louisiana culverts and found that the correlation was valid *[4]*.

Studies conducted by Temple et al revealed that exposure times of ten years or less in low resistivity environments caused severe damage to most underground-coated metal culverts. They concluded that coatings alone would not provide the required life of 50 to 70 years *[5]*.

In 1988, the Louisiana Department of Transportation funded its first project involving the use of cathodic protection on a number of coated culverts *[1]*. Eight different types of coated steel culverts were located in low resistivity soil and water for a period of five years. One set of the culverts received cathodic protection and the other set did not. Zinc anodes were used both internally and externally in the low resistivity environment. It was concluded that any coated culvert could be protected by cathodic protection.

As an extension of this work, in 1996 the Louisiana Department of Transportation funded the current study to apply the technology of cathodic protection to the field. The plan was to apply cathodic protection to an existing culvert system, "retrofit", and to a new culvert installation. These installations would provide the information necessary to establish the economic feasibility of using cathodic protection and to reveal any and all problems that would be associated with such an installation.

From this information, an expert system could be developed which would provide the state with information such as the economics of each culvert cathodic protection installation as well as how to physically install the anodes.

OBJECTIVES

The study's objectives includes the following:

1. To install and monitor cathodic protection on a previously installed ten foot diameter bituminous coated galvanized steel culvert system at the 122-mile marker on I-49. The system consisted of three parallel culverts that were 360 feet long each.

2. To install and monitor cathodic protection on a new culvert installation on Highway 757 in Eunice. The bituminous-coated galvanized steel culvert was four feet in diameter and 60 feet long.

3. To use the above information to develop an expert system in Visual Basic which will provide the user with the following information:

   a. A procedure for the generic installation of cathodic protection on a new or retrofit culvert system.

   b. The economics of installation of a cathodic protection system broken down by categories such as labor, equipment, and materials for the installation.

   c. A physical layout of the culverts and the location of the anodes around and inside the structure.

   d. A technical manual that gives the entire calculation procedure used in the program.

   e. A "User's Manual" to assist in the running of the model.

   f. Input Data sheets for a new or retrofit culvert.

SCOPE

The scope of this project included the installation and monitoring of a cathodic protection system on a new and a retrofit culvert. Both culverts were bituminous-coated galvanized steel. The new culvert was relatively small, four feet in diameter and 60 feet long, while the retrofit culvert system was ten feet in diameter and was 1080 ft of length. Each system was monitored for current demand and potential to show that they were being protected from corrosion by the cathodic protection.

Due to the relatively different sizes of the two culverts installed in this study, the information obtained was broad enough in range to be able to predict with some certainty the cost of future installations. An expert system has been developed which gives the economics of any installation anywhere in the state of Louisiana. The number of anodes required for the installation is determined based on the type of coating used. The location of the anodes and a generic installation procedure is also provided.

METHODOLOGY

In 1988 the Louisiana Department of Transportation funded its first project involving the implementation of cathodic protection on coated culverts. It concluded that any new-coated culvert could be protected both internally and externally by cathodic protection.

The current study, which started in 1996, was designed to apply this technology to the field. The plan was (1) to apply cathodic protection to an existing culvert system, (2) to apply cathodic protection to a new culvert system, and (3) to develop an expert system that would be helpful in future cathodic protection installations.

Both cathodic protection systems were installed by Corrosion Control, Inc. of Lafayette, Louisiana in an efficient and timely manner. The data on the cost of all equipment and labor was carefully recorded for use in developing the expert system. The two installations were very different in size and therefore represented a broad range of culvert systems in the state. Data measurements were made on a regular basis on both installations that verified the effectiveness of the cathodic protection.

A windows based expert system was developed to predict the cost of a retrofit or new culvert cathodic protection installation. The "California Chart" provided the basis for the corrosion rate of culverts in various soils. The two field installations also provided data on the amount of time required to perform the installations and verified the cost of the installation.

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DISCUSSION OF RESULTS

This study was designed to complete a project, started back in 1988, of evaluating the economic feasibility of applying cathodic protection to metal culverts in Louisiana [1]. This project consisted of installing cathodic protection on retrofit (existing) and new culvert system and monitoring the test results. From this information, an expert system could be designed which would provide the cost of installing cathodic protection on any culvert anywhere in the state.

This report documents the cathodic protection installation process for the two culverts. The retrofit system has been monitored for two years and the new culvert has been monitored for a period of one year.

Retrofit Culvert

The State of Louisiana uses metal culverts at various locations of the state for drainage purposes. About 12 years ago, three ten-ft diameter culverts were installed under I-49 with a life expectancy of 70 years. These culverts which are buried 20 ft under the interstate I-49, are located at the 122-mile marker south of Natchitoches. They have a bituminous coating applied on top of the zinc coating (galvanization) as is required of all metal culverts. The low resistivity soils around the culverts give a high corrosion rate, extra protection should be provided to protect these culverts since coatings alone would not provide the required life of 70 years. After taking into account the resistivities of the soil and water around the culverts, cathodic protection appeared to be a viable alternative. The culvert system consists of three parallel culverts that are 360 feet in length each. These ten gauge thick (0.138 inches) culverts are at an angle of 58° to the interstate and have a five-inch by one-inch corrugation. Knowledge of these dimensions is necessary to design a good cathodic protection system. However, to provide complete protection to the culverts, cathodic protection must be provided internally as well as externally.

The primary interest of this study was to determine the economic feasibility of using cathodic protection to protect the culverts. This requires knowledge of the amount of current required to completely protect the culverts. New installations have the advantage of having undamaged coating; conversely, the retrofit installation has the disadvantage of coating damage proportional to the time elapsed since its installation. The culverts at this site had been installed for 12 years at the time this study was started. This made protection of the culverts difficult to predict since the process of corrosion had already begun. The physical condition of the exposed culverts on the outside was negligible. The bituminous coating on the outside of the visible culverts was almost gone and bare zinc was exposed at many places. It was not possible to visually examine the outside coating on the buried culvert. The internal condition of the culverts was not good either: The bottom 2.5 feet of the three culverts were badly damaged and bare steel was partially exposed on the inside along the entire length of the culverts. The coating on top of the culverts' interior was in good condition with some damage observed in some places. There was 3 feet of thick mud inside these culverts from the spring floods that required cleaning before the actual installation of the cathodic protection system. It has been observed that, depending upon the season, water flows inside these culverts. Extreme cases of completely dry culverts to 3 feet of water inside the culverts have been observed. Figure 1 shows the three culverts on the south side of I-49. Figure 2 shows a close-up of the inside of one of the culverts. The amount of removed coating is visible in this photograph.

