International Journal Of Advance Research In Science And Engineering http://www.ijarse.com
IJARSE, Vol. No.2, Issue No.8, August 2013 ISSN-2319-8354(E)

MONITORING CORROSION RESISTANCE IN BRIDGE DECK REINFORCING STEEL: FIELD INVESTIGATION

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ABSTRACT

This paper presents a study that investigated the use of corrosion resistant reinforcing steel in the deck slab of two newly constructed prestressed concrete girder bridges. The decks of the two bridges were constructed with two different types of steel; one with 'Micro-composite Multi-structural Formable Steel', and the other with epoxy-coated mild reinforcing steel. During the construction of the bridges, embeddable sensors were installed on selected reinforcing steels in the bridge decks to identify signs of corrosion initiation and severity. Using a conventional voltmeter, data were recorded, by measuring DC voltage and DC current, periodically to assess and compare the performance of reinforcing steel in terms of corrosion resistance. Overall field investigation consisted of construction documentation, and during- and post-construction monitoring of the bridges. A summary of the field investigation and its monitoring results are presented and discussed.

Keywords: Bridge, Corrosion, Monitoring, Prestressed Concrete, Reinforcing Steel.

I INTRODUCTION

Reinforcing steel corrosion is one the most costly forms of deterioration and causes prevalent challenges for reinforced concrete bridges. In the United States, maintenance and replacement costs for deficient bridge decks are measured in billions of dollars [1]. This problem has increased significantly and is likely to continue getting worse. Although corrosion of the reinforcing steel is not the only cause of all structural deficiencies, its contribution is so significant that it has become one of the biggest major concerns and has reached alarming proportions in various parts of the world. It was recognized in the mid-1970s that even a small amount of chloride from deicing salts could cause serious disruptive effects on steel members in concrete. The chemical attack, besides reducing the effective steel cross-section, causes cracking and delamination of concrete cover with obvious consequences on the structure. However, the use of deicing salts on the road is not likely to decrease. Since inspection of reinforcing steel embedded in a concrete structure cannot be done easily, the presence of corrosion cannot usually be detected until the problem becomes significant. While early detection of corrosion within reinforced concrete structures would provide engineers with an opportunity to remedy the problem, this alone will not abate the nature of the problem. Mitigating or even eliminating the corrosion induced deterioration of reinforced concrete structures requires innovative solutions.

Over the last three decades, bridge engineers have tried numerous techniques for corrosion protection in bridge decks, including increased concrete cover depth and the application of epoxy coating over the reinforcing steel [2]. Increasing concrete cover depth, however, increases both dead load and construction costs and is in general unnecessary for structural reasons. In addition, although the application of epoxy coatings may limit the exposure of the steel to chlorides, oxygen, and moisture, cracked epoxy coating in combination with high chloride concentrations may result in corrosion of reinforcing steel, which in turn affects the overall performance of bridges. Further, it is believed that epoxy coatings in aging bridge decks may become brittle and eventually delaminate from reinforcing steel under high chloride concentration [3].

In the recent past, the use of reinforcing steel with enhanced corrosion-resistance, such as Micro-composite Multi-structural Formable Steel (MMFX) reinforcement, has been considered as an alternative protective measure against corrosion. MMFX reinforcing steel is a relatively new form of corrosion resistant steel with higher mechanical properties than conventional reinforcing steel [4]. While MMFX reinforcing steel appears to be a good option, availability of study on its actual corrosion performance and cost-effectiveness, other than what has been advertised and published by the manufacturer, is limited. In an effort to address this concern, a dual-phase investigation was conducted that included both a laboratory test and a field monitoring. The laboratory investigation consisted of accelerated corrosion tests on MMFX, epoxy-coated, and uncoated reinforcement to determine the initiation of corrosion and the rate of corrosion growth, and traditional mechanical property tests to establish the basic mechanical/structural properties on MMFX reinforcing steel. The results of the laboratory investigation can be found in the reference given [5].

