APPENDIX 'B'

EMPRESS OVERPASS RESISTANCE TESTING

Building Strength with Integrity™

474 Dovercourt Drive * Winnipeg, MB, R3Y 1G4 * Phone (204) 489-6300 * Fax (204) 489-6033

June 19th, 2018

Andrew Gilarski, M.Sc., P.Eng.
Morrison Herschfield
59 Scurfield Boulevard, Unit #1
Winnipeg, MB R3Y 1V2

Re: Empress Overpass Pier Cap Resistance Testing - Winnipeg
To Confirm Viability Electrochemical Chloride Extraction Application (ECE)

Dear Mr. Gilarski,

Vector Corrosion Technologies was contracted to perform 'Surface Resistance Testing' on the Empress Ave. Overpass North pier cap and piers to determine the suitability of Electrochemical Chloride Extraction (ECE) on the sub-structure. Records indicate that a polymer modified bonding agent was used in concrete repair locations and the concern is the bonding agent may restrict the current and ionic flow of the ECE process. This restriction in current and ion flow may lead to a slow down the overall ECE process and cause the number of days to completion to be increased. At the time of testing it was noted there was a well bonded coating on the pier cap and piers. This coating was thick and elastomeric in nature. The coating on east face of the east facing leg was the only location where the coating was not well bonded, cracking and peeling off.

Prior to commencing any 'Surface Resistance Testing', the structure was tested to confirm whether the rebar within the structure was electrically continuous. Electrical continuity of the reinforcing steel is necessary for corrosion potential testing and for corrosion mitigation by cathodic protection. Rebar continuity is verified by contacting various steel elements with lead wires from a high impedance multi-meter and tested using the DC millivolts settings. As per ACI 222R-01 Standard in Section 4.3.1.6a, if the potential difference between the reinforcing bars is less than one (1) mV, then the reinforcing steel is deemed electrically continuous.

Rebar was exposed and tested in three locations spread-out across the structure and electrical continuity of the rebar was verified. See Table 1 for Testing results.

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Connection ID	mV DC with High Impedance Multi-meter		
	C1	C2	C3
C1			
C2	0.0		
C3	0.0	0.1	

Table 1

With electrical continuity of the reinforcement confirmed the following step was to confirm whether or not the coating was considered an electrolytic barrier. The simplest way to test this was to perform a singular corrosion potential measurement at a predetermined location through the coating and then on the bear concrete at the same spot. For this survey, we used a copper/copper sulfate reference electrode (CSE), which is a copper rod immersed in a saturated solution of copper sulfate ($CuSO_4$). When the reference electrode is connected to the embedded reinforcing steel through a digital multi-meter, the voltage difference between the stable reference electrode and the steel can be measured with the voltmeter. If the measurement through the coating and on the bare concrete are within 5.0 mV DC of each other than the coating would not be considered an electrical barrier. See Table 3 for corrosion potential results.

Corrosion Potential Test Results	
Through Coating	-45 mV DC vs. CSE
Bare Concrete	-115 mV DC vs. CSE

Table 2

The results show a 70-mV difference between the coating and bare measurement; therefore, it is too highly resistive to consider performing any 'Surface Resistance Testing' and the coating was removed at the four (4) test locations.

The coating was removed by using a cordless grinder and exposing a 12" x 12" square area of bare concrete. The surface of the bare patch was wetted with an electrically conductive solution and a 12" x 12" steel plate was placed over the patch. To reduce the contact resistance a wetted (with the same solution) micro-fiber cloth was placed between the plate and concrete. The steel plate was connected and to one side of an AC Resistance Meter and the nearest rebar connection was connected to the other side of the same resistance meter. Measurements were recorded at all four (4) locations. See Table 3 for recorded data.

