top rebars and the break joint for a temporary filler, sometimes used in construction by stages, and sufficient lap length for transfer of flexural stress. The ties are needed to ensure that the dowels and the rebars move in harmony, thus preventing the occurrence of voids found at the bent dowels.

ACKNOWLEDGMENT

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Cathodic Protection of Continuously Reinforced Concrete Pavement

GLENN R. KORFHAGE

Some sections of continuously reinforced concrete pavement (CRCP) in Minnesota are experiencing a spalling-type deterioration caused by corrosion of the reinforcing steel. In an attempt to develop a method of stopping this corrosion, a cathodic protection system was designed and installed along a 1000-ft section of Interstate CRCP just north of St. Paul. High silicone chromium iron alloy anodes energized by a constant-current output rectifier were placed at the edge of the 10-ft bituminous shoulder at 50-ft intervals. On half the project, the anodes were buried in a trench that was backfilled with coke breeze. On the other half of the project, canisters containing the anodes packed in coke breeze were placed in post holes and backfilled with additional coke breeze. It appears that both types of installation are providing at least partial cathodic protection to the pavement.

During the late 1960s, the Minnesota Department of Transportation (MnDOT) constructed considerable mileage of continuously reinforced concrete pavement (CRCP). In rural areas pavement thickness was generally 8 in and in urban areas 9 in. The steel reinforcement was 0.6-0.7 percent and was deformed wire mesh or deformed reinforcing bar.

During the past seven years, an increasing number of CRCP sections in Minnesota have begun to show a spalling-type deterioration. The frequency of this deterioration progressed from isolated and random in 1975 to widespread and concentrated on certain pavement designs by 1978. Pavements showing the most severe spalling are of the two-course construction type with a steel-to-concrete ratio of 0.60-0.65 percent. Reinforcement used was deformed wire mesh with specified clear cover of 2-4 in. In most cases the steel had been placed at the minimum specified cover of 2 in.

In 1976, a survey of a deteriorating section of CRCP on I-94 between downtown St. Paul and downtown Minneapolis was conducted. Tests performed during this survey included cover measurements, delamination detection, and half-cell potentials for corrosion detection. A visual survey was also performed. Strong evidence was found to support the theory that corrosion-induced spalling was occurring. Survey results showed that corrosion-potential measurements were generally at or well above the corrosion threshold of 350 mV relative to the copper sulfate electrode. Many measurements were in the range of 500-600 mV of active corrosion. The maximum potential noted on corrosion-damaged bridge decks in Minnesota was also about 600 mV. Delamination surveys revealed that 13 percent of the pavement tested was delaminated. Reinforcing steel cover generally measured 1.75-2.25 in.

At the time of the survey on I-94 (August 1976), nearly all noticeable spalling-type deterioration was confined to the oldest sections of CRCP in the metropolitan area. However, it was feared that eventually the problem could become very extensive.

A research study was undertaken to develop procedures for stopping or at least reducing the rate of corrosion in CRCP. One known method for preventing corrosion of steel is cathodic protection. It has been used successfully to protect buried pipelines for many years. More recently it has proved to be an effective means of arresting corrosion of rebars in concrete bridge decks (1,2). By using procedures developed in these two applications as a starting point, a design was developed to cathodically protect a section of CRCP.

The location selected for the cathodic protection installation is on I-35W a few miles north of St. Paul. Factors considered in making the selection were pavement type, traffic, state of deterioration, and convenience for monitoring. The pavement type is one that has exhibited the most frequent and severe corrosion-related deterioration. It was approximately 10 years old and was built by using two-course construction techniques. The slab is 8 in thick and has a steel-to-concrete ratio of 0.6 percent. Reinforcing steel is deformed wire mesh. Clear cover over the reinforcement was specified at 2-4 in. Average daily traffic was 8000-9000 vehicles/day, which included about 500 trucks.