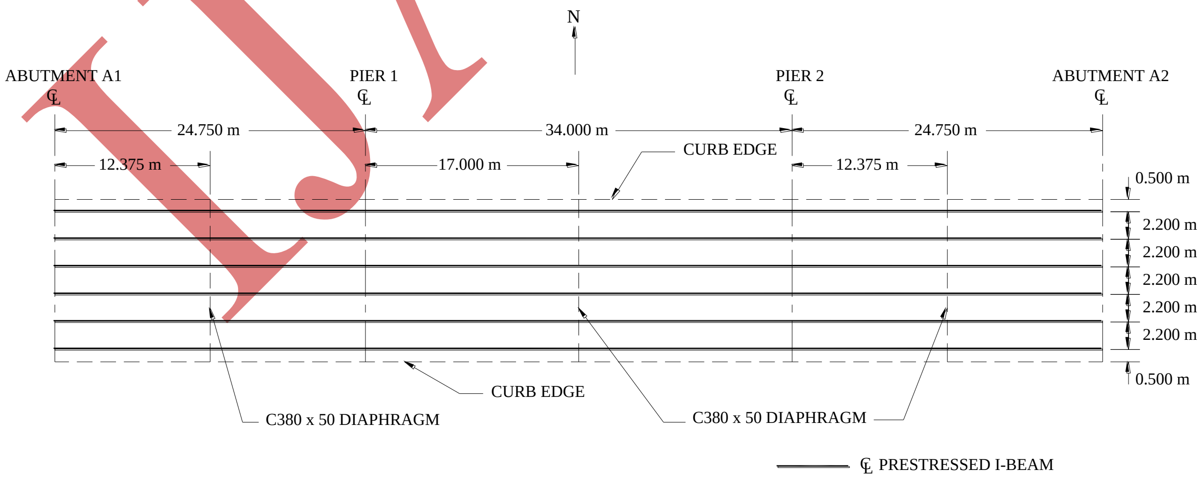
This paper presents the field monitoring portion of the study that investigated corrosion performance of reinforcing steel in the deck slab of two prestressed concrete girder bridges. Two bridge decks were constructed with two different types of reinforcing steel; one with MMFX reinforcing steel, and the other with epoxy-coated mild reinforcing steel. The primary objective of the field investigation was to monitor and evaluate the corrosion resistance of MMFX and conventional epoxy coated reinforcing steels. The overall field monitoring investigation consisted of construction documentation, and during- and post-construction monitoring of two side-by-side bridges. Embeddable sensors were installed, during construction, on selected reinforcing steels and periodic measurements were made to assess the corrosion performance of two different reinforcing steels.

II DESCRIPTION OF BRIDGES

The subject bridges (Fig. 1) are located on US 20 over South Beaver Creek in Grundy County, Iowa. The twin bridges are three-span prestressed girder bridges with 83.5 m (274 ft) in total length consisting of two 24.75 m (81.20 ft) end spans and a 34 m (111.55 ft) center span. The primary members of the bridges consist of six pre-stressed concrete beams spaced at 2,200 mm (7.22 ft) on center. The bridge deck is a nominal 200-mm (1-in.) thick cast-in-place, reinforced concrete slab that includes a 13-mm (1/2-in.) integral wearing surface. The roadway width is 12 m (39.37 ft) allowing two traffic lanes with a narrow shoulder on each side. The decks of the two bridges were constructed with two different types of reinforcing steel; MMFX steel in the eastbound bridge, referred to as ‘MMFX bridge’ (Fig. 1c) and epoxy coated steel in the westbound bridge, referred to as ‘Epoxy bridge’ (Fig. 1d). There was essentially no difference in how these two bridges were constructed. The top transverse reinforcing steel was placed parallel to and 65 mm (2.56 in.) clear below the top of the slab while the bottom transverse reinforcing steel was placed parallel to and 25 mm (1 in.) clear above the bottom of the slab (Fig. 2). Approximately 50 mm (2 in.) of clear distance from the face of concrete to near reinforcing steel was used. All slab and diaphragm reinforcing steels were tied in place and adequately supported before the deck concrete was poured. The pier and abutment diaphragm concrete was placed monolithically with the floor slab. Moderate curbs were constructed integral with the deck and concrete guardrails connected to the curbs.

