Report for

WILBUR SMITH AND ASSOCIATES
LOUISVILLE, KENTUCKY

CTLGroup Project No 210727

EVALUATION OF MILTON MADISON BRIDGE SUBSTRUCTURES

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EVALUATION OF MILITON MADISON BRIDGE SUBSTRUCTURES

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EVALUATION OF RIVER PIERS, MILTON MADISON BRIDGE

EXECUTIVE SUMMARY

CTL Group was retained by Wilbur Smith and Associates to perform an evaluation of the concrete river piers supporting the main spans of the Milton – Madison Bridge. The bridge carries US 421 over the Ohio River between Madison, Indiana and Milton, Kentucky. The evaluation of the concrete piers is part of a project to determine the feasibility for reusing the piers to support a replacement superstructure. The evaluation included a hands-on field inspection to document the existing conditions in the field along with the use of Non-destructive testing (NDT) techniques and the extraction of concrete samples for laboratory testing and concrete material evaluation.

FIELD INVESTIGATION

The field investigation consisted of documenting the conditions in the field. To perform this task, CTLGroup coordinated access to the piers, via boat and direct access to the face of the piers through swing stages, with the support of a rigging contractor. Results of the field investigation revealed the presence of delaminated areas and cracking and spalling in different portions of the pier faces. Additionally, an area of eroded concrete along a construction joint/lift-line, resulting in the exposure and corrosion of vertical reinforcement was identified in pier 5.

NON DESTRUCTIVE TESTING

Impulse response (IR), half cell potential and Ground penetrating radar (GPR) were performed to evaluate the corrosion potential and general layout of the steel reinforcement respectively. IR confirmed the presence of delaminations. Half cell potential measurements indicated areas of likely active corrosion of embedded reinforcement in several piers. Cover survey, performed with the use of GPR, revealed that spacing of the vertical reinforcement is in general agreement with the spacing noted in the original construction drawings. In most cases, concrete cover of the reinforcing steel was found to be greater than the cover noted in the construction drawings.

MATERIALS TESTING

Material testing was performed to evaluate compressive strength, static modulus of elasticity, and chloride ion concentration. The overall quality and characteristics of the concrete were evaluated through petrographic examination.

The average compressive strength of the concrete cores, extracted from the face of the piers, was 10297 psi. The elastic modulus of elasticity of the two samples tested was found to be 6.0 x 10^6 psi and 6.3 x 10^6 psi.

Chloride ion concentration test results indicate that the concrete has been subjected to an external source of chlorides. Nevertheless, chloride levels found at the depth of the reinforcement are not of concern with the exception for those reported for pier 5.

Petrographic examination of vertical cores extracted during previous visits and cores extracted from the face of the piers, indicate that localized zones of lower quality concrete exist along the lift-lines and/or construction joints. Furthermore, cracking on core C-8 was identified to extend the entire length of a sample (12.8 in.). Outside of the areas of cracking and liftlines, concrete was found to be of good quality.

CONCLUSIONS

The quality of the concrete, as confirmed by petrographic examination and compressive strength testing, is considered to be good.

Delaminated areas of significant size were identified in piers 6 and 8 in locations where previous repairs were performed and on the north face of the original concrete of pier 5. These locations should be monitored and repaired in the near future.

Liftlines and cracks were observed on the face of the piers. Liftlines extend along the horizontal plane of the piers and were found to have a locally weaker material long the plane of the liftline. Based on petrographic examination, performed on a core with a vertical crack, it is likely that vertical cracking occurred at an early age of the concrete. The significance of cracks and/or liftlines should be evaluated structurally if the piers are to be reused. Open cracks and/or liftlines should be repaired to prevent the ingress of moisture and reduction in durability if the piers are to be reused.

Erosion of a liftline near the waterline of pier 5 has exposed reinforcement and cause significant amount of corrosion of the reinforcement that should be addressed.

EVALUATION OF MILTON MADISON BRIDGE SUBSTRUCTURES

By

* Christopher A. Ligozio

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1 INTRODUCTION

As authorized by Wilbur Smith and Associates, CTLGroup evaluated the river piers of the Milton-Madison Bridge, Carrying US 421 over the Ohio River between Madison, Indiana and Milton, Kentucky.

The purpose of the evaluation is to assess the condition of the existing river piers above the waterline. The evaluation of the river piers is part of a project to determine the feasibility for reusing the piers to support a replacement superstructure

2 OBJECTIVE AND SCOPE OF WORK

The overall objective of this project is to investigate the condition and the likely remaining life of piers 5 through 8. The results of this work will be further used to evaluate the possibility of retrofitting the concrete piers to accommodate a wider superstructure.

In order to meet the objective, CTL Group's scope of work included the following:

1. Coordinated and managed access to the bridge piers.

2. Performed a condition survey of the faces of piers above the water level. The condition assessment consisted of performing visual inspection, crack mapping, hammer sounding and delamination survey of the accessible surfaces on the face of the piers.

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3. Performed the following non destructive testing techniques:

    a. Impulse Response (IR): IR was performed on either the north or the south face of each pier and was used to identify delaminations, honeycombing and sub-surface voids.

    b. Ground Penetrating Radar (GPR): GPR scans were performed to characterize the concrete cover of vertical and horizontal steel reinforcement. Scan locations were selected in the field and scans were performed on the north and south face of piers 5 through 8. A total of 135 scans were performed.

    c. Half cell potential: Half cell potential testing was performed to identify suspected areas of corrosion in selected regions of the pier faces. Areas most commonly tested were above the ledge, below the cap and the cap.

4. Extracted twelve (12) four in. nominal diameter concrete core samples and 135 concrete powder samples. The following test plan was performed:

    a. Performed compressive strength testing on a total of six (6) concrete core samples. Testing was performed in accordance with ASTM C-42 “Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete”. Two out of the six core samples were also tested for modulus of elasticity.

    b. Two (2) static modulus of elasticity tests were performed according to ASTM C-469 “Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression.”

    c. Performed petrographic examination of fifteen (15) concrete cores. Testing was performed according to ASTM C856-04 “Standard Practice for Petrographic Examination of Hardened Concrete” and includes concrete cores extracted during two previous visits.

    d. Performed acid soluble chloride ion content testing on 118 powder samples. Testing was performed in accordance with AASHTO T 260 Standard Method of Test for Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials

5. Prepared this report summarizing our findings and conclusions

3 DESCRIPTION OF STRUCTURE

The existing structure was originally constructed in 1929 and carries two lanes of traffic with a 20 ft. curb to curb width. The structure is comprised of steel girder and deck truss approach spans with 4 through truss main spans ranging from 254 to 727 ft. The main spans are supported on reinforced concrete piers founded on bedrock (Photo 1, appendix A). For the purpose of this report, each face of the pier is comprised of an upper portion and a lower portion separated by a ledge (Photo 2, Appendix A). Typically, the upper portion of the piers is tapered and ranges from 35 to 46 ft. in height, with a rectangular cross section that decreases in width towards the top of the pier. The longer dimension of the rectangular cross section is oriented parallel to the east-west direction. The lower portion of the pier has a larger cross section than the upper portion, creating a ledge between the two. The ends of the piers at this level and below are of semicircular shape. A general location and a key plan of the bridge is included in Appendix B.1

4 FIELD INVESTIGATION

4.1 SUMMARY

CTLGroup personnel, Christopher Ligozio, Scott Wyatt, Salvador Villalobos Chapa, Suad Paratusic, Jerry Harano and Maumer Klaric, were on site for the field investigation between February 24, 2009 and March 6, 2009. Access to the face of the piers and coring services were provided by Bridge Inspection Systems of Toronto, Ohio. Representative photos of the existing conditions in the field are included in Appendix A. In addition to the condition survey concrete core samples and powder samples were extracted from the face of the piers and subjected to testing.

