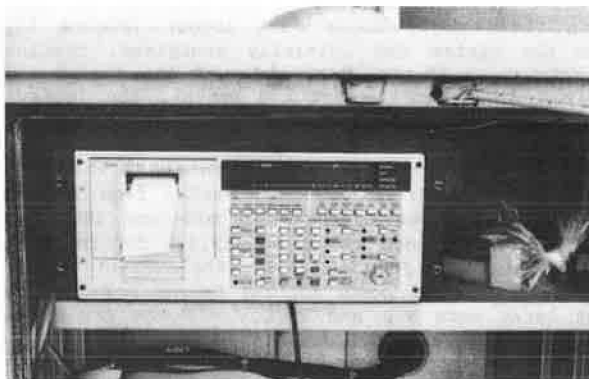


Figure 9. In-place reference cell.



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 neces-

sitating 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

field, various anode spacings were used to determine optimum spacing for corrosion protection. These experiments indicated that the platinized niobium anodes could not spread the voltage evenly across the bridge deck to establish proper cathodic protection. Because of the higher voltages required to overcome concrete resistance, some acid formed at the anodes and attacked the concrete.

The problem of corrosion of rebars in concrete bridge decks has been recognized for years (1); the problem is no longer confined only to the decks. It has been observed that corrosion-induced deterioration is occurring in reinforced concrete bridge substructures (2). This is becoming a growing concern to transportation agencies.

The principle of cathodic protection has been employed for years to stop corrosion on buried pipelines, concrete water tanks, and the hulls of ships. Since 1977, cathodic protection has been a standard method adopted by the Ministry of Transportation and Communications (MTC) to protect the reinforcing steel in bridge decks from corrosion (1). The current method of cathodic protection does not lend itself easily to installation on bridge substructures, since it is difficult to apply a conducting layer to a vertical surface. Platinized niobium anode wires have been used in an attempt to impress direct current into a bridge deck without the use of a conductive mix (3). If this system proves feasible on a bridge deck, it could easily be applied to the support systems of bridge decks. The anode wire could be set and cemented in grooves cut into the length of bridge columns or bents. The spacing of the anodes, to produce an even distribution of current, would depend on the conductivity of the concrete and would have to be determined by a field project. It was decided to do this test on a bridge deck, since it would be easier to set out a series of different anode spacings and the results would be applicable to both support systems and decks.

A bridge in Toronto was selected for this purpose. This was Bridge No. 9, located in the Highway 401-Don Valley interchange. It is a voided, post-tensioned structure 113 m (370 ft) long by 9.6 m (31.5 ft) wide, and it was built in 1966. This deck had some minor cracking, but corrosion was not a serious problem. Since the deck was in good condition, there was no need for repairs to spalls and delaminations. This made Bridge No. 9 an ideal choice for the experiment; also, it received the same salting treatments in winter as did the busy highway associated with it.

#### ANODE DESCRIPTION

The term "platinized anode" refers to an anode that is made by applying a thin coating of platinum over a substrate of niobium, which is passive under anodic conditions (4). The purpose of the substrate is to reduce the overall cost of the anode since a solid platinum anode would be extremely expensive. The use of a passivating material has the effect of confining the current discharge to the platinum surface (4).

In addition to the passive substrate of niobium, an inner core of copper was used for increased conductivity. This was necessary in long, thin anodes due to the higher resistivity of niobium (4). Also, an outer layer of copper was provided to protect the platinum layer from scratches during handling.

#### TEST INSTALLATION

One end of the bridge was chosen for the test installation. The entire deck was not treated. The reinforcing steel (rebars) in this deck was about 50

mm (2 in) below the deck surface. The rebars were No. 5 deformed bars, and both the longitudinal and the transverse bars were set on 300-mm (1-ft) centers.

The installation was designed to test the following anode spacings: 1.22 m (4 ft), 0.91 m (3 ft), 0.61 m (2 ft), and 0.30 m (1 ft) to see which would give an acceptable distribution of current across the deck. The anodes were set in grooves cut into the deck. The grooves were 10 mm (3/8 in) wide by 19 mm (3/4 in) deep.

In order to determine the applied and polarized potentials on the rebars, a series of small copper and copper sulfate half-cells were set in holes drilled into the deck. The positions of these half-cells and the anodes with reference to the rebars are shown in Figure 1. Each half-cell was connected by its own wire to a jack on the control panel (Figure 2). The applied or "instant-off" voltage could then be read at the panel by a high-impedance voltmeter.