(a) Side view **(b) Bottom view (center span and west pier)**

(c) 'MMFX bridge' deck concrete placement **(d) 'Epoxy bridge' deck concrete placement**



(e) General framing plan

Figure 1 – Photographs and general framing plan of bridges.

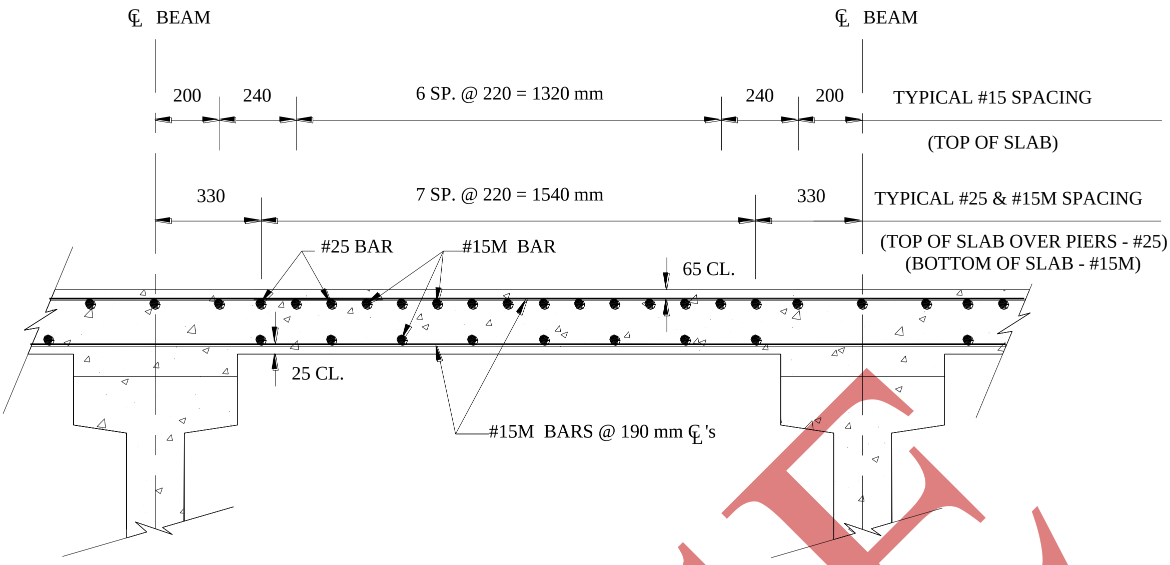


Figure 2 - Typical cross section of bridges.

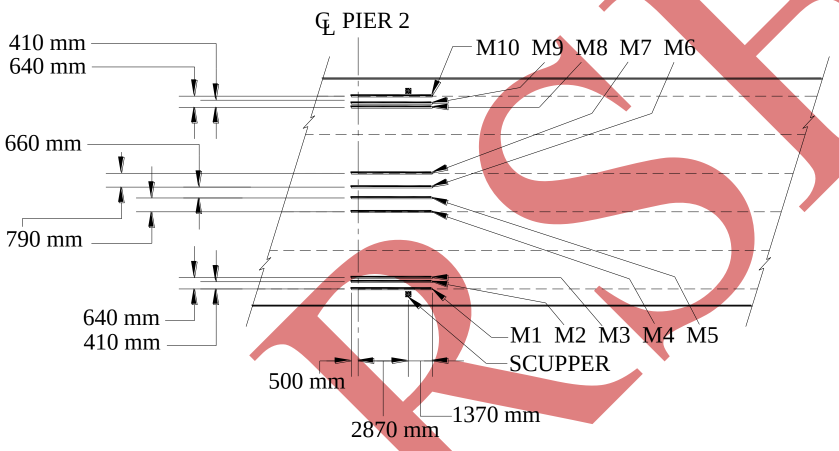
III FIELD INSTRUMENTATION AND CORROSION MONITORING CONCEPT

Embeddable electrode sensors were used to monitor for onset of corrosion, and intensity of corrosion growth once it starts. Each sensor is comprised of a solid silver-silver chloride wire electrode wrapped in a permeable, non-conducting PVC covering. Although the sensors do not address the specific electrochemical mechanisms, it provides a reliable and cost-effective monitoring system to measure the basic electrochemical processes.

