Experience with Cathodic Protection in Missouri

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Use of cathodic protection of reinforced concrete bridge decks in Missouri has developed rapidly because of the significant number of all concrete structures, such as box beam, box girder, voided, and flat slab, that are in need of roadway surface repair. Various cathodic protection systems have or are being used in these rehabilitation efforts. As a result of Missouri's experience with cathodic protection systems an awareness has developed of the need for close inspection during placement and continued evaluation and monitoring during operation. Maintenance requirements may not totally cease simply because cathodic protection has been placed on a structure.

Missouri has many concrete box girder, box beam, voided, and solid slab structures built about the time the initial interstate program was in full swing. These structures pose unique problems when reconstruction of the concrete riding surface or roadway portion of the deck is warranted. Obviously, the roadway portion or deck surface cannot be easily removed in its entirety and replaced, as on steel stringer types of structures, without replacing the false work and holding the remainder of the structure in place during reconstruction. Furthermore, many of these structures are located in congested interchanges over other heavy traffic roadways where use of extensive false work will be impossible without rerouting traffic. To gain additional life from these structures, repairs are made and cathodic protection is placed on the roadway portion of the deck surface. The use of cathodic protection is not limited, however, to these specific types of structures. Missouri has rehabilitated or has under contract for rehabilitation as of January 1, 1987, 71 all-concrete structures and 20 steel frame or stringer structures for a total of 91 structures with cathodic protection systems.

During construction and operation of Missouri's cathodic protection systems, various problems have surfaced that merit alerting users or potential users of cathodic protection systems. This report is in no way intended to be derogatory of cathodic protection or its theory of operation. It is intended to show the care that must be exercised by contractor and contracting agency for the design, placement, and maintenance of cathodic protection systems.

HISTORY

Missouri's experience with cathodic protection dates back to 1975 when a cathodic protection system, similar to the Stratfull design with Duriron pancake anodes and coke breeze asphaltic electrolite, was placed on twin concrete box girder bridges. This design was used once again in 1977 on twin steel I-beam structures in conjunction with a bridge deck rehabilitation study.

In 1978, the Stratfull design was modified to consist of strings of anodes placed within zoned areas on the bridge deck. This system was placed on a voided slab structure that had been rehabilitated and widened. The widening consisted of voided slab non-integral lanes constructed on each side of the parent structure.

The sawed slot system, using platinum-niobium-copper wire anodes as suggested by the Federal Highway Administration (FHWA) and several cathodic protection companies, has been the standard cathodic protection system placed after July 1984. This design was changed in early 1985 to a platinum-niobium-copper wire primary with a carbon strand secondary system as a cost reduction measure. However, the carbon strand secondary system was quickly removed as a design choice when information was produced indicating that the carbon strand life might be extremely short because of possible rapid decomposition at the energy levels considered operational for bridge deck cathodic protection systems. Several sawed slot designs have been modified during construction to provide for placement of anode and anode backfill material on the scarified surface in a mound configuration. These modifications were required because the top reinforcing steel in the deck concrete was too close to the scarified surface to permit sawing of the slots. The first designs in 1984 incorporated an asphaltic concrete overlay on the deck surface to protect the system and eliminate the visual grid effect. Overlay design was changed in 1985 to a Latex-modified concrete. Present practice, except for special cases, allows the option of low slump or Latex-modified concrete overlays.

Experimentation continues with cathodic protection in Missouri as the use of new products is considered and technology continues to be enhanced. Surface-applied systems such as Raychem, Ferex 100; Eltech, Elgard 210; and Matcor/Thoro Conductive coating have been used in experimental installations.