This report describes the design and installation of the cathodic protection system and discusses the preliminary indications of its effectiveness in arresting corrosion of the CRCP.

SYSTEM DESIGN

Corrosion of steel is an electrical as well as a chemical process. In its basic form it is caused by stray current discharging from one area of the steel (the anode) and returning to another (the cathode) (Figure 1). A driving potential of less than 0.5 V is able to cause the current jump.

Corrosion, or oxidation, occurs at the anode only, whereas hydrogen evolution or reduction occurs at the cathode. As corrosion continues, its by-product, pack-rust, accumulates at the anode, whereas there is no harmful side effect at the current-receiving cathode. If all steel could be placed in a current-receiving mode, the discharge would be stopped and corrosion would cease.

Cathodic protection of buried pipelines is accomplished by placing anodes in a conductive backfill material, usually near the in-place pipeline (3). A ground connection is attached to the pipeline, and when the system is energized, an electrical potential field is set up between the pipe and the anode. Current flows through the field to the pipe, which is the cathode of the system. This system is illustrated in Figure 2. With the pipe in a current-receiving mode, stray current discharge cannot occur and corrosion is stopped.

Reinforcing bars in concrete bridge decks have also been protected with impressed current. Achieving this protection required a somewhat more specialized system. To conduct the current, a coke-modified asphalt overlay and special anodes were placed on the deck surface (Figure 3). In this case the special asphalt overlay created the electrical field needed to distribute current to protect the rebars.

The design of the cathodic protection system for CRCP was achieved by integrating essential elements from the pipeline and bridge-deck systems and is shown in Figure 4. The concept involved burying anodes in a trench or in post holes backfilled with conductive coke aggregate and located along the right shoulder. A ground connection was attached to the continuous reinforcing at five locations to complete the circuit. The anodes, when energized, would create a potential field between themselves and the steel within the CRCP. This field would conduct current to the reinforcing steel in a manner similar to that in which the soil conducts current to the pipeline. With pavement-reinforcing steel in a current-receiving mode, it was believed that corrosion would be stopped. With corrosion stopped, the forces necessary to generate pressure-causing cracks and eventual potholes in the pavement would be eliminated.

A prerequisite to achieving effective cathodic protection is uniform current distribution. If distribution is nonuniform, then hot spots (overprotection) will occur at some locations and cool spots (underprotection) will occur at others. Several factors influence current-distribution characteristics; some can be controlled, others cannot. These factors are as follows:

1. Resistivity in the medium separating the anode and cathode,
2. Continuity of the steel in the structure under protection,
3. Uniformity of the applied potential, and
4. Proximity of the source (anode) to the protected structure (pavement).

In addressing each of these factors, it is immediately apparent that the first factor, resistivity, is generally fixed and cannot be altered except perhaps by environmental influences of temperature and moisture.

The second factor, continuity, can be tested for and, when deficient, corrected by installing cross links over the break. This is not considered to be a major problem.

Figure 1. Corrosion process.

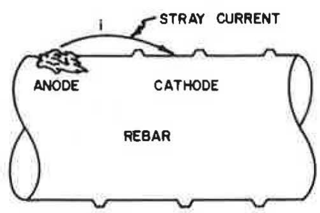


Figure 2. Pipeline cathodic protection system.

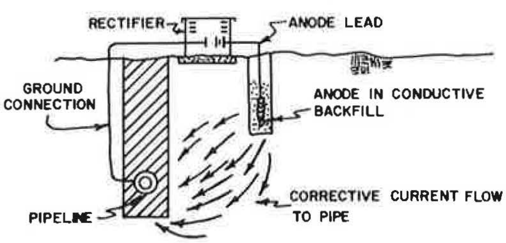


Figure 3. Schematic of bridge-deck cathodic system.

