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Testing of Randolph Street Bridge

Background:
In 1986, the deck of the bridge that carries Randolph Street over I-35E in St. Paul, Minnesota, was rehabilitated. The rehabilitation process included the application of a Low Slump Dense Concrete (LSDC) overlay that varied in depth from 2.28 to 4.2 inches. Cortec MCI-2000 was added to the LSDC at 1 lb/yd^3 (0.6 kg/m^3) for the two westbound traffic lanes. Prior to overlay, the deck was milled to a depth of 0.5 in (13 mm) and the areas of unsound concrete were removed. The cavities from the removal of the unsound concrete were filled with the overlay concrete. The general slope of the bridge for water runoff appears to be towards the northeast.

Corrosion assessments were conducted on the eastbound (control) and westbound (MCI) travel lanes of the structure by Virginia Tech researchers on two occasions, June 1991 and August 1992. The assessments included visual inspection, delamination survey, cover-depth survey, chloride contents as a function of depth, corrosion potentials, and estimates of corrosion current densities (i_{corr}). SHRP-S-658 contains all information from the 1991 and 1992 study.

In November 2000, technicians from Cortec Corporation and American Engineering Testing returned to the bridge and took new measurements. These included Gecor 6 readings and copper/copper sulfate half-cell potentials. A new chloride analysis was also taken at various depths. Cortec report number 01-019-1425 contains the data obtained in 2000.

This report, 07-151-1425, will contain data obtained during the June 2007 evaluation. A technician from American Engineering Testing used a Profometer to locate rebars in concrete and did Chloride testing. Technicians from Cortec Corporation did alkalinity testing and took GalvaPulse readings of corrosion current and corrosion rate, and Gecor 6 readings of resistivity and half-cell potential.

Purpose:
The purpose of this study was to follow-up on the benefit of MCI-2000 in reducing reinforcing steel corrosion.

Materials:
Geocisa Gecor 6
GalvaPulse
Proceq SA Profometer
Rotary Impact Type Drill with a ½" bit
Alkalinity Test Kit
Tap water

Methods:
AASHTO: T260 – Procedure C, Sampling and Testing for Chloride-Ion in Concrete and Concrete Raw Materials
Gecor 6 method for measuring concrete resistivity and half-cell potential
GalvaPulse method for measuring corrosion current and corrosion rate
Alkalinity

Procedures:
Chloride Contamination Levels
Powdered concrete samples for chloride analysis were taken at mean depths of 0-1, 1-2, and 2-3 in (0-25, 25-51, and 51-76 mm) from 3 different locations on each side of the bridge.

A diagram of these locations is included at the end of this report. Samples were taken using a rotary impact type drill with a ½" sized bit. Three-gram samples that passed through a #20 sieve were obtained from each depth. The powder was then mixed with 20 ml of digestion solution for a total of 3 minutes and then 80 ml of stabilizing solution was added. A calibrated electrode coupled to an Orion Model 720-pH/ISE meter was then immersed in the solution, and the chloride-ion concentration was recorded. This method was consistent with the AASHTO: T260 Procedure C. The standard deviation for this chloride test was determined by testing the six pulverized concrete Quality Assurance (QA) samples of known chloride content. Each QA sample was tested five times.

Corrosion Current Measurements
Corrosion current density (i_{corr}) estimates were taken with the Gecor 6 instrument in November 2000 and a GalvaPulse instrument in July 2007. These same estimates were taken in June 1991 and August 1992 using a 3LP device. The i_{corr} measurement using the 3LP device is proportional to the corrosion rate through Faraday's Law. The Gecor 6 and GalvaPulse measure the corrosion rate of steel in concrete by "polarization resistance" or "linear polarization" techniques. This is a non-destructive technique that works by applying a small current to the rebar and measuring the change in the half-cell potential. Then the polarization resistance, R_p, (the change in potential measured), is divided by the applied current. The corrosion rate, i_{corr}, is obtained from the polarization resistance, R_p, by means of the "Stearn and Geary" relationship:

$i_{corr} = B/R_p$, where B = 26 mV.