Surface Resistance Testing	
Location 1	0.53 kΩ
Location 2	3.10 kΩ
Location 3	2.15 kΩ
Location 4	3.40 kΩ

Table 3

With these values we're able to calculate the theoretical circuit resistance for the ECE system over the entire pier using the total surface area, the values recorded above entered into the parallel resistance formula where the total resistance is the reciprocal of the sum of the reciprocal resistances (see equation below).

$$\frac{1}{RTotal} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \frac{1}{RN} \dots$$

Even though we measured varied resistances throughout the pier at four (4) locations, we assumed uniformity in the above equation for simplicity. Therefore, with the pier and pier cap having an approximate surface area of 1,500 SF, this means that are 1,500 – 12" x 12" resistors in parallel throughout the pier (see Table 4 for theoretical circuit resistance). With uniformity assumed the formula can be re-written as:

$$RTotal = 1/(\frac{No.\ of\ Parallel\ Paths}{Location\ Resistance})$$

Or

$$RTotal = \frac{Location\ Reistance}{No.\ of\ Parallel\ Paths}$$

			RTotal
Location 1 – Bonding Agent	530 Ω	530/1,500	**0.35 Ω**
Location 2 – Bonding Agent	3,100 Ω	3,100/1,500	**2.07 Ω**
Location 3 – Bonding Agent	2,150 Ω	2,150/1,500	**1.43 Ω**
Location 4 – No Bonding Agent	3,400 Ω	3,400/1,500	**2.27 Ω**

Table 4

Considering that Location 1, 2 and 3 are situated in a polymer bonding agent contain patches and had the lowest circuit resistances, it is unlikely the bonding agent is affecting the overall circuit resistance. However, ECE Specifications usually state that there is to be no more than 40 V DC driving voltage and typically have three (3) criteria for completion whichever comes first of the following:

1. No more than 60 days or,
2. No more than 60 Amp-Hours per SF of surface area or,
3. Until the chlorides have been reduced to below threshold in the vicinity of the reinforcing steel.

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Reverse calculations for a 1,500 SF of concrete surface area suggests that a maximum circuit resistance of 1.56 Ω would be ideal to achieve 60A-Hrs/SF over a 60-day period. If the piers were uniform in resistance then Locations 1 and 3 would have a low enough circuit resistance to meet Criteria No. 2, but Locations 2 and 4 would not.

Concrete resistance is greatly affected by moisture content along with many other factors. A combination of the well bonded elastomeric coating and the extremely dry conditions over the last 6 months can explain the higher resistance values as seen at Locations 2 through 4. For the ECE process the coating would have to be completely removed. This would open up the surface pours and allow atmospheric moister to penetrate the structure and cause the resistance to go down. It was noted earlier the coating at Location 1 was cracked and peeling and therefore that leg had a higher moisture content leading to a lower resistance. Also, as the ECE process runs the pier is continuously being wetted and the overall resistivity will go down everywhere and likely be of similar value Location 1 resistance results.

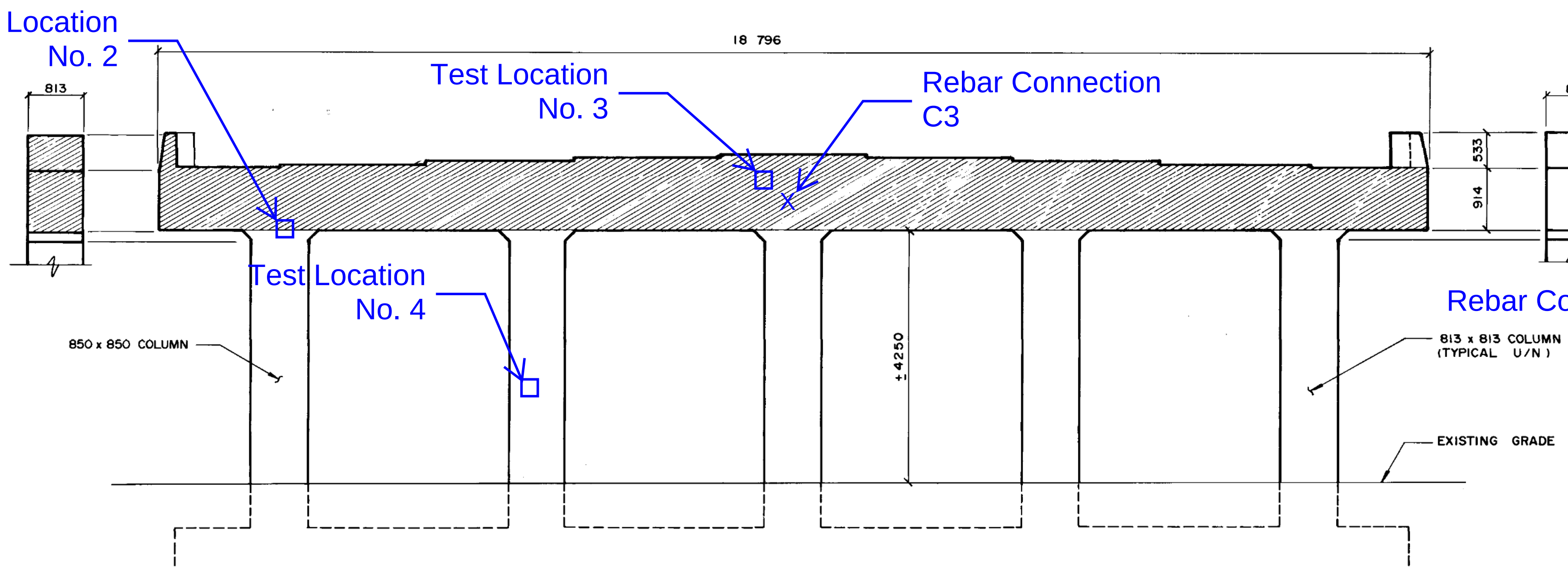
In conclusion, I am confident the bonding agent was not interfering with the overall resistance of the structure as seen in Table 4 where the presumable bonding agent locations tested lower than the non-bonding agent location. In this case the higher measured resistances can be attributed to the dryness of the structure because of two factors; firstly the well bonded coating acting as an air barrier and secondly the extremely dry environment conditions over the last 6 months. In order for ECE to be effective on this structure the coating will need to be removed prior to installation. This will allow the structure to breath and lower the over circuit resistance and lead to successful ECE application over the presumed 60-day time frame.