OBSERVATION OF COKE BREEZE CATHODIC PROTECTION SYSTEM

Stability of Coke Breeze Asphaltic Concrete

The Stratfull design with Duriron anodes placed in the curb line used a coke breeze asphaltic electrolite for current distribution

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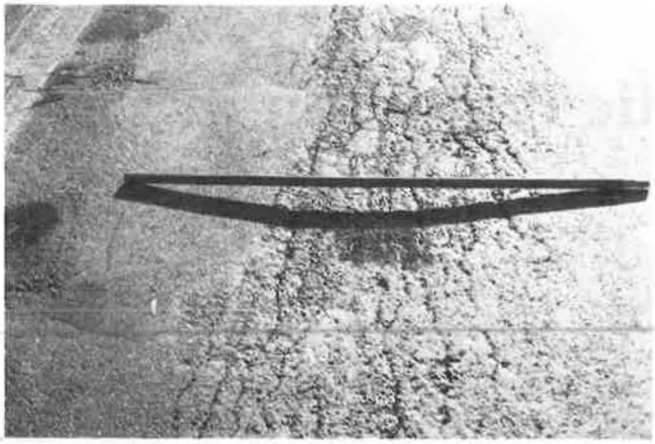

FIGURE 1 Wheel rutting in outer wheel path of driving lane.

and an asphaltic-concrete overlay for the riding surface. Performance of this system has been satisfactory considering the heavy traffic. However, lack of long-term stability of the coke breeze asphaltic mixture is now presenting some problems. Over the past 9-year life of these structures, wheel rutting (Figure 1) has continued to increase with time. Cracking and depression of the porphyry rock asphaltic concrete overlay in the wheel path area (Figure 2) will eventually require extensive maintenance to re-establish the design thickness of the coke breeze mixture and replace the porphyry rock asphaltic concrete overlay.

Drainage of Infiltrating Water

The success of any cathodic protection system is dependent on the electrical resistance of the concrete in the deck and the anode backfill or electrolite material. On Missouri's first installation, galvanized steel plates were placed over the curb outlets to create a ponding effect for rainwater in the coke breeze asphaltic mixture. This was done to maintain high moisture content to enhance the lowering of electrical resistance. The result was frost heave during the first winter (Figure 3). Cracking in the asphaltic overlay was random, blocky, and full depth. Maintenance operations included sealing cracks and removing curb outlet cover plates as soon as the problem was detected. No subsequent massive failure of the porphyry rock asphaltic concrete has been noted; however, as time passed, the edges of the cracks spalled and worked into shallow potholes (Figure 4). Maintenance is now routine on these structures to prevent further excessive loss of overlay and to maintain a rideable surface.

Corrosion of Anodes

The basic principle of cathodic protection is that the constructed anode system convert the reinforcing steel in the concrete to a cathodic state by sacrificial or impressed current placed in the deck through the anodes. Any corrosion activity, therefore, should be related to the constructed anode system. In

FIGURE 2 Longitudinal cracking in wheel paths of driving lane and transverse cracking in outer shoulder where coke breeze asphaltic mixture is being shoved from the wheel path.

FIGURE 3 Cracking in wearing surface, porphyry asphaltic concrete, after first winter of exposure and frost heave.

FIGURE 4 Continued deterioration of cracking shown in Figure 3 resulted in spalling of wearing surface to the interface with coke breeze asphaltic mixture.

the coke breeze cathodic protection system, the anodes were made of silicon chromium cast iron alloy to minimize the yearly rate of loss due to corrosion. Nevertheless, the corrosion product has caused volume expansion around the anode sufficient to raise the asphaltic overlay material, causing some spalling (Figure 5). A brownish-colored corrosion product has also migrated to curb outlet areas and spilled onto the slope protection (Figure 6) under the bridge, causing an aesthetic problem. This product, mostly iron oxide, also appears to penetrate the concrete deck through structural cracks, as evidenced by the product flowing from the void tube vent holes (Figure 7) and staining the bottom of a voided slab deck.