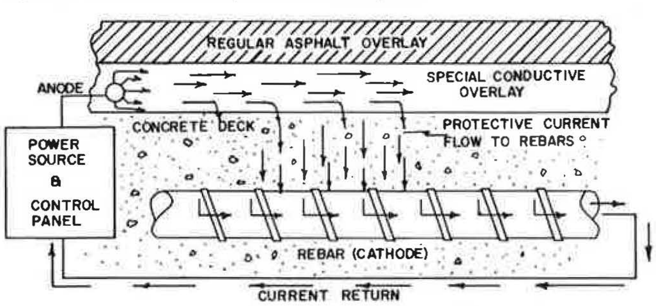


Figure 4. Cathodic protection for CRCP.

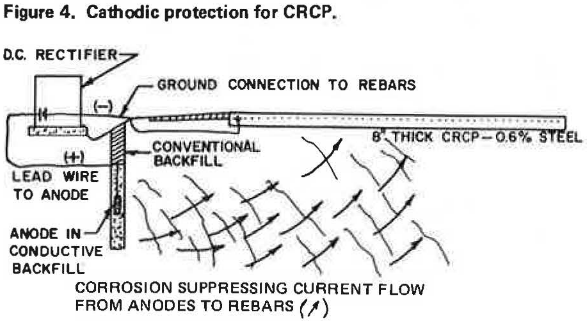


Figure 5. Trench method.

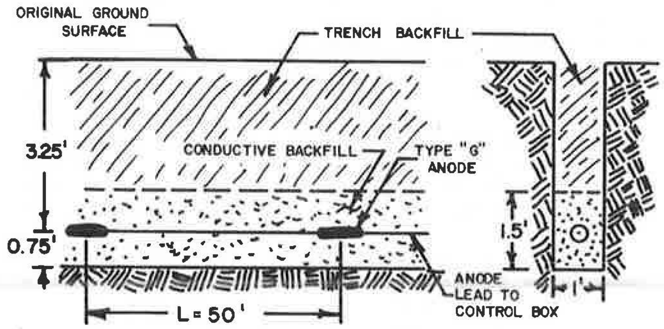
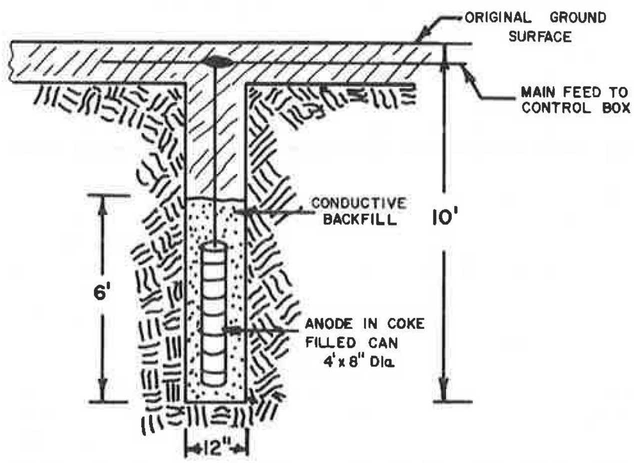


Figure 6. Post-hole method.



The third and fourth factors are the most significant but can be treated by proper design. The third factor, uniformity of applied potential, is controlled through use of reference cells in the protected structure (pavement). Theoretically these reference cells act as sensors. If applied potentials get too low, the power can be increased.

The two most commonly used methods for applying impressed current cathodic protection to pipelines are the distributed-anode groundbed and the remote-anode groundbed. Experience with these two methods seems to indicate that the distributed-groundbed approach offers the most uniformly applied potential and is the most responsive to control efforts.