4.2 CONDITION SURVEY

The condition survey of the faces of the bridge piers consisted of hammer sounding and visual inspection of the north and south faces of the piers. Access to the pier faces was provided by a powered swing stage rigged to the beams on the underside of the bridge deck (Photo 3). Hammer sounding was not performed on the east and west faces of the piers due to the lack of

access to these areas. During the condition survey visually detectable cracks, spalls and delaminations (identified by hammer sounding), were marked on the surface of the concrete and documented on base sheets. Sheets CS-1 through CS-8, included in Appendix B.2, represent existing conditions observed on site.

- The majority of the concrete surfaces appeared to have paste erosion particularly in areas located in the lower portion of the piers and near the waterline. Erosion can be identified as loss of surface mortar exposing the aggregate in the concrete (Photo 4).

- Areas of delamination were identified on the surface of all four concrete piers. Delaminations are identified as hollow sounding areas, typically only a few inches deep due to corrosion of reinforcement or poorly bonded overlay repairs. Pier 5 exhibited areas of delamination on the north face above the ledge at the section transition and on the south face near the top of the pier. These correspond to the original construction concrete. Pier 6 and 8 exhibited only minor localized delaminated areas, primarily in areas were previous repairs were performed (Photo 5). Pier 7 exhibited some localized delamination along the horizontal ledge at the section transition.

- Spalling was observed on the lower portion of Pier 6 at the level of the ledge (Photo 6).

- Vertical and horizontal cracking was observed on the faces of all piers. No particular pattern was observed on the cracks and these don't appear to compromise the structural integrity of the piers (Photo 7).

- Lift lines and/or construction joints were observed on the surface of the concrete of all piers (photo 8). The lift line located near the waterline on pier 5 has eroded up to 4 inches deep, exposing several vertical reinforcement bars. The exposed reinforcement presents significant cross section loss due to corrosion (photos 9 and 10).

5 NON-DESTRUCTIVE TESTING

5.1 IMPULSE RESPONSE TESTING

Impulse response (IR) testing was completed on the north face of pier 5 and the south face of piers 6, 7 and 8. A contour map with the test results of mobility and mobility slope is included in appendix C.2. Impulse response testing is generally used to identify subsurface features such as delaminations, honeycoming and variation in concrete density. Detailed information about the methods used during testing is included in Appendix C.1. IR testing measures structural mobility

to identify defects. Based on our experience, when the measured mobility is ten times larger, or more, than the lowest measured mobility there is a high possibility that honeycombs, delaminations, changes in density or cross section of the member exist. Average mobility is typically used to detect shallow features, less than 1 ft deep, and the mobility slope to detect features between 1 and 2 ft.

For all piers, high mobility was observed in areas of shallow delaminations. It should be noted that in some of the test locations the mobility and mobility slope appear with higher values (blue and yellow color). This could be an indication of a test point performed near a crack, indicating a localized reduction in stiffness due to the crack.

5.2 GROUND PENETRATING RADAR

Ground penetrating radar was used to conduct a concrete cover survey of the steel reinforcement. The north and south faces of all piers were tested to characterize the cover of the vertical and horizontal reinforcement. Results and approximate location of the scans is included in Appendix C.3. This technique is widely used in the concrete industry to detect rebar location and determine the depth of the reinforcement. Detailed information about the procedure used during testing is included in Appendix C.1.

The following generalizations can be made about the test results:

- In general the vertical reinforcement appears to be located behind the horizontal reinforcement.
- In general spacing of the vertical and horizontal reinforcement was found to be around 18 and 36 in. respectively. This result is in general agreement with the construction drawings.
- In general cover to steel reinforcement was found to range between 1.5 in and 6 in. The measured cover values were generally larger than those found in the construction drawings.

5.3 HALF CELL POTENTIAL

Half cell potential values were obtained in selected locations on the face of the piers. A contour map showing potential measurements is presented in Appendix C.4. A copper/copper sulfate reference half cell was used for this project.

Generalities about the tests results indicate the following:

- Locations above the ledge on the north face of pier 5 and on an area of the cap and below the cap of the south face of pier 8 were found to have potential measurements more negative than -350 mV, indicating the likely onset of corrosion.

6 MATERIAL TESTING AND EVALUATION

6.1 SUMMARY

Material testing was performed on concrete core samples to evaluate compressive strength and static modulus of elasticity. Testing of powder samples, extracted in the field and from core samples, was performed to evaluate the chloride levels in the concrete. Additionally, petrographic examination was performed on cores extracted from the piers. The objective of the pretrographic examination is to evaluate and document the properties of the material.

6.2 COMPRESSIVE STRENGTH TESTING

Compressive strength testing was performed on six (6) 4 in. nominal diameter concrete core samples. Two of these cores were also tested for static modulus of elasticity. Core Tests were performed in accordance with ASTM C-42, “Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete”. Testing was performed more than 5 days after their extraction of the samples and they were kept in air dry condition until the day of testing.

Compressive strength test results ranged from 7000 psi to 13570 psi with an average compressive strength of 10297 psi. Table 1 summarizes the compressive strength test results. Detailed information regarding the test results is included in Appendix D.1. Concrete core location is included with the condition survey in Appendix B.2.

Table 1. Summary of Compressive Strength Test Results.

Core ID	PIER	FACE	F'c (psi)	Average
C-1	6	South	10380	10297
C-2*	6	North	11150	
C-3B	6	North	7000	

C-4*	8	South	11500
C-7	7	North	8180
C-11A	5	South	13570

*Core tested for modulus of elasticity

6.3 STATIC MODULUS OF ELASTICITY

Static modulus of elasticity tests was performed on cores C-2 and C-4 extracted from the north face of pier 6 and south face of pier 8 respectively. Tests were performed in accordance with ASTM C-469, “Standard Test Method for Static Modulus of Elasticity and Poisson’s Ratio of Concrete in Compression”.

Test results for static modulus of elasticity of cores C-2 and C-4 are 6,000,000 psi and 6,300,000 psi respectively. Detailed information regarding the test results is included in Appendix D.2. Concrete core sample location is included with the condition survey in Appendix B.2.

6.4 ACID SOLUBLE CHLORIDE ION CONCENTRATION TESTING

Chloride ion concentration testing was performed on a total of 118 powder samples. Three of these powder samples were extracted in the laboratory from core sample C-9. Acid-soluble (total) chloride content test results were used to evaluate the chloride levels in the concrete at different depths in reference to the exposed surface. Testing was performed in accordance with reference standard AASHTO T260-97 (2001), “Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials”. Concrete core and powder sample locations and summary tables are included with the condition survey in Appendix B.2.

Table 2 summarizes the total chloride ion concentration of the concrete sampled at different depths. Specific laboratory test reports are included in Appendix D.3. Chloride ion concentration test results are reported as percentage of the total sample weight and include both paste and aggregate.

Generalities about the test results include the following:

- Total chloride ion content values at depths of 3.5 to 4.5 in. from the surface of the concrete indicate that chlorides were not admixed to the concrete during the construction process.

- Larger concentration of chloride ions near the surface of the concrete and a decreasing gradient of the chloride levels relative to the depth of sampling indicates that the concrete has been exposed to an external source of chlorides.

- Chloride levels and depth of sampling at pier 5 indicate that chloride levels in several locations are higher than the 0.03% threshold value, for chloride induced corrosion.

Table 2. Summary Of Total Chloride Ion Concentration Test Results.