Should you have any questions comments or concerns feel free to call me on my direct line at (204)928-8078 or email me at andreh@vector-construction.com

Sincerely,

André Hudon, C.E.T., NACE CP2
VECTOR CORROSION TECHNOLOGIES LTD

enc.
Transposed Field Notes



Continuity Inspection:

C1 to C2 = 0.0mV DC
C1 to C3 = 0.0mV DC
C2 to C3 = 0.1mV DC

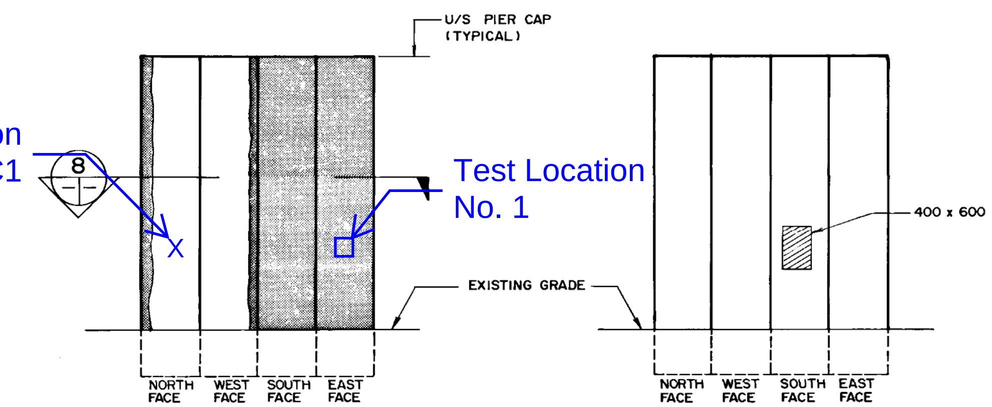
1 NORTH ELEVATION
1 : 50

12" x 12" Resistance Measurements

Location 1 - 0.53 kΩ
Location 2 - 3.10 kΩ
Location 3 - 2.15 kΩ
Location 4 - 3.40 kΩ