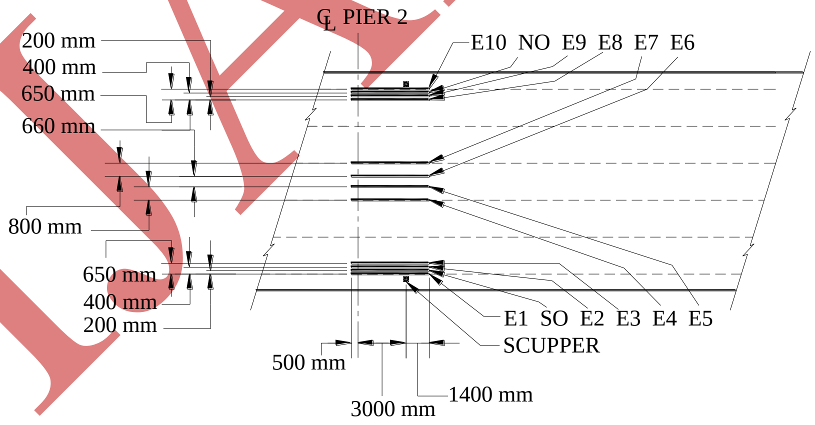
Both bridges were instrumented with the sensors permanently embedded in the concrete deck. A total of twenty No. 25 (ASTM) top reinforcing steels (10 sensors on each bridge – M1 through M10 on MMFX bridge, and E1 through E10 on Epoxy bridge) in the negative bending moment region near the eastern drainage points were instrumented (Fig. 3). Each sensor was wound around the length of approximately 4.6 m (15 ft) of each reinforcing steel and then connected to a red lead wire with a protected butt splice (Fig. 4). A black wire is then attached directly to the reinforcing steel using a stainless steel clamp. These lead wires were run out of the deck and were used to measure internal voltage and electrical current to assess corrosion development. On the Epoxy Bridge, two additional short sections of MMFX steels were instrumented with electrodes and placed between other epoxy coated steels (i.e., one on the north side - referred to as ‘NO’, and one on the south side - referred to as ‘SO’) to compare with the epoxy steels within the same environment.

The electrical process induced by steel cathode corrosion is an electrochemical process. Electric potential differences arise when an electrochemical reaction (corrosion) takes place [6]. With the electrode, the potential between a sensor and reinforcing steel is measured. The electrode sensor serves as a cathode and the reinforcing steel as an anode, thereby creating a 'battery'. The electrochemical process, on the other hand, is separate and distinct from the battery formed by the electrode cable (silver-silver chloride), steel, and alkaline concrete. This electrochemical reaction occurs when a local pH value at the concrete-steel interface drops below 9 due to an incursion of chlorine atoms [7]. During this process, electrons are released as a product of the chemical reaction. Therefore, the corrosion site acts as another independent 'chemical battery'. These two batteries then become additive to one another and the internal voltage increases. By measuring DC voltage (in volts, V or millivolts, mV) and DC current (in milliamps, mA or microamps, μA) with a voltmeter, it can be determined if corrosion activity on each reinforcing steel is occurring, and if so, how severe it is.

The actual output value depends mostly on the conditions of the concrete after placement. It is normal to expect high voltage levels (it could be over 1000 mV) shortly after concrete placement since considerable moisture is present; while concrete is fresh and uncured, it is highly active and generates high output. This initial 'spike' typically subsides back to within the 'normal' range of less than 300 to 400 mV as the concrete cures. In general, electrical current readings below 0.100 mA (1000 μA) can be considered a weak site of corrosion. When corrosion occurs, however, a natural DC current starts to flow again from one area to another and this electrical current reading increases significantly; if it exceeds 1000 μA, corrosion activity is considered quite active.



(a) MMFX bridge



(b) Epoxy bridge

Figure 3 –General instrumentation of silver-silver electrode sensors.