The criteria for estimating the condition of the reinforcement in relation to the different devices' measured value of the rate of corrosion have been defined as[1]:

Table 1. Corrosion intensity versus corrosion current and rate of corrosion found by LP3 device (K.Clear)

Corrosion Current ($\mu A/cm^2$)	**Corrosion Rate (μm/year)**	**Intensity of Corrosion**
<0.5	<5.8	Passive condition
0.5-2.7	5.8 to 31.3	Low corrosion (damage possible in 10-15 years)
2.7-27	31.3 to 313.2	Moderate corrosion (damage possible in 2-10 years
>27	>313.2	High corrosion (damage expected in 2 years or less)

Table 2. Corrosion intensity versus corrosion current and rate of corrosion found by Gecor 6

Corrosion Current ($\mu A/cm^2$)	**Corrosion Rate (μm/year)**	**Intensity of Corrosion**
<0.5	<1.2	Negligible corrosion
0.5-2.7	1.2 to 5.8	Low corrosion
2.7-27	5.8 to 11.6	Moderate corrosion
>27	>11.6	High corrosion

Table 3. Corrosion intensity versus corrosion current and rate of corrosion found by GalvaPulse

Corrosion Current ($\mu A/cm^2$)	Corrosion Rate (μm/year)	Intensity of Corrosion
<0.5	<5.8	Passive condition
0.5-2	5.8 to 58	Negligible corrosion
2-5	58 to 174	Moderate corrosion
>27	>174	High corrosion

Concrete Resistivity Measurements
Gecor 6 calculates the concrete resistivity by means of the formula:

Resistivity = 2 * R * D, where

R = resistance by the "iR drop" from a pulse between the sensor counter-electrode and the rebar network
D = counter-electrode diameter of the sensor

The value of the concrete's resistance is used as an additional parameter for the interpretation of the rate of corrosion. According to Andrade[2], the following interpretation of the results is possible:

Table 4. GeCor 6 correlation of resistivity measurements to corrosion rate.

Resistivity	Corrosion Rate
>100 to 200 kΩ · cm	Very low, even with high chloride and carbonation
50 to 100 kΩ · cm	Low
10 to 50 kΩ· cm	Moderate to high where steel is active
<10 kΩ · cm	Resistivity is not the parameter controlling corrosion rate

Carbonation
Carbonation of concrete is a process by which carbon dioxide from the air penetrates the concrete and reacts with the hydroxides, such as calcium hydroxide, to form carbonates. This process increases shrinkage on drying (promoting crack development) and reduces the alkalinity of the concrete. High alkalinity is needed to protect embedded rebar from corrosion; consequently, concrete should be resistant to carbonation to prevent steel corrosion[3]. The carbonation of powdered concrete samples taken from the bridge was determined by using phenolphthalein (alkalinity) measurements.

Attached Figures/Tables:
East and Westbound Randolph St. Bridge Deck Test Locations (Figure 1)
East and Westbound Randolph St. Bridge Deck Average Half-Cell Potential, Resistivity and Corrosion Rates by Location (Figure 2)
Average Half-Cell Potential versus Year (Figure 3)
Average Corrosion Rate versus Year (Figure 4)
Average Chloride Contamination levels (Table 5)
Average Corrosion Currents using GalvaPulse (Table 6)
Average Corrosion Rates using GalvaPulse (Table 7)
GalvaPulse Measurements for Control Side of Bridge (Table 8)
GalvaPulse Measurements for MCI-2000 Treated Side of Bridge (Table 9)
Alkalinity Results (Table 10)
Summary of Half-Cell Potentials (Table 11)
Summary of Resistivity Measurements (Table 12)

Summary of Results:

1. In 2001, it was predicted the chloride concentration in the control side of the bridge would reach of 0.4wt% (of cementious materials) at the rebar in 19.5 years from the application of the overlay, or in the year 2005, if the chloride level continues to increase at its current rate. The MCI-2000 treated side was estimated to reach 0.4wt% (of cementious materials) of chlorides in 36 years from the application of the overlay, or in the year 2022. Revision of these predictions based on calculations from 2007 show that the Control side is estimated extended to the year 2016 and the MCI-2000 treated side is now estimated to the year 2013. It is not surprising that these would occur about the same rate, or even faster on the MCI side, where there is a tendency for water to pool at the bottom of the northeast corner.

   The decrease in rate of ingress of chloride could be due to less being used to de-ice roads as winters have been milder the past few years. However, in 2000 and presently, the chloride content in all areas was over 300-400ppm, which has known to cause problems with corrosion and increase the freeze/thaw cycles. (See Table 5 for data and calculation.)

2. Corrosion currents of rebar have increased on both sides of the bridge since the year 2000, when the MCI-2000 treated side had very low corrosion currents, an average of 0.013 $\mu A/cm^2$, approximately 40% below readings taken on control side (average of 0.022 $\mu A/cm^2$). These reading were taken in cold weather, but the 2007 readings were taken when it was warmer. It hadn't been raining, but areas were wetted very well before measurements were taken. The MCI-2000 treated side had an average of 0.21$\mu A/cm^2$ and the control side had as average of 0.34 $\mu A/cm^2$; giving the MCI-2000 treated side corrosion currents still approximately 40% lower. (Data is presented in Table 6.)