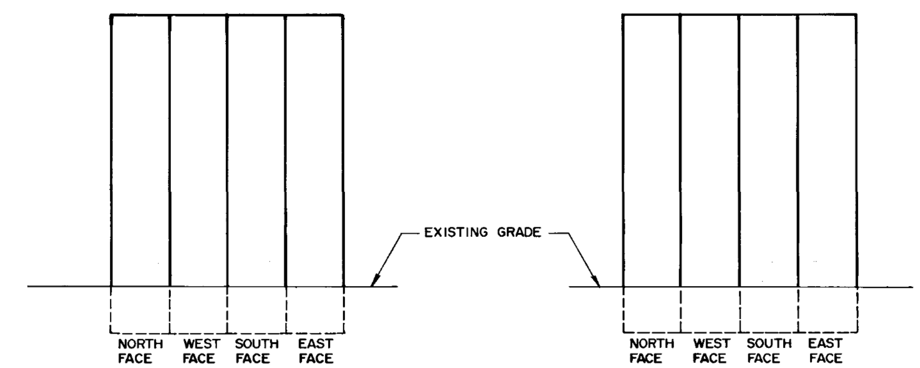
Coating Impedance Verification Test

With Coating: -45mV DC vs. CSE
Without Coating: -115mV DC vs. CSE



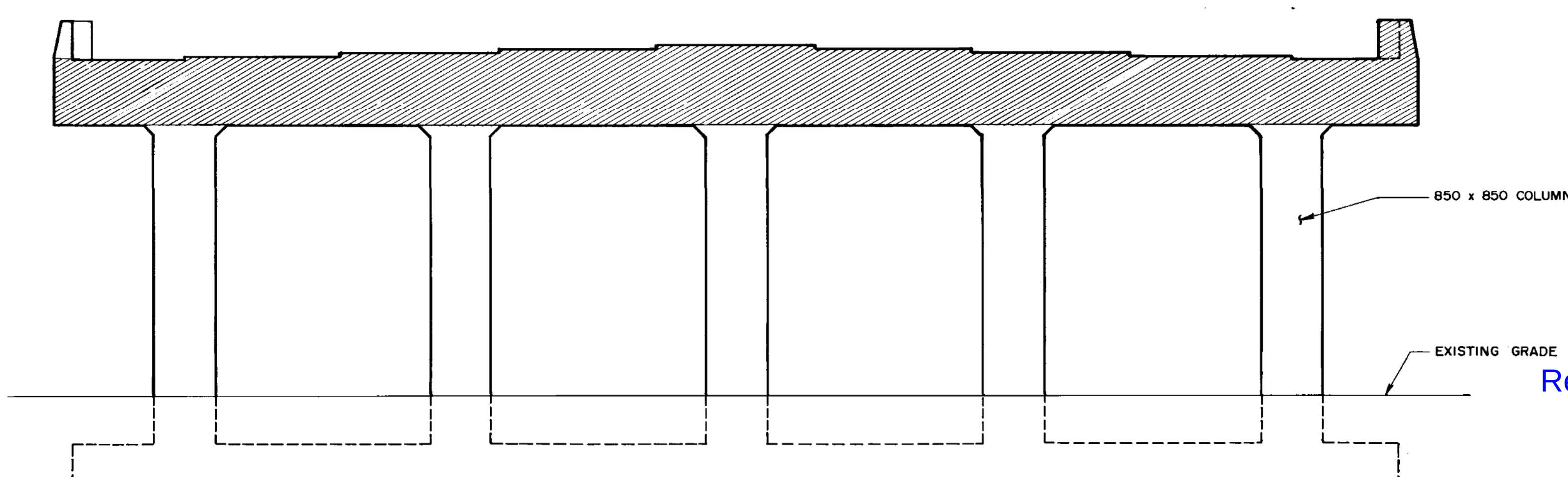
3 EAST COLUMN
1 : 50

4 EAST-CENTER COLUMN
1 : 50

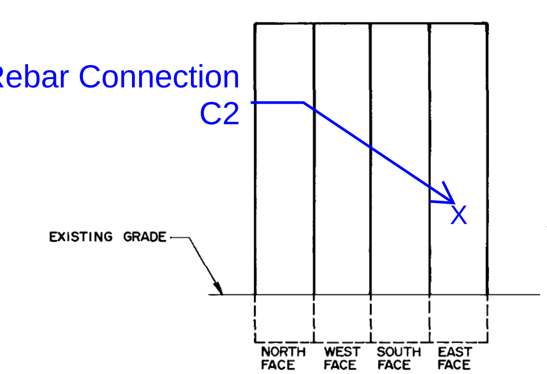


5 CENTER COLUMN
1 : 50

6 WEST-CENTER COLUMN
1 : 50



2 SOUTH ELEVATION
1 : 50



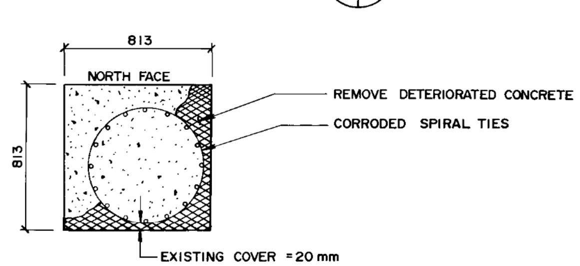
7 WEST COLUMN
1 : 50

LEGEND:

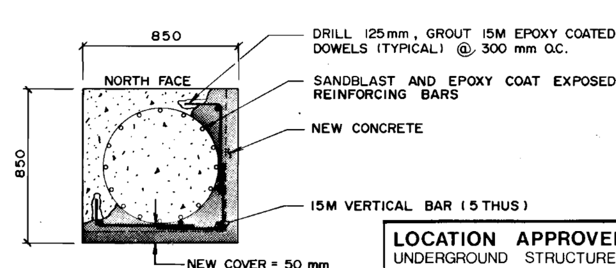
TYPE 1 REPAIR
— APPLY CEMENT WASH TO EXISTING SURFACE.

TYPE 2 REPAIR
— CHIP 25mm TO SOUND CONCRETE.
— SANBLAST & EPOXY COAT EXPOSED REINF.
— APPLY BONDING AGENT.
— BUILD UP SURFACE TO PREVIOUS LEVEL BY TROWELLING ON CEMENT MORTAR.

TYPE 4 REPAIR
— CHIP OFF 75mm MINIMUM TO SOUND CONCRETE.
— SANDBLAST & EPOXY COAT EXPOSED REINF.
— DRILL IN DOWELS AND TIE REINF. AS DIRECTED BY THE CONTRACT ADMINISTRATOR.
— APPLY BONDING AGENT.
— INSTALL FORMWORK
— CAST CONCRETE WITH 9mm AGGREGATE



8 SECTION
SHOWING PIER COLUMN BEFORE DEMOLITION
1 : 20



8 SECTION
SHOWING PIER COLUMN REPAIR
1 : 20

AS-BUILT
DATE 9/02.26 BY