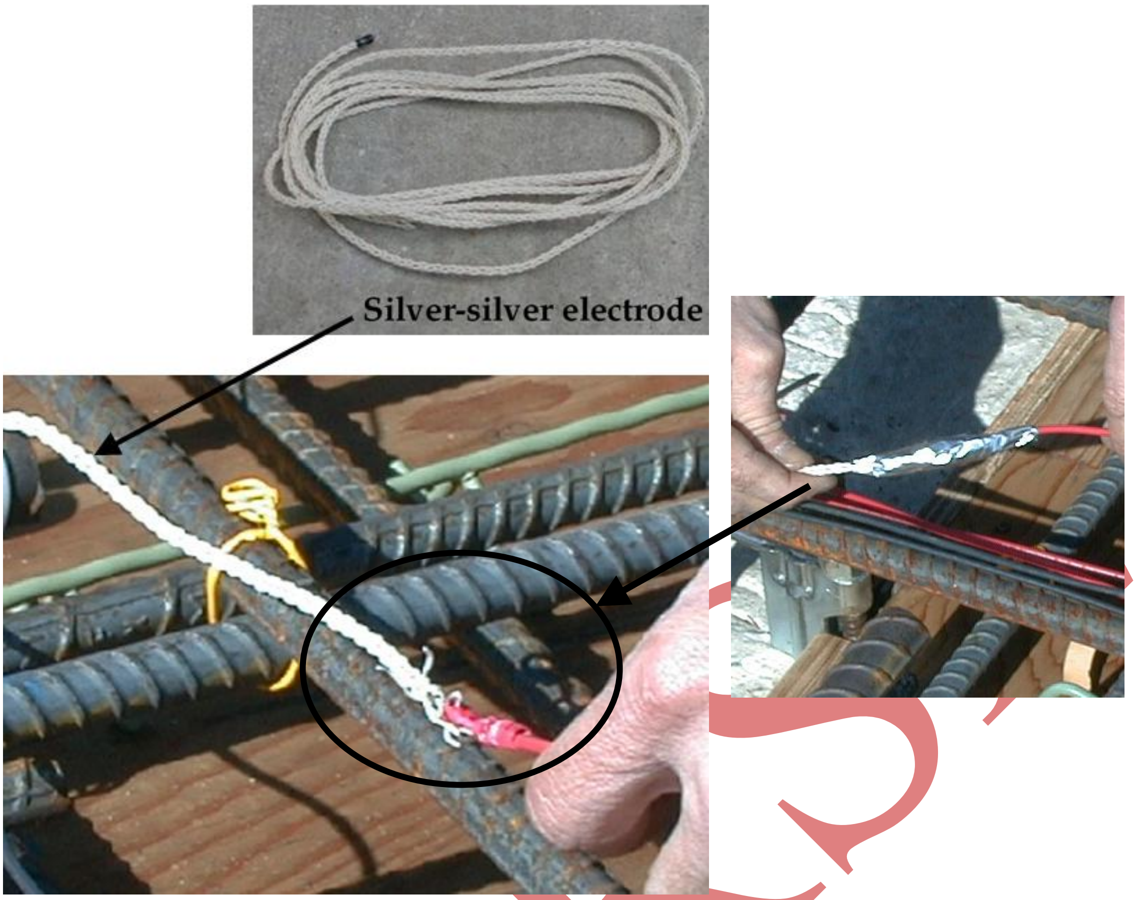
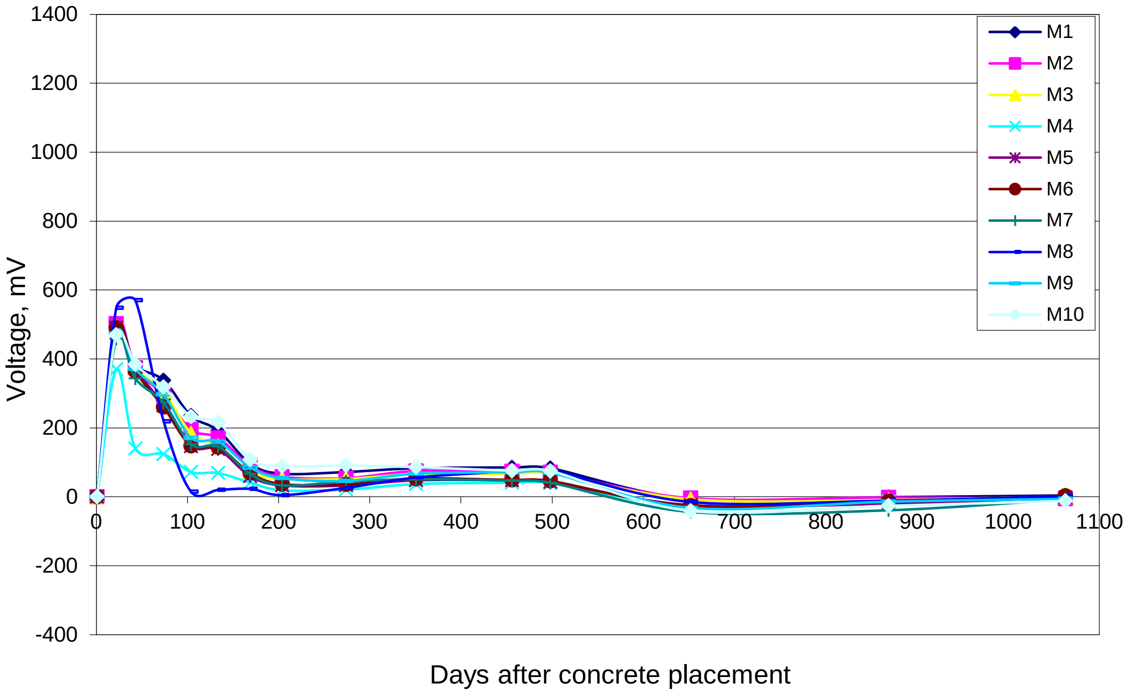


