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Bridge Deck Rehabilitation by Using Cathodic Protection with a Low-Slump Concrete Overlay

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ABSTRACT

The design and construction of a state-of-the-art cathodic protection system for a reinforced-concrete bridge deck by the Minnesota Department of Transportation is described. The bridge selected was the 42nd Street Bridge (Bridge 9616) over I-35W in South Minneapolis. The system selected was a distributed-anode system with a low-slump concrete overlay as a wearing surface. The system was constructed in the summer of 1983. The cathodic protection system has primary and secondary anodes for current distribution. A primary anode system of platinized niobium wire placed transversely across the bridge feeds a secondary anode system of carbon strands placed longitudinally on the bridge. Both the wire and the strands are covered with conductive polymer concrete. Power from a rectifier is supplied to the anodes through a conduit running along the north crash rail of the bridge. Rehabilitation of the bridge was completed in 30 working days, and the system was activated in December 1983.

In 1982 the Minnesota Department of Transportation decided to pursue the design and construction of a state-of-the-art cathodic protection system for a bridge deck rehabilitation. This project was to be undertaken with the participation of the Demonstration Projects Division of FHWA as part of Demonstration Project 34, Cathodic Protection.

Minnesota had previously placed an early design of cathodic protection. This system was placed in 1975 on the Duluth Street Bridge on Trunk Highway (T.H.) 100 (Bridge 27002) in Golden Valley. This system utilized a conductive coke breeze layer stabilized with asphalt and containing the cathodic protection hardware covered by an asphalt overlay as a wearing surface (Figure 1). Because of the instability of the conductive coke layer, the asphalt wearing surface showed distress and was reconstructed in 1981 by cold milling off 1 in. of the original overlay and replacing that with 2 in. of new material. By 1983 the wearing surface once again exhibited surface distress. Although the cathodic protection system had functioned satisfactorily, it was believed that an updated design might provide a more stable wearing surface.

After an investigation of bridges slated for rehabilitation, it was decided to contract for the design and construction of a cathodic protection system on the 42nd Street Bridge over I-35W in South Minneapolis. The designer selected was Kenneth Clear of Kenneth C. Clear, Incorporated. The rehabilitation contract was awarded to the low bidder, Arcon Construction Company of Mora, Minnesota. Egan McKay Electric of Minneapolis was the subcontractor.

It was decided to use a distributed-anode cathodic protection system on the bridge with a low-slump concrete overlay for the wearing surface.

BACKGROUND

The 42nd Street Bridge (Bridge 9616) over I-35W in South Minneapolis was constructed in 1964. The bridge is a precast concrete beam span made up of four spans

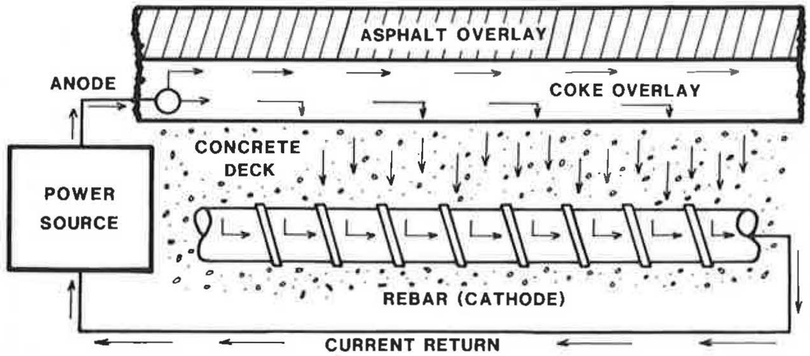

FIGURE 1 Trunk Highway 100 cathodic protection system.

(Figure 2). The two end spans are 25 ft on the west end and 31 ft on the east end. The two center spans are each 71 ft 6 in. long for a total length of 199 ft. The width of the roadway across the bridge is 52 ft, and there are 5-ft wide sidewalks on both sides. The roadway surface area is 10,348 ft^2 and the total sidewalk area is 1,990 ft^2, giving a total area of 12,338 ft^2 to be cathodically protected.

A September 1981 inspection of the 42nd Street Bridge revealed 5 percent delamination of the surface area of the roadway. The inspection also revealed that there were spalled areas on the caps at Piers 1 and 3 because of leaking of the expansion joints. The columns on the west pier (Pier 1) were in poor condition, and the ends on about 10 out of 24 of the precast girders (six each span) had also deteriorated because of the leaking expansion joints.

