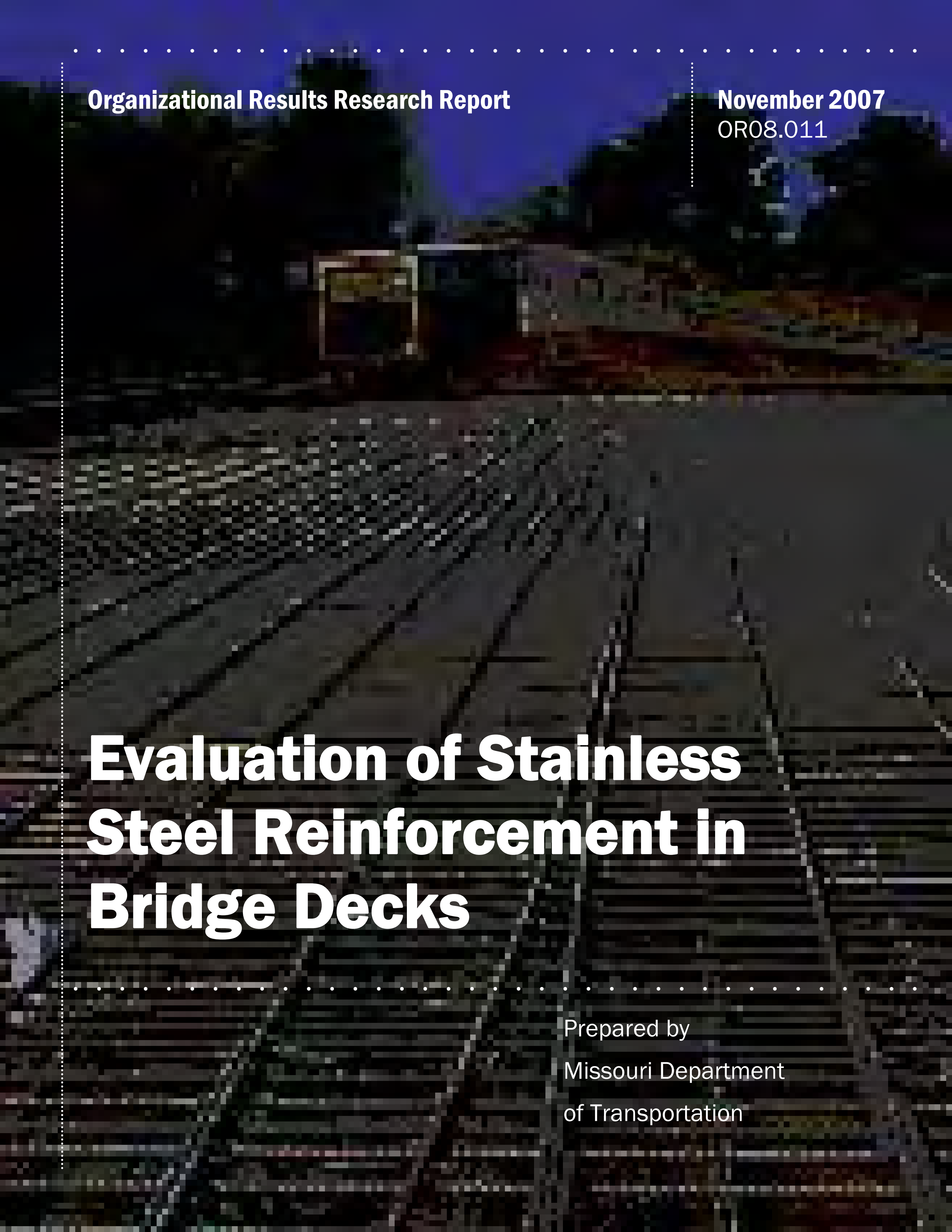

Organizational Results Research Report

November 2007
OR08.011

Evaluation of Stainless Steel Reinforcement in Bridge Decks

Prepared by
Missouri Department
of Transportation

Follow up and Final Report

RI00-027

Evaluation of Stainless Steel Reinforcement in Bridge Decks

Prepared for the
Missouri Department of Transportation
Organizational Results

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16. Abstract:
This report is a follow up and final report to the report on the “ **Evaluation of Stainless Steel Reinforcement, Construction Report.** RDT 03 – 003”. The results of interim testing during the bridges first five years are reported for Missouri’s first cast-in-place bridge deck using solid stainless steel reinforcing bars. This deck was compared to a conventionally constructed deck using precast p/s stay-in-place panels and a top mat of epoxy coated reinforcing steel. The deck construction was completed in 2001. Fiber-optic chloride sensors were embedded in both decks but no data was obtained from them. From the physical testing done, both destructive and non-destructive, conclusions of the assessments made of the corrosion conditions of the bars and decks were made. Recommendations for maintenance of the decks and on future testing were made.

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Introduction

MoDOT is using innovative materials to design longer lasting reinforced concrete bridge decks. Stainless steel reinforcement has greater corrosion resistance than that of the conventional reinforcement. In this project, bridge A6059, the first in Missouri utilizing stainless steel reinforcement in the deck (see Figure 1) was completed in 2001.

Figure 1. Stainless Steel Reinforcement of Bridge A6059

Minimization of concrete cracking and spalling results in greater durability, less maintenance and repair, a longer service life, and lower life-cycle costs. The advantages of stainless steel reinforcement used in this project is documented, also, any early failure of the epoxy-coated rebar used in the companion bridge will be monitored.

Scope of Work

The control bridge A6060 was constructed using conventional epoxy coated rebar. It has identical roadway width and girder spacing with bridge A6059, but has different span lengths and skew. The bridges are on the same route with bridge A6060 approximately 600 feet (180 meters) east of A6059. This will allow a good evaluation of the durability and performance of the subject bridge deck in comparison to the conventional deck. The details of the construction of these bridges can be found in the original report published in 2003 “Evaluation of Stainless Steel Reinforcement Construction Report”. (Found as report RDT 03-003, RI 00-027 on MoDOT’s Innovations Library at http://168.166.124.22/RDT/reports/Ri00027/RDT03003.pdf).