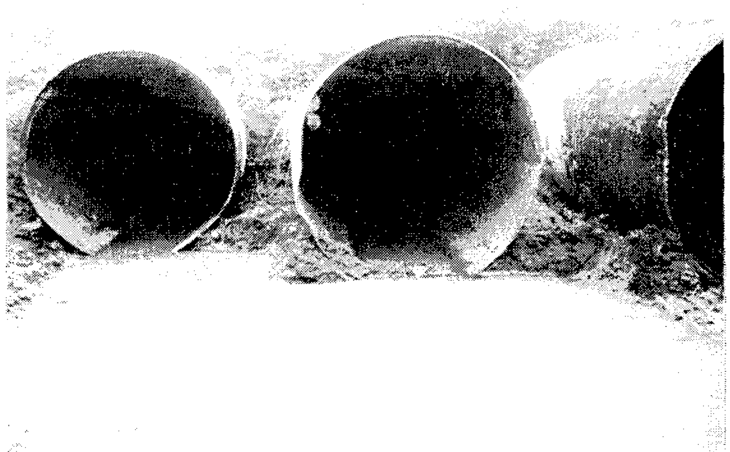

Figure 1
Three culverts on the south side of I-49 at the 122 mile marker

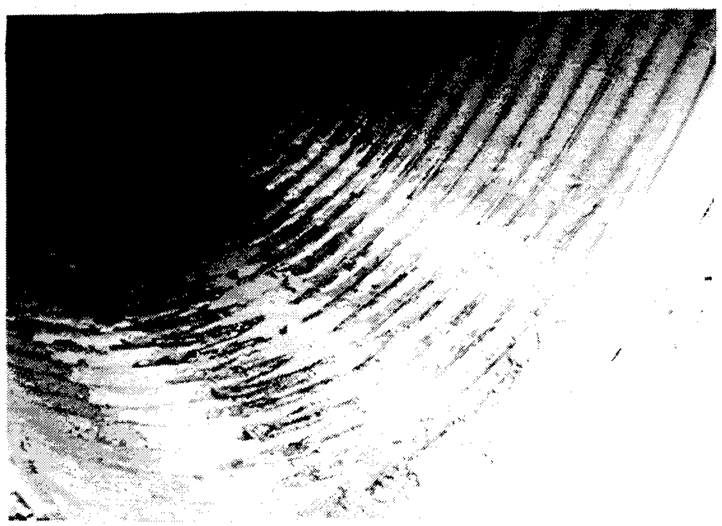

Figure 2
A Close-Up view of the inside of a culvert at I-49

To select the type of anode to use in this system, the pH and minimum resistivity of the soil and water had to be determined. Table 1 gives the values that were obtained during several visits to the site. The values are greater than 550 ohm-cm and less than 10,000 ohm-cm so magnesium was the anode chosen in this case.

Table 1
Minimum Resistivities and pH of Soil and Water at I-49

Date	Resistivity (ohm-cm)		pH	
	Soil	Water	Soil	Water
April 27, 1997	2200	1000	-	6.94
June 6, 1997	1500	5800	6.9	7.2
August 6, 1997	-	6800	-	6.8
October 8, 1997	-	3800	-	7.8
Jan 31, 1998	3700	4950	6.8	7.2
March 6, 1998	-	2300	-	6.9
June 10, 1998	4600	-	-	-
Oct 5, 1998	-	5400	-	7.1

a. Internal Anode Installation Prior to the actual installation of cathodic protection for these culverts, three ft of very thick mud was observed inside the culverts. Cleaning was judged necessary. The services of DOTD personnel and equipment were utilized under the supervision of Mr. Carlton Neil Bennett, an engineering supervisor of the Natchitoches DOTD. Backhoes were used to alternately dam the inlet flow to two of the three culverts on both ends and the undammed culvert was cleaned using the flow of water. The remaining dirt was removed from the culverts using wheelbarrows. A total of 400 cubic yards of dirt was removed from the three culverts. It took a total of 12 working days to clean the culverts and the cost of cleaning these culverts was estimated to be $13,000. Only after the culverts were cleaned could cathodic protection be installed internally.

Corrosion Control Inc., a Lafayette based contracting company, was responsible for the installation of internal as well as external cathodic protection for these culverts. A combustible gas detector was used as a precaution to check the atmosphere for the presence of combustible gases inside the culverts. Ten 44 lb H-1-Grade B magnesium anodes with dimensions 17.5 in by 8.5 in by 4 in and an open circuit potential of -1.5 V versus copper / copper sulfate in soil were installed inside the culverts as seen in Figure 3. The anodes were welded to the culvert to provide electrical continuity. Steel straps shaped like a " T " were used to electrically connect the different sections of a culvert as seen in Figure 4. A total of nine straps had to be welded in each of the ten sections of culvert that made the length of 360 feet. It took one full day to weld these straps and install 30 internal anodes in all three of the parallel culverts.

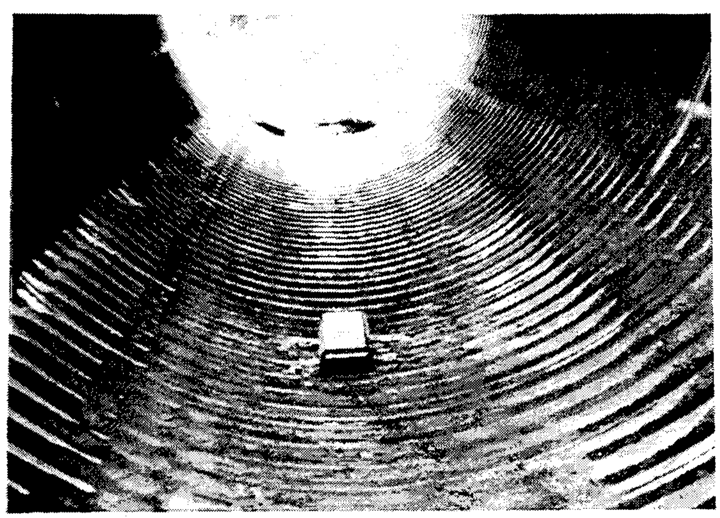

Figure 3
Internal anode attached to culvert

Figure 4
Metal strap used to electrically connect the culverts and band

b. External Anode Installation On the outside of this culvert system, a total of 114 high potential 20 D2 magnesium anodes was installed. Each anode had an open circuit potential value of -1.75 V and represented 20 lb of cylindrical (D) shaped anodes, which were about 5 feet in length. The anodes, which each had a copper lead at the end for electrical connection, were cylindrical in shape due to the backfill surrounding the anode as shown in Figure 5. Holes 14 ft deep and eight inch in diameter were drilled symmetrically on both sides of the interstate as well as between interstate lanes. Figure 6 shows holes being drilled on the north side of I-49. Two anodes were placed in each of the holes with about two feet of dirt and ten gallons of water poured down the hole on top of each anode. A total of 57 holes were drilled at symmetrical locations on the outside of these culverts.