Another pair of structures having a coke breeze cathodic protection system did not have curb outlets because they were located over another roadway. Because of the freezing problems encountered in the asphaltic overlay of the first coke breeze systems, holes were drilled in the curb lines near the low end of the structures near the raised expansion device to provide drainage. The result was successful drainage of the water but also the drainage of the brownish corrosion product onto the steel stringers (Figure 8). These observations may be of significant concern if this material is conductive enough to cause a short in the cathodic protection circuits.

FIGURE 5 Corrosion of anodes caused swelling of asphaltic layers, cracking, and emission of brownish-colored corrosion product on surface.

FIGURE 6 Corrosion product from anodes migrated to curb outlets provided for water drainage, causing staining on slope protection and bridge parapet walls.

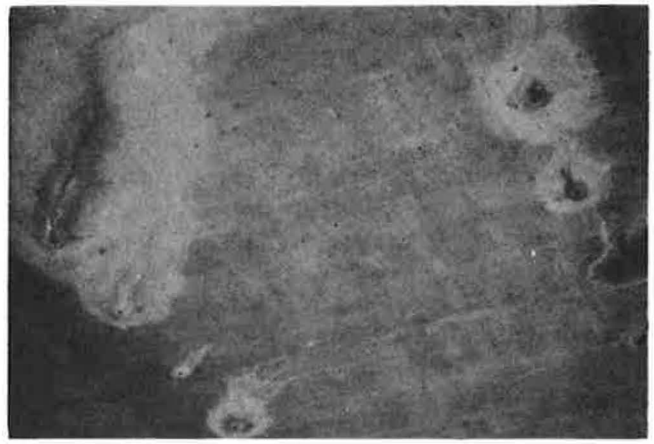

FIGURE 7 Corrosion product also found its way through cracks into the void tubes and eventually onto the bottom of the deck at the void tube vents.

FIGURE 8 Corrosion product and water drained from deck through improperly placed drains caused staining and corrosion of steel stringers.

Corrosion of Areas Not Covered by Cathodic Protection System

Areas remote to the cathodic protection system probably do not receive the benefit of the system, even though continuity tests indicate interconnection with the deck reinforcing steel. The coke breeze asphaltic electrolite is placed on the deck surface to distribute current to every square inch of the deck reinforcing steel by the shortest path possible, straight down. Curbs, parapets, curb outlets, exterior bottom edges, and bottoms of the decks are areas that are remote and probably receive little or no influence from the cathodic protection system placed on the surface of the deck. The first structure rehabilitated with a coke breeze cathodic protection system did not show significant deterioration in the curb outlet areas before placing cathodic

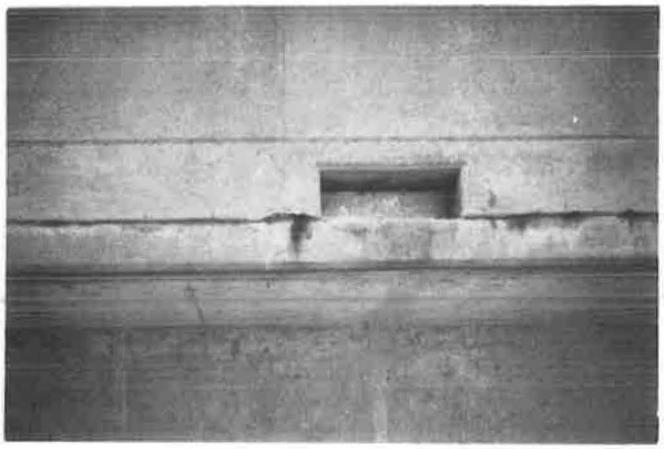

FIGURE 9 Deterioration continues in unprotected outer parapet areas. Curb outlet Number 3 during installation of cathodic protection in 1975.