3. In two out of three locations on the MCI treated areas of bridge, the corrosion rate values were much lower than the control, showing the effectiveness of the MCI inhibitor. Only the SW (control) portion of the bridge had corrosion rate readings that would be considered an active (although low level) versus the other 5 passive corrosion levels. Figures 1 and 2 show the location of rebar and readings, as well as the average half-cell readings, corrosion rates and concrete resistivities for both the control and MCI treated sides. Raw data from the GalvaPulse measurements of the bridge is included in Tables 8 and 9.

4. The concrete on the 21 year old bridge deck overlay showed alkalinity measurements between 1320 to 1680mg/L. The areas that had been treated with MCI show higher amounts, which can indicate the presence of MCI and resistance to carbonation. (See Table 10 for raw data.)

5. The resistivities measured by the Gecor 6 in 2000 ranged from 100 kohm.cm to 600 kohm.cm. In 2007, the range was 36 kohm.cm to 80 kohm.cm. This shows in increase in possible corrosion which is consistent in the rise of other parameters measured such as Cl-, Corrosion current, and corrosion rates. (See Table 12.)

6. The Average Half-Cell Potential versus Year (shown in Figure 3) and the Average Corrosion Rate versus Year (shown in Figure 4) show MCI treated side lower than control except for the first reading taken after the repair. It is important to note that three different instruments have been used for these measurements and that Tables 1 through 3 should be used to interpret the values. (A summary of half-cell potentials can be found in Table 11 and a summary of resistivity measurements can be found in Table 12.)

References:

1) Germann Instruments, Inc., Galvapulse TM GP-5000 Instruction and Maintenance Manual, 2005

2) Andrade, C., Fullea, J., Alonso, C., "The Use of the Graph Corrosion Rate-Resistivity in the Measurement of Corrosion Current", International Workshop MESINA, Instituto Eduardo Torroja, Madrid, Spain, 1999.

3) Kosmatka, Steven and Panarese, William, Design and Control of Concrete Mixtures Thirteenth Edition, Portland Cement Association, Skokie, Illinois, 1994 rev. pp. 72.

4) Thomas, M.D.A. and Bentz, E.C., Life-365 Computer Program for Predicting the Service Life and Life-Cycle Costs of Reinforced Concrete Exposed to Chlorides. University of Toronto, Toronto, Canada, April 21, 2000, pp. 9.

Project: 07-151-1425

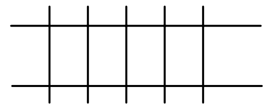
Figure 1: Location of Rebar on Randolph Street Bridge
Eastbound Lane = Control; Westbound Lane = MCI Treated
(Note: this chart has been flipped from previous report so N is on top)

CURB

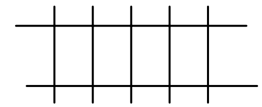
NORTH 35E

LOCATION 1 (MCI)

LOCATION 2 (MCI)



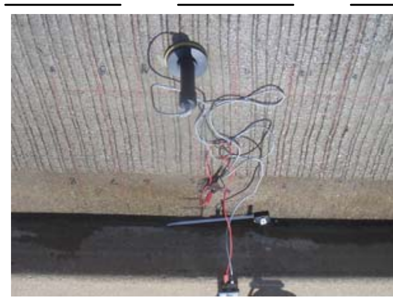
LOCATION 3 (MCI)



← EAST BOUND TRAFFIC – CONTROL ←

→ WEST BOUND TRAFFIC – MCI-2000 →

SOUTH 35E



LOCATION 6 (Control)

LOCATION 5 (Control)

LOCATION 4 (Control)

CURB

Figure 2: Randolph Street Bridge Half-Cell Potential, Corrosion Rate, Resistivity, and Chloride Results
Eastbound Lane = Control; Westbound Lane = MCI Treated
(Note: this chart has been flipped from previous report so N is on top)

CURB

LOCATION 1 (MCI)
-104 mV (50% probability of corrosion)
2.42µm/year (passive condition)
62 kΩ•cm (very low corrosion rate)

LOCATION 2 (MCI)
-101 mV (<10% probability of corrosion)
2.53 µm/year (passive condition)
65 kΩ•cm (very low corrosion rate)