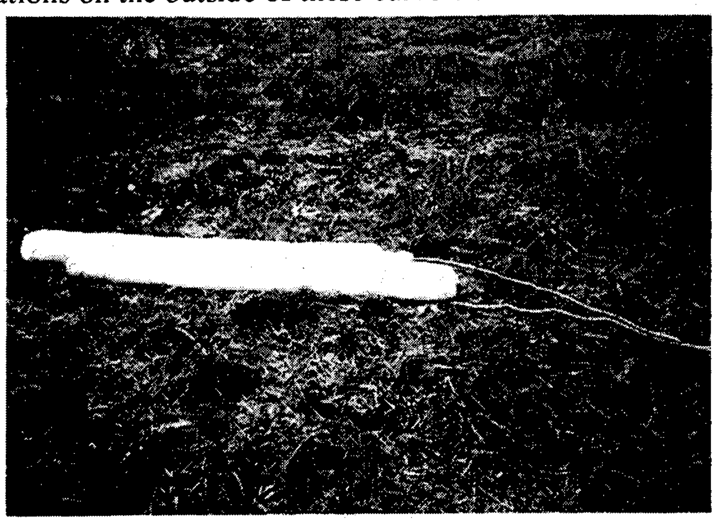

Figure 5
External Anodes Packed in Backfill

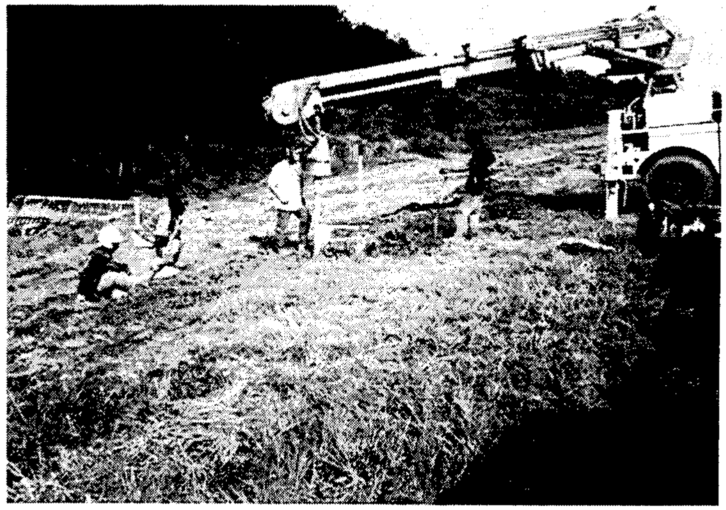

Figure 6
Hole being drilled for installation of two external anodes

Test stations were set up on each side of the interstate with the culverts and the anodes connected to them. There were four junctions in the test station on the south side of I-49 and five junctions in the test station on the north side of I-49. One of these leads was from the anodes between the interstate lanes, which required a bore under the interstate. Culvert numbers one, two, and three on the south side were connected to junction numbers 1, 2, and three respectively in the test station on the south side. All of the external anodes on the south side were connected to junction number 4 in the test station on the south side. The connections in the test station on the north side were set up similarly with the additional junction number 5 connecting the anodes between the interstate. Figure 7 shows the north side test station. The test stations allow measurement of the amount of current required by each culvert by measuring the voltage drop through a 0.01 Ω resistor. Since these anodes are known to be consumed at a rate of 18 lb/amp-yr, the amount of anode material consumed per year can be calculated. This information is important in determining the cost involved. If necessary, more anode material can be supplied later depending on the consumption rate.

It took five days to complete this job. The first day was used to install the internal anodes and make the electrical connection. The next four days were needed to drill the 57 holes and connect all of the anodes to the culverts.

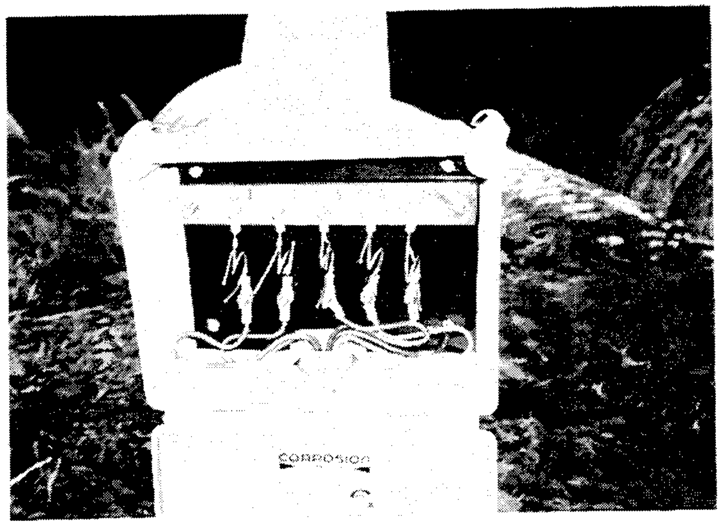

Figure 7
North test station for monitoring the current to culverts

New Culvert Installation The proposed site of the new culvert installation on LA Hwy 757 was visually inspected. Soil was taken from the site along with the water flowing in the ditch for pH and resistivity measurements. Table 2 shows the values for the site in question and it formed the basis for selecting magnesium anodes.

Table 2
Minimum resistivity and pH of soil and water at LA Highway 757culvert

Date:	Resitivity (ohm-cm)		pH	
	Soil	Water	Soil	Water
September 2, 1998	3300	15500	6.8	6.9
December 29, 1998		10,200		6.0

Figure 8 shows the trench being dug for the culverts that are shown on the right side of the photograph. The two four-foot diameter bituminous-coated steel culverts were 30 feet long each. Before the internal anode could be physically attached, an electric hand grinder was used to remove the bituminous coating away from the bottom portion of the culvert where the connections were to be made. The anodes could then be welded to provide an electrical connection. The six internal anodes used had dimensions of four inch by four inch by 1.5 foot long. In case of corrugated pipes, welding can be difficult and care must be taken to ensure welding of at least a part of the anode to the culvert. The internal anodes must be preferably long and thin so that there is a maximum amount of exposed area.

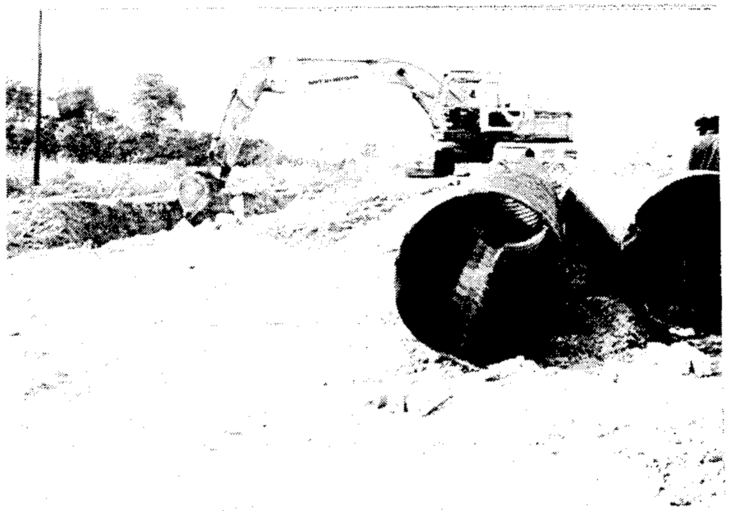

Figure 8
Trench being dug for installation of new culvert at Hwy 757

Figure 9 shows the layout of the anodes inside the culverts after being welded. The welded parts were coated with tar to reduce the exposed metal. A portable welding machine, welding screen and gas masks were needed to perform the entire operation. It was also necessary to have an adequate lighting system. During welding, gases can accumulate and should be removed by having a draft fan at one end of the culvert. This is especially true in small diameter culverts where the air circulation is restricted.

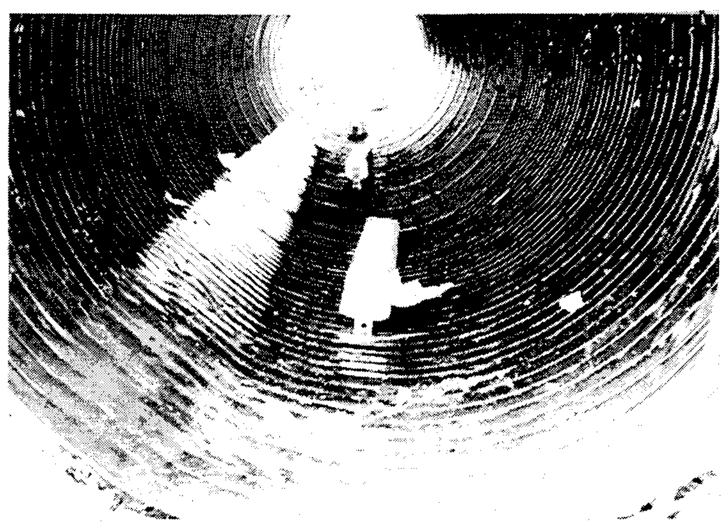

Figure 9
Internal anodes inside one of the culvert sections at Hwy 757.