FIGURE 11 Deterioration of underside of deck because of water and salt intrusion under surface-mounted angle iron and preformed elastomeric joint assemblies.

protection. The photograph in Figure 9 was taken during reconstruction in 1975, and that in Figure 10 was taken in 1986. Corrosion in this area appears heavy with deep crusting and flaking of the reinforcing steel. The lower edge of the original voided slab structure in another coke breeze cathodic protection system is spalling and continuing to corrode heavily because of salt and water ingress through joints on the surface of the deck (Figure 11). Future designs should consider the entire superstructure, and possibly the substructure, in the development of a cathodic protection system. More than one specific type of system might possibly be used to protect a given structure. For example, a sawed slot system on the deck with a conductive paint system on the parapet, curb outlet, and bottom edge areas could be used.

Electrical Wiring Exit Port Seals

Electrical wiring for the anodes, probes of various kinds, and negative ground connections to the reinforcing steel must run from the structure to the rectifier. A hole is generally drilled through the deck concrete and the conduit placed and sealed in the hole through which wires are routed. The wires are then sealed at the tube entrance before the overlay material is placed. Where seals fail, water and salt will settle in the conduit system at the low points. Corrosion of the metal conduit and freezing temperatures caused deterioration of the conduit system (Figure 12). Attempts to drain the water by drilling holes in the conduit have not been totally successful. Use of plastic conduit has prevented a corrosion; however, freezing water (Figure 13) is still a problem.

Corrosion of Lead Wire Connectors

Lead wire used in the cathodic protection of bridge decks is large-gage stranded copper wire with a tough temperature- and light-resistant coating. The purpose of the heavy-gage stranded copper is to reduce the lead resistance that must be considered for circuit output load, especially in long runs. The tough, temperature- and light-resistant coating is needed to prevent damage and deterioration during and after installation. Wiring pigtails are factory installed by the manufacturer on anodes and electrical probes required for installation with the cathodic

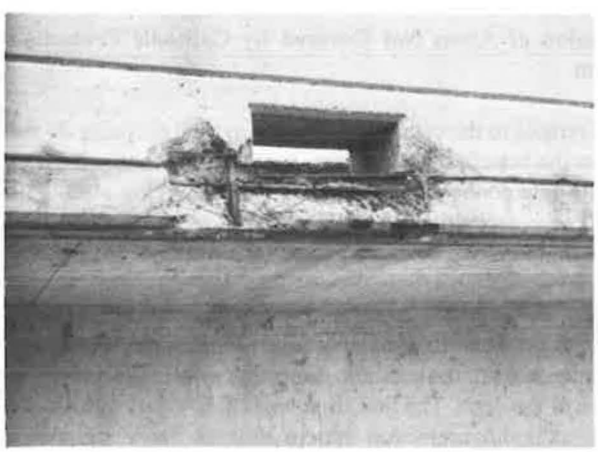

FIGURE 10 Curb outlet Number 3 as observed in 1986.

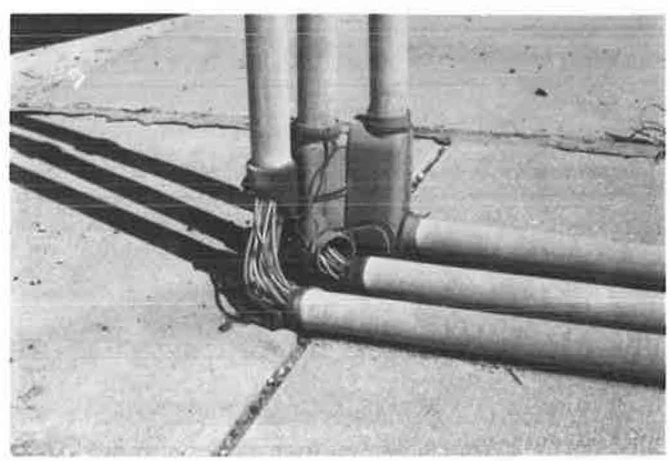

FIGURE 12 Deterioration of joints in conduit protecting wiring from bridge to rectifier assembly.