Pier	Face	sample no	Orient.	Approximate Location on Pier Face	Depth(in.)			
					0.5-1.5	1.5-2.5	2.5-3.5	3.5-4.5
5	North	1	H	Cap, 30" below top	**0.071**	**0.033**	0.014	0.007
		2	H	Upper Wall, 44" below top	0.015	0.012	0.009	0.006
		3	H	Upper Wall, 22 ft below top	**0.070**	0.022	0.021	0.006
		4	H	Upper Wall, 33 ft below top	**0.074**	0.006	0.004	0.007
	South	1	H	Cap, 28" below top	**0.051**	0.016	0.010	0.008
		2	H	Upper Wall, 6 ft below top	**0.039**		0.017	0.010
		3	H	Upper Wall, 24 ft below top	**0.116**	**0.078**	**0.048**	**0.049**
		4	H	Upper Wall, 35 ft below top	**0.062**	**0.061**	0.025	0.015
		5	V	Top of Cap, near center	0.025	0.007	0.009	0.008

Pier	Face	sample no	Orient.	Location	Depth(in.)			
					1.0-2.0	2.0-3.0	3.0-4.0	
6	North	1	H	Lower Wall, 3 ft below Step	0.006	0.014	0.005	
		4	H	Upper Wall, 42 in. below top	0.005	0.009	0.008	
		5	H	Upper Wall, 9 ft below top	0.007	0.008	0.007	
	South	1	H	Lower wall, 1 ft below step	0.004	0.006	0.005	
		4	H	Upper Wall, 45 ft below top	0.007	0.006	0.005	
		5	H	Upper Wall, 38.5 ft below top	0.007	0.003	0.013	
		6	H	Upper Wall, 11 ft below top	0.004	0.005	0.004	

Notes:
Critical threshold chloride value of 0.03 % by weight of total sample, based on ACI Committee 201 recommendation that specifies that chloride contents greater than 0.15% by weight of cement are likely to result in corrosion of reinforcement in regular reinforced concrete.

Table 2. Summary Of Total Chloride Ion Concentration Test Results (cont.).

Pier	Face	sample no	Orient.	Location	Depth(in.)			
					0.5-1.5	1.5-2.5	2.5-3.5	3.5-4.5
7	North	1	V	Top of Cap, South edge	0.005	0.004	0.011	0.010
		2	H	Cap, 17" below top	0.010	0.004	0.006	0.004
		4	H	Upper Wall, 8 ft below top	0.004	0.004	0.005	0.007
		5	V	Top of Cap, near center	0.009	0.004	0.004	0.009
	South	1	H	Upper Wall, 45 ft below top	0.019	0.004	0.001	0.007
		2	H	Upper Wall, 10 ft below top	0.002	0.002	0.006	0.002
		3	H	Upper Wall, 32 ft below top	0.002	0.002	0.003	0.006
Pier	Face	sample no	Orient.	Location	Depth(in.)			
					0.0-1.0	1.0-2.0	2.0-3.0	3.0-4.0
7	South	C-9	V	Ledge, 14'6" from east edge	**0.131**	**0.081**	0.020	0.011

Pier	Face	sample no	Orient.	Location	Depth(in.)			
					0.5-1.5	1.5-2.5	2.5-3.5	3.5-4.5
8	North	1	H	Upper Wall, 6 ft below top	0.006	0.012	0.010	0.003
		2	H	Upper Wall, 43.5 ft below top	0.010	0.006	0.003	
		3	H	Lower Wall, 18 ft below step	0.013	0.010	0.003	0.005
		4	H	Upper Wall, 5 ft below top	0.011	0.006	0.005	0.006
	South	1	H	Upper Wall, 6.5 ft below top	0.019	0.013	0.012	0.004
		2	H	Upper Wall, 18 ft below top	0.005	0.005	0.006	0.001
		3	V	Top of Step	0.014	0.004	0.001	0.016
		4	H	Lower Wall, 18 ft below step	0.002	0.003	0.010	0.001

Notes:
Critical threshold chloride value of 0.03 % by weight of total sample, based on ACI Committee 201 recommendation that specifies that chloride contents greater than 0.15% by weight of cement are likely to result in corrosion of reinforcement in regular reinforced concrete.

6.5 PETROGRAPHIC EXAMINATION

Petrographic examinations were performed on a total of 15 concrete cores. Eight (8) cores extracted during the field being reported, between 2/24/09 through 3/06/09, were extracted from the face of the piers. The remaining cores were drilled vertically from the top deck of the bridge during different field visits. Petrographic examinations were performed in accordance with ASTM C-856 - 04 “Standard Practice for Petrographic Examination of Hardened Concrete”. Table 3 provides a summary of the test samples subjected to petrographic analysis. The complete petrographic report regarding the cores extracted from the face of the piers and core C4-ER and C4-ES is included in appendix D. 4.1. The complete petrographic report of remaining cores samples is included in appendix D. 4.2.

Table 2. Summary Of The Test Samples Subjected To Petrographic Analysis

Core ID	Pier	Extracted on	Approximate Distance From Top of Pier (ft.)	Location On Face of Pier	Comments
C1-CR (2)	8	1/16/2009 through 1/19/09	99		Near/below waterline
C1-EW (2)	8		165		Near bottom of pier
C2-CQ	7		102		Near/below waterline
C2-GR & C2-GS	7		168		Near bottom of pier
C3-CS	6	2/6/09 through 2/9/09	98		Near waterline
C4-CM	9		74		Near waterline
C4-ER to C4-ES*	9		137		Footing
C-11	5	2/24/09 Through 3/6/09		Lower wall, 34.5' below step	Approx. 1.5' above waterline
C-12	5			Upper wall, 43.5' below top	Taken at a horiz. lift line
C-7	7			Lower wall, 33' below step	Approx. 2' above waterline
C-8	7			Lower wall, 13' below step	Taken at a vertical crack
C-9*	7			Lower wall, at step	near area of delamination
C-10	7			Upper wall, 36' below top	Taken at a horiz. lift line
C-5	8			Lower wall, 33' below step	Taken at a horiz. lift line
C-6	8			Upper wall, 27' below top	Taken at a horiz. lift line

* Test results included on the report with samples extracted during 2/24/09 through 3/06/09

Generalities about the petrographic examination include the following

- Quality of all concrete cores was judged to be fairly good. Concrete core segments from the different piers appear to have similar constituents, each consisting of natural gravel and sand, distributed in a hardened non air entrained air paste. Aggregate distribution within individual cores is generally uniform.

- Cores extracted from the face of the piers appear to have deterioration in the form of surface erosion manifested as paste loss and aggregate exposure and protruding to variable reliefs. No substantial micro cracking, scaling or paste softening was identified near the surface of the concrete

- Cores C-5, C-6, C-10 and C-12 (extracted from the face of the piers) and cores C4-ER, C4-ES, C2-GR, and C2-GS (extracted vertically a along the length of the pier) exhibit a distinct and abrupt or weak and barely visible discontinuity. Some of these cores exhibit locally different color and soft paste above and below the vicinity of the discontinuity. This feature has been identified as a lift line or a cold joint.

- Carbonation was documented to be present near the exposed surface of the cores and near the lift line even in portions where the concrete did not fracture along the discontinuity.

- A major crack was documented to be present along the entire length (12.8 in.) of core C-8. Carbonation was identified along the vicinities of the crack. The path of the vertical crack propagated around the aggregate, in contrast to the fresh fracture surfaces created on the specimen during the petrographic examination. This is an indication that cracking may have occurred at an early age of the concrete.

7 CONCLUSIONS

Based on the results obtained from our work performed the following conclusions are presented:

Based on petrographic examination and compressive strength test results, the overall concrete quality of the piers was found to be good.

Areas of delamination were identified in piers 5, 6 and 8. Delaminations in piers 6 and 8 were found in areas corresponding to previous repairs. The north face of Pier 5, above the ledge, was found to have a large area of delamination. This region was also identified as a region with halfcell potential readings more negative than -350mV indicating that corrosion could be the cause of delamination in the area of pier 5. Measured chloride contents at pier 5 were elevated, likely due to the presence of a deck joint, and exceeded threshold values at the depth of the reinforcement at several locations. Given the combination of elevated chlorides, delaminations, and halfcell potential readings, active, chloride induced, corrosion of the reinforcement is likely.

Additionally, the erosion of concrete along the liftline at the waterline of Pier 5 has exposed reinforcement, resulting in significant loss of reinforcement cross section. This condition is significant structurally and should be addressed.