After the internal anodes were installed, the next step was to dig holes at the bottom of the site on which the coated culvert was about to be laid for the purpose of installing the external anodes. Three holes about 32 inches deep and eight inches in diameter were dug. Figure 10 shows the manual digging of the holes for the external anode installation. Each hole was filled with a 32-pound magnesium anode packed with gypsum. Water was placed in the hole to increase conductivity. The leads from all of the external anodes were connected to a single lead wire that was then connected to both ends of the culvert.

Figure 10
Manual digging of holes for installation of external anodes.

Figure 11 shows the electrical sections being made to each section of the culvert. The culvert was then lifted and placed in the trench.

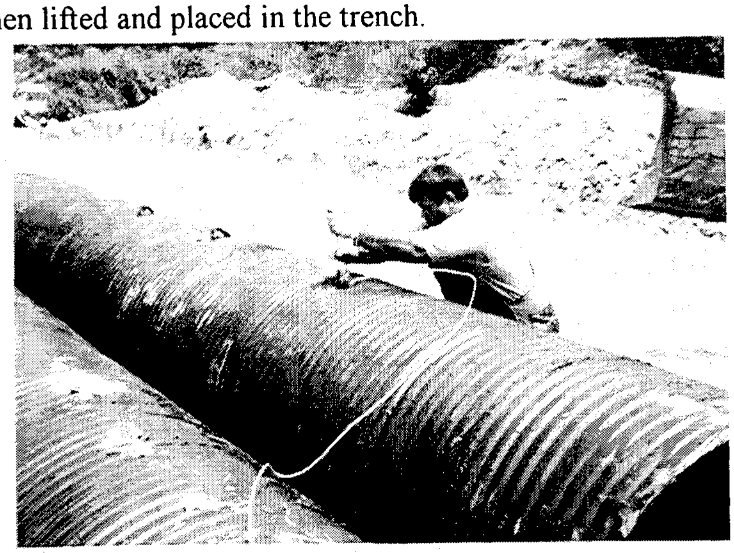

Figure 11
Electrical connection is being made to a section of culvert.

Once the coated culvert was placed in the trench, a steel strap was used to electrically connect the two sections of the culvert as shown in Figure 12.

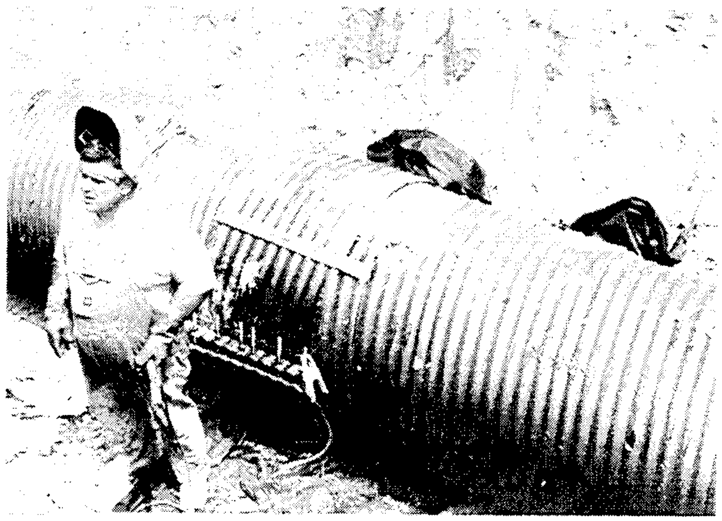

Figure 12
An external metal strip is used to electrically connect the culvert and band.

The steel bands were welded to the two adjacent sections of the culverts and then coated with tar and wrapped with insulating cloth.

Once the culvert was in place, dirt was added on both sides of the culvert to bury it. Figure 13 shows the culvert being buried with dirt. A copper wire was welded to the top of both ends of the culvert. A test station on each end of the culvert connected the two copper wires from the anode bed and the culvert through a 0.01Ω shunt resistor.

Figure 13
The culvert is being buried with dirt.

Figure 14 shows the culvert with the test station in place for potential and current measurements. The current required by the culverts could then be measured at the test stations. The potential of the culvert is designed to drop below the -1.1V potential of the galvanized metal to a potential close to that of the high potential magnesium anodes which is -1.7 V versus a copper/copper sulfate reference electrode.

Figure 14
The buried culvert with the test station in place.

It took approximately one day to complete the job. About half of the time was spent installing the internal anodes and half of the time was spent installing the external anodes.

Monitoring of the Culverts When cathodic protection is applied to an underground structure, there is a negative shift on its potential from its native value. To protect steel from corroding, the potential value must be more negative than –0.85 V versus copper/copper sulfate and to protect zinc it must be more negative than –1.1V versus copper/copper sulfate. Therefore, on a regular basis, the voltages on both culverts were measured and the average value was calculated. The monitoring was initially performed by Kedar and was continued and expanded in the work done by Balakrishnan *[6],[7]*.

In addition to the potential measurements, it was also necessary to monitor the current required of the external anodes for both culvert systems. These current measurements were obtained by measuring the voltage across the 0.01Ω shunt resistors that were installed at the test sites. It was not possible to measure the current expended by the internal anodes since they are in direct electrical contact with the culvert.

Retrofit Culvert Measurements. The three culverts at the I-49 test site were numbered one, two, and three; with one being the southernmost culvert. The way the system was initially designed, it was possible to measure the current and potential of each of the 3 culverts individually. The installation was performed on May 31, 1997 and readings were made periodically after that time.

Table 3 shows the current in amps that are going to each culvert and to the total culvert system. It is clear that the current is leveling off after about two years to about three amps/yr for the total system. Figure 15 shows the leveling effect. It can be seen that the final current is about half of the initial current value at time equal zero. At a consumption rate of 18-lb magnesium/amp-yr, this amount of current is consuming about 55 lb of magnesium/yr as can be seen in Figure 16. At $5/lb this corresponds to an annual cost of $275/yr for external corrosion protection.

Proof that the external current is protecting the culverts can be seen in Figure 17. All three culverts are well above the –1.1 V value that is needed to protect the zinc and steel of the culverts. The system is operating equally well for all three of the culverts. The cyclic nature of the data is likely due to the seasonal condition around the culverts.