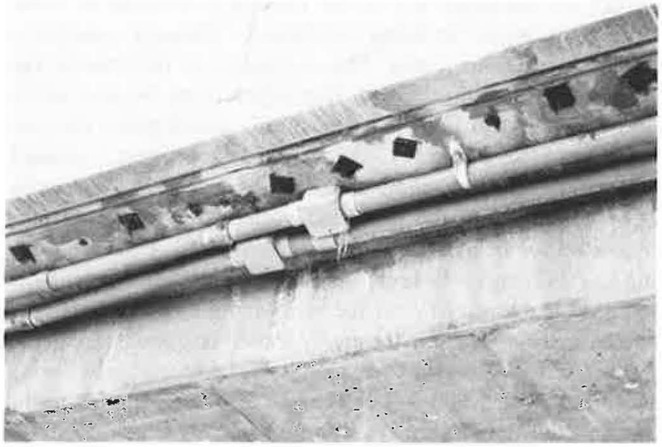

FIGURE 13 Icicles from intrusion of water into conduit assemblies because of incomplete sealing of holes carrying wiring from deck to rectifier assembly.

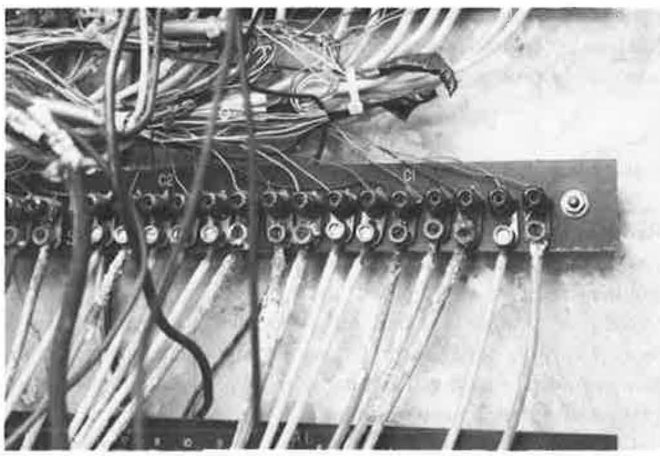

FIGURE 14 Corrosion product at lug terminals apparently caused by emission of corrosive materials following the capillaries in stranded wire from the deck to the rectifier.

protection systems. Evidence of corrosion and discharge of various products at connections in the rectifier and controller assemblies where the lead wires terminate (Figure 14) indicate a definite need for better sealing of wire connections at the probe or anode end. The small holes between the stranded wires seem to provide ideal passageways for waterborne chemicals or materials to reach the rectifier. The inability of the wire coating to penetrate and seal these holes could be alleviated by injecting a sealant into the exposed holes between the strands before connections are made to the devices. Products allowed to seep into the lead wires may also cause deterioration of the wire, resulting in a loss of current to a zone of protection.

Design of Expansion-Joint Rehabilitation

Rehabilitation of bridge decks normally results in an increase in total thickness because of the placement of new overlay. Expansion joints must be raised, with provision at the ends of the bridges made to contain the overlay material, especially asphaltic materials. The simplest design was to place angle irons back to back with a preformed elastomeric joint seal inserted between them. The angle irons were attached to the deck by concrete anchor assemblies epoxied in place with nonconductive materials. Results from these designs indicated a lack of stability under traffic loading. The angle irons pull loose from the deck by stripping the anchor assemblies out of the concrete. Cracking and spalling of the overlay occur at joints and parallel to the angles. Water and salt leak under the joint and drain down the edge of the concrete deck to cause further corrosion problems, as already mentioned. To correct this problem, the designs were changed to require complete removal of a portion of the deck at the joint location and to recast the concrete with a 1-ft-wide concrete haunch at the elevation of the proposed overlay system. Steel angles were inverted and cast into the haunch system with a preformed elastomeric joint seal placed between them. Later these designs were changed to install other types of compression expansion joint systems, which eliminated the angle iron anchor assembly. These designs required a small portion of the deck to be removed and recast with the joint-anchoring device in place.