Lift lines, Vertical and horizontal cracking were documented to be present on the face of all the piers. Horizontal and vertical cracks appear to be deep and likely occurred at an early age of the concrete, as the cracks were found to propagate around the aggregate. Cores extracted through and along the lift lines indicate that a localized region of weaker paste exists along the horizontal plane of the liftlines. This was confirmed with petrographic analysis of vertical and horizontal cores. The zone of locally weaker material may not pose a concern from the

structural integrity point of view, but should be investigated in the retrofited piers. Intrusion of deleterious substances through the cracks could compromise the durability of the structure and should be addressed.

Other than the localized deterioration noted, Piers 6, 7 and 8 are generally sound, with no obvious concrete durability issues noted. Service life analysis for these piers should be conducted to confirm adequate life with respect to surface erosion, existing chlorides, and freeze thaw deterioration. It is likely that the level of rehabilitation necessary to obtain the required additional service life will be minor to moderate. It should also be noted that the concrete is non air entrained and has not been exposed to chlorides. Exposure to chlorides in a freezing and thawing environment can further accelerate deterioration.

The condition and likely active corrosion of reinforcement observed at Pier 5 are more significant. The likely chloride induced corrosion of the reinforcement indicates a significant durability concern and will need to be addressed to extend the service life of Pier 5. Potential rehabilitation techniques could include replacement of surface concrete or electrochemical chloride extraction. Service life analysis for this pier should consider the rehabilitated condition.

End of Report

APPENDIX A

Figures

- **Figures 1 through 9 (5 pages)**

Photo 1. General View of the bridge.

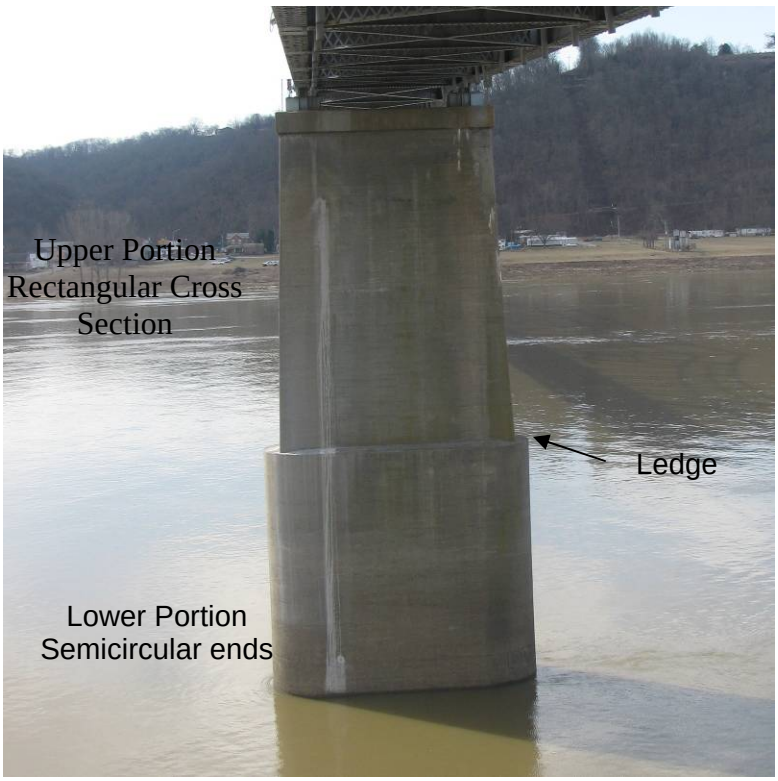


Photo 2. General shape of the concrete piers.

Photo 3. Swing stages on the face of the piers.

Photo 4. Eroded surface at core location on bottom portion of Pier.

Photo 5. Delaminated area on the north face of pier 5.

Photo 6. Spalling at the ledge of pier 7.

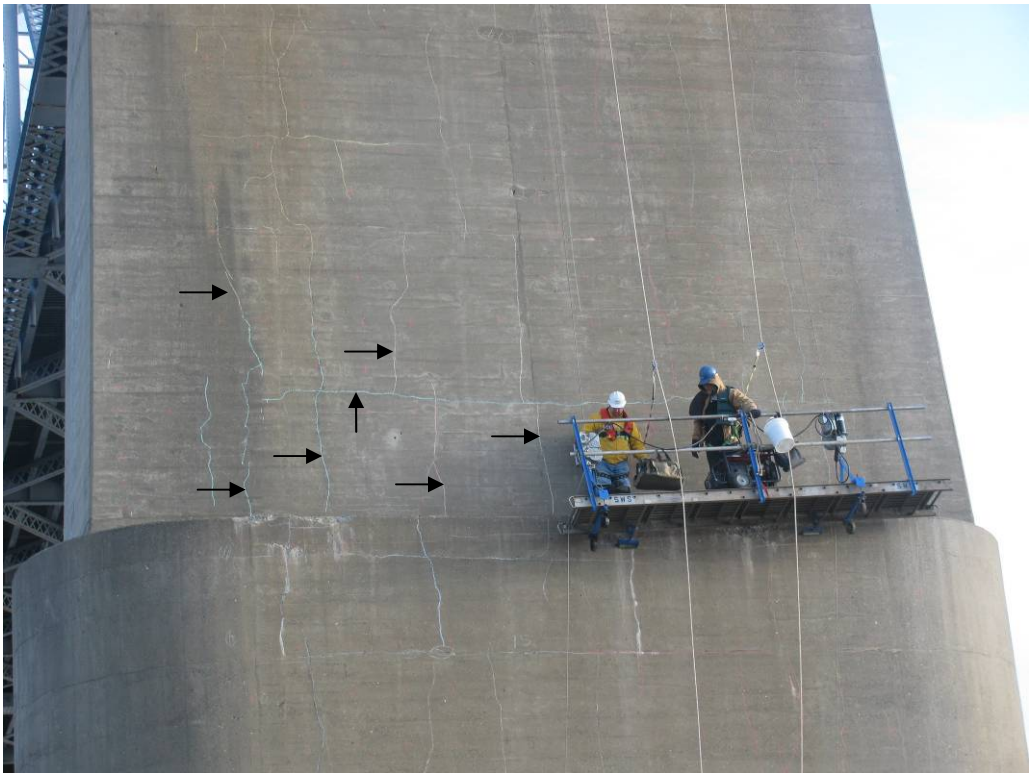


Photo 7. Cracking on face of pier.

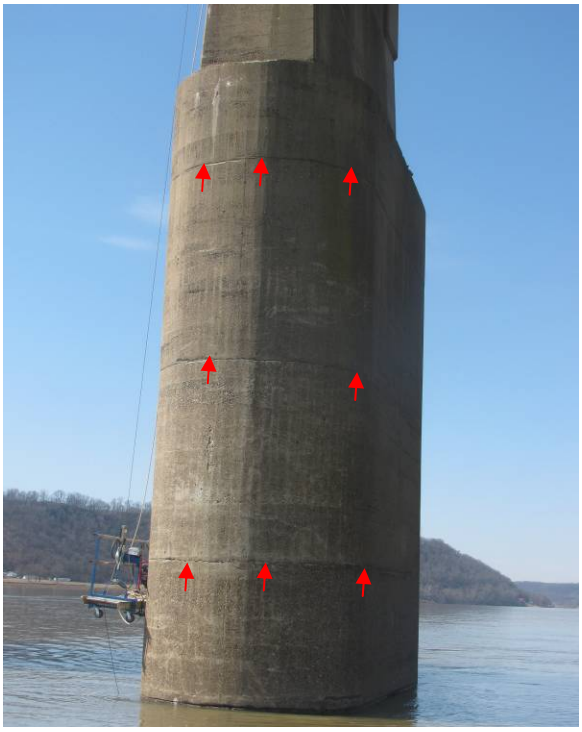


Photo 8. Lift lines and/or construction joints.

Photo 9. Eroded liftline/construction joint at pier 5.