Table 3
External current requirements of the culverts at I-49

Total Current (amps) Vs Time				
Date	**Culvert 1**	**Culvert 2**	**Culvert 3**	**Total**
31-May-97				
6-Aug-97	1.49	1.55	1.59	4.63
8-Oct-97	1.18	1.18	1.37	3.73
12-Dec-97	1.01	0.97	1.24	3.22
6-Mar-98	1.09	1.08	1.29	3.46
10-Jun-98	1.18	1.08	1.25	3.51
5-Oct-98	1.06	0.99	1.17	3.22
21-Jan-99	1.06	0.90	1.18	3.14
5-May-99	1.02	0.99	1.07	3.08

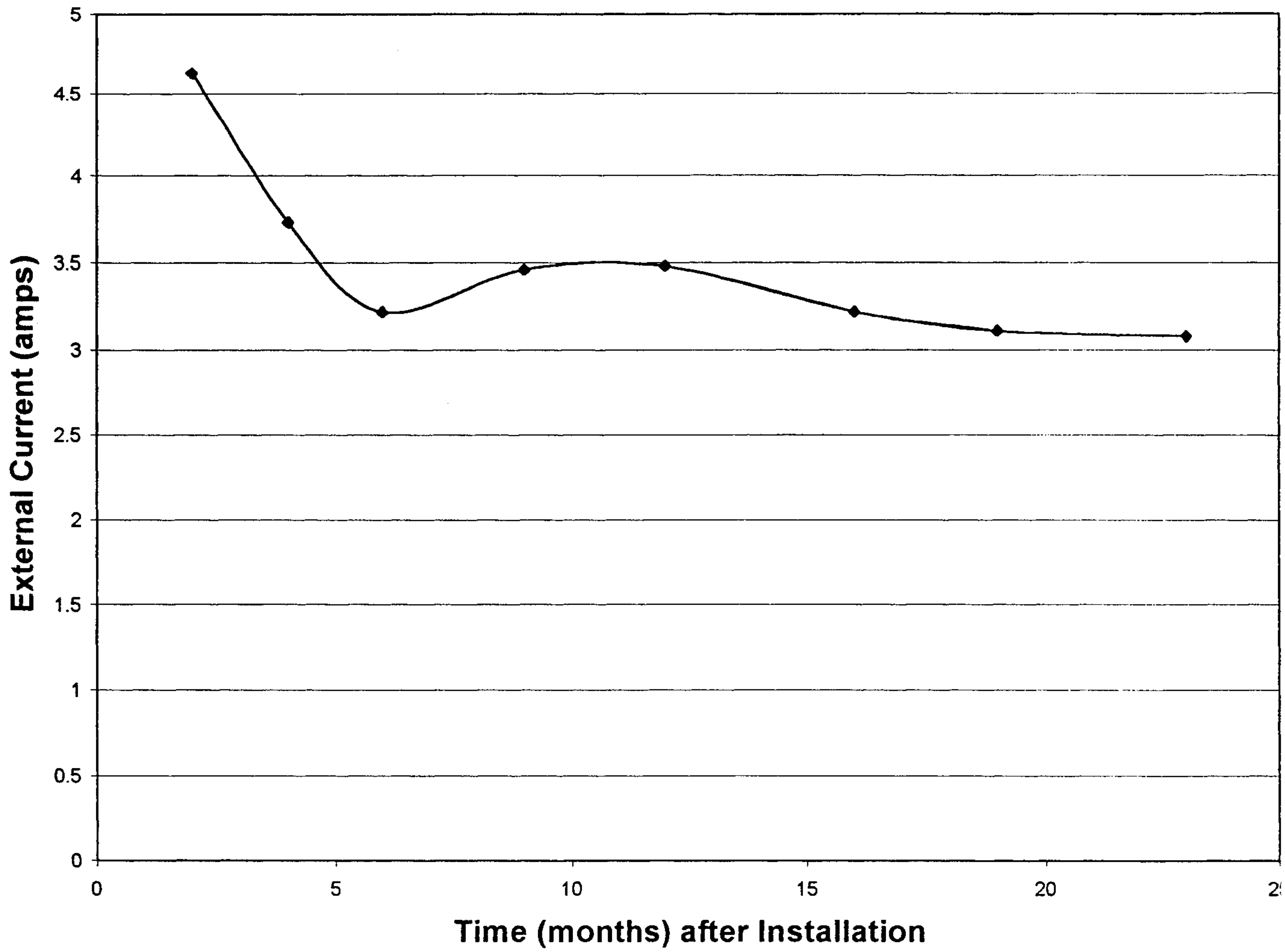

Figure 15
Total external current versus time (Culverts at I-49)

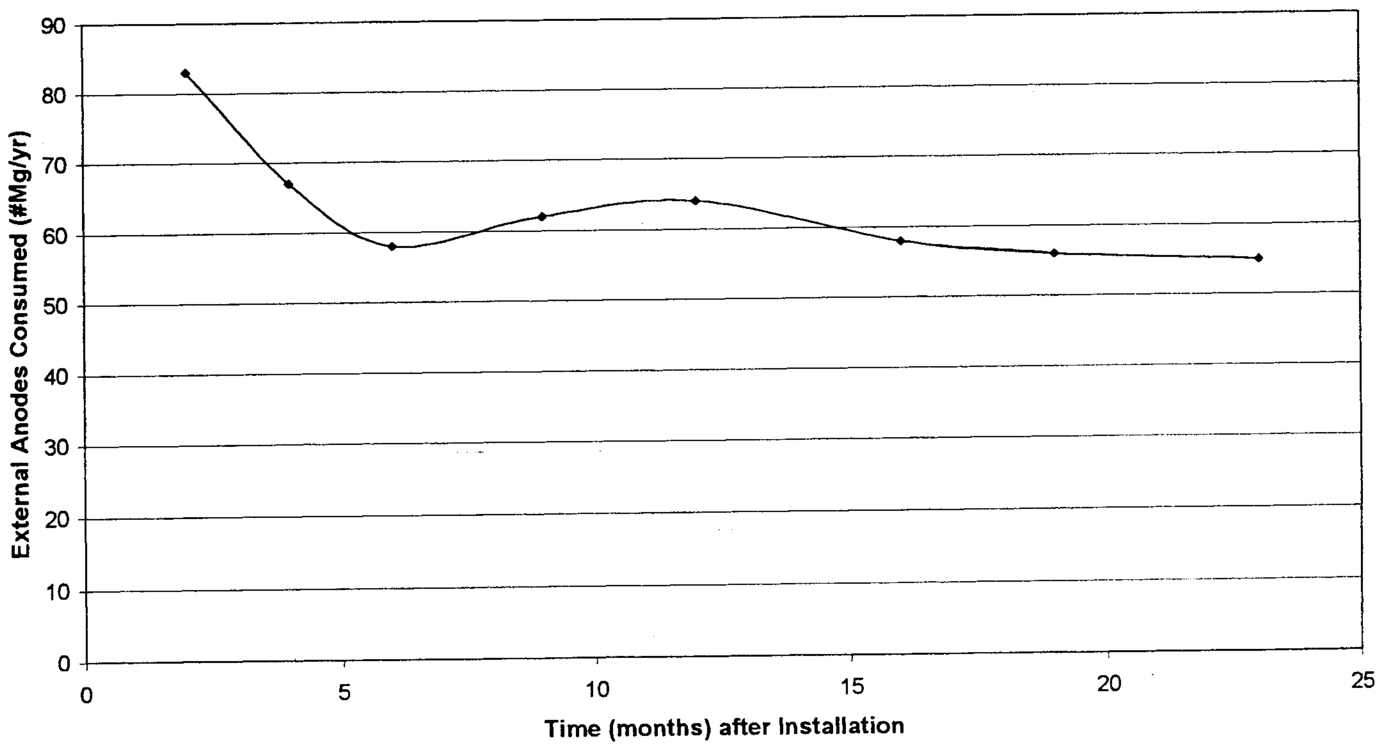

Figure 16
External anodes consumed versus time (culverts at I-49)