In general, the disturbed-anode groundbed design involves placing an array of anodes along the structure requiring protection. The anodes are usually placed in a continuous trench backfilled with a conductive aggregate or in post holes as prepackaged assemblies; each assembly contains an anode surrounded by conductive aggregate. The purpose of the conductive aggregate is to make the anode bigger, thus distributing the current more uniformly. In both cases the anode leads are connected to a main line from the controller. It is common practice to provide separate circuits of staggered anode wiring arrangements so that if part of the system goes out, the domino effect is avoided and protection can be maintained. When the review of all available information was completed and consideration given to all options, a decision was reached to use the distributed-anode groundbed concept for this trial system. It was felt that this approach would provide the most uniformly applied potential and current density. It was also decided that a constant-current output rectifier would be used rather than a constant-voltage rectifier.

The two schemes for anode installation, continuous-trench and post-hole approach, were used in this study. The test area was divided into two major sections, each 500 ft long. The first 500-ft section would be protected with a continuous-trench anode scheme (Figure 5) and the second 500-ft section with the post-hole method (Figure 6). Each test area was further subdivided into five zones, and each zone would be independently controlled at the rectifier.

For this section of pavement, it was determined that the steel surface area was 0.55 ft^2/ft^2 of pavement. A running foot of pavement 24 ft wide would therefore have approximately 13 ft^2 of steel. Since a 1000-ft experimental test section was planned, protection of 13 000 ft^2 of steel would be required. Based on the maximum current output criterion of 1 mA/ft^2 of steel, the system should have the capability of supplying a total of 13 A. The anode selected for both trench and post-hole type cathodic systems was the high silicone chromium iron alloy cylinder. The cylinder is 9 in long and 2 in in diameter. It has a maximum current output of 0.8-1.0 A. Based on current requirements, each anode is capable of protecting 50 lineal ft of pavement with some allowance for increasing output to a given zone if necessary. In order to monitor the potential applied to the steel, reference cells were placed in each lane at 100-ft intervals. The reference cells were zinc encapsulated in zinc sulfate and gypsum.

INSTALLATION OF SYSTEM

Installation of the system took place in mid-November 1978. This operation was a combined effort of personnel from District 9 Maintenance, the Electrical Services Unit, and the Physical Research Section.

Excavation for the 500-ft-long trench system began at the south end of the installation by using a small trenching machine. The trench was 4 ft deep and 8 in wide.

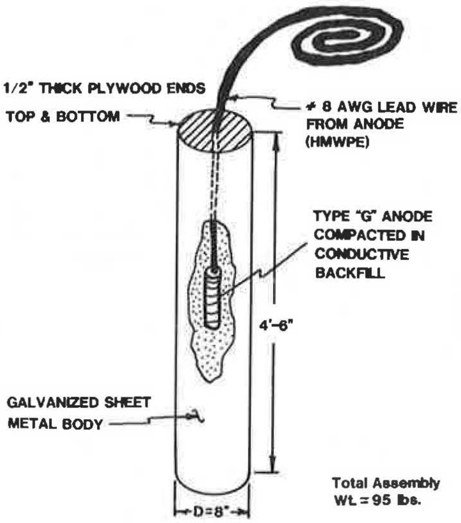
The excavated material was generally granular, ranging from coarse to fine sand with little or no silt. Trenching proceeded at a speed of 2-3 ft/min with minor delays when rocks were encountered.

Conductive coke breeze and anodes were placed after a sufficient length of trench had been dug. A 1-ft layer of coke breeze (uncompacted) was placed in the trench as shown in Figure 7. Discharge of the coke breeze into the trench was accomplished by using a sanding truck with an auger-fed distribution chute. The rotary sand-spreader device had been removed and a 3-ft metal chute fabricated and installed. Anodes were placed on top of the first layer of coke at specified locations. Wires from all five separate anode strings were placed in the trench on top of the first layer of coke. Each anode string consisted of two anodes connected by 50 ft of cable. Once the anodes had been positioned, a second 1-ft layer of coke was placed. After this layer had been placed, leveled, and tamped, considerable consolidation was evident. The amount of settlement of the two layers was observed to be of the order of 2-4 in. This left the consolidated depth of coke at approximately 20-22 in.