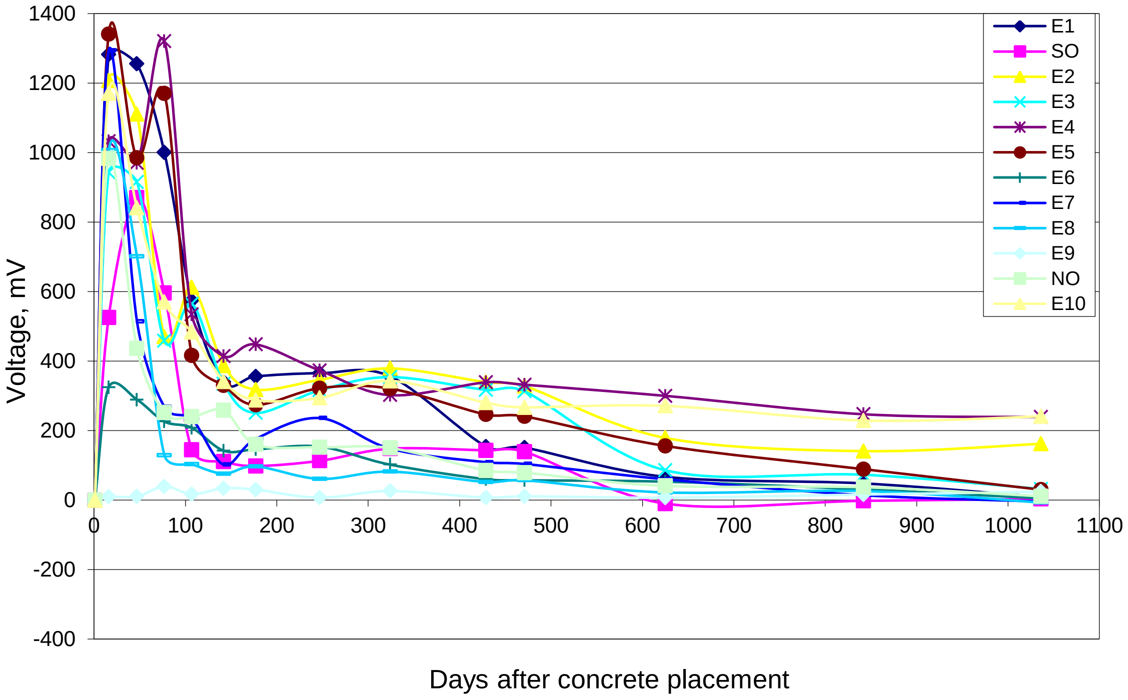
Figure 4 - Electrode sensor butt-spliced and protected with butyl rubber and aluminum-foil.