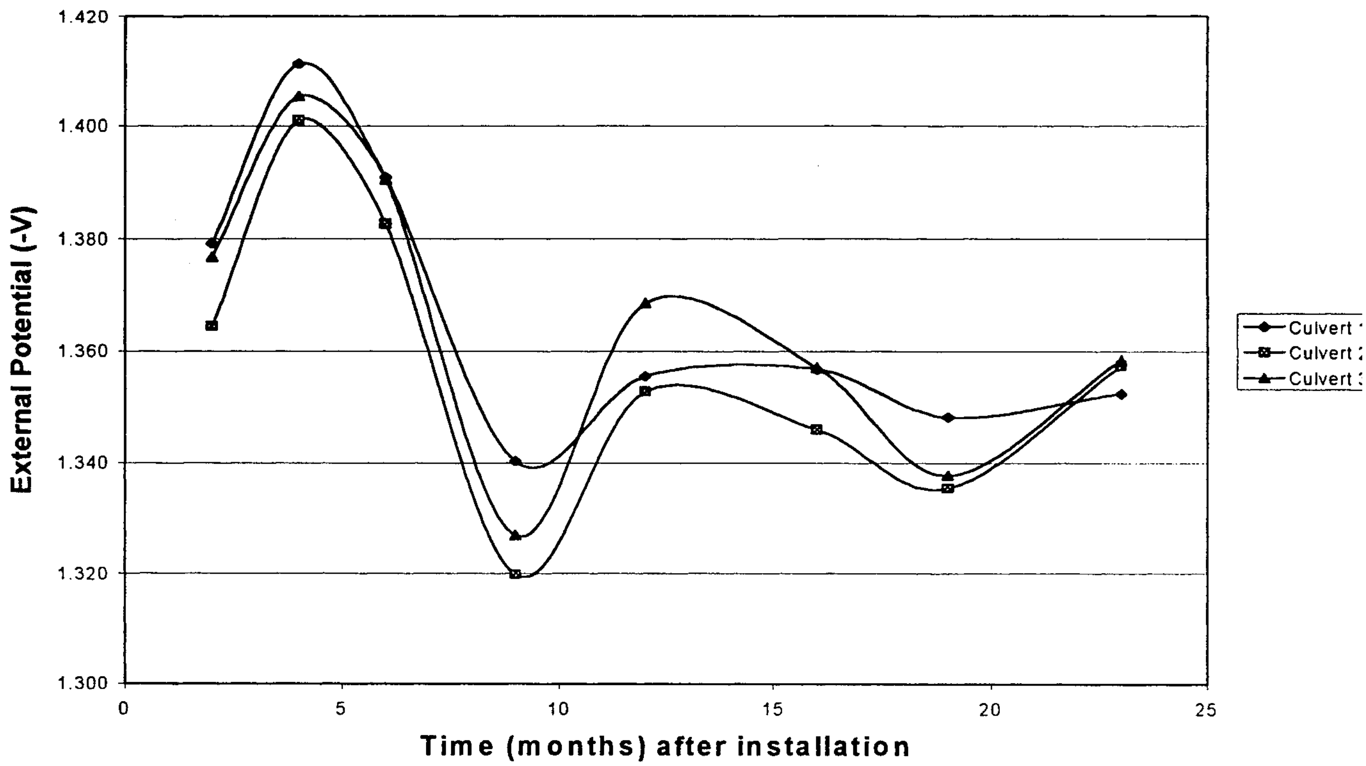

Figure 17
Potential of each culvert versus time (culverts at I-49)

It is much more difficult to quantify the effect of the anodes inside of the culvert. In an attempt to do this, culvert number three was monitored internally for its potential to determine if any cathodic protection was achieved. Figure 2 showed previously that there was some severe coating damage to the internal culvert coating. About one-third of the coating was removed. Potential readings were made from the north end of culvert number three to a distance 60 feet inside of the culvert. The average value of potential is given versus time in Figure 18.

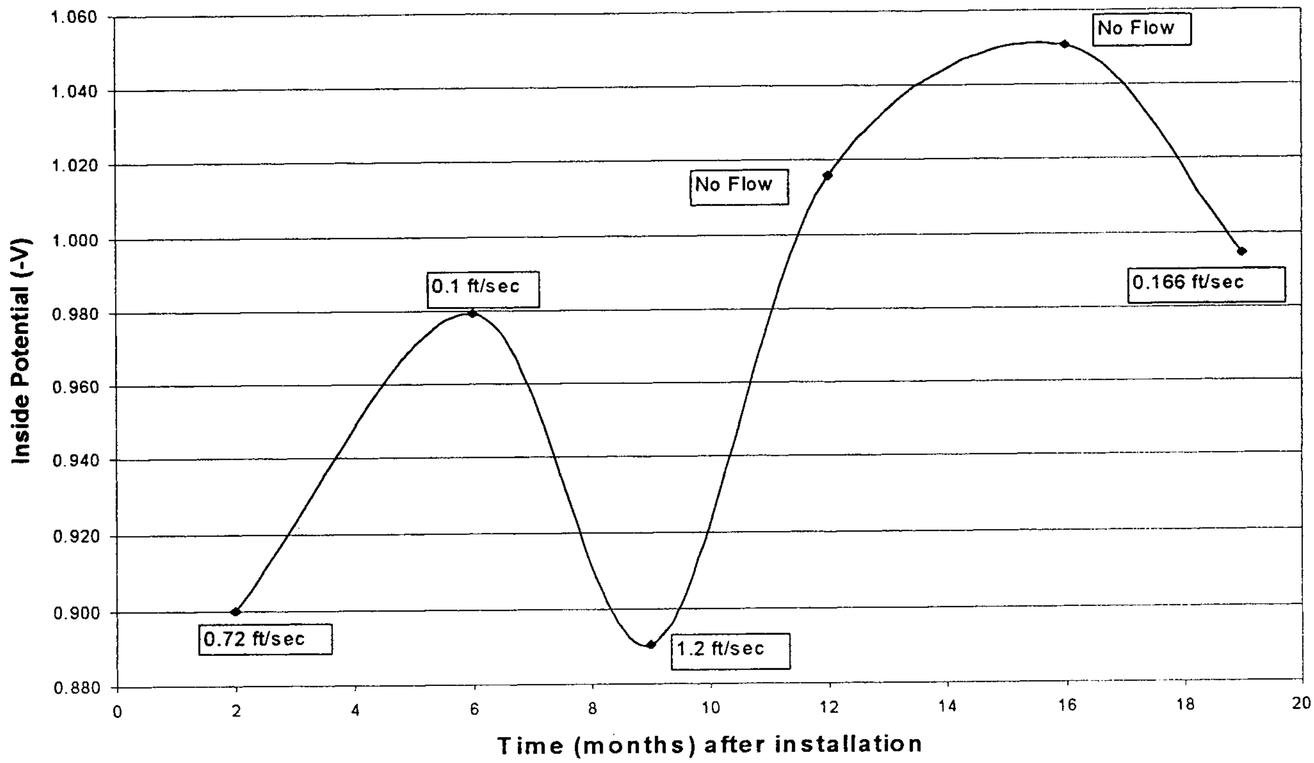

Figure 18
Plot of internal potential versus time as a function of flow rate (Culvert at I-49)

It should be noted that the average potentials were a function of the water flow rate through the culvert. The potentials at the "no flow" condition gave the highest values as expected, but they were not high enough to protect the galvanizing on the culvert. However, even at the highest velocities, the potentials were still low enough to protect the steel in the culverts.