Personnel from MnDOT's Electrical Services Unit performed various tests for continuity and resistance of the anode strings to ensure that they were functioning properly prior to burial. When the first layer of coke was in place, they positioned the anodes at their proper locations in the trench and ran the lead wires to a temporary junction box located where the permanent controller would be installed.

Figure 7. Placement of coke breeze.

Figure 8. Canister anode assembly.



After the second layer of coke had been placed and compacted, the trench was backfilled with the excavated material. Final consolidation and leveling were achieved with a motor grader.

Installation of the post-hole system began the day following completion of the trench-type system. Initially a light-duty auger was tried, but problems occurred when the holes caved in. After a larger, more rigid drilling device was brought in, these problems were substantially eliminated. However, the bottom portions of the larger auger holes did cave in, and it was necessary to drill to a depth of about 15 ft in order to obtain an open hole to a depth of 10 ft after the auger was removed. As soon as the auger had cleared the hole, the canister containing the anode was lowered by using ropes. Eye bolts had been attached to the top of each assembly for this purpose. Once the anode was in place, a measurement was made to determine the depth to the top of the canister. The hole was then backfilled with 2-3 ft of coke aggregate. Backfill was completed by using the excavated material. A 10-ft No. 6 AWG lead was coiled at the top of each anode for eventual connection to a main feed line from the rectifier.

The canister anodes used were 4.5 ft long and 8 in in diameter. It was necessary to use prepackaged anode assemblies to eliminate problems associated with coke placement in the unstable soil. Canister assemblies are quite simple, as may be seen in Figure 8.

Two anode leads were spliced to each of the five feeder cables that were buried in a trench 4 in wide by 18 in deep in the road shoulder. The feeder cables terminated at the temporary junction box. Split bolt connectors were used to connect the leads to the feeders. An epoxy-type splice kit was used to seal the connection against the elements.

The reference cells were placed under contract in the fall of 1979. The concrete was removed to the depth of the steel by using saws and jackhammers. The reference cells were then placed and connected as shown in Figure 9, and the lead wires were run to the junction box. A reference cell was placed in the center of each traffic lane and midway between the two anodes comprising each anode pair.

METHOD OF EVALUATION AND RESULTS

The system was energized in March 1980. Field evaluation consists of both internal and external monitoring. Internal monitoring consists of measuring applied potentials and current output to each of the anode circuits or zones. Each circuit consists of two anodes and two reference cells cast into the pavement slab. Readout data are obtained by means of a Fluke Model 2240B data logger (Figure 10). When the system was initially energized, readings were taken at 15-min intervals. As the system stabilized (which took about two weeks), the interval was increased and now is 12 h.

Initially the current output from each of the 10 zones in the system was approximately 1.3 A. The voltage being applied varied somewhat from zone to zone. Mean values measured in mid-June 1981 were 7.1 V for the trench system and 13.4 V for the post-hole system. On July 16, 1981, the current was increased to 1.8 A. Mean voltage values measured one week later were 9.0 and 15.1 V for the trench and post-hole systems, respectively.

The accuracy of the zinc reference cells is questionable. Testing was done in late June 1981 (under the guidance of Ken Clear of the Federal Highway Administration) to determine whether the reference cells were functioning properly. It was determined that only about half of them were reliable. Because of the marginal reliability of the reference cells, it is difficult to determine how effective the cathodic protection installation is. However, there are indications that the system is providing at least partial protection.

Two criteria used for evaluating cathodic protection of underground structures were applied (4). These criteria were as follows:

1. A negative voltage of at least 0.85 V as measured between the structure surface and a saturated copper-copper sulfate half-cell contacting the electrolyte, and
2. A negative voltage shift of at least 300 mV in criterion 1.