LOCATION 3 (MCI)
-302 mV (50% probability of corrosion)
2.29 µm/year (passive condition)
66 kΩ•cm (very low corrosion rate)

NORTH 35E ↑

← WEST BOUND TRAFFIC – MCI-2000 ←

→ EAST BOUND TRAFFIC– CONTROL →

SOUTH 35E ↓

LOCATION 6 (Control)
-85 mV (50% probability of corrosion)
3.86µm/year (passive to low corrosion)
70 kΩ•cm (very low corrosion rate)

LOCATION 5 (Control)
-399 mV (<10% probability of corrosion)
1.83µm/year (passive condition)
42 kΩ•cm (very low corrosion rate)

LOCATION 4 (Control)
-112 mV (50% probability of corrosion)
5.15 µm/year (passive condition)
36 kΩ•cm (very low corrosion rate)

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Figure 3: Average Half-Cell Potential versus Year

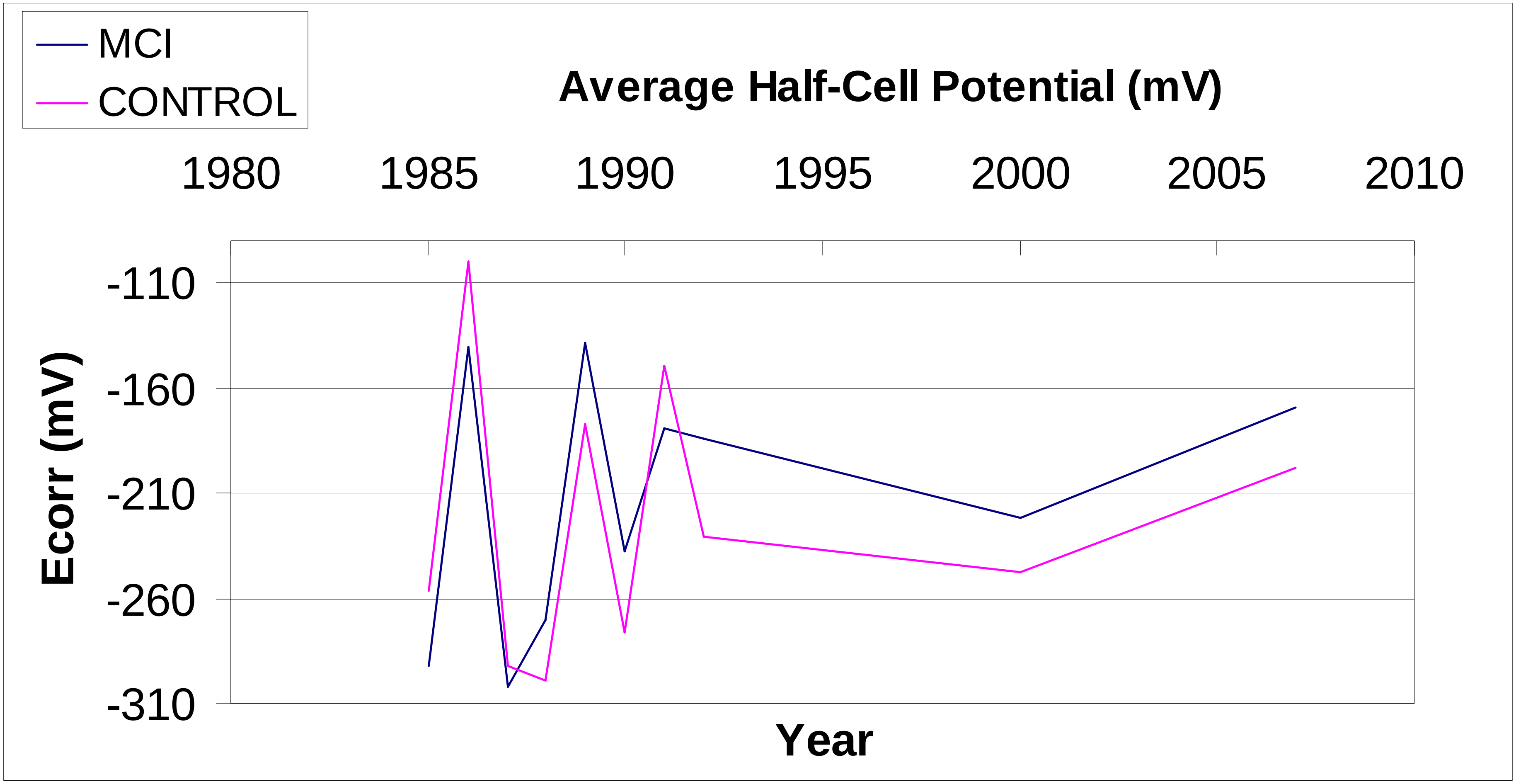