In July 1982 the Office of Research and Development did some additional testing of the 42nd Street Bridge. Delamination detection was done using a Delamtect. This supported the 1981 bridge inspection. Testing with a pachometer revealed that the concrete cover over the reinforcing steel was 1 in. to 2 3/4 in. The average depth of cover was 1 3/4 in. Drill dust samples were taken to determine the chloride in the bridge deck. Although there was a great deal of variation among the samples, average values were as follows: from 0 to 1/2 in., 4,300 parts per million (ppm); from 1/2 to 1 in., 1,900 ppm; from 1 to 1 1/2 in., 900 ppm; and from 1 1/2 to 2 in., 400 ppm.

A copper-copper sulfate half-cell was used to take potential readings on the bridge deck. This indicated that there was active corrosion at the bridge ends and at the expansion joints. There was also some active corrosion in the middle of the bridge deck.

With this information in hand, the design of the cathodic protection system of the 42nd Street Bridge began.

EXPERIMENTAL WORK

Design

The cathodic protection system for the 42nd Street Bridge is a distributed-anode cathodic protection system with a low-slump concrete overlay. Power is supplied to each of the four zones or spans of the bridge by a transverse primary anode system (Figure 3). The primary anode wire is 0.031 in. in diameter. It has a copper core with 35 percent of the cross-sectional area being niobium and a 25-μ-in. coating of platinum.

The anode is further distributed by placing longitudinal carbon strand conductors electrically continuous with the primary anodes. The carbon conductors are composed of 5 strands with 4,000 filaments per strand. These are then wrapped with Dacron to make the material fieldworthy. The carbon strands

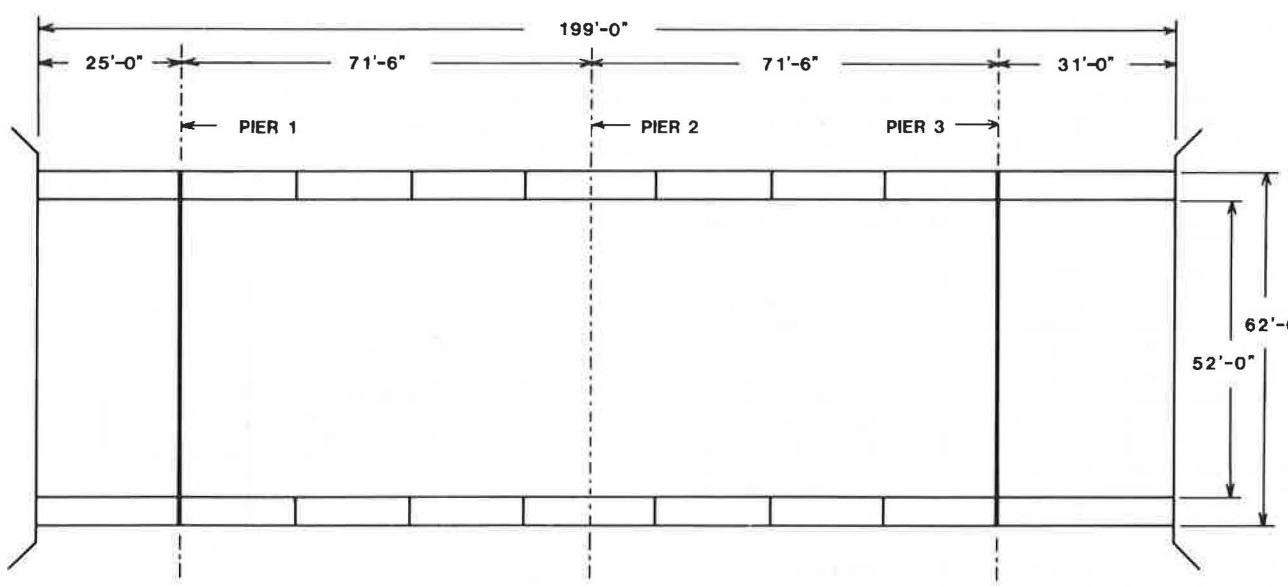

FIGURE 2 42nd Street Bridge over I-35W.