When the system was first turned on, about one-third of the reference cells indicated a voltage more negative than -0.85 V. In late October 1980, 12 of 19 reference cells met this criterion; by late December, 14 of 19 were more negative than -0.85 V. In late October, 5 of 19 reference cells indicated a negative voltage shift of more than 300 mV. In late December, 9 reference cells showed a shift more negative than 300 mV, but 16 showed a shift greater than 200 mV. Results in 1981 were not so good as those in 1980. Possibly the change in values was caused by an increase in moisture content of the subgrade, base, and/or concrete.

Figure 9. In-place reference cell.

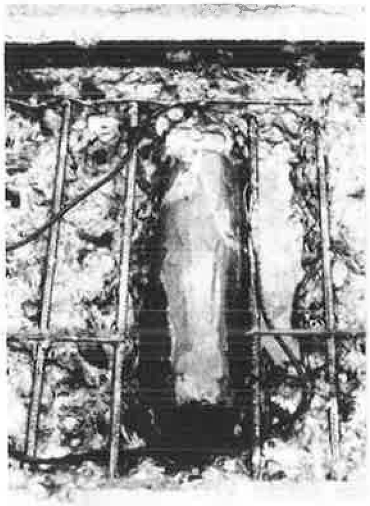
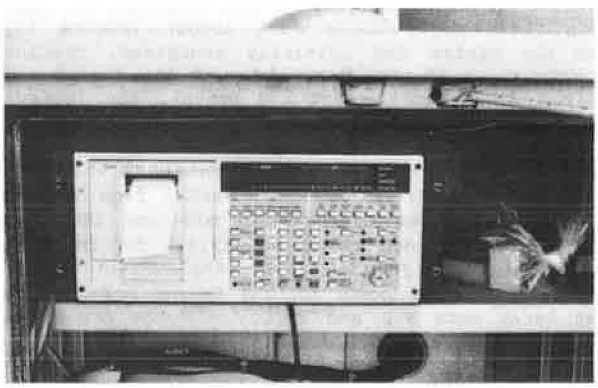


Figure 10. Fluke Model 2240B data logger.



Copper-copper sulfate half-cell tests were conducted several times. Mean values were -516 mV in 1979, -432 mV in June 1981, and -375 mV in September 1981. Thus, the cathodic protection system was effective in reducing electrical potential values. It would be desirable to have the half-cell values reduced to below -350 mV.

Neither internal nor external monitoring has indicated any significant difference in effectiveness between the trench system and the post-hole system. However, the passing lane seems to be protected better than the driving lane even though the anodes are closer to the latter. A possible reason for this is that the mortar used to backfill around the reference cells in the passing lane was intentionally contaminated with calcium chloride. Unfortunately, the calcium chloride was inadvertently omitted in the mortar used in the driving lane.

FINDINGS AND CONCLUSIONS

Experience with this project to date indicates that it is feasible to use cathodic protection as a means of arresting corrosion in CRCP by modifying technology previously developed for protecting buried pipelines and bridge decks. Further work is needed to determine such particulars as amount of current and spacing and location of anodes. At present the trench system is recommended over the post-hole system because, while the effectiveness of the two systems is similar, the former uses less electricity.

ACKNOWLEDGMENT

The contribution of Robert Tracy, former MnDOT research project engineer, to this study is acknowledged. He developed the concept and design of the system described in this paper following discussions with experts on cathodic protection of bridge decks and buried pipelines. The many contributions of Andrew Halverson, research project engineer, and Mark Hagen, research assistant, are also gratefully acknowledged. Special thanks go to Ken Clear, Office of Research, Federal Highway Administration, for his assistance in evaluating the effectiveness of the cathodic protection system.

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Evaluation of Platinized Niobium Wire Anodes for Cathodic Protection of Bridge Support Structures

H.J. FROMM AND F. PIANCA

An investigation was conducted to determine whether platinized niobium wire could be used as anode material to provide cathodic protection without necessitating the use of a conductive surface mix, as has been done previously. Experiments were carried out both in the field and in the laboratory. In the