IV RESULTS AND DISCUSSION

Figures 5 and 6 present the internal voltage and electrical current readings collected from both bridge decks for three years. All MMFX bridge data appear to be as one would expect; although the data increased above 400 mV (see Fig. 5a) at the initial stage, they returned to within the 'normal' range of less than 300 mV after concrete cure (i.e., the initial 'spike' has ceased). Note that even at this initial stage, the electrical current remained below 1000 µA (Fig. 6a). At approximately three months after concrete placement, all voltage levels for the MMFX bridge dropped steadily and remained within 'normal' range and stayed less than 100 mV. At this point, it appears that there is no ongoing corrosion activity. The epoxy coated reinforcing steels, on the other hand, behaved somewhat unexpectedly. Readings on the Epoxy bridge were higher (about two times higher than the readings on the MMFX bridge) than originally expected. During the initial stage, shortly after concrete placement, some of readings increased over 1200 mV (Fig. 5b). Although these high data readings dropped below 400 mV, some of readings (E2, E4 and E10) were still above or close to 200 mV. Theoretically, there should be nearly zero readings if the reinforcing steel is coated perfectly; steel will be perfectly protected without any 'contact' between the coated steel and the concrete. As shown in Figs. 5b and 6b, however, it is speculated that the 'contact' had been made on some of the specimens being monitored. This is an indication that there was at least one or more defect (i.e., coatings may have been nicked and/or scratched during the process of layout) in the epoxy coating on some reinforcing steels.