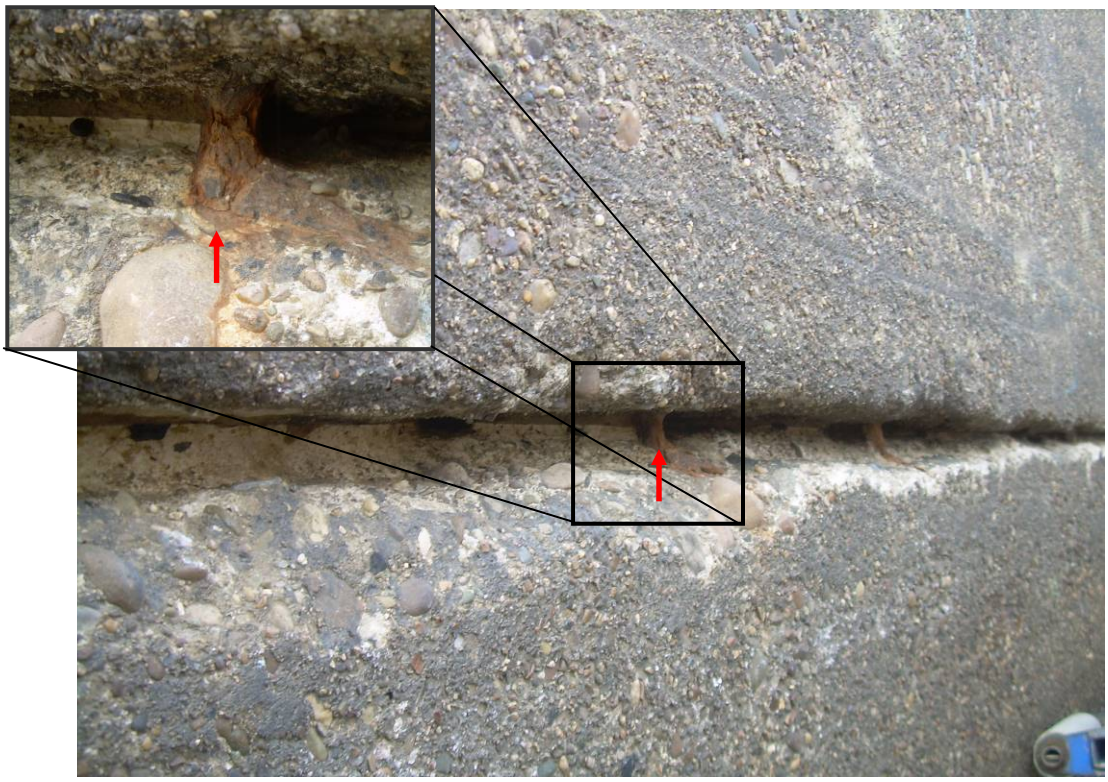


Photo 10. Close up of the eroded construction joint at the bottom of pier 5. A total of 6 bars were fond to be exposed.

APPENDIX B

General Location of Structure and Condition Survey

- **APPENDIX B.1 – General Location (Sheets Cover page & GL-1)**
- **APPENDIX B.2 – Condition Survey (Sheets CS-1 through CS-8)**