Figure 4: Average Corrosion Rate versus Year

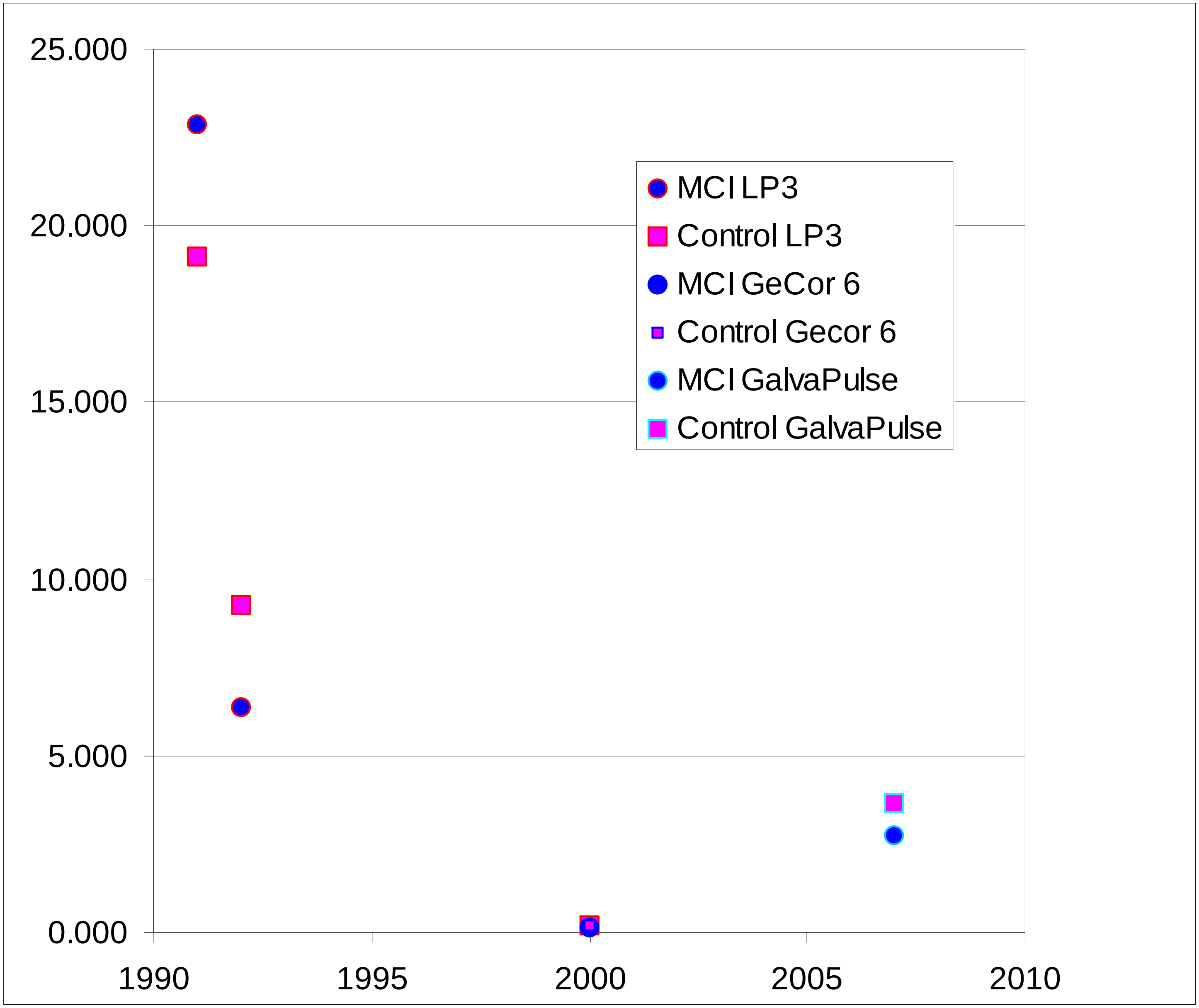

Table 5. Cl content in lbs/yd^3

	MCI Side (Average)			Control Side (Average)		
Depth	(0-1")	(1-2")	(2-3")	(0-1")	(1-2")	(2-3")
2007	11.7	1.0	2.6	20.0	7.4	2.3
2000	11.7	1.6	1.3	17.2	6.2	2.4
1992	6.5	1.1	1.9	9.5	3.5	2.5
1991	3.5	0.0	0.7	7.7	2.5	1.9

Calculation for Time until Chloride Threshold of 0.4wt% (of cementious materials) is Reached

Control

2.3 lbs/yd^3 chlorides at 2" 21 years after overlay was placed. 836 lbs/yd^3 of cement in mix
2.3/836 *100 = 0.28% Cl- by weight of cement in 21 years
0.28%/21 = 0.013%Cl- per year *30 years =0.4% Cl-
1986+30=2016 (expected year chloride threshold will meet 0.4wt% in control concrete.)

