FINDINGS AND CONCLUSIONS

The rehabilitation of the 42nd Street Bridge went well. Although it took a great deal of time to place the conductive PC, the contractor managed to improve production after the first half of the deck had been completed.

There was a slight shortage of both the platinized niobium wire and carbon strand anode materials. One platinized niobium primary anode ended less than 1 ft short. This was probably the result of the accidental cutting and resultant splicing of the material. There was about a 3-ft shortage of carbon strand material. This can be accounted for in the method used to hold the wire in line on the deck. Over 200 ft was wasted at the ends of the zones where the turn was made with the carbon strand to parallel previous strands.

As mentioned earlier, it was difficult to drill through the bridge deck in order to provide a drain hole for the conduit run. Also, it would be desirable to have expansion joints between any two fixed points on the conduit run. This system has expansion joints, but at one location the polyvinyl chloride conduit pulled out of a junction box as temperature changed.

All things considered, the project was successful. The shortage of platinized niobium wire was handled by using carbon strand material. The shortage of carbon strand could not be corrected, but the break in the carbon strand was made between two primary anodes, and thus electrical continuity was maintained.

The new overlay was tested with the Delamtect shortly after construction. No delaminations could be found. The overlay has been through a harsh winter. There is some surface deterioration as a result, but there is no apparent cracking. The deterioration takes the form of scaling and is possibly the result of low entrained air in the concrete. Delamtect testing done in 1984 revealed some potential small delaminations. These were too small to confirm, but testing will continue.

The rectifier has been in operation only a short time, but early tests have indicated that this will be an efficient system to operate. The evaluation of the system will begin in the summer of 1985.

The contents of this paper reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policy of the Minnesota Department of Transportation or FHWA. This paper does not constitute a standard, specification, or regulation.

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Cathodic Protection of a Four-Lane Divided Continuously Reinforced Concrete Pavement

ANDREW D. HALVERSON and GLENN R. KORFHAGE

ABSTRACT

The design and construction in 1982 of a second cathodic protection system for continuously reinforced concrete pavement by the Minnesota Department of Transportation is described. Corrosion of the reinforcing steel in this type of pavement has been a severe maintenance problem. An initial cathodic protection research project was successful in retarding this corrosion, so the department contracted for the design of a second system. This resulted in three separate designs, each 1,800 ft long, with separate power sources. They are (a) a trench system with the anodes placed in a trench 4 ft deep by 1 ft wide (b) a shallow-post-hole system with the anodes placed in augered post holes 12 ft deep, and (c) a deep-post-hole system with the anodes placed in augered post holes 15 ft deep. The pavement is grounded every 200 ft of each roadway by attaching wire to the reinforcing steel. Construction began in October 1982 and was completed in 1983. The systems were activated in December 1983 at current levels determined by E log I tests. Initial testing of the systems based on readings taken on corrosion probes placed during construction has indicated that they will be effective. Extensive testing has been delayed because of equipment problems that have shut down one system.

The deterioration of continuously reinforced concrete pavement (CRCP) is a serious problem in the state of Minnesota. This deterioration is primarily the result of chloride-induced corrosion of the reinforcing steel and is similar to the problem afflicting concrete bridge decks.

It can generally be stated that the products that build up on the surface of the reinforcing steel as a result of corrosion occupy a great deal more volume than the steel from which they were formed. As these materials build up, they produce stress in the concrete matrix. Because of its low tensile strength and brittle nature, the concrete fails and cracks. The crack propagates to the surface, and spalling and potholing result.

The distress in CRCP is visible throughout the year in the form of old patches on the pavement surface, and the spalls and potholes are a particular problem in the spring (Figure 1).

FIGURE 1 Deterioration of CRCP.

BACKGROUND

The first CRCP in Minnesota was constructed in 1963 on Interstate 35 near Faribault in the southern part of the state. This was a test section of freeway nearly 11 mi long. The pavement was not jointed. It contained a high percentage of reinforcing steel, 0.5, 0.6, or 0.7 percent. It was intended that, with temperature change, the pavement would develop many small, closely spaced cracks held tight by the reinforcing steel; this would eliminate the need to saw, seal, and maintain pavement joints. The cracks developed as expected, but a maintenance-free pavement was not the result.