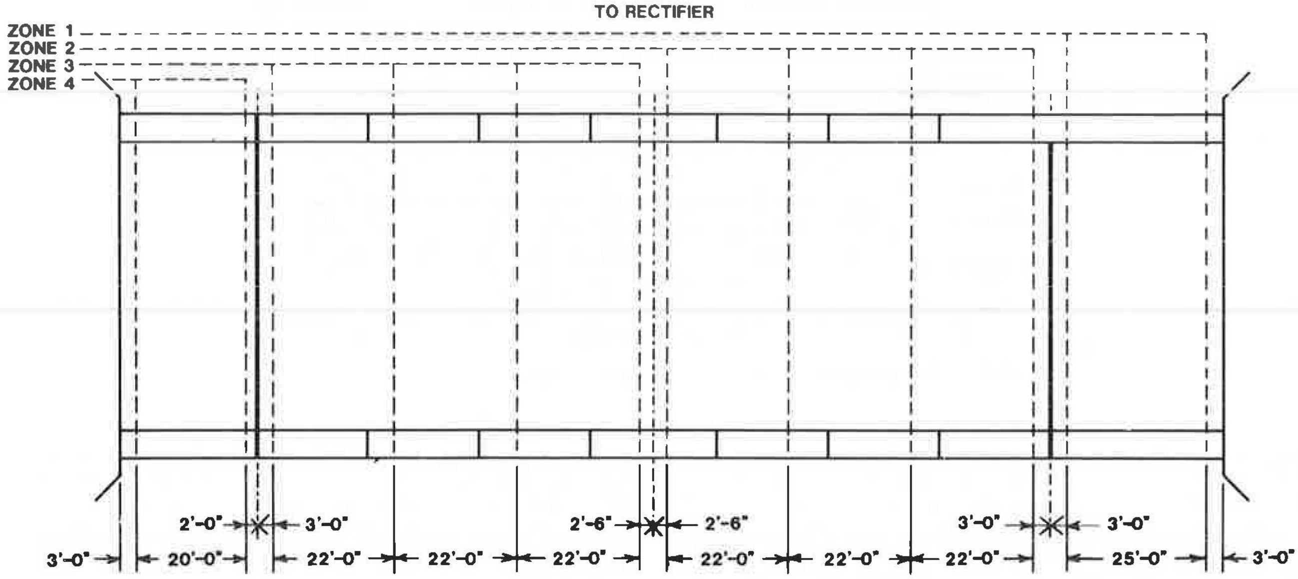

FIGURE 3 Platinized niobium primary anode system.

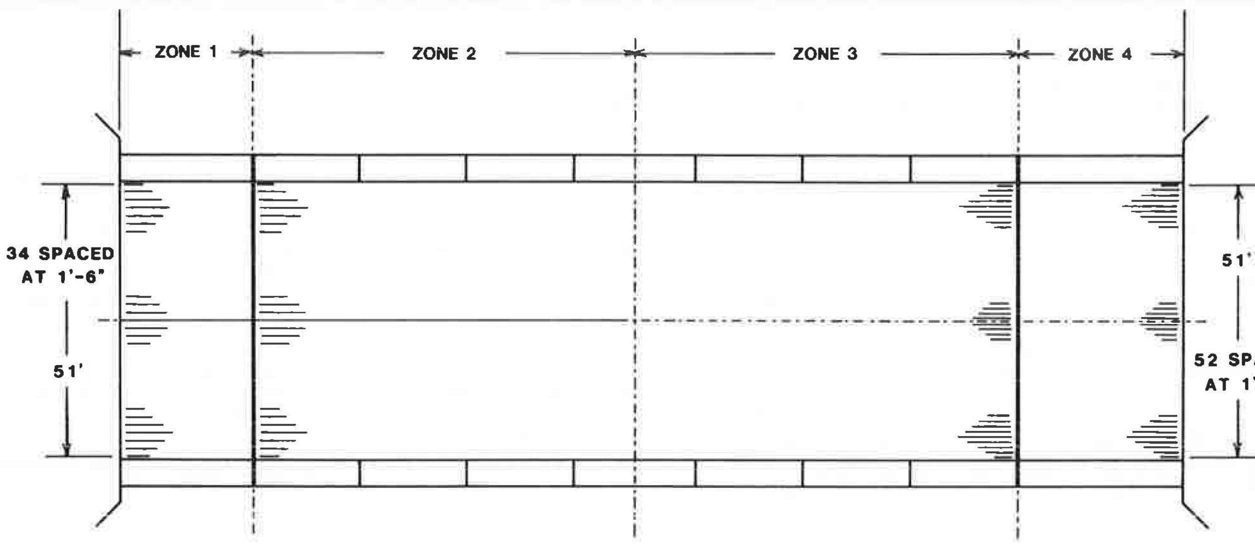

FIGURE 4 Carbon strand secondary anode system.