MCI

2.6 lbs/yd^3 chlorides at 2" 21 years after overlay was placed. 836 lbs/yd^3 of cement in mix
2.6/836 *100 = 0.3% Cl- by weight of cement in 21 years
0.3%/21 = 0.014% Cl- per year *27 years =0.4% Cl-
1986+27=2013 (expected year chloride threshold will meet 0.4wt% in MCI concrete.)

Table 6. Corrosion Current using GalvaPulse, μA/cm^2

MCI-2000					**CONTROL**			
	NW	NC	NE			SW	SC	SE
Rebar #	Average	Average	Average		Rebar #	Average	Average	Average
1	0.164	0.196	0.127		1	0.345	0.129	0.419
2	0.235	0.235	0.109		2	0.778	0.151	0.268
3	0.180	0.177	0.205		3	1.008	0.156	0.292
4	0.210	0.204	0.241		4	0.371	0.156	0.341
5	0.193	0.260	0.261		5	0.294	0.180	0.345
6	0.202	0.237	0.284		6	0.314	0.172	0.346
7	0.200		0.232		7			0.321
Average	0.20	0.22	0.21		Average	0.52	0.16	0.33

Table 7. Rate of Corrosion using GalvaPulse, μm/year

MCI					**CONTROL**			
	NW	NC	NE			SW	SC	SE
Rebar #	Average	Average	Average		Rebar #	Average	Average	Average
1	1.901	2.276	1.477		1	3.999	1.500	4.866
2	2.730	2.726	1.267		2	9.019	1.755	3.107
3	2.089	2.048	2.376		3	11.690	1.812	3.384
4	2.439	2.369	2.798		4	4.305	1.805	3.956
5	2.242	3.016	3.025		5	3.408	2.089	3.998
6	2.345	2.745	3.296		6	3.642	1.998	4.014
7	2.315		2.687		7			3.719
Average	2.29	2.53	2.42		Average	5.15	1.83	3.86