Construction of CRCP as a standard practice began in Minnesota in 1967 and, through the late 1960s, over 200 route miles were completed. Total lane mileage of CRCP is much higher, because the roads are multilane freeways and the additional mileage of ramps at interchanges should be included. By 1970 the construction of CRCP had been discontinued. Initial failures were already apparent. These were tension failures, evident in the form of open cracks where reinforcing had corroded, had been reduced in cross section, and had finally ruptured (1). By 1974 the oldest pavements began to exhibit isolated cases of spalling and shallow potholing. During 1975 maintenance operations to patch open holes became frequent, and by 1976 the maintenance reached a significant level.

In 1977 the Minnesota Department of Transportation (MnDOT) initiated a performance and condition review and a research investigation to examine the state of the art for rehabilitation of deteriorated CRCP. As part of the research, a critical section of pavement received a bituminous overlay, a marginally critical section was rehabilitated by removing the upper portion and any delaminated areas and overlaying with a low-slump concrete overlay, and another section was placed under cathodic protection.

The cathodically protected section of pavement is 1,000 ft on southbound I-35W in Blaine. The concept of cathodic protection of a highway pavement is new, but cathodic protection has been used for a number of years on pipelines, bridges, and more recently on other structures. In a technique from the pipeline industry, a current is impressed from a rectifier to a buried, remote anode to neutralize the corrosive current by polarizing the steel, making it entirely a current-receiving cathode (Figure 2).

The 1,000-ft section of I-35W is divided into two designs for cathodic protection. One-half of the section is protected with a a trench-type system, and the other is protected with a post-hole system. In the trench system a Duriron anode is placed 3 1/4 ft deep in a trench 4 ft deep. Anodes are placed every 50 ft and lie within a 1 1/2-ft-deep lift of conductive metallurgical coke breeze (Figure 3). In the post-hole system the anodes are also 50 ft apart. However, they are placed in a 10-ft-deep augered post hole (Figure 4). The anodes are contained in a galvanized sheet metal canister 8 in. in diameter and 4 1/2 ft long. The canister is filled with coke breeze, and the post hole is backfilled with coke breeze to a depth of 6 ft.

Visual observation of the cathodically protected pavement has revealed less surface distress and patching than is evident on adjacent unprotected pavement. In addition, in the summer of 1982, the department contracted with Donahue and Associates to conduct an investigation of selected segments of CRCP by using infrared thermography. This investigation, which included the original cathodically protected pavement, revealed numerous significant areas of delamination on unprotected pavement but only minor areas of delamination on the protected pavement.

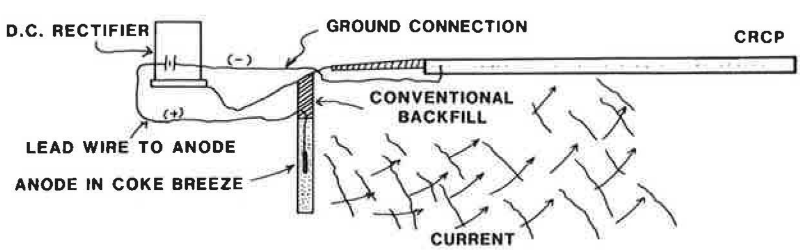

FIGURE 2 Cathodic protection of CRCP.

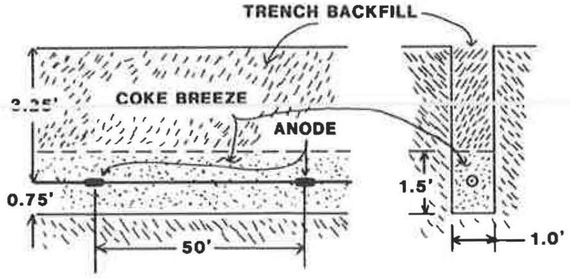

FIGURE 3 Trench-type cathodic protection system.