are 99 percent carbon and have a tensile strength of 250,000 psi. Secondary anodes are placed in two patterns (Figure 4). On half of the deck they are placed 1 1/2 ft apart and on the other half of the deck they are 1 ft apart. The two patterns were used to determine the most economical system for future applications.

The primary and secondary anodes are held on the deck with a ribbon of conductive polymer concrete (PC). This material provides additional anode material and protects the wire and carbon strands during placement of the overlay.

The sidewalks of the bridge are protected by a slotted cathodic protection system in which the same primary anodes are used but the wire and carbon strands are placed in slots cut in the sidewalk and backfilled with conductive PC (Figure 5). All carbon strands in the slotted sidewalk system are placed 1 ft apart.

Power for the distributed anode system is supplied by a rectifier with an alternating-current input of 115 V and 60 cycles capable of a direct-current output of 24 V and 14 A to each of the four zones. This would provide up to 3 mA per square foot of concrete.

Power from the rectifier to the distributed anodes is supplied through a buried rigid metallic conduit

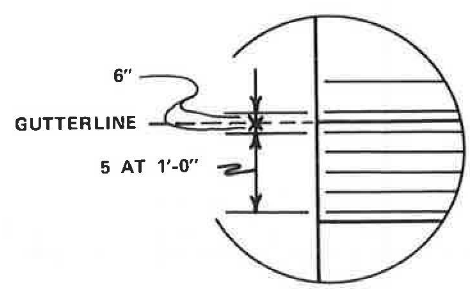

FIGURE 5 Cathodic protection of bridge sidewalks.

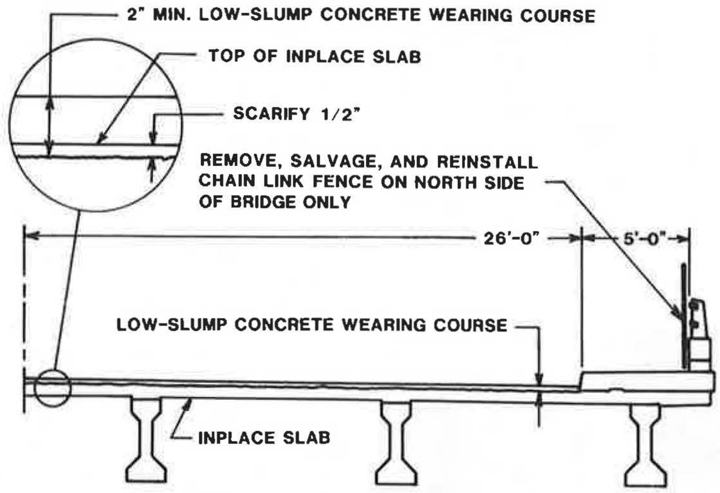

FIGURE 6 Typical section of 42nd Street Bridge.

from the rectifier to the bridge and polyvinyl chloride along the north crash rail of the bridge. Placement of the conduit on the bridge required removing and replacing a chain link fence (Figure 6).

The low bid for the rehabilitation of the 42nd Street Bridge was $163,200. This includes $3,500 for the rectifier, $37,900 for the cathodic protection system, and $2,000 for removal and reinstallation of the chain link fence. The total of $43,400 for the work related to cathodic protection is based on a price of $3.50/ft^2 of protected area.

Construction

Rehabilitation of the 42nd Street Bridge began July 11, 1983. After closing the bridge, the contractor milled off 1 in. of the bridge deck and began to repair the substructure. On July 19 and 20, the slots were cut in the sidewalk for the carbon strands and the platinized niobium wire anode. Concrete removals in delaminated areas and at the expansion joints also began at this time.