Shoving and Washboarding of Asphaltic Concrete Overlay

Overlays are placed on all cathodic protection installations in Missouri to protect the system from damage or wear and to give a better riding surface after deck repairs are made. However, attention should be directed to the design configuration and location of the structure when specifying the type of overlay. Asphaltic overlays tend to yield under continual stop-go movements. The use of a coke-breeze mixture may tend to aggravate such deterioration. One installation of the coke breeze cathodic protection system was on a structure with a 4 percent grade and electrically operated signals on both ends. The traffic in the stopping and acceleration areas caused washboarding, spalling, shoving, and potholing. Maintenance of the asphaltic overlay on this structure (Figure 15) was required shortly after becoming operational. Leveling efforts in the humped areas resulted in exposing the coke-breeze asphaltic mixture, which had been shoved to the extent of having a thickness greater than the total overlay design.

FIGURE 15 Deterioration of asphaltic concrete overlay caused by stopping of vehicles.

OBSERVATION OF OTHER CATHODIC PROTECTION SYSTEMS

Some of the problems already mentioned will probably not occur in the new methods now being implemented in the cathodic protection of concrete bridge decks. However, care during installation must be the same, if not greater, for the system to function. Sawed slot and mounded anode systems were heavily promoted during the early 1980s. These systems appear to be operating satisfactorily, although the first installation in Missouri is only 2 years old. The problem with these systems observed to date, and mentioned later in this paper, will be primarily related to the construction phase of placing the cathodic protection systems.

Sawed-Slot and Mounded Anodes

Sawed-slot designs enable the anode backfill material to be placed in a confined self-forming environment. The mounded systems do not have the benefit of forming. Placement of the normal anode backfill mixture, because of its very low viscosity, therefore requires careful and possible repeated application to achieve the desired effect. Too much backfill material placed at one time in the mounded system may cause significant spreading of the backfill material, with reduction in the amount of scarified surface left exposed (Figure 16), upon which bond of the overlay is dependent. Without sand applied to the final application, the anode backfill material will have a glossy smooth finish that will probably have less bond strength with a concrete overlay. Sawed slots, however, are time and labor intense, making placement expensive, especially for concrete made with chert gravel aggregate.

Concrete Cover on Reinforcing Steel After Scarification

Concrete cover over the reinforcing steel in the deck must be checked after preparation for placement of the anode system to ensure that no shorts will occur. Various thicknesses of cover have been quoted as being satisfactory. Missouri specifies a minimum of ½-in. cover. The contractor is responsible for determining compliance with this requirement. Several structures have had to be redesigned during construction because sawing of slots was impossible owing to excessively high steel after scarifying was completed. These decks have normally been converted to the mounded systems, or the contractor requested use of a different anode system. Where the reinforcing steel is found to be high, a non-conductive epoxy coating is required to be placed over the reinforcing bar and under the anode. In the sawed slot, the epoxy should be placed only in the bottom of the slot. However, inspection of several jobs during construction revealed that epoxy had also been applied to the walls of the slot (Figure 17). The immediately exposed surface of the anode backfill material after placing has been found to be nonconductive because of settlement of the carbon material or flushing of the epoxy matrix. The result of the coated walls of the slot and the nonconductive exposed surface of the anode backfill material is complete encapsulation of the anode in a nonconductive sheath. If this condition exists for an appreciable length or width of the deck, the reinforcing steel may not be adequately protected.

Rectifier and Controller Assemblies

Rectifier and controller assemblies are normally housed in convection-cooled cabinets close to the subject structure. Placing the cabinet near the end of the structure, where it is visible to the public rather than under the structure where vandalism is more likely to occur, is preferred. By so placing these units, however, dirt, water, and salt spray from passing vehicles have presented a maintenance problem.