Two zinc half-cells were installed next to the rebars (Figure 3). These half-cells with their re-

Figure 1. Anode and probe locations.

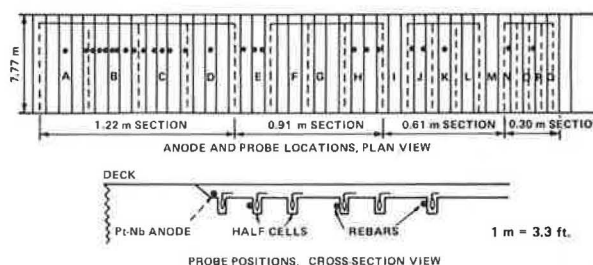


Figure 2. Control panel.

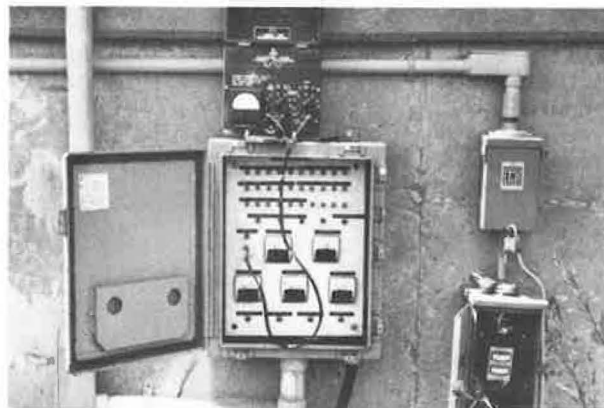


Figure 3. Deck wiring diagram.

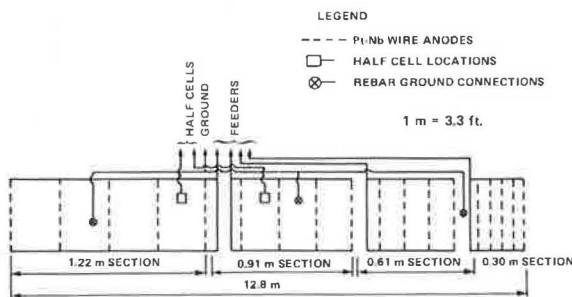


Figure 4. Laboratory test specimen.

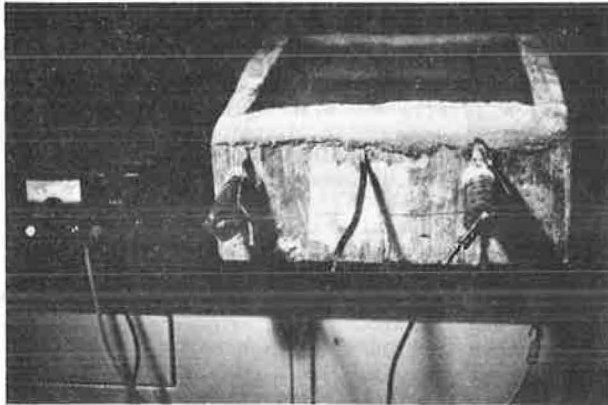


Figure 5. Voltage versus distance, 1.22-m section, applied voltage 6.0 V.

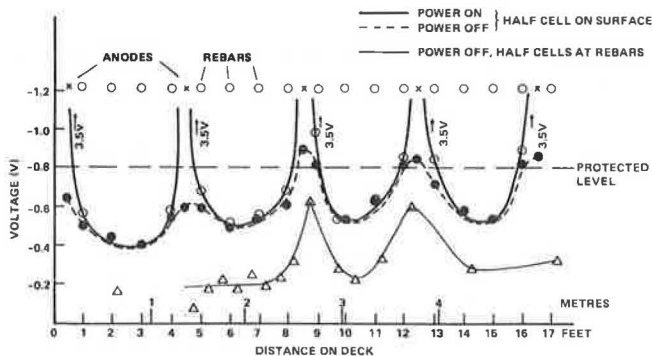
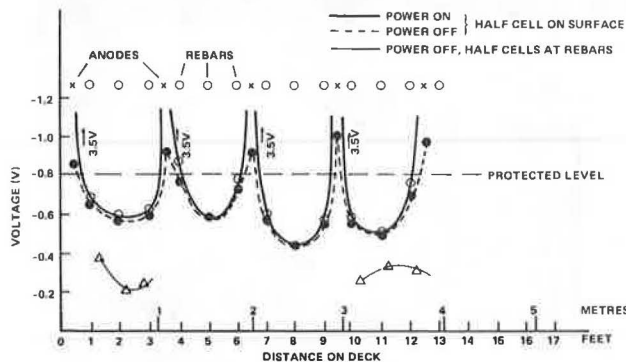


Figure 6. Voltage versus distance, 0.91-m sections, applied voltage 6.0 V.