Holes were drilled through the sidewalk to drain the polyvinyl chloride conduit system carrying the wires that supply power to the deck. This proved to be a difficult task because of the amount of reinforcing steel in the deck. A hole was also drilled from the primary anode slot in the sidewalk through the curb to the bridge deck (Figure 7). This was done to lead the platinum wire from the sidewalk slot to the deck surface and back to the sidewalk slot on the other side of the bridge. By doing this, the contractor did not have to saw the face of the curb.

Miscellaneous steel in the deck was made electrically continuous with the reinforcing steel, and the reinforcing steel had a lead wire cadwelded to it to provide the system ground.

Corrosion probes were placed at the top and bottom reinforcing steel mats in each end span and at the top level in each center span (Figure 8). These probes consisted of a 6-in. piece of 5/8-in. reinforcing steel embedded in a 3 x 3 x 8-in. block of concrete containing about 15 lb of chloride per cubic yard of concrete.

The steel had a wire lead attached, and a ground wire was cadwelded to the reinforcing steel mat at a point near the probe. This, in effect, creates a strong corrosion cell. The effectiveness of the cathodic protection system can be revealed by the corrosion activity or lack of such activity in the corrosion probe.

FIGURE 7 Drilling hole through curb for primary anode wire.

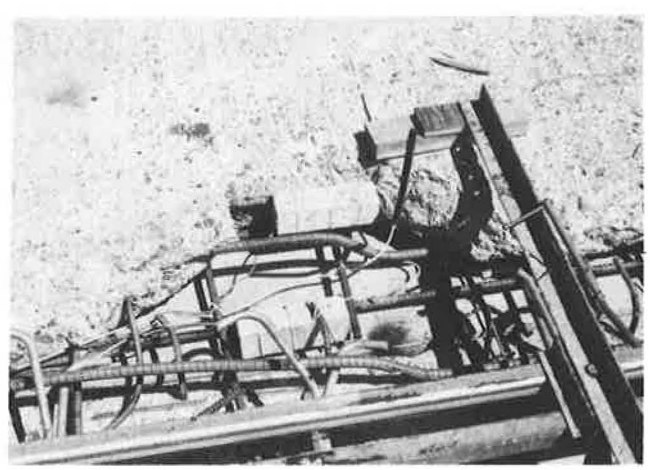

FIGURE 8 Corrosion probes at top and bottom mats.

A silver-silver chloride reference cell was placed in each span of the bridge on August 5 to provide control of the rectifier output. These were placed as close to the depth of the steel as spacing of the steel would permit. The reference cells were patched with a salt-bearing concrete proportioned and supplied by the designer. Before the reference cell was placed, the patch area was moistened. A bed of fresh concrete was prepared, the reference cell was placed in it, and the patch was completed (Figure 9).

FIGURE 9 Patching reference cell.

After the expansion joints were placed but before the cathodic protection system was installed, the contractor sandblasted the bridge deck.

Figure 10 shows the beginning of work on the distributed-anode system on August 11. The electrician is leading the platinized niobium wire from the sidewalk slot through the hole in the curb to the bridge deck and across the deck. Behind the electrician are wooden pegs placed in holes that were drilled in the bridge deck. The pegs are either 1 or 1 1/2 ft apart depending on the required spacing of the carbon strand secondary anodes. The carbon strand was strung out on the deck from one end of a zone to the other, wrapped around two pegs, and strung back to the other end. Wrapping the strand around these pegs allowed it to be pulled tight and the proper spacing of either 1 or 1 1/2 ft between the strands could be maintained until the PC ribbons were placed. After the PC was cured, the pegs were pulled and the excess carbon strand was removed.

Placing the conductive PC was a time-consuming process. It began with the combining and mixing of the resin and hardener. This was done outdoors where ventilation was no problem. Mixing was done in the container in which the resin had arrived. The resin was shipped in 1-gal units in Imperial gallon-sized metal cans.

The resin and hardener were then added to a heavy-duty plastic bag containing a preweighed amount of conductive coke. The liquids and coke were mixed in the plastic bag by using a rolling motion; this was carried out on a plastic-covered piece of plywood (Figure 11). The mixed PC was transferred to a pail and then to a hand-made hopper and extruder (Figure 12). After the conductive PC ribbon was placed, it was sprinkled with dry coke, which was beneficial to the cure of the PC.