Convection cooling of the cabinets is cheaper, but without filtering and proper design of large roof overhangs dirt and water will enter the vents and collect on the components (Figure 18). In some instances dirt, water, and salt have settled on the printed circuit boards and caused shorts and burnouts. A few cabinets have been constructed using forced ventilation

FIGURE 16 Placement of anode backfill material in the mound configuration is difficult because of the low viscosity of the material.

FIGURE 17 Improper placement of epoxy in slots to prevent shorts to high rebars.

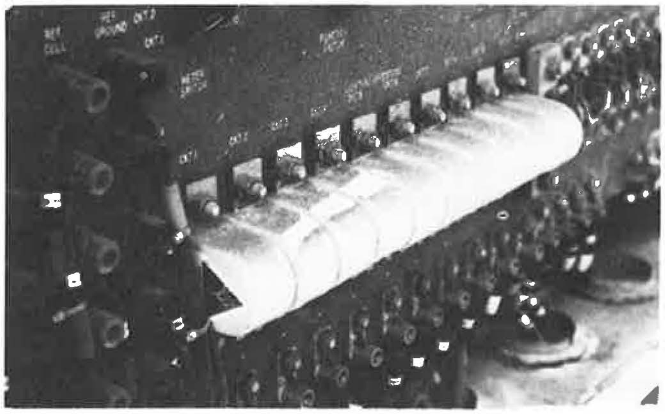

FIGURE 18 Dirt and water on the face of a rectifier-controller unit constructed with convection-cooled cabinet.

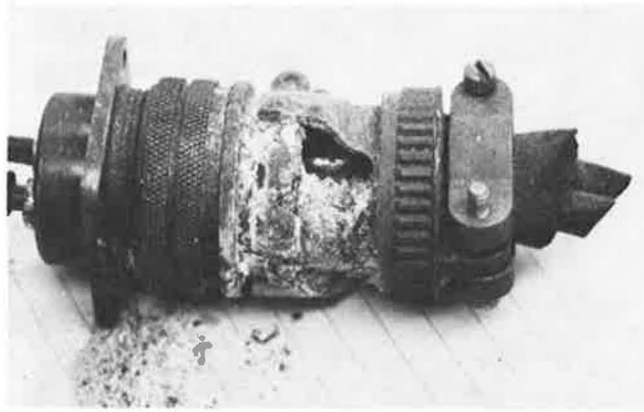

FIGURE 20 Amphenol connector removed from the rectifier unit shown in Figure 19, lower left connector.

and these appear to be cleaner and have not presented problems. Future designs will require forced ventilation, and that all circuit boards be factory-coated with dielectric resins, mounted in the chassis vertically. All field-connected terminals should be coated to prevent corrosion.

Corrosion of Lead-Wire Connections

Wiring from the cathodic protection system on the deck continues to present problems at the connections in the controller assemblies. Amphenol connectors were specified for each respective zone to contain input and output leads to the anode system and its respective instrumentation. This was done to prevent accidentally reversing the input and output leads to a zone if replacement of the controller unit should be necessary. However, because of corrosive materials flowing through the wiring or dirt, water, and salt coming through the ventilation openings, severe connector corrosion has occurred.

The connectors shown in Figures 19 and 20 were in a unit that had been operational for only a few months. To correct this situation, simple screw lug terminals and permanent noncorrosive identification tags attached to the lead wires are being specified so that observation and maintenance will be easier. To prevent the possibility of reversing the positive and negative lead wires to anodes and instrumentation, color-coded wiring should be specified.