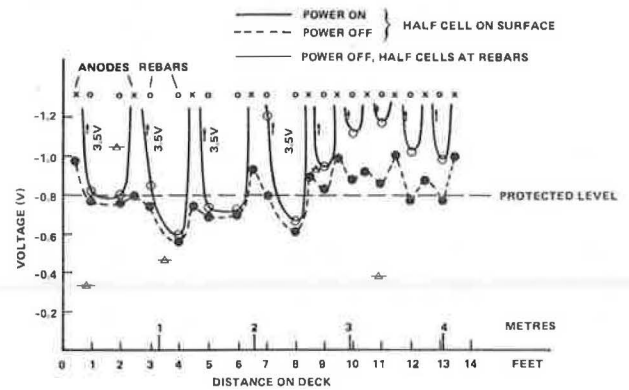
spective grounds were used to control and maintain the output voltage of the autovolt rectifier.

The anode wires were placed in their respective grooves. These grooves were then covered with a special nonshrinkable grout supplied by the supplier of the anode wire. Both ends of each anode wire were connected to the rectifier. This minimized the voltage drop due to the lengths of the narrow-gauge wire. The circuit is shown in Figure 3.

#### LABORATORY TEST SPECIMEN

In conjunction with the field investigation, a laboratory experiment was initiated to examine the physical and electrical properties of the platinized

Figure 7. Voltage versus distance, 0.61-m and 0.3-m sections, applied voltage 6.0 V.



anodes and their effect on the concrete. A concrete specimen 400 mm by 300 mm by 120 mm (16 in x 12 in x 5 in) was made. This experimental specimen contained two prerusted rebars. These were set 200 mm (8 in) apart and positioned 25 mm (1 in) below the surface. The concrete used contained 2 percent salt (NaCl) by weight of the cement. Therefore, a corrosive condition existed and, at the same time, an excess of free chloride ions was present. After the specimen had been cured, three grooves were cut in its surface to a depth of 6 mm (0.25 in). Two of these grooves were directly over the rebars; the third was midway between these rebars. Platinized anode wires were placed in these grooves and covered with grout. A dyke was formed on the surface around the entire specimen. Water was ponded on the surface and cathodic protection was applied to the specimen by using a wire anode directly over one rebar. In order to get a polarized potential of 1 V on the other rebar, 7 V were required for this protection. The experimental slab and connections are shown in Figure 4.

#### OBSERVATIONS AND DISCUSSION

Power was applied to the platinized wire system on the bridge in January 1981. An application of 6 V DC was made, and when equilibrium had been established after several days, potential readings were taken. These readings were repeated periodically for six months and the deck surface was examined. Potential readings were taken near rebar level by means of the built-in copper and copper sulfate half-cells and on the surface by means of a copper and copper sulfate half-cell pressed on the deck surface. The on-off readings were obtained with a current interrupter in the anode circuit.

The voltage readings on the surface over the anodes were higher than those obtained at rebar level, the reason being that the anode wires were closer to the surface than to the imbedded half-cells. Samples of the series of readings taken are shown in Figures 5, 6, and 7. The on-instant-off readings are shown for those taken on the surface and only the instant-off readings for the subsurface half-cells. The on readings for these were very close to the off readings.

Figures 5 and 6 show that readings taken near the anodes were high but dropped off rapidly as the distance from the anode increased. In the 1.22-m (4-ft) section (Figure 5), the potential midway between two anodes was approximately 20 percent of the value obtained over the anode. This midpoint potential was not sufficient to protect the rebars. A minimum value of -0.8 V is required. To achieve

proper protection, the rectifier would have to operate at a higher potential than the 6 V used here. Such a high potential could cause disbonding of the concrete from the rebars in areas close to the anodes (5). Sufficient potential for protection was not achieved in either the 0.9-m (3-ft) or the 0.61-m (2-ft) section, as is shown in Figures 6 and 7.

The instant-off voltage was higher and more acceptable only in the 0.3-m (1-ft) spacing section

Figure 8. Acid attack over anode on laboratory specimen.



Figure 9. Five centers of acid attack in grout.



Figure 10. Single center of acid attack in grout.



(Figure 7). However, this spacing was not acceptable since it would greatly add to both the material and construction costs of the installation and would be too labor-intensive for most applications.