Table 8. GalvaPulse Measurements for Control Side of Bridge

SW	rebar 19mm area 5659 current 19							
point	17	27	37	47	57	67		
ecorr	-83.76	-127	-153.7	-120	-82.82	-68.32		
Icorr	1.0982	0.3803	0.6393	0.3973	0.4059	0.3292		
resistance	7.8	8	7.6	8.6	8.5	8.9		
Corr Rate	12.73912	4.41148	7.41588	4.60868	4.70844	3.81872		
point	18	28	38	48	58	68		
ecorr	-78.14	-90.07	-87.27	-83.76	-68.08	-69.95		
Icorr	0.3527	0.3655	0.2171	0.2041	0.2198	0.2449		
resistance	14	12	14	13	12	13		
Corr Rate	4.09132	4.2398	2.51836	2.36756	2.54968	2.84084		
point	19	29	39	49	59	69		
ecorr	-71.36	-58.49	61.53	-59.42	-44.92	-66.68		
Icorr	0.1956	0.1359	0.1788	0.1915	0.3147	0.1991		
resistance	16	16	15	16	13	13		
Corr Rate	2.26896	1.57644	2.07408	2.2214	3.65052	2.30956		
point	110	210	310	410	510	610		
ecorr	-74.16	-72.29	-75.1	-72.99	-68.55	-78.84		
Icorr	0.1695	0.1488	0.2232	0.2288	0.1287	0.1872		
resistance	14	17	15	14	12	15		
Corr Rate	1.9662	1.72608	2.58912	2.65408	1.49292	2.17152		
SC	rebar 19mm area 5659 current 39							
point	15	25	35	45	55	65	75	
ecorr	-246.3	-288	-318.4	-360.7	-288.4	-295	-282.8	
Icorr	0.1848	0.2243	0.2236	0.1984	0.2067	0.1946	0.1988	
resistance	8	8.9	7	5.1	6.6	8.3	10	
Corr Rate	2.14368	2.60188	2.59376	2.30144	2.39772	2.25736	2.30608	
point	16	26	36	46	56	66	76	
ecorr	-356.3	-362.4	-389.3	-396.8	-471.2	-442.4	-409.2	
Icorr	0.1852	0.2099	0.1945	0.1768	0.2471	0.1952	0.2334	
resistance	8.3	9.1	7.6	8.4	6	8.7	11	
Corr Rate	2.14832	2.43484	2.2562	2.05088	2.86636	2.26432	2.70744	
point	17	27	37	47	57	67	77	
ecorr	-348.3	-387.6	-427	-426.7	-405	-401.2	-392.8	
Icorr	0.2132	0.1221	0.1413	0.2302	0.2129	0.2094	0.2166	
resistance	10	12	11	6.2	8.1	8.9	10	
Corr Rate	2.47312	1.41636	1.63908	2.67032	2.46964	2.42904	2.51256	
point	18	28	38	48	58	68	78	
ecorr	-361.4	-387.6	-406.1	-382.3	-380.9	-359.3	-333.4	
Icorr	0.1478	0.143	0.1678	0.1122	0.1471	0.1705	0.1521	
resistance	12	10	6.3	12	12	12	17	
Corr Rate	1.71448	1.6588	1.94648	1.30152	1.70636	1.9778	1.76436	
SE	rebar 19mm area 5659 current 39							
point	14	24	34	44	54	64	74	84
ecorr	-28.54	-43.75	-58.49	-72.99	-82.59	-35.09	-18.95	-5.147
Icorr	0.6206	0.5476	0.4054	0.5968	0.524	0.2966	0.4428	0.349
resistance	6.9	7.5	7.6	8.4	8.4	9.3	8.3	8.100
Corr Rate	7.19896	6.35216	4.70264	6.92288	6.0784	3.44056	5.13648	4.0426
point	15	25	35	45	55	65	75	85.000
ecorr	-174.3	-193.2	-128.4	-91.71	-80.95	-88.2	-83.06	-91.950
Icorr	0.2649	0.5281	0.3879	0.2811	0.8402	0.3523	0.1732	0.263
resistance	9.4	7.6	10	12	11	11	12	11.000
Corr Rate	3.07284	6.12596	4.49964	3.26076	9.74632	4.08668	2.00912	3.05196
point	16	26	36	46	56	66	76	86.000
ecorr	-190.6	-154.4	-125.4	-111.8	-110.9	-98.26	-97.33	-100.300
Icorr	0.2925	0.2117	0.3423	0.1697	0.2508	0.2541	0.1423	0.295
resistance	10	12	9.5	11	10	12	16	12.000
Corr Rate	3.393	2.45572	3.97068	1.96852	2.90928	2.94756	1.65068	3.42548