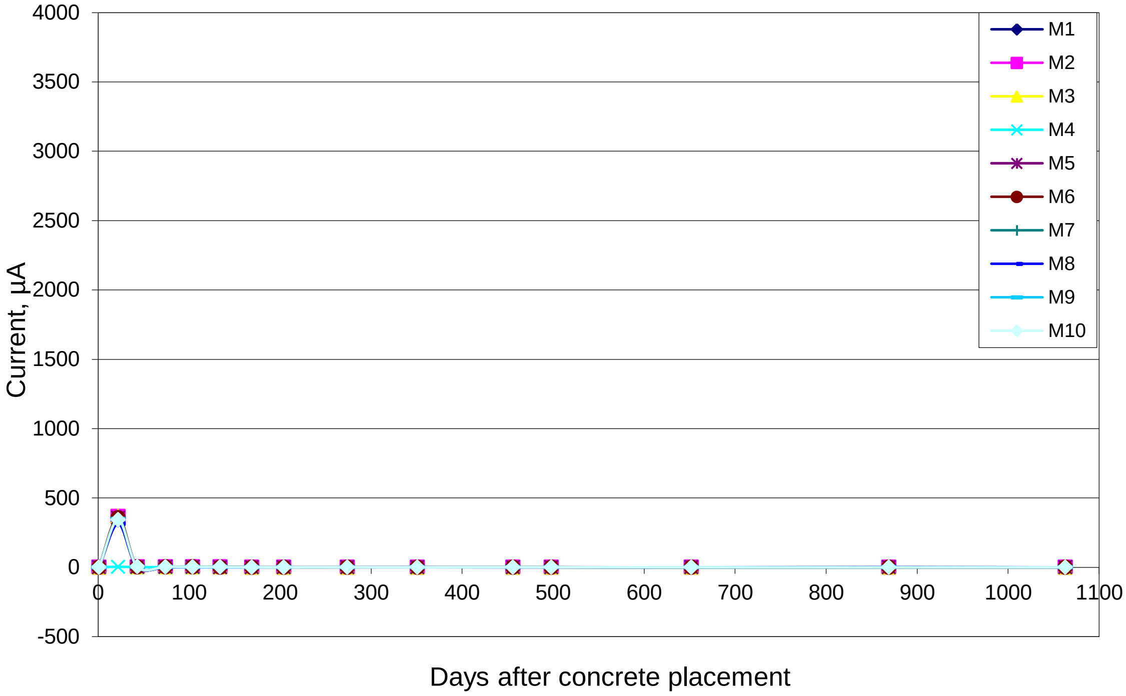


(a) MMFX bridge

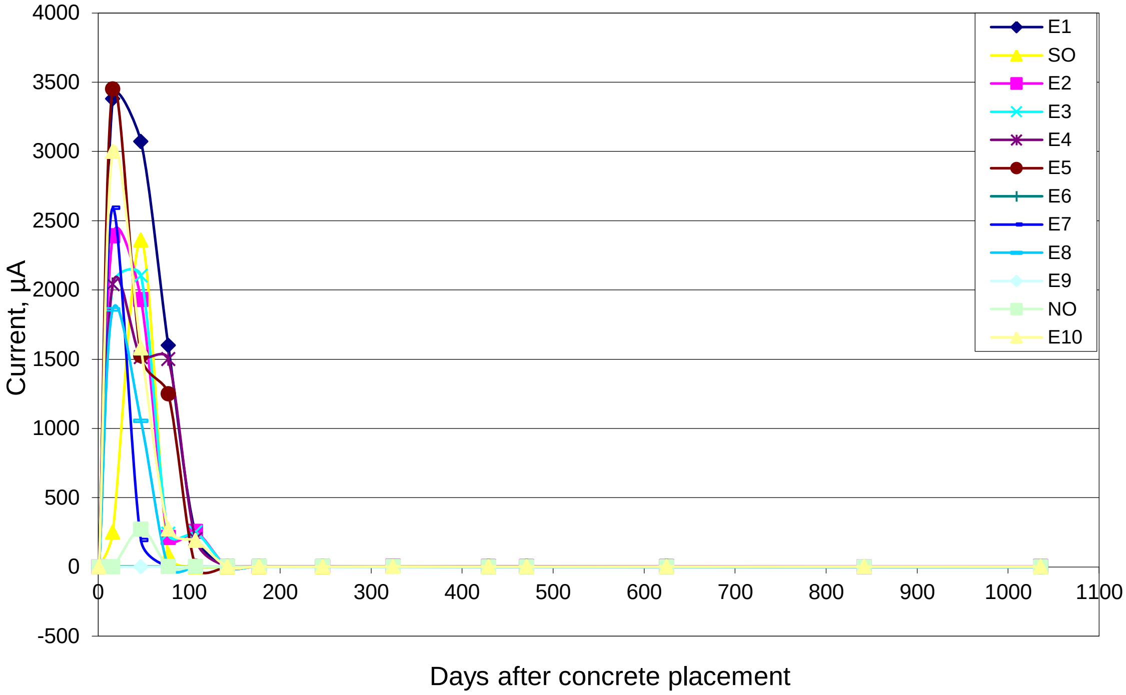


(b) Epoxy bridge

Figure 5 – Voltage readings from electrode sensors on instrumented reinforcing steels.



(a) MMFX bridge



(b) Epoxy bridge

Figure 6 – Electrical current readings from electrode sensors on instrumented reinforcing steels.

Overall, the field monitoring data indicates that corrosion-related measurements were lower for the MMFX bridge than for the Epoxy bridge. Some of the reinforcing steels (E2, E4, and E10), in particular, showed relatively high data readings. However, no significant corrosion activity was observed in either bridge deck; electrical current readings have stayed close to zero after concrete cured as shown in Fig. 6. Visual inspections of both bridges were also regularly made to identify any sign of potential cause of corrosion (e.g., crack, spall, delamination, etc), and no obvious external signs of damage were observed.

Although it may require over a decade of monitoring to make a valid corrosion performance evaluation of the deck reinforcing steel, it is the authors' opinion that, with continued monitoring and evaluation, the field monitoring system would provide an evidence of corrosion resistance of the MMFX reinforcing steel under service. Reinforced concrete with the materials that exhibit better corrosion resistance than commonly used uncoated steel reinforcements may improve both the life expectancy and cost-effectiveness of bridge structures.

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