The deck readings shown in Figures 5, 6, and 7 were taken just after the deck surface had dried after a rainstorm. It seemed to make no difference when the readings were taken. Just after a rainstorm and dry, dry after several days, or summer or winter, the readings were all very similar.

An examination of the deck after six months of operation showed damage occurring to the concrete over some anodes. This is discussed in the next section.

Water was ponded on the surface of the laboratory experimental specimen. Cathodic protection (7 V) was applied to the specimen by means of an anode directly over a rebar. Three days later, a cavity 6 mm long developed directly over the current-carrying anode. The other anodes were used to apply power to the specimen, and cavities appeared over these anodes. This also is discussed in the following section.

#### CONCRETE DAMAGE

The higher potentials necessary in the Pt-Nb wire system for cathodic protection can lead to concrete damage. The chloride ions in salt-laden concrete will migrate more rapidly to the anode areas, causing an acidic condition to develop and possibly attack the concrete. This effect has now been observed in two field installations on bridge decks and on the experimental laboratory slab.

The laboratory slab sample, which was described previously, showed some damage. The grout used to cement the wire anodes in the grooves had been attacked in three places and the bare wire exposed. Each of the three anode wires was used in turn as the powered anode, and a green stain of copper chloride formed over the concrete. The acid action also caused a build-up of yellow-green foam at the center of attack. This was caused by escaping carbon dioxide. This gas was formed as the acid attacked the carbonates in the concrete. One of the attack sites and the exposed wire are shown in Figure 8.

On the bridge, after six months of application of cathodic protection, several active centers developed. Figure 9 shows an area in which five active centers developed close together, and the Pt-Nb wire was exposed. Figure 10 shows one center in which the wire was exposed, and Figure 11 shows a de-

Figure 11. Developing center of acid attack.





veloping center. This bridge is under heavy ramp traffic and no water or moisture would remain on the surface for any length of time; the traffic would remove it and hence no stains of copper chloride were visible.

If this installation was kept under power (cathodic protection), it is believed that soon more of the anode wire would be bared and little or no power would be transferred to the deck slab. In fact, the wires might be damaged and broken by traffic passing over them.

One bridge, belonging to the City of Toronto, had an experimental system of platinized wire installed on it more than two years ago. The road surface was covered with asphaltic concrete, thus concealing the anode grooves. There were two lines of grouted-in anode wire visible down the length of each sidewalk. There were many locations along each of the anode lines and the dark areas where attack was taking place (Figure 12). The concrete in some of these areas was soft and could be dug out with a knife blade. Figure 13 is a close-up of a center in which active attack on the concrete was taking place and a cavity had formed. The froth over the center was caused by escaping  $\text{CO}_2$  gas. The moisture in the cavity was tested with pH paper. The paper stained a deep red, showing a pH of 1 or less, indicative of a high acid concentration. The wire was exposed in the bottom of the hole and the platinum color was showing; all of the copper coating had been eaten by the acid. Several such active centers were observed on the deck. Another is shown in Figure 14.

Vrable (5) also reported damage to concrete when platinized wire anodes were used.

It has been shown by Scott (6) and Vrable (5) that the application of larger amounts of current, more than is needed for effective cathodic protection, can cause a weakening of the bond between the rebar and the surrounding concrete. In the normal cathodic protection system, the current is distributed evenly over the deck by a conductive asphaltic concrete layer from which it flows to the rebars. In the wire system, there are points at which the current is concentrated and others at which the flow is considerably smaller. This can be seen by an examination of Figure 15. Here the Pt-Nb wires were

Figure 14. Municipal bridge: acid attack center.



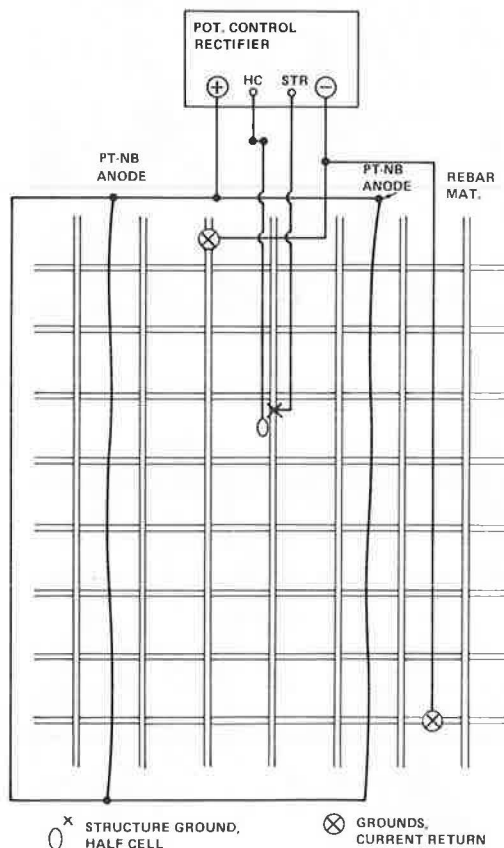
Figure 12. Municipal bridge: centers of acid attack along anode wires in sidewalk.