Current Research Results

Costs for the rebar on this job bid in December 1999 were \$ 1.40/Kg (\$ 0.64/lb) for conventional black steel. \$1.77/Kg (\$ 0.80/lb) for epoxy coated steel (MoDOT's normal bridge deck rebar) and \$5.63/Kg (\$ 2.55/lb) for the solid stainless steel. This price makes the cost of solid stainless about 3 times as expensive as Missouri's regular design with epoxy coated rebar and 4 times as expensive as black rebar. This is well worth it, if it eliminates worry about corrosion problems and potholes caused by corrosion within the service life of the bridge deck, expected to be 75 years for both decks. The advantages of stainless steel reinforcement will be documented using non-destructive fiber optic chloride sensors, permeability testing, half-cell potentials readings and visual inspection.

1999 Prices of Reinforcing Steel (converted to \$/pound)		
Uncoated (Black)	Epoxy Coated	Solid Stainless Steel
\$ 0.64 /LB	\$ 0.80 /LB	\$ 2.55 /LB

Figure 2. Sensor Housings Installation

An evaluation of the constructability and performance of stainless steel reinforcement was conducted. The bridges will be researched utilizing non-destructive tests to monitor salt application and chloride penetration in correlation to presence of (or lack of) corrosion. Fiber optic chloride sensors were incorporated into both bridge decks. Ten sensors were set on each bridge at different horizons. The sensor housings were installed during the deck construction before concrete was poured. See pictures in Figure 2 for the installation of sensor housings. The picture on the left is for the stainless steel bridge deck, and the one on the right is for the epoxy coated rebar bridge. Cylinders were taken to establish the compressive strength of the concrete for each bridge. Cylinders were also taken and tested for chloride permeability of both bridges according to AASHTO T277. Chloride samples were taken from the cylinders to get a base line chloride content of the concrete. These original properties (in some cases measured at 1 year old) of the concrete are listed in Table 1. Fiber optic chloride sensors were installed into the sensor housings shortly after the bridges were open to traffic. In addition, half-cell potentials were taken and will continue to be taken to determine corrosion rates on the bridge containing stainless steel reinforcement.