Table 9. GalvaPulse Measurements for MCI-2000 Treated Side of Bridge

NW	rebar 19mm area 5659 current 34						
point	11	21	31	41	51	61	71
ecorr	-21.75	-54.51	-137.8	-138.9	-109.4	-47.02	-19.18
Icorr	0.1085	0.1443	0.1256	0.1816	0.1	0.1355	0.1241
resistance	11	9.2	11	7.5	12	11	10
Corr Rate	1.2586	1.67388	1.45696	2.10656	1.16	1.5718	1.43956
point	12	22	32	42	52	62	72
ecorr	-59.89	-35.56	-48.9	-65.04	-68.32	-62.47	-115.1
Icorr	0.0961	0.1708	0.1224	0.0977	0.0829	0.2162	0.0778
resistance	15	8.8	12	11	8.9	8.9	12
Corr Rate	1.11476	1.98128	1.41984	1.13332	0.96164	2.50792	0.90248
point	13	23	33	43	53	63	73
ecorr	-112.3	-97.8	-68.78	-70.42	-81.89	-92.41	-102.7
Icorr	0.074	0.1302	0.0829	0.0828	0.1079	0.1304	0.1215
resistance	18	13	15	16	13	12	14
Corr Rate	0.8584	1.51032	0.96164	0.96048	1.25164	1.51264	1.4094
point	14	24	34	44	54	64	74
ecorr	-183.2	-110.4	-69.95	-82.82	-74.16	-88.44	
Icorr	0.1237	0.1006	0.1134	0.1677	0.1654	0.2121	
resistance	11	10	10	10	9.6	7.7	
Corr Rate	1.43492	1.16696	1.31544	1.94532	1.91864	2.46036	0
NC	rebar 19mm area 5659 current 39						
point	11	21	31	41	51	61	
ecorr	-82.82	-108	-207.7	-193.9	-143.6	-164.2	
Icorr	0.2269	0.2042	0.2297	0.2772	0.2794	0.3849	
resistance	11	11	10	8.9	10	9.2	
Corr Rate	2.63204	2.36872	2.66452	3.21552	3.24104	4.46484	0
point	12	22	32	42	52	62	
ecorr	-65.27	-91.95	-102.9	-110.2	-140.3	-157.6	
Icorr	0.2152	0.3079	0.1957	0.2112	0.3639	0.3314	
resistance	12	7.9	12	12	10	8.9	
Corr Rate	2.49632	3.57164	2.27012	2.44992	4.22124	3.84424	0
point	13	23	33	43	53	63	
ecorr	-73.93	-48.66	-50.53	-68.08	-68.32	-101.7	
Icorr	0.1946	0.1805	0.2039	0.2226	0.1734	0.3362	
resistance	16	16	16	11	15	13	
Corr Rate	2.25736	2.0938	2.36524	2.58216	2.01144	3.89992	0
NE	rebar 19mm area 5659 current 39						
point	11	21	31	41	51	61	71
ecorr	-193.7	-236	-302	-334.8	-354.9	-398.9	-429.8
Icorr	0.2078	0.1198	0.3638	0.5317	0.2463	0.5523	0.2574
resistance	11	12	9.3	7	9.4	7.6	8.5
Corr Rate	2.41048	1.38968	4.22008	6.16772	2.85708	6.40668	2.98584
point	12	22	32	42	52	62	72
ecorr	-281.9	-288.9	-320.5	-341.8	-375	-401.9	-432.6
Icorr	0.1932	0.2854	0.7807	0.4434	0.9579	0.6074	0.4858
resistance	8.6	11	9.9	8.2	6.8	7.2	6.8
Corr Rate	2.24112	3.31064	9.05612	5.14344	11.11164	7.04584	5.63528
point	13	23	33	43	53	63	73
ecorr	-105.9	-124.9	-184.3	235.1	-331.3	-361.2	-435.8
Icorr	0.1474	0.0858	0.1639	0.1352	0.8829	0.8293	0.6082
resistance	18	23	13	16	5.7	5.1	6.4
Corr Rate	1.70984	0.99528	1.90124	1.56832	10.24164	9.61988	7.05512

Table 10. Alkalinity Results

MCI Treated Concrete				Control Concrete			
Concrete Sample ID	# of drops	Alkalinity as $CaCO_3$ ppm (# of drops x20x6)	Average, ppm	Concrete Sample ID	# of drops	Alkalinity as $CaCO_3$ ppm (# of drops x20)	Average, ppm
N.C. 0-1"	12	1440	1480	S.C. 0-1"	11	1320	1280
N.E. 0-1"	13	1560		S.E. 0-1"	11	1320	
N.W. 0-1"	12	1440		S.W. 0-1"	10	1200	
N.C. 1-2"	13	1560	1560	S.C. 1-2"	12	1440	1520
N.E. 1-2"	13	1560		S.E. 1-2"	13	1560	
N.W. 1-2"	13	1560		S.W. 1-2"	13	1560	
N.C. 2-3"	14	1680	1680	S.C. 2-3"	13	1560	1640
N.E. 2-3"	14	1680		S.E. 2-3"	14	1680	
N.W. 2-3"	14	1680		S.W. 2-3"	14	1680	
All samples tested @ a 1:6 dilution				All samples tested @ a 1:6 dilution			

Table 11. Summary of Half-Cell Potentials

MCI-2000			CONTROL		
NW X Average	NC X Average	NE X Average	SW X Average	SC X Average	SE X Average
-99	-66	-191	-86	-355	-145
-93	-78	-211	-96	-395	-141
-107	-101	-258	-111	-423	-118
-125	-112	-298	-99	-427	-117
-111	-111	-342	-77	-411	-115
-101	-138	-385	-41	-402	-91
-94		-429		-381	-86
					-78
Average of each horizontal bar					
-104	-101	-302	-85	-399	-112
Overall Average					
	-169			-198	

Table 12. Summary of Resistivity Measurements

MCI-2000			CONTROL		
NW X Average	NC X Average	NE X Average	SW X Average	SC X Average	SE X Average
67	65	90	51	70	55
66	83	79	64	62	38
59	70	68	74	50	33
49	53	62	56	50	30
64	68	50	63	36	37
63	47	47		41	44
70		67			36
2	65	66	70	42	36
Average			Average		
64			50		