Figure 13. Municipal bridge: acid attack center,  $\text{CO}_2$  foam and pH < 1.



Figure 15. Circuit diagram for cathodic protection with Pt-Nb wire.



stretched and grouted in grooves 19 mm (0.75 in) deep midway between the transverse rebars. They were thus 152 mm (6 in) from each transverse bar. Where they crossed the longitudinal bars, however, they were only about 55 mm (2 in) above them. There would be, then, three times the current density flowing at each longitudinal rebar crossing as was flowing to each point on the transverse rebars. This concentrated current could weaken the bond between the rebar and the concrete after a period of time. This loss of strength might not be too serious in a slab bridge deck where the deck is supported on beams. It could, however, be a serious matter if the system were applied to, say, a parking garage floor in which there are no supporting beams between the pillars or to a support system under a bridge deck.

In the preceding section, it was shown that in order to get the necessary polarized voltage on the rebars, it would be necessary to use a 300-mm spacing of the wires. There would then be many points on each crossing rebar where the bond would be weakened, thus reducing the strength of the structure to which it was applied, whether it was a deck, parking garage floor, or a supporting structure for a bridge.

#### CONCLUSIONS

The conductivity of concrete is too low to permit an even distribution of power to the rebars by using a wire anode system without a conductive surface layer. The high DC voltages necessary to achieve the minimum polarized protection level of -0.8 V (with respect to the copper and copper sulfate half-cell) will overprotect some areas and could cause disbonding of the concrete from the rebars and reduce the strength of the structure.

The high DC voltages applied to the rebars at-

tract chloride ions and cause an acid situation to develop. The acid attacks and destroys the concrete grout surrounding the wire and bares it. This reduces electrical contact with the concrete structure and reduces still further the passage of current into the structure.

The wire anode system is a good method for applying the current necessary for cathodic protection of bridge substructures, but it will have to be used in conjunction with a conductive surface layer. This is necessary so that a low applied potential can be used and still obtain an even distribution of current across the structure.

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## Scanning Rust Crystals and Salt Crystals with Electron Microscope

CARL F. CRUMPTON AND G.P. JAYAPRAKASH

Corrosion of reinforcing steel in concrete can create expansion pressures of 4700 psi. At 0°C, salt (halite) crystal growths can create pressures of 8140 psi at a supersaturation ratio of 2. Scanning electron micrographs of rust from corroding reinforcing steel in concrete show crystal laths and fretwork or boxwork crystals that eventually fill in and build up in layers. X-ray diffraction showed goethite and magnetite in the layers. Limonite, which is non-crystalline and does not show in X-rays, was also present. Halite crystal forms observed in air voids were fibers, columns, spirals, and ribbons. Entrained air voids help prevent or reduce salt crystal growth damage to concrete by providing empty space for the crystals to grow into. Scanning electron micrographs of the rust crystals and salt crystals are included.

Kansas salt corrosion studies of concrete reinforcing steel were done to see how volume increases of up to 13 times (1) and expansion pressures of as much as 4700 psi (2) could occur from the corrosion process. Studies were made on the scanning electron microscope at Kansas State University with some concrete taken from as near a freshly corroding rebar as possible. Swordlike laths of rust were found

growing into the concrete near the steel as seen in Figure 1. Concrete petrographers can recognize the potential for one-dimensional growth here and also see the shape similarity to minerals such as ettringite, the growth of which in hardened concrete is known to be detrimental (3).

Another form of rust observed was a boxwork (Figure 2) or a fretwork of thin, apparently triangular-shaped walls with one of the points of the triangles growing away from the reinforcing steel such as that shown in Figure 3. Eventually both the lathlike and the fretwork structures become filled in with massive rust as seen in Figure 4, in which a few laths can still be seen around the edges of the glob of massive rust. Eventually reddish-, brownish-, and blackish-hued layers of such rust build up. These often contain what appears to be drying shrinkage cracks as shown in Figure 5.

Through X-ray diffraction studies of the layered rust we found the minerals goethite and magnetite.