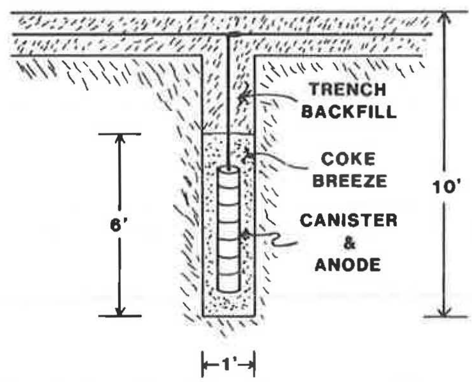

FIGURE 4 Post-hole cathodic protection system.

EXPERIMENTAL WORK

In 1982 at the request of the department's Oakdale District Office, efforts to design and construct 1 mi of cathodic protection for a segment of CRCP began. The segment chosen was a four-lane divided section of I-35E north of St. Paul. The department contracted with Kenneth C. Clear, Inc., to design the system. Rectifiers were ordered by the department, and bids were requested for construction of the project.

System Design

The section of I-35E to be protected is located in the city of Vadnais Heights, north of St. Paul. It begins at a bridge over LaBore Road Connection and the Burlington Northern Railroad (Bridge 9567) and ends at the White Bear Lake city limits. The pavement was constructed in 1970. It is 8 in. thick and contains 0.7 percent steel by cross-sectional area. The reinforcing steel consists of tied bars. The average daily traffic is 29,300.

Test results from a 1981 CRCP inventory survey (2) revealed about 2.3 in. of concrete cover over the reinforcing steel. Chloride contents, as determined by drill dust samples, were about 3,990 parts per million (ppm) from 0 to 1/2 in.; 2,550 ppm from 1/2 to 1 in.; 1,960 ppm from 1 to 1 1/2 in; 1,070 ppm from 1 1/2 to 2 in.; and 630 ppm from 2 to 2 1/2 in. Electrical potentials were taken with a copper-copper sulfate half cell. All readings taken revealed active corrosion. Delamination detection was done with a Delamtect. This revealed less than 1 percent delamination, which was corroborated by infrared thermography done in 1982 and 1983.

Efforts to build a cathodic protection system began April 9, 1982. It was decided that this second system should be built in the median of the freeway in order to protect both roadways. A consultant agreement for design and testing was signed in May. The design resulted in three separate systems, each with its own source of power. There are a trench system and two post-hole systems. Each of these is 1,800 ft long, and each has five zones with independent electrical control.

The first system is in a trench 4 ft deep by 1 ft wide. Nine inches of conductive metallurgical coke breeze is placed in the trench and compacted. The 2 x 60-in. Duriron anodes are 60 ft apart. There are six anodes per zone, which is 360 ft long. The anodes are covered with 9 in. of coke breeze, which is also compacted. The remainder of the trench is backfilled with excavated material (Figure 5).

The second system, immediately north of the trench system, is a shallow-post-hole system. The anodes are in 12-in. diameter post holes that are 12 ft deep and 36 ft apart. There are 10 anodes per zone. The 1 1/2 x 60-in. anode is contained in an 8-in. diameter galvanized metal canister 7 ft long. The anode is backfilled with coke breeze within the canister, and the canister is backfilled with coke breeze within the post hole (Figure 6).

The northernmost system uses deep post holes. The anodes are in 12-in. diameter post holes augered 15 ft deep that are 17 ft apart. There are 20 anodes per zone. The 1 1/2 x 60-in. anodes are in a 10-in. diameter galvanized metal canister that is 7 ft long. The anode is backfilled with coke breeze within the