APPENDIX B.1

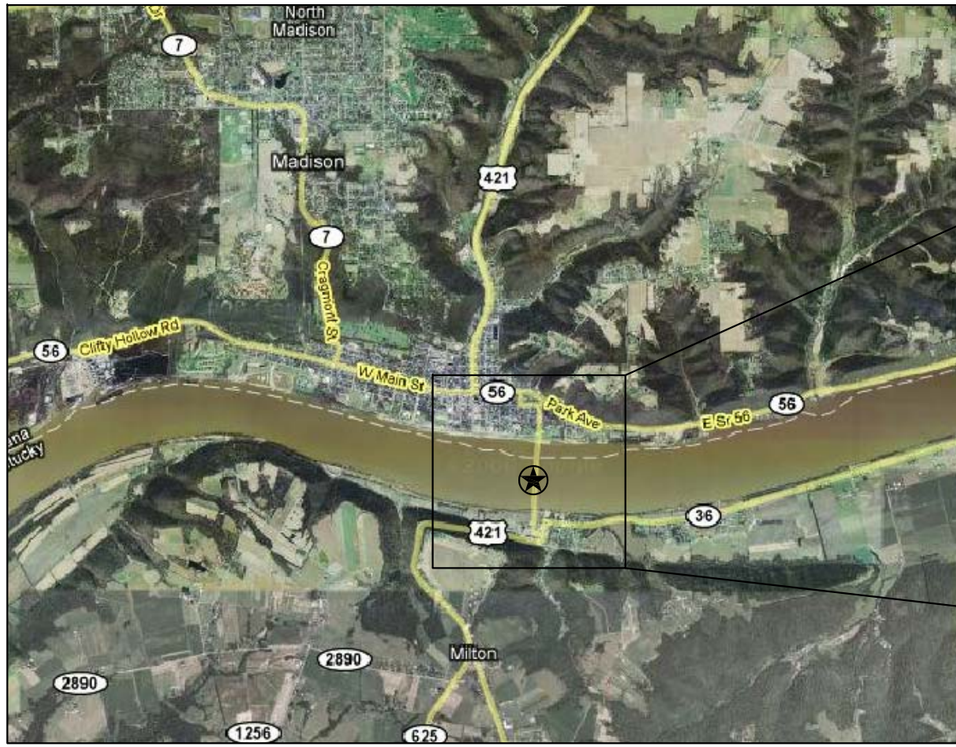
Cover Page & General Location

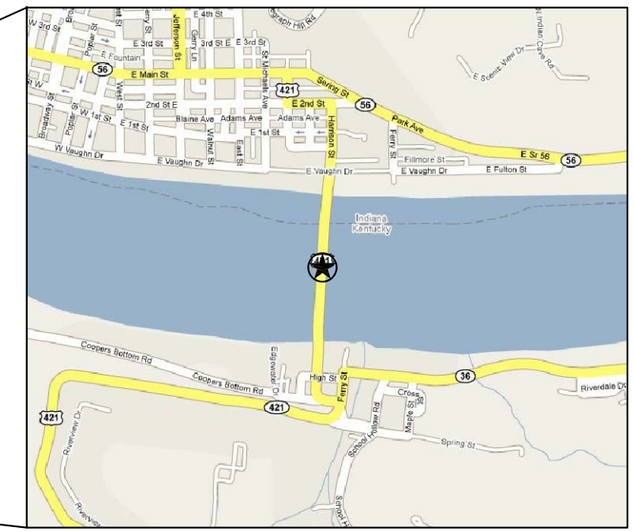
- **Cover Page**
- **Sheet GL-1**

EVALUATION OF MILTON MADISON BRIDGE SUBSTRUCTURE

JUNE 10, 2009

CTLGROUP PROJECT No.: 210727





LOCATION MAPS

N

ENGINEERS PLANNERS ECONOMISTS
WilburSmith ASSOCIATES

Wilbur Smith Associates
465 East High Street
Lexington, KY 40507

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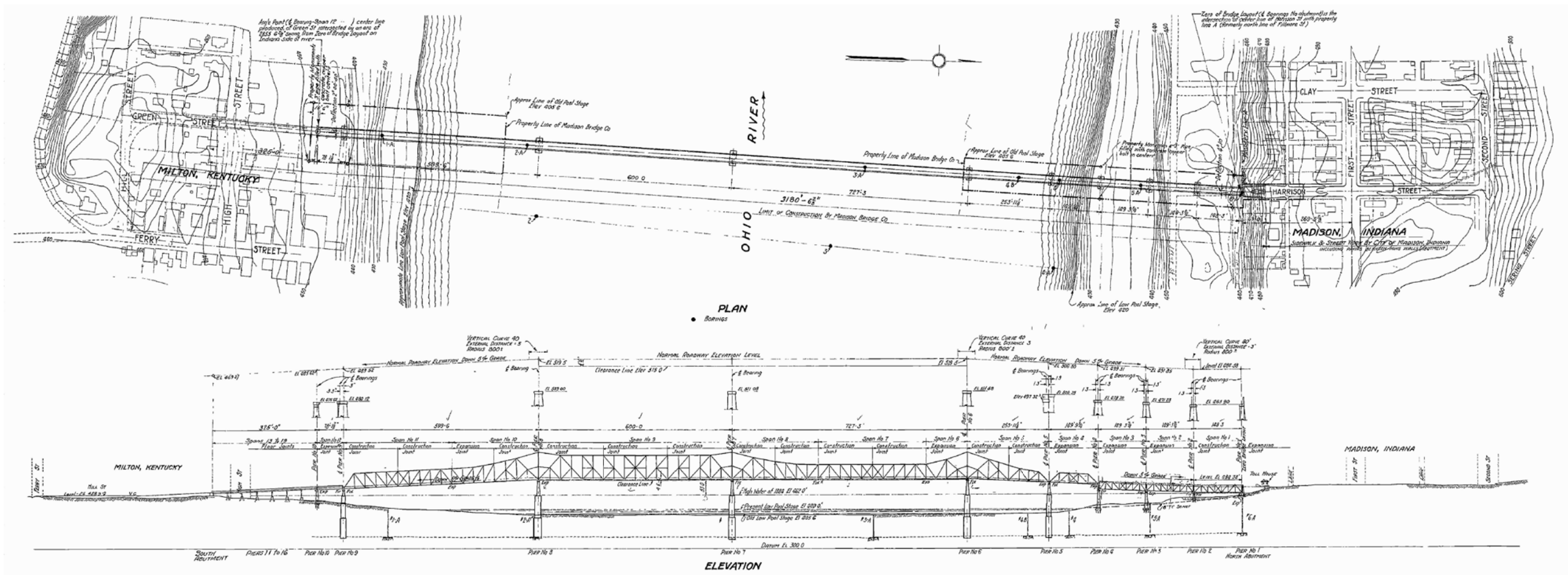

1 PLAN AND ELEVATION

NTS

NOTE: PLAN AND ELEVATION TAKEN FROM ORIGINAL DRAWINGS DRAW BY THE J. G. WHITE ENGINEERING CORPORATION LABELED H-7025-6 DATED 3-6-28

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Evaluation of Milton Madison Bridge Substructures

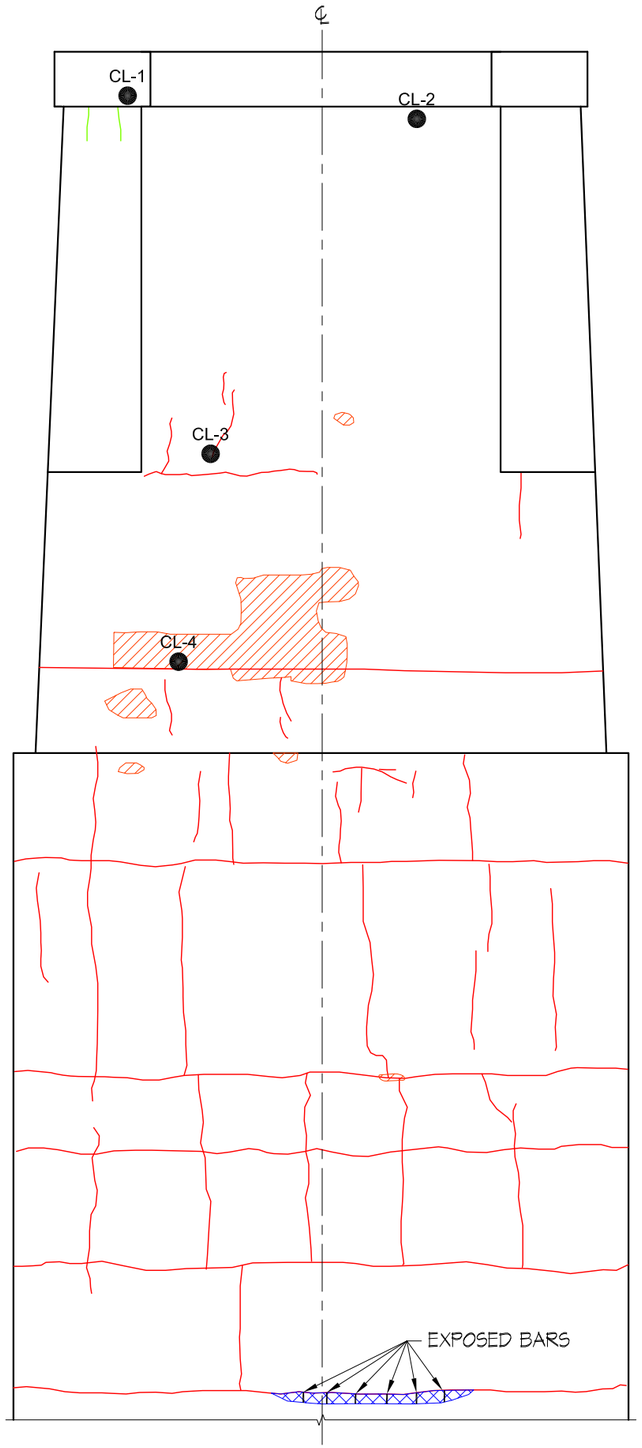
Sheet No.:

GL-1

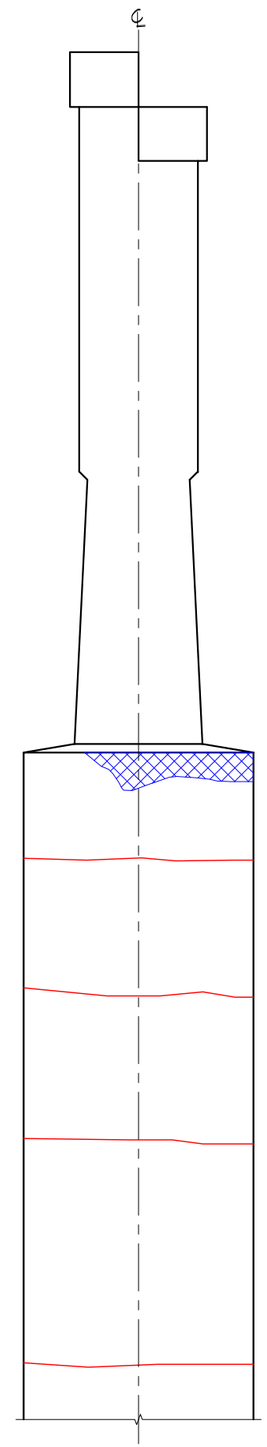
APPENDIX B.2

Condition Survey

- **Sheets CS - 1 through CS – 8**



1 PIER 5 NORTH FACE
NTS



2 PIER 5 WEST FACE
NTS

Pier 5 North Face

sample no	Depth(in.)			
	0.5-1.5	1.5-2.5	2.5-3.5	3.5-4.5
1	0.071	0.033	0.014	0.007
2	0.015	0.012	0.009	0.006
3	0.070	0.022	0.021	0.006
4	0.074	0.006	0.004	0.007

LEGEND:

- CRACK
- DELAMINATION
- SPALL
- EFFLORECENCE
- CL-# CHLORIDE SAMPLE LOCATION
- C# CORE LOCATION
- C# CORE LOCATION ON CRACK OR LIFT LINE