New Culvert Measurements. The 60-foot long, four-foot diameter new bituminous culvert system has been monitored both externally and internally for the effectiveness of cathodic protection. The measurements have been made for a period of about one year. Figure 19 shows that the external current at this point in time is about 0.23 amps for the culvert. It should steadily decrease as the earth and scales compact on the culvert. This current corresponds to a magnesium consumption of four lb/yr or $20/yr cost for corrosion protection.

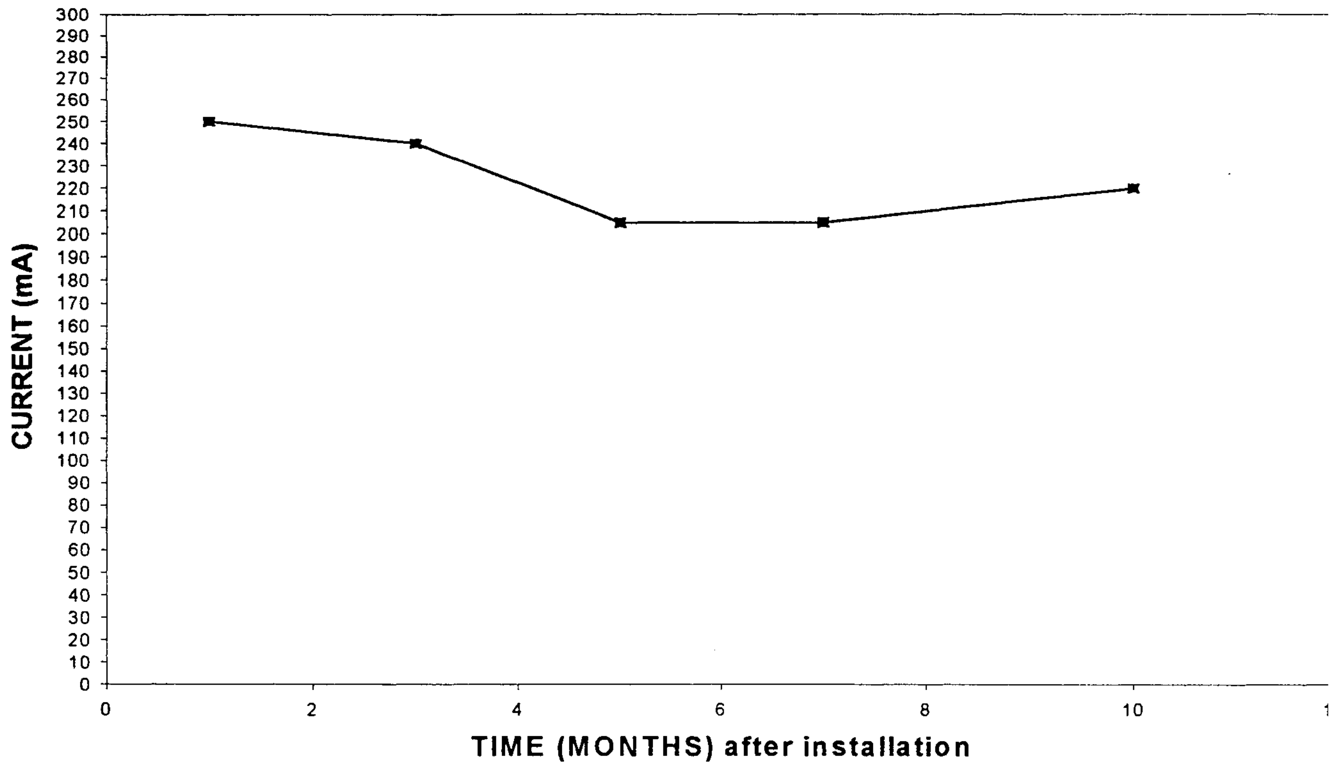

Figure 19
New culvert system current versus time

The potential values obtained on the culvert look very positive. Figure 20 shows that all of the measured values, internal and external, were more negative than the −1.1V value needed to protect the galvanizing on the culvert. The external potentials obtained are close to those obtained by the retrofit culvert. The internal values are much better in this culvert than the retrofit because of the better coating system in place. In this case, both the internal and external cathodic protection are working well.

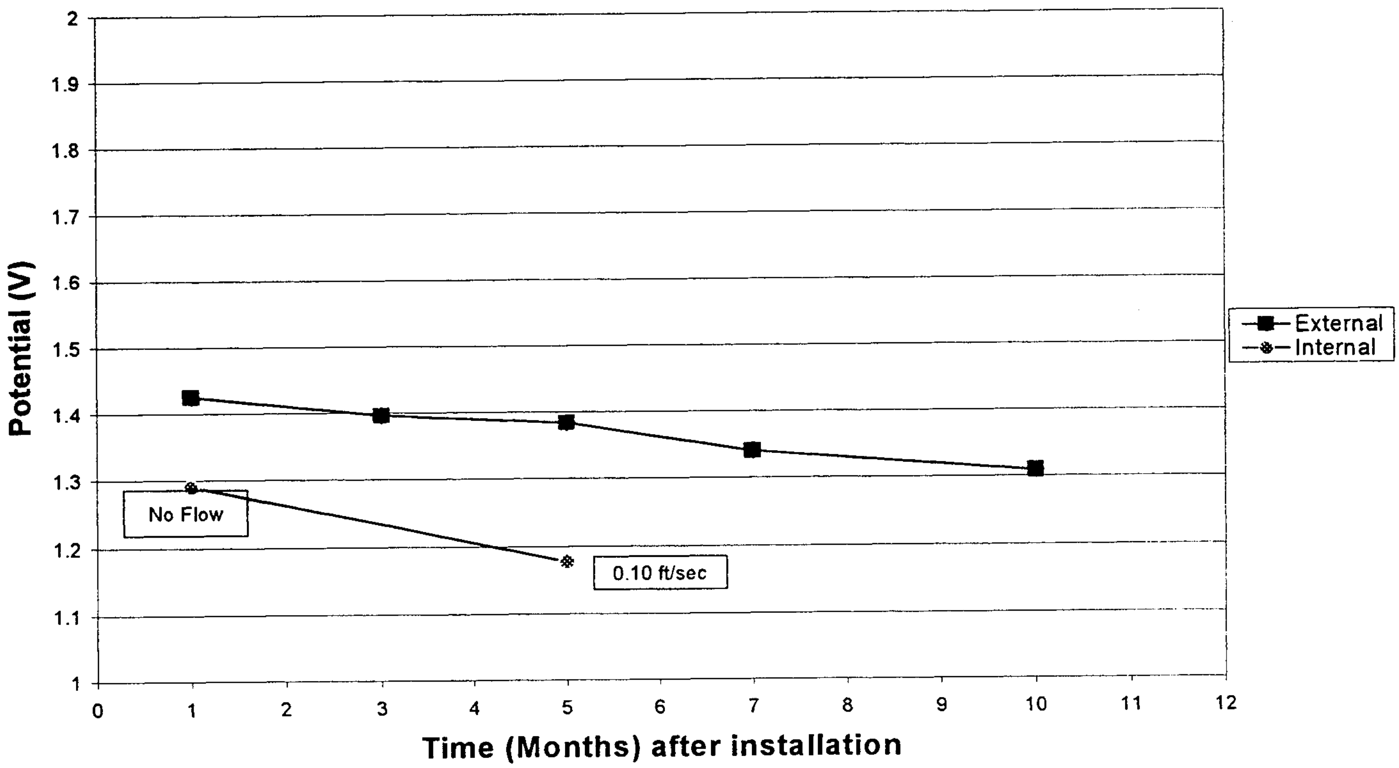

Figure 20
New culvert system potential versus time

Expert System

Based on the results of the field study conducted in this work, a computer model has been developed which is capable of predicting the life of a culvert in the field and the cost of installing cathodic protection to extend the life of the culvert. The computer model was developed in Visual Basic 5.0 so that a windows platform could be used.