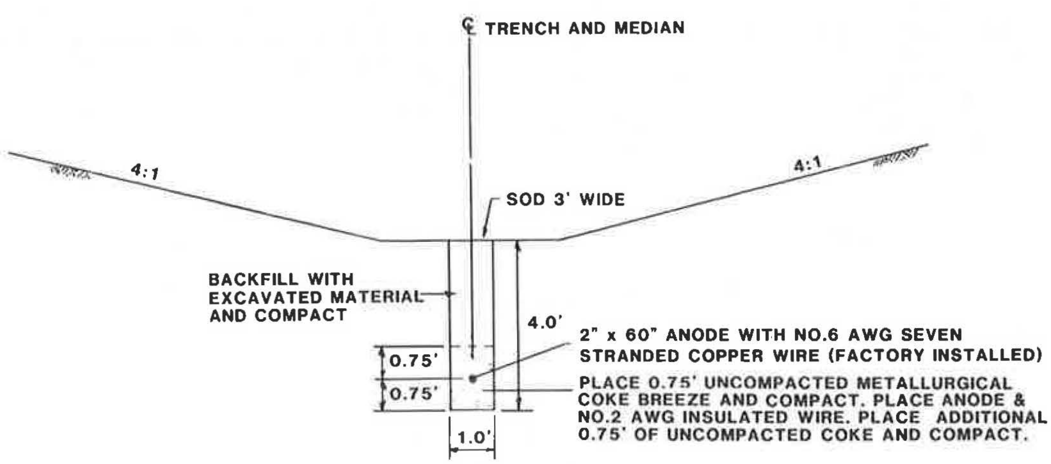

FIGURE 5 Trench-type cathodic protection system: construction details.

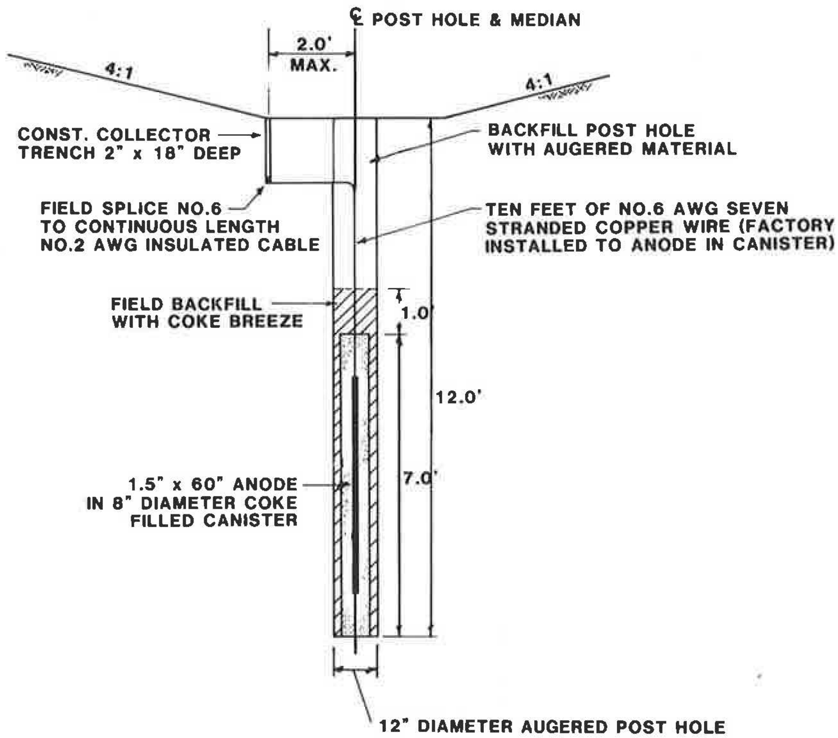

FIGURE 6 Shallow-post-hole system.

canister, and the canister is backfilled with coke breeze within the post hole (Figure 7).

The system is grounded every 200 ft. A ground wire is attached to the reinforcing steel. This wire leads to a header cable in a collector trench that is 4 ft off the edge of the pavement. The header cable is continuous along the northbound and southbound roadways for 5,400 ft (Figure 8). Power is supplied to each system by a rectifier with a 240-V alternating-current input. The rectifiers for the trench and shallow-post-hole systems are capable of an output of 50 V direct current at 32 A for each of the five zones. The rectifier for the deep-post-hole system is capable of an output of 80 V at 32 A per zone.

The deep-post-hole system was designed because part of the project is located on a fill section through a swampy area, which has higher soil resistivity. The trench and shallow-post-hole systems are lower in elevation than the deep-post-hole system and are in the fill in the swamp. The soil resistivities are similar there and much lower than that of the deep-post-hole system, which is on an ascending grade. The deep-post-hole system was designed to reach a wetter soil with lower resistivity.