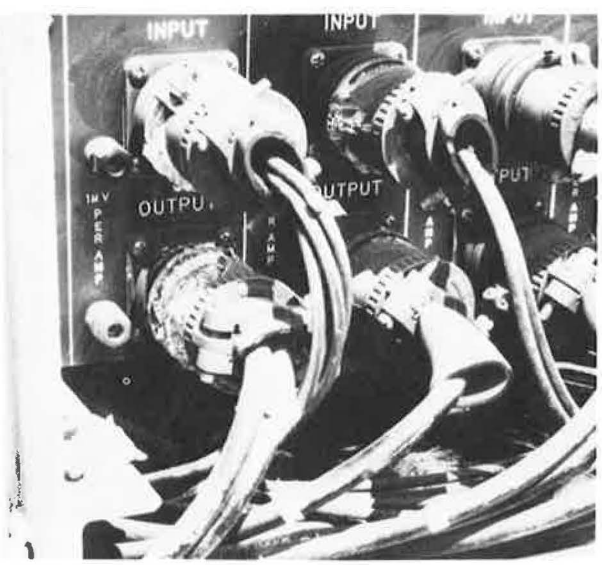

FIGURE 19 Amphenol connectors in rectifier unit showing corrosion.

FIELD EVALUATION OF NEW PRODUCTS

The newer experimental systems mentioned earlier in this paper are being activated after construction, or are presently under construction.

Raychem, Ferex 100

Raychem, Ferex 100 appears to be a durable anode system that is relatively easy to place compared with the other systems already discussed. Three installations with this product have been completed at this time. The only problem noted in placement was the inability to place the edge connecting rods neatly because of very rough concrete scarification, owing to hand-tool removal in the curb lines, (Figure 21). Rough surfaces cause the clip devices to rest at various angles, in turn causing the anode material to come loose easily during placement of the overlay. Experience has shown that mixer trucks can roll over this product without protection boards providing there are no sudden stops or starts.

Matcor-Thoro Conductive Coating

Plans were made for Matcor-Thoro conductive coating to be placed on a structure redesigned for the mounded system because of high steel. The system was changed to an experimental Matcor-Thoro conductive coating because of the structure's 4.74 percent grade and inability of the contractor to confine the specified anode backfill material to the immediate anode area only. Matcor-Thoro was applied with air jets as a spray (Figure 22). The strength and resistance properties appeared to be low

FIGURE 21 Raychem material is hard to hold in place if hand scarifying in curb lines is rough.

FIGURE 22 Application of Matcor/Thoro conductive coating.

and high, respectively, according to standard laboratory tests. There appeared to be some separation, or a floating of the carbon material to the surface, in the mixture after placing because of its relatively slow rate of set and moderate viscosity. The Matcor-Thoro material was placed in two lifts with the second receiving a comb texturing to enhance bonding with the Latex-modified concrete overlay.

After the first stage of construction was completed and opened to traffic, the concrete overlay experienced progressive delamination. Continued use of this material was rejected when the delamination problems were not adequately identified. During removal of the first-stage overlay, it was observed that the separation plane was between the two layers of Matcor-Thoro material in several locations. No further use of this product is now planned until the manufacturers have a chance to correct the problem.

Eltech, Elgard 210

Eltech, Elgard 210 is an expanded wire mesh of catalyzed titanium metal. To date, only the first stage of construction has been completed; however, the product was relatively easy to place and appeared quite durable. The mesh is resistance welded to the primary current distributor bars. The only problem encountered with this mesh is the sharp edges, which create handling problems.

SUMMARY AND CONCLUSIONS

The field of cathodic protection of reinforced concrete bridge decks is relatively new. Manufacturers and contracting agencies are continuing to develop, design, and build easily installed yet efficient protection systems. The problem items mentioned in this report are being, or have been, corrected on subsequent designs. More important, these observations have established the fact that simple design drawings and specifications are not the only ingredients to make a cathodic protection system work smoothly. Proper training of the inspectors and contractors in understanding the necessity for extreme (more than normal) care in placement of the anodes and instrument probes is imperative. A complete autopsy of a bridge when an old overlay system is removed and the original concrete deck is exposed for testing will indicate more accurately whether cathodic protection is working successfully. In the near future, it is anticipated that such an observation will be available from a widening and rehabilitation project proposed on one of the earlier coke breeze cathodic protection systems mentioned in this paper.

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