The program is designed to predict the cost of a new or retrofit culvert cathodic protection installation. Table 4 lists the input parameters that are needed to run the program. They consist of "culvert information" and "environmental information". This data is stored for a given culvert and can be retrieved to rerun at a later time. The program estimates the corrosion rate for both the culvert using the California average life chart. These current density values are multiplied by the years of life required and the exposed surface area of the culvert to give the current requirement. Knowledge of the effectiveness of the coating on the culvert is very important in this calculation. A list of Standard Values is in the program that gives default coating efficiency values. It is possible to change these coating efficiencies if it is desired to do so.

The anode material of choice is usually assumed to be magnesium, but in low resistivity environments, less than 550 ohm-cm, zinc could be used. The program allows the user to select the types of anode required.

Table 4
Input parameters for the "new" path in the program

Type of information	Input parameter
Culvert information	Coating
	Diameter (ft)
	Thickness (in)
	Number of culverts
	Total measured length of the culvert system (ft)
	Corrugation factor
	Required life of the culvert (years)
Environment information	Minimum soil resistivity (ohm-cm)
	Soil pH
	Water resistivity (ohm-cm)
	Water pH
	Avg. depth of water inside the culvert (ft)
	Average water velocity (ft/sec)

There are other default values in the Standard Values that are used in the economic calculation. They are shown in Table 5 as follow:

Table 5
Variable labor and corresponding costs

Technical Labor	$800/day
Common Labor	$6/hr.
Welding Cost	$600/hr.
Drilling Cost	$30/hole

These values can be changed if they are not representative of a particular area in the state. A percent contingency is used to allow for extras that are needed to complete a job. A small culvert installation may need a higher contingency than a large culvert installation

The primary information that was needed to perform the necessary economics for costing a cathodic protection installation was the amount of time required to perform the internal and external installation and the cost of that time. By using the data obtained from the two culverts installations performed in this study, it was possible to develop the data in Tables 6 and 7. It gives the work timetable for a large, medium and small culvert system. The culvert system at I-49 had a surface area of about 37,000 ft^2 and is classified as large, while the Eunice installation had an area of about 820 ft^2 and is small. It was decided to define a large culvert as having greater than 25,000 ft^2 and a small one as having less than 10,000 ft^2. This breakdown allows an economic cost estimate to be performed on any culvert in the state.

The computer program calculates the material and labor costs and the days required completing the installation.

Table 6
Days of installation for internal cathodic protection

Internal Cathodic Protection Installation

	Days Required			Number Common Laborers
Size Culvert	Welding	Technical	Common	
Large	1	1	1	4
Medium	1	1	1	3
Small	1/2	½	1/2	2

Table 7
Days of installation for external cathodic protection

External Cathodic Protection Installation

	Days Required			Number Common Laborers
Size Culvert	Welding	Technical	Common	
Large	0	4	4	4
Medium	0	2	2	3
Small	0	½	½	2

Given that information about any culvert in the state, a decision can then be made whether cathodic protection should be installed. As an example, Table 8 shows an economic breakdown for a particular culvert and the number of days to perform the job.

The expert system contains a help file that provides the user with the following information that can be printed if necessary:

1. **User Manual:** This informs the user about the procedure needed to run the program correctly.

2. **Technical Manual:** This manual gives the logic and all of the equations used in the calculations.

3. **Generic Anode Installation:** This file gives the generic procedure or installing the anodes both internally and externally for a new or retrofit culvert.

4. **Data Sheets:** The data sheets for both a new and retrofit culvert are given.

Table 8
Total cost of cathodic protection

		Internal Cost	External Cost
Materials	$ $	328	1514
Labor	$	860	826
Total		1188	2340
Total Cost involved	$	3528	
No. of days required to complete the job:		1	
		Print	
	Ok		

CONCLUSIONS

I-49 Culvert

- The cost of installing a cathodic protection system on this culvert system was $25,863.
- Three feet of mud had to be removed from inside the ten-foot diameter culvert at an additional cost of $13,000, before the internal anodes could be installed.
- After cathodic protection was installed, all external potential values were more negative than −1.1 V, which means that the galvanizing on the steel culvert is completely protected.
- This protection of the zinc on these culverts is important since the coating is attached to the zinc and will detach if it corrodes.
- The external current demand of the I-49 culvert has decreased to 3.0 amps from an original value of about 6.0 amps.
- The culvert is requiring 55 lbs. of magnesium/year to protect its external structure. This costs about $275/yr.
- Internal cathodic protection has not been achieved at the I-49 site due to a large amount of damaged coating caused during the 12 years of exposure to the environment.
- Had cathodic protection been installed initially in the culverts, it is likely that the zinc would have remained and the internal coating would have been in better condition.
- The potential values inside the culvert were found to be a strong function of the water flow rate. As the velocity of the water increased, the internal potential value dropped off.

LA Highway 757 Culvert

- The cost of installing the cathodic protection on this four-foot diameter, 60-ft long culvert was $3,495.
- There was some coating damage observed during installation.

- The external potentials are very good with values more negative than –1.10 V being observed.

- The current demand on the external side of the culvert is holding steady at 220 ma. This corresponds to a magnesium anode consumption rate of four lb/year.

- The internal potentials are more negative than –1.1 V, which means that internal cathodic protection is working at this time in the life of the culvert.

Expert System

- An expert system has been developed which uses culvert and environmental information to predict the life of the culvert in the field.

- The program uses this information to predict the pound of internal and external anode material required to protect the structure.

- The material and labor costs of the cathodic protection installation is estimated by the program as well as the number of days required for installation.

- The program provides a generic procedure to assist in anode installation.

RECOMMENDATIONS

Whenever the culvert life predicted by the new expert system is less than that required by the DOT, cathodic protection should be considered. The results of this study have shown that any culvert structure can be economically protected from external corrosion and that a new culvert can also be successfully internally cathodically protected. In the case of retrofit culverts, a thorough examination of the condition of the internal coating is required before internal cathodic protection should be attempted. Excess coating damage will make internal cathodic protection impractical.

First consideration should be given to interstate culvert system that will likely not last for 70 years in state soils. Replacement of these culverts would be extremely costly. Culverts that do not have standing water would be good candidates for external cathodic protection only. This would greatly reduce the cost of the cathodic protection system.

From the 1988 study, it was apparent that a polymer coated galvanized steel culvert required less cathodic protection current than the bituminous coated culverts *[1]*. A field study should be performed to verify this fact. This might assist DOTD in the selection of the proper coating to be used in conjunction with cathodic protection. This would be especially helpful in the harshest environments where the corrosion rates are high.

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