Construction

The contract for the cathodic protection system, minus rectifiers, was put out for bids in August 1982. The contract was let at a low bid of about $131,000. Rectifiers were purchased by the state for about $38,000 and were to be installed by the contractor. Thus, the total cost of the system was $169,000, or about 70 cents ft^2. The contract was let September 10, 1982.

The contractor began work on October 11 by establishing traffic control. The contract allowed 10 working days during which the passing lanes of each roadway could be closed for construction. After those 10 days, only temporary lane closures were allowed.

The contractor first established the system grounds, which were made to the reinforcing steel at 200-ft intervals. A cable locator was used to find the transverse steel. A small milling machine was then brought in to grind the concrete to the depth of the steel (Figure 9). Jackhammers were used to further expose the steel, which was cleaned by using an electric drill with a wire brush. A number 8 stranded copper wire was cadwelded to the longitudinal and then the transverse reinforcing steel, and each cadweld was tested for soundness with a hammer. A hole was drilled through the soil and under the 4-ft-wide bituminous shoulder on the median side of each roadway to an 18-in.-deep collector trench (Figure 10). The trench was originally opened up with a backhoe at each ground connection and later completed with a trenching machine. The ground wire could then be passed under the shoulder without damage to the shoulder. A 9-in. section of 1/2-in. polyvinylchloride conduit was placed around the wire to counteract any shear effects at the edge of the concrete pavement. Figure 11 shows the conduit and the ground wire cadwelds.

A number 1 AWG insulated cable with high-molecular-weight polyethylene (HMWPE) insulation was placed in each collector trench and was continuous through the length of the trench. The number 8 AWG ground lead from the reinforcing steel was cadwelded to the number 1 header cable and enclosed in an epoxy encapsulation kit made for direct burial.

Each collector trench also contained three number 12 twisted wires, to be used as test leads for potential readings. The leads terminated in test stations buried along the shoulder (Figure 12), which made it possible to take electrical potentials on the surface of the pavement without running long lead wires and without running wires across the pavement.

The system grounds were patched with concrete.

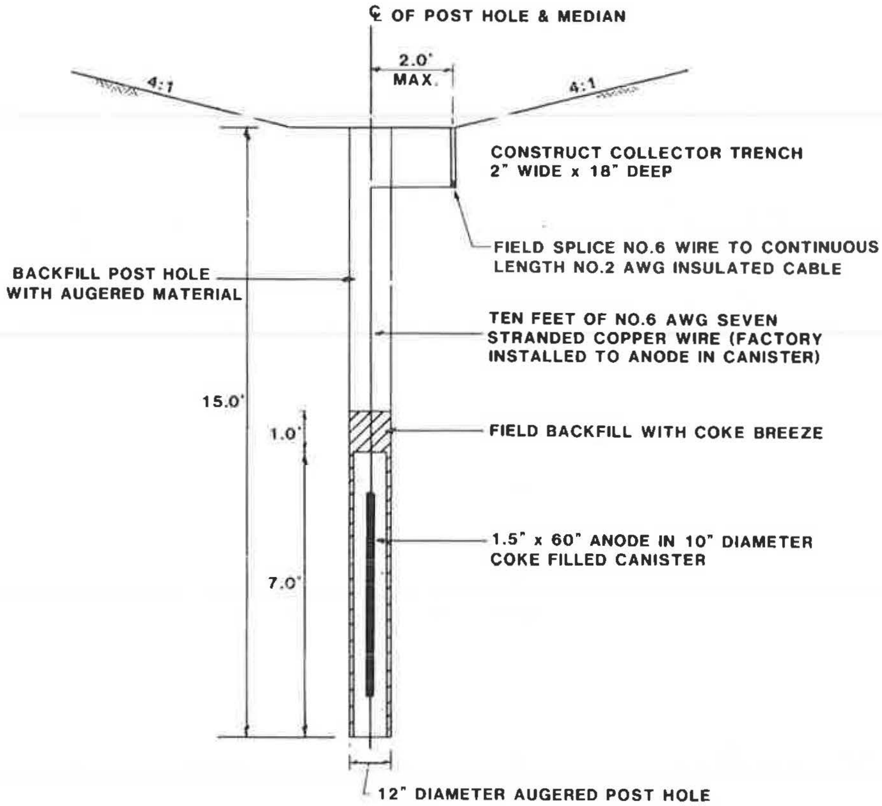

FIGURE 7 Deep-post-hole system.