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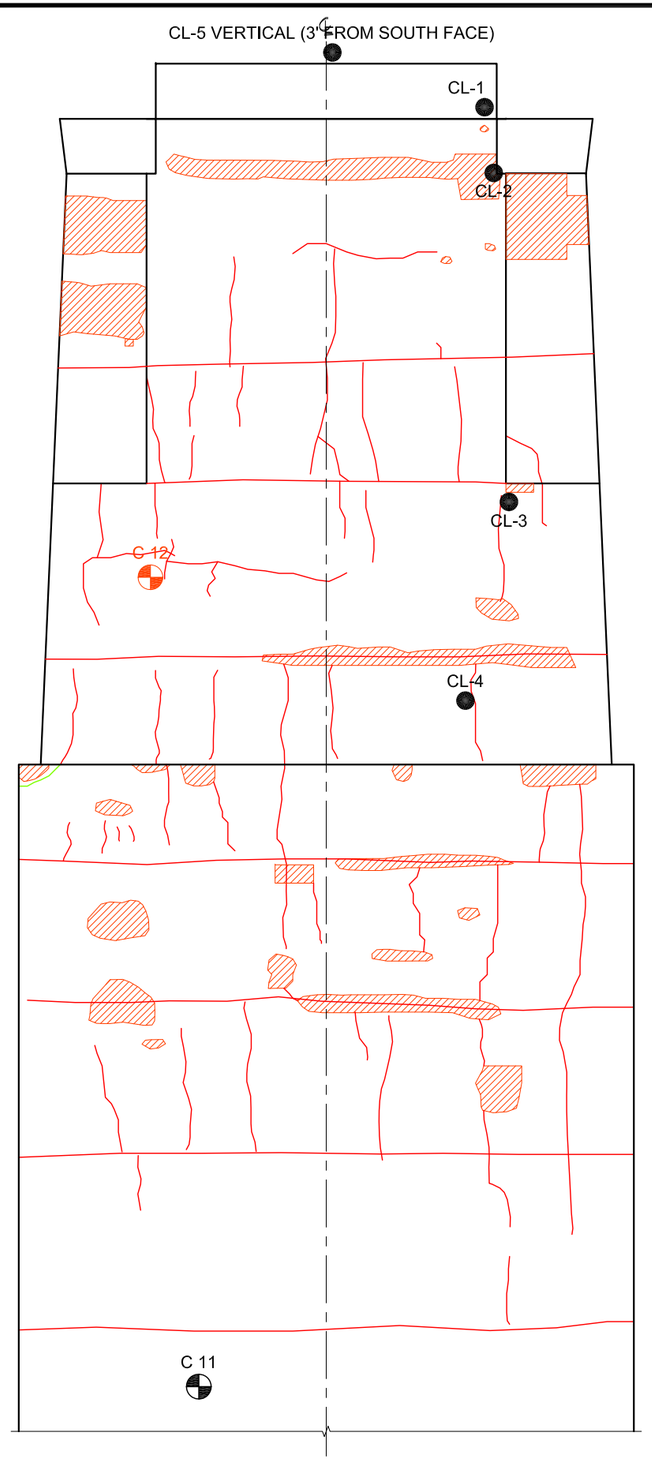
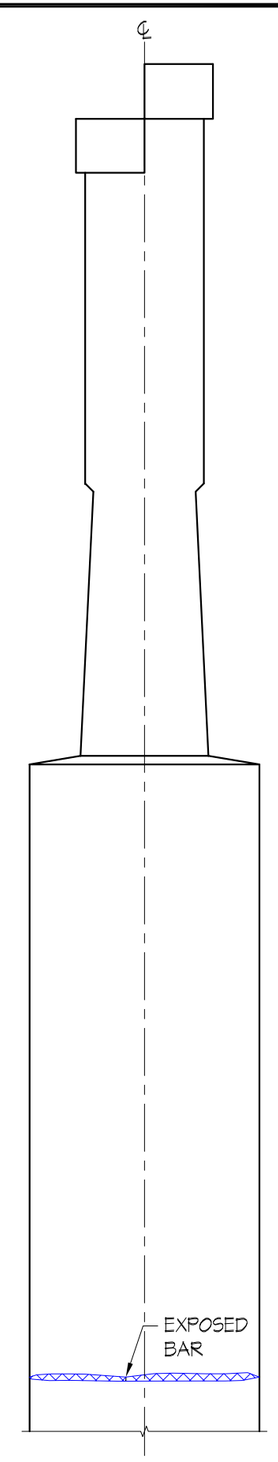
Sheet No.:

1



1 PIER 5 SOUTH FACE
NTS



2 PIER 5 EAST FACE
NTS

Pier 5 South Face

sample no	Depth(in.)			
	0.5-1.5	1.5-2.5	2.5-3.5	3.5-4.5
1	0.051	0.016	0.010	0.008
2	0.039		0.017	0.010
3	0.116	0.078	0.048	0.049
4	0.062	0.061	0.025	0.015
5	0.025	0.007	0.009	0.008

LEGEND:

- CRACK
- DELAMINATION
- SPALL
- EFFLORECENCE
- CL-# CHLORIDE SAMPLE LOCATION
- C# CORE LOCATION
- C# CORE LOCATION ON CRACK OR LIFT LINE

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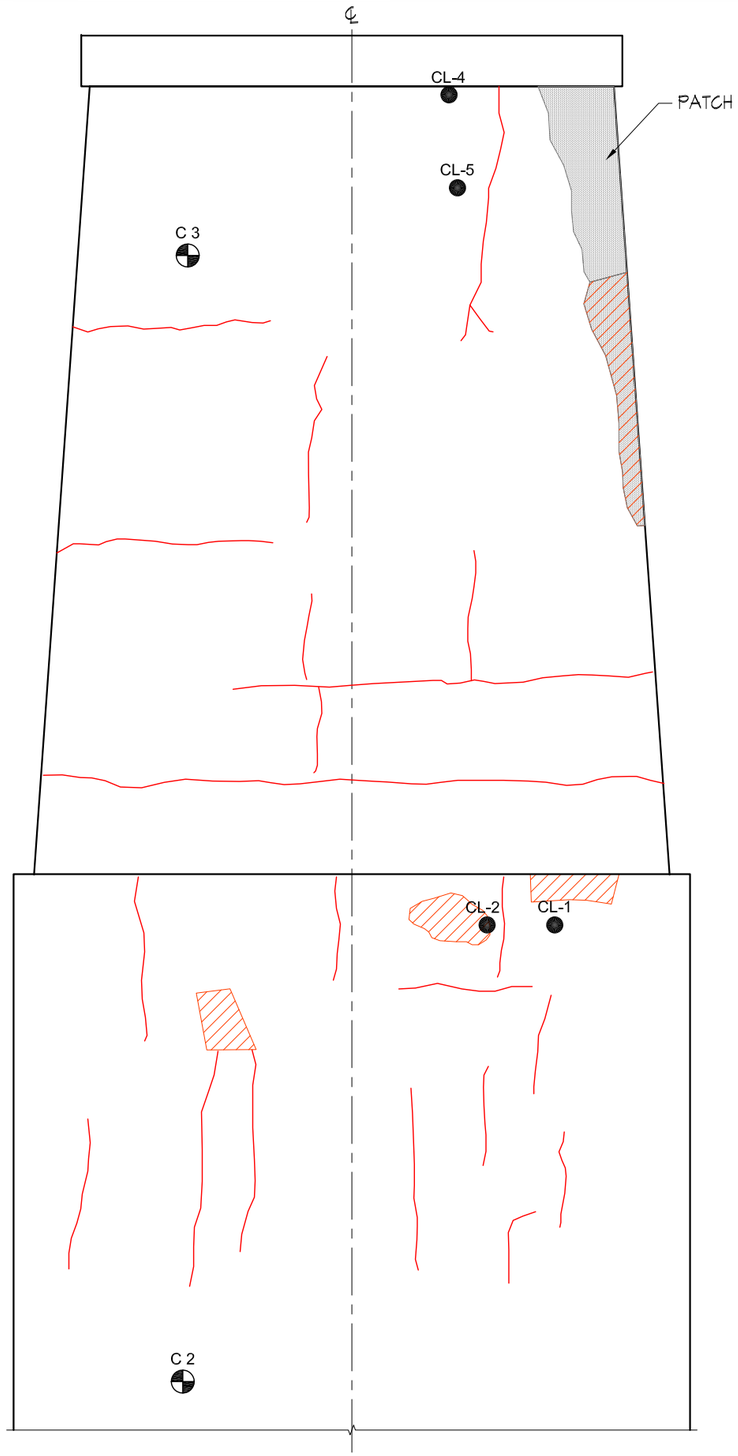
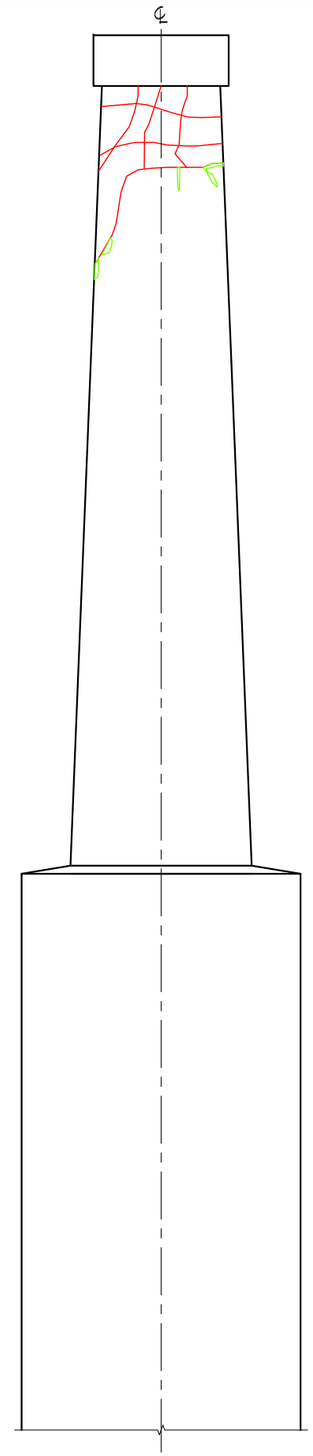
Evaluation of Milton Madison Bridge Substructures