CHECKED BY

B-5903-13

LOCATION APPROVED
UNDERGROUND STRUCTURES
N/A
SUPV. U/G STRUCTURES COMMITTEE — DATE

NOTE:
LOCATION OF UNDERGROUND STRUCTURES AS SHOWN ARE BASED ON THE BEST INFORMATION AVAILABLE BUT NO GUARANTEE IS GIVEN THAT ALL EXISTING UTILITIES ARE SHOWN OR THAT THE GIVEN LOCATIONS ARE EXACT. CONFIRMATION OF EXISTENCE AND EXACT LOCATION OF ALL SERVICES MUST BE OBTAINED FROM THE INDIVIDUAL UTILITIES BEFORE PROCEEDING WITH CONSTRUCTION.

B.M.
ELEV.

NO.	REVISIONS	DATE	BY

WARDROP ENGINEERING INC.

DESIGNED BY F.C.
DRAWN BY G.I.
CHECKED BY
APPROVED BY
HOR. SCALE / VERTICAL: AS NOTED
DATE JANUARY 12, 1991
AUTHORIZED BY — DATE
W. NAUMKO / STREETS & BRIDGE ENGINEER
ACCEPTED BY — DATE
G.R. SMITH / BRIDGE ENGINEER

ENGINEER'S SEAL
PROVINCE OF MANITOBA
C. D. STEWART
REGISTERED ENGINEER

CONSULTANT DRAWING NO.
890007-02-00

THE CITY OF WINNIPEG
WORKS AND OPERATIONS DIVISION
STREETS AND TRANSPORTATION DEPARTMENT

EMPRESS STREET OVERPASS
STRUCTURE REHABILITATION, STRENGTHENING AND RELATED WORKS

NORTH PIER
EXPOSED CONCRETE SURFACE REPAIRS

CITY DRAWING NUMBER
B100-90-10D