Before patching, the reinforcing steel was sandblasted and then cleaned with compressed air. The holes were grouted and patches were then placed by using concrete supplied by a concrete mobile. Patches were sprayed with a membrane-curing compound.

A corrosion probe was placed in both roadways in each system in the passing lane near the centerline. The probe consisted of a 6-in. piece of 5/8-in. reinforcing steel with a number 8 stranded wire attached. The steel was cast in a 3 x 3 x 8-in. block of salt-laden concrete in order to create a strong corrosion cell. The concrete contained 15 lb of chloride per cubic yard of concrete.

The probe was placed at the level of the reinforcing steel in the pavement and the wire was passed through a saw cut to the edge of the pavement and then to the collector trench in the same manner as that used for the system grounds. Each corrosion probe also had its own ground wire. The probe was patched along with the grounds (Figure 13). The wire was sealed in the saw cut with epoxy. Test stations were provided for each corrosion probe.

The trench system was installed in a trench 4 ft deep by 1 ft wide excavated with a backhoe. The trench system was wired into five zones with six anodes in each zone cadwelded to a continuous length of number 2 AWG insulated cable between the anodes and the rectifier. Splice kits covered each weld.

The splice kits consisted of a plastic sheath placed around the cadweld. This sheath was then

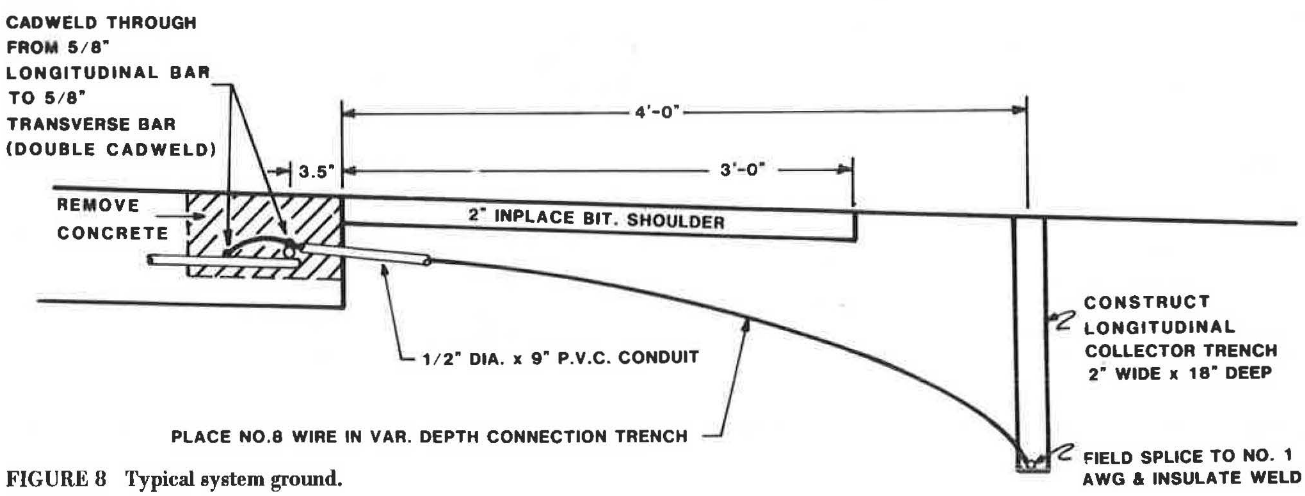

FIGURE 8 Typical system ground.

filled with a two-part epoxy that was shipped in a container with two compartments. The materials were combined by breaking the partition between the two components, and the epoxy was poured into the sheath. The epoxy was then allowed to harden (Figure 14) and the splice kits were tested with a holiday detector to ensure their effectiveness.