Table 1: Original Properties of Deck Concrete

Bridge No.	Compressive Strength (psi)	Chloride Content (%)	Chloride Content (Lbs./cy)	Permeability (Coulombs)
A6059	8,800 (1-year)	0.005	0.2	1924 (1 year)
A6060	5,556 (28-day)	0.003	0.1	1403 (1 year)

Monitoring Performance

The original work plan intended the following to be accomplished in follow up inspections. Field observations and data collection concerning the condition and performance of each bridge deck will follow construction of the bridges. The fiber optic chloride sensors will be monitored every year for five years to verify any indications.

A construction phase report was completed and published to document the constructability with the stainless steel rebar and installation of the test systems. This interim report documenting current conditions was to be prepared at the end of the first five years. Preparation of a final report discussing and comparing over-all performance and documenting project findings was to be included in this report. Any maintenance or rehabilitation costs associated with either bridge deck should be documented throughout the service life of each structure, in an effort to determine and compare life-cycle costs.

Follow-Up Inspections

Follow-up inspections were not done on the fiber optic sensors yearly as planned because of the increased cost of the fiber optic equipment needed. It was estimated that a light source and spectrometer would cost around $2,000 but in 2002 there was no longer a low cost light source or spectrometer available except at three times the cost, $6,000 - $7,000. As an alternate a bid was obtained in 2002 from Dr. Peter Fuhr to travel back to Missouri to read the sensors. That bid was reasonable at $2,000, but it was decided to wait another couple of years when there would be a better probability of the chloride ions actually reaching the level of the sensor inlets. Because the prices have not gone down for test equipment and because Dr. Fuhr is no longer available to make the trip back, the fiber optic sensors have never been re-tested. The only data available is the initial readings done after the sensors were installed in 2001, which showed they were calibrated at the correct threshold level. In speaking with the Vermont Agency of Transportation, the same type sensors installed in three of their bridges in 1997 by Dr. Fuhr, those sensors have never had a positive reading; they were tested the first 3 years in a row after installed and again at 5 and 7 years and never tested above the threshold that they were set to detect.

Vermont has not been able to test the sensors lately because the fiber optics used were state of the art in 1997 but now are not manufactured and only one company has the equipment necessary to test them, and rental costs for the equipment is in the vicinity of $35,000. MoDOT's system has fiber optic material that does not need this special equipment, however, the cost is significant enough that it was decided not to purchase the needed equipment now. It may be beneficial to try and test the fiber optic sensors on our bridges at 8-10 years to see if some meaningful data can be obtained.

Bridge Deck Testing

A physical bridge deck condition survey was done on the two bridges in July 2006. The decks were sounded for delaminations and also the cracks were plotted on the surface profile maps, chloride samples were taken from the bridge to compare it to data from when the decks were new in 2001. Half-cell data was taken on the stainless steel reinforced deck, Bridge A-6060, to check for any active corrosion. Bridge A6059 is reinforced with epoxy coated steel so it was originally set up with a test grid to try and do impedance testing to detect any breaks, or "holidays" as they are called, in the epoxy coating allowing corrosion of the steel underneath. MoDOT's testing using the impedance method showed it wouldn't work in this application so no impedance testing was ever attempted.

Results of the 2006 bridge deck condition survey are as follows:

1. There was no delamination or spalling found on the surface of either bridge deck.

2. On Bridge A6059, the stainless steel reinforced concrete deck, there was 57 linear feet of cracking at five years old. The bridge is built with a 30° skew and most of the cracking was found at the skewed ends of the bridge deck, there were a couple of cracks also found over the interior bents. The rate of cracking for A6060 was 10.34 LF/ 1,000 SF (0.038M/M^2).
   Bridge A6050, the epoxy coated reinforced steel concrete deck, which doesn't have a skew, had no cracking found at five years old.