Sheet No.:

2



1 PIER 6 NORTH FACE
NTS



2 PIER 6 WEST FACE
NTS

Pier 6 North Face

sample no	Depth(in.)		
	1.0-2.0	2.0-3.0	3.0-4.0
1	0.006	0.014	0.005
4	0.005	0.009	0.008
5	0.007	0.008	0.007

LEGEND:

- CRACK
- DELAMINATION
- SPALL
- EFFLORECENCE
- CL-# CHLORIDE SAMPLE LOCATION
- C# CORE LOCATION
- C# CORE LOCATION ON CRACK OR LIFT LINE

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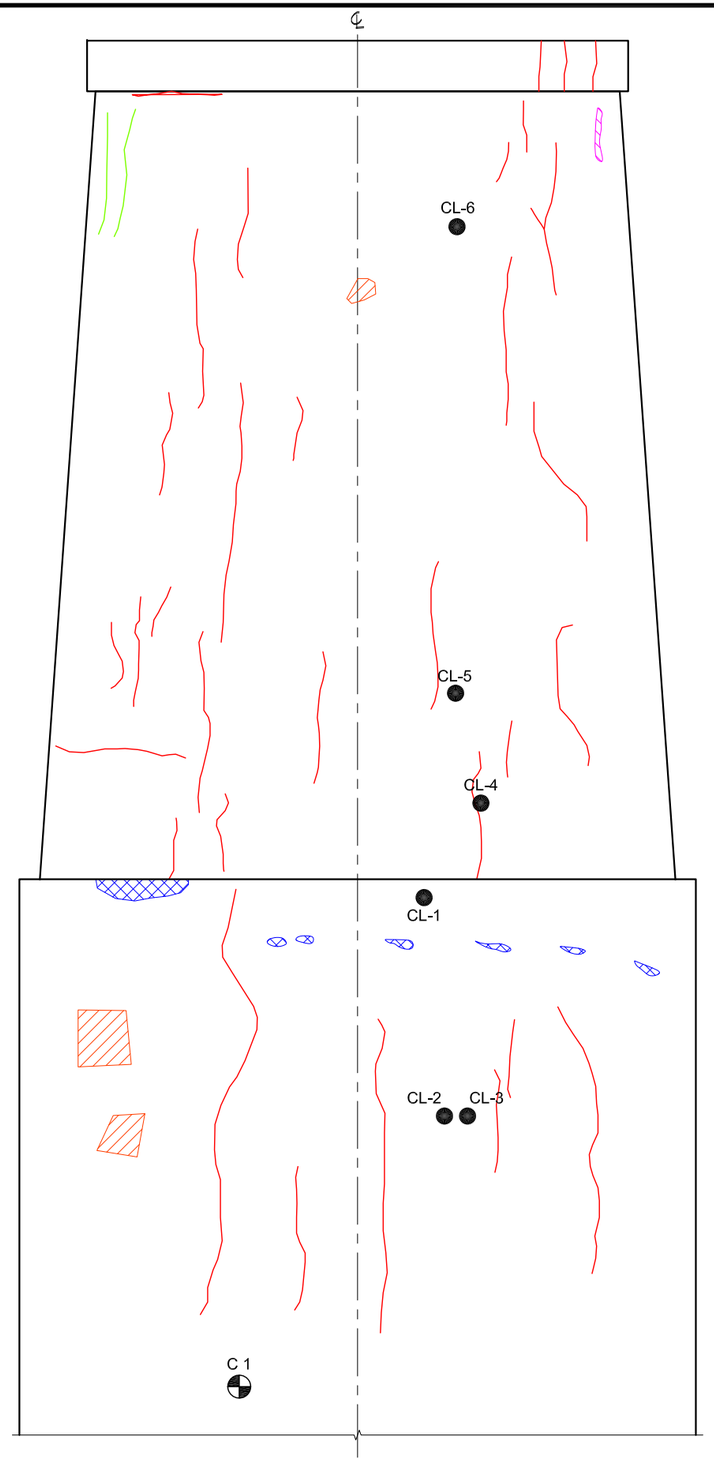
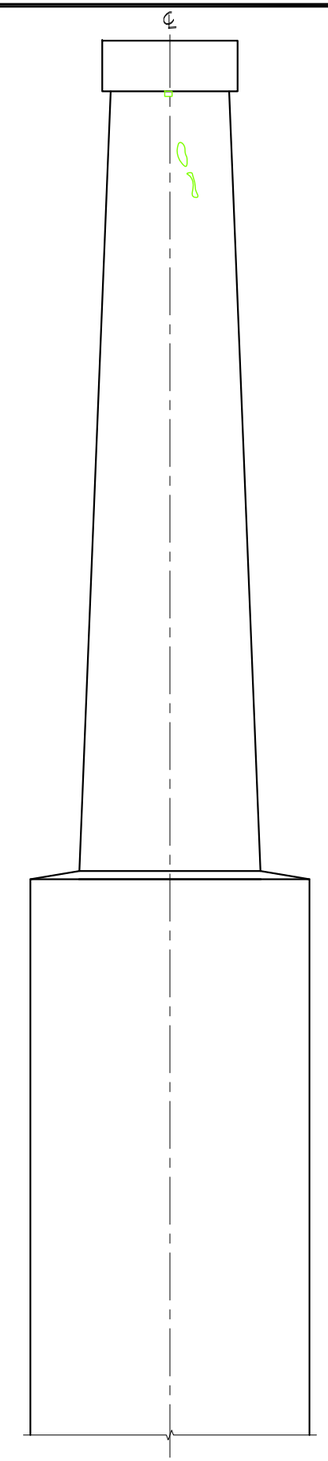


1 PIER 6 SOUTH FACE
NTS



2 PIER 6 EAST FACE
NTS

Pier 6 South Face

sample no	Depth(in.)		
	0.5-1.5	1.5-2.5	2.5-3.5
1	0.004	0.006	0.005
4	0.007	0.006	0.005
5	0.007	0.003	0.013
6	0.004	0.005	0.004

LEGEND:

- CRACK
- DELAMINATION
- SPALL
- EFFLORECENCE
- ASR
- CL-# CHLORIDE SAMPLE LOCATION
- C# CORE LOCATION
- C# CORE LOCATION ON CRACK OR LIFT LINE

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