The first plexiglass hopper and extruder was supplied by the designer of the cathodic protection system and was copied by the electrical subcontractor. Several of these plexiglass devices were used. With time, the PC would bond to the plexiglass

FIGURE 11 Mixing resin, hardener, and coke.

FIGURE 10 Passing platinum wire through curb.

FIGURE 12 Placing PC ribbon.

and start to clog the hopper and the extruder. This made for slower production and for a smaller ribbon. Specifications called for the ribbon to be 1 to 1 1/2 in. wide and 3/8 to 5/8 in. thick. It took a total of 14 hr to complete the first half of the bridge deck. The second half of the bridge was completed in about 8 hr. The first half of the low-slump overlay was placed August 12, the day following completion of half of the cathodic protection system and 1 month after work had begun.

Before the low-slump concrete was placed, a sand cement grout was placed on the bridge deck and brushed around. Concrete was supplied by a concrete mobile to a Bidwell paver.

The platinum wire for the second half of the protective system was coiled underneath a greased steel plate, which was paved over (Figure 13). Later a saw cut was made to provide a sharp vertical edge against which the remainder of the overlay was to be placed. When the excess concrete was removed, the steel plate was exposed, and the cathodic protection system was placed on the remaining behalf of the bridge deck.

FIGURE 13 Plate covering platinum wire.

Originally, the cathodic protection system was designed so that traffic could be maintained over the bridge during construction. However, rehabilitation of the bridge permitted complete closure of the structure. The only problem associated with this portion of the project was that a platinized niobium wire was cut with a jackhammer and had to be spliced. The grid system design should account for any future problem that may occur because of splicing or from any breaks that may develop.

On August 17 the distributed-anode system was placed on the south half of the bridge. On August 18 the bridge deck was cleaned, and the remainder of the riding surface was placed 2 days following the placement of the protective system, on August 19. This was started early in the morning in order to avoid the hottest part of the day. The paving went well. An Astroturf drag was used to provide surface texture, and transverse tining was placed by hand to within 1 ft of each gutterline. A sprayed membrane-curing compound was applied.

Following the paving of the bridge deck but before the bridge was opened, the sidewalk slot system of protection was placed. The slot system on the north side was placed on August 22 and 23 and the south side on August 24. The platinum wire was placed in the transverse slots and conductive carbon strands were placed in the longitudinal slots.

The conductive coke was weighed for each batch of PC mixed. A coloring agent was added to the coke filler to lighten the color of the material and make it more closely resemble the sidewalk concrete. The coke and coloring agents were thoroughly mixed.

The hardener and resin were combined and then mixed together. These were then added to the conductive coke material and mixed in the same manner as the ribbon material on the bridge deck. The corner was cut off the mixing bag, and the conductive PC was placed directly into the slot from the bag (Figure 14). Silica sand instead of coke was placed on the fresh polymer sidewalk because sand is lighter in color but still helps both curing and traction. It took three working days to prepare and complete the sidewalks of the bridge. It took a total of about 6 hr to place the conductive PC on each side. At the same time, the approaches were paved, and the bridge was opened late in the evening of August 24, 45 days after construction began. The remaining work on the conduit runs and junction boxes was done while there was traffic on the bridge deck.

FIGURE 14 Placing conductive PC in sidewalk slot.

Because of production delays, the rectifier was not received until December. It was promptly placed and activated on December 20. The rectifier is capable of 24 V direct current and 14 A for each of the four zones.

On the basis of E log I tests conducted before activation, the system is operating at the cathodic protection current. The corrosion probes in the bridge deck do not show corrosion activity. The system is operating at 0.3 A for Zone 1, the west end span, and 0.9 A for Zone 2. These zones have 1 1/2-ft secondary anode spacing. Zones 3 and 4, with 1-ft secondary anode spacing, are both operated off one circuit because of a defective circuit card. They draw a total of 1.2 A. Voltage varies but is about 1.5 V in all cases.

Extensive testing of the cathodic protection system could not be done in 1984. In April the control panel of the rectifier was stolen, and this was not replaced until the end of August 1984. The system was inoperable all summer. Testing will be done when time and weather permit. The system will then be changed to operate on four circuits as planned.

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

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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.