3. Concrete samples taken from the deck for chloride content are shown in Table 2 and the locations samples were taken at in the deck surface profiles in Figure 3.

Table 2: Chloride Content of Concrete Deck in 2006

Bridge A6059 (homogeneous Cl^- in 2001 – 0.2 lbs/cy)

Sample	#/cy @ ½"	#/cy @ 1"	#/cy @ 1 ½"	#/cy @ 2"
# 1	6.2	3.9	2.3	0.8
# 2	5.5	0.8	0.4	0.2
# 3	3.5	0.04	0	0.1
# 4	1.6	0.2	0.4	0.1

Bridge A6060 (homogeneous Cl^- in 2001 – 0.1 lbs/cy)

Sample	#/cy @ ½"	#/cy @ 1"	#/cy @ 1 ½"
# 1	4.3	2.0	0.04
# 2	1.2	0.08	0.1
# 3	0.4	0.4	0.08
# 4	0.4	0.1	0.1

Bridge A6059

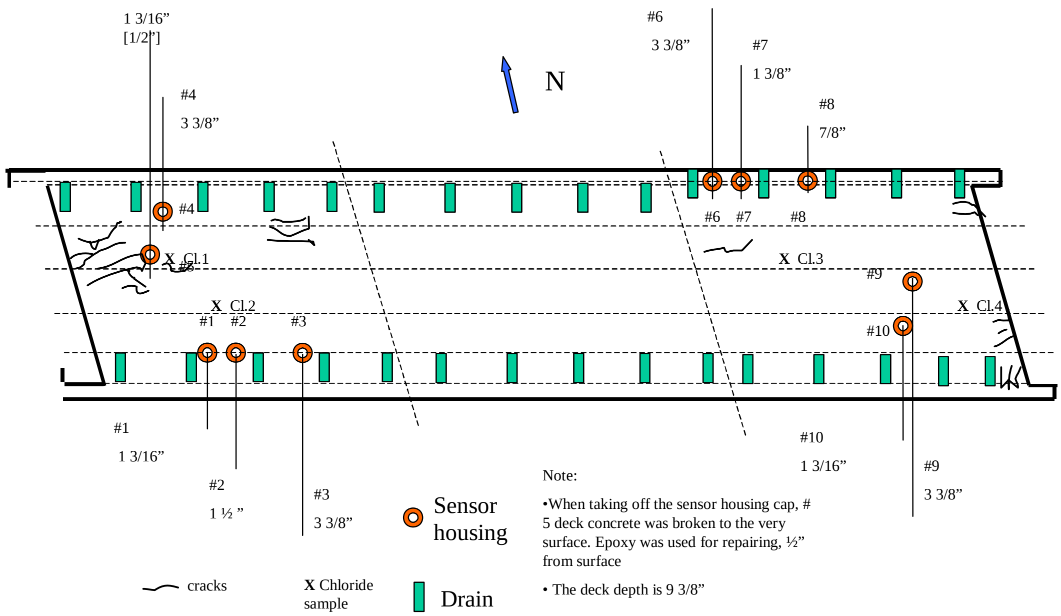

Figure 3: Surface Profile of Bridge A6059 in year 2006

Bridge A6060

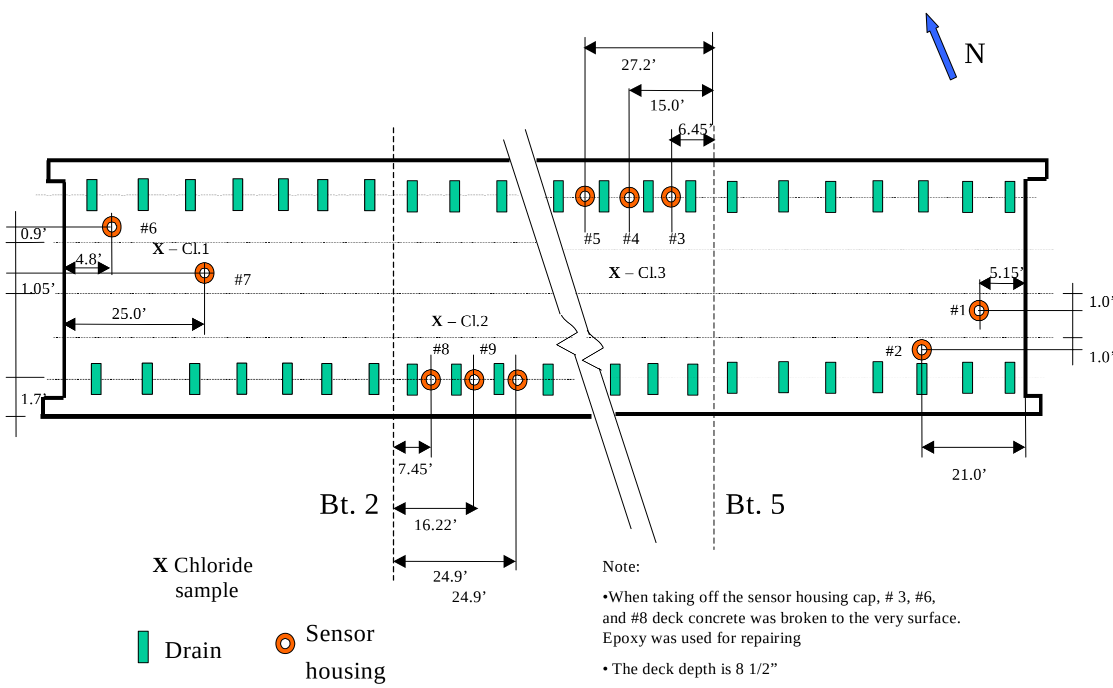

Figure 3 (continued): Surface Profile of Bridge A6060 in year 2006

4. Half-cell test were taken in 2001 and 2006 on bridge A6059 the stainless steel reinforced deck. The reference electrode used was again a CSE, Copper Sulfate Electrode and according to the test method ASTM C 876. The test is based on the difference in electrical potential of the CSE and regular milled steel reinforcing. Test results can be seen in Table 3 below (individual test are recorded in the Appendix). The 9.1% tests more negative than –200mv, those that may be corroding, were not expected in 2001 when the deck was first tested. They may be because of the stainless alloy, AISI Type 316LN, and the CSE cell being of a higher potential difference