Construction of the trench system went well. The construction of the post-hole systems was another matter, however. The contractor worked on the deep system first. A high-speed drill was used to auger the 15 ft. The soil was a very fine sand. The sides of the post hole tended to collapse inward and this eventually became quite a problem. The anodes and canisters were lowered into the post holes by a choker using another truck with a boom (Figure 15). The canisters were then backfilled with coke breeze.

As mentioned, the soil posed a problem. The contractor started at the highest part of the project. As each hole was drilled, the work went to a lower level and came nearer the water table. The sides of the holes would not hold and the contractor had to

FIGURE 9 Concrete milling machine.

FIGURE 10 Drilling under bituminous shoulder.

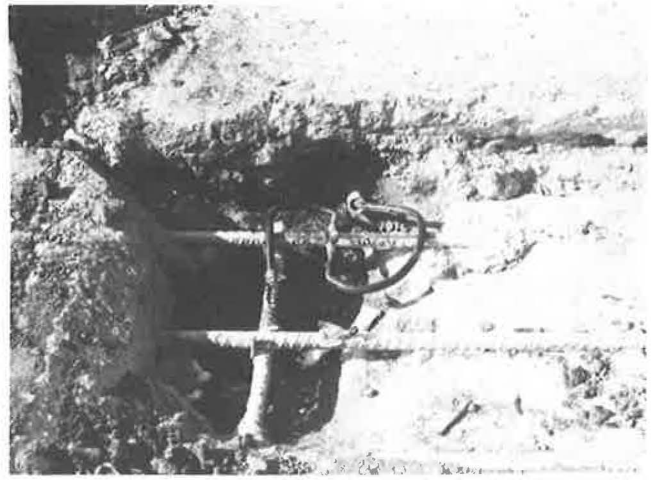

FIGURE 11 Completed cadwelds and conduit.

FIGURE 12 Test station.

FIGURE 13 Corrosion probe.

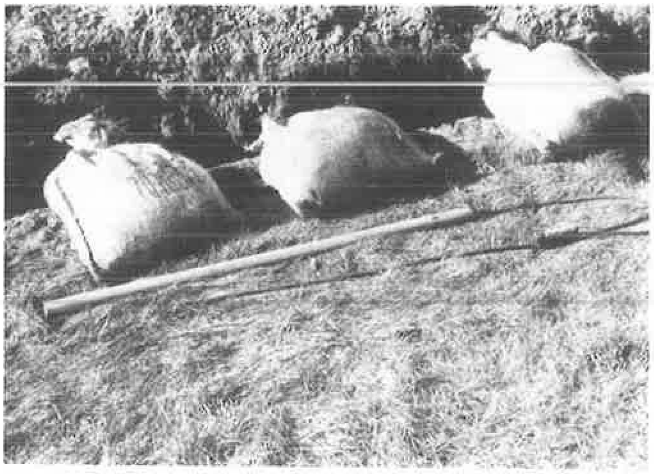

FIGURE 14 Completed splice kit.

FIGURE 16 Drilling in casing.

FIGURE 15 Lowering canister into post hole.

switch to a much slower auger. Eventually, the holes were predrilled with a higher-speed auger and completed at low speed in a casing (Figure 16).

When work stopped for the winter, the contractor had completed all but the lead wires for the anodes for the two post-hole systems and the placement of the rectifiers, which had not yet been delivered.

In the summer of 1983, the contractor made the cadweld connection of the number 8 AWG anode lead to the number 2 AWG header cable for each anode of the post-hole systems. A splice kit was used to cover each cadweld, and each splice kit was again checked with a holiday detector. A 3-in. rigid metallic conduit was passed under the roadway to carry the cables from the median to the rectifiers, which are located on the backslopes.