than of regular steel that ASTM C 876 is based. The stainless alloy does have a higher potential difference with the CSE but as of now there is no correction factor for this alloy. (See the Galvanic Series of Metals chart and alloy Type 316LN composition in the Appendix.) The half-cell tests do offer some comparison with the 2006 values, however, as you can see in 2006, 26.6% now test more negative than – 200 mv. This is a marked increase in percentage possibly corroding, signaling that conditions have become more conducive to corrosion, but not necessarily that the stainless steel is actually actively corroding. Higher chloride levels in the concrete and some minor cracking allowing moisture in, especially on the skewed ends of the bridge, account for this.

Table 3: Half-cell Testing of Stainless Steel Reinforced Deck on Bridge A6059

Original Half-Cell Tests - 2001

Range	No. Tests	Percentage
<-350 mv	1	1.3
>-350 mv, <-200 mv	6	7.8
>-200 mv	70	90.9
No Readings	3	
Total Tests	77	100.0%

Half-Cell Tests at 5 years in 2006

Range	No. Tests	Percentage
<-350 mv	9	5.2%
>-350 mv,<-200 mv	37	21.4%
>-200 mv	127	73.4%
No readings	16	
Total Tests	173	100.0%

5. Costs of maintaining the bridge decks and salt applied during winter de-icing have been hard to document because of maintenance operations procedures in this rural area of northern Missouri. Costs charged to the two bridges since they were opened started in 2003 and are shown in Table 4.