Also in the summer of 1983, the designer conducted E log I tests to determine the power levels at which the systems would be operated. All systems were finally activated in November and December 1983. The trench system and the post-hole systems were set to operate at between 8 and 9 A per zone. This results in about 8 to 9 V per zone for the trench system and 9 to 10 V for the shallow-post-hole system. The deep-post-hole system operates at from 7 to a maximum of 21 V per zone as the system gets into high-resistivity soil. The embedded corrosion probes showed no corrosion activity.

Extensive half-cell testing has not been completed. In the late summer of 1984, all five circuit cards in the rectifier for the trench system were lost because of electrical damage. The three systems have not been in operation at the same time since.

When all systems were operating at about 0.5 mA/ft^2 of concrete, the monthly operational costs were about $60, $70, and $100 for the trench system, shallow-post-hole system, and deep-post-hole system, respectively.

FINDINGS AND CONCLUSIONS

With the exception of the soil problem, the construction of the cathodic protection system was successful. The same contractor had built the original pavement protection system, but he was still not familiar with this type of work. If more projects are let, more efficient ways should certainly be found to build them.

The use of a cable locator and a milling machine in establishing the system ground worked quickly and well. Drilling under the shoulder for the ground lead was an excellent idea. However, when the system ground trench was not backfilled promptly, the sides collapsed at several locations and the shoulder was damaged.

The handling of the coke was difficult. It was delivered in 100-lb sacks on pallets. The material was stockpiled when delivered and had to be handled more than once before it was finally placed.

The cadwelding required some trial and error but went very well after that. The splice kits all checked out well with the holiday detector and only one failed to set properly. That one was removed and replaced.

The rectifiers were ordered in late September 1982 and they arrived late in April 1983. One unit was damaged during handling by MnDOT and was returned in July for inspection and a new cabinet. The repaired unit was received in November and was promptly placed.

Initial testing of the system has indicated that the corrosion probe can be polarized. This indicates that the reinforcing steel can be, too. Extensive copper-copper sulfate half-cell tests are sorely needed. This is work that was intended to be done in 1984, but the operation of one of the rectifiers was lost before the testing could be scheduled.

When the recent CRCP inventory is reviewed (2), it may be seen that, of all of the projects surveyed, the reinforcing steel is at the minimum depth, all sections have chlorides in excess of the amount that induces corrosion, most sections have wide cracks, there is active corrosion on all CRCP, and most sections exhibit delaminations. Once again, more than 200 route-mi of CRCP are involved and at least four times that number of lane miles.

Cathodic protection is looked on as one possible solution to the CRCP problem. Any such decision will be influenced by the cost and effectiveness of the system.

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Early Performance of Eight Experimental Cathodic Protection Systems at the Burlington Bay Skyway Test Site

DAVID G. MANNING and HANNAH C. SCHELL

ABSTRACT

The initial phases of a research program to develop an effective cathodic protection system for use on bridge substructures are described. Four experimental cathodic protection systems were installed on the columns of the Burlington Bay Skyway Bridge in Burlington, Ontario, in 1982 and four more were added in 1983. Seven were impressed-current systems and one was a galvanic system. Each system covered approximately 40 m^2 of concrete surface. Several types of instrumentation were developed to monitor the effectiveness of the cathodic protection. All eight systems are being monitored, and the data collected through July 1984 are presented. All the impressed-current systems were found to be effective in stopping corrosion, but the components of some systems were not sufficiently durable. Insufficient power was available from the galvanic system for it to be practical. The future work required to develop a full-scale operational cathodic protection system for bridge substructures is discussed.

Four experimental cathodic protection systems were installed on the columns of the Burlington Bay Skyway in Burlington, Ontario, in 1982 and four more were added in 1983. The project is part of a research program to develop a means of rehabilitating corrosion-damaged bridge substructures. The specific objectives of this project and the details of the test site were described in two earlier papers (1,2). This paper summarizes the important features of each system and their performance up to July 1984.

DESIGN AND CONSTRUCTION

With the exception of System 4, all the installations were impressed-current systems. Each impressed-current system was powered by an unfiltered full-wave rectifier operating under constant current control. A summary of the main features of each system is given in Table 1 and a more complete description follows.

Systems 1 to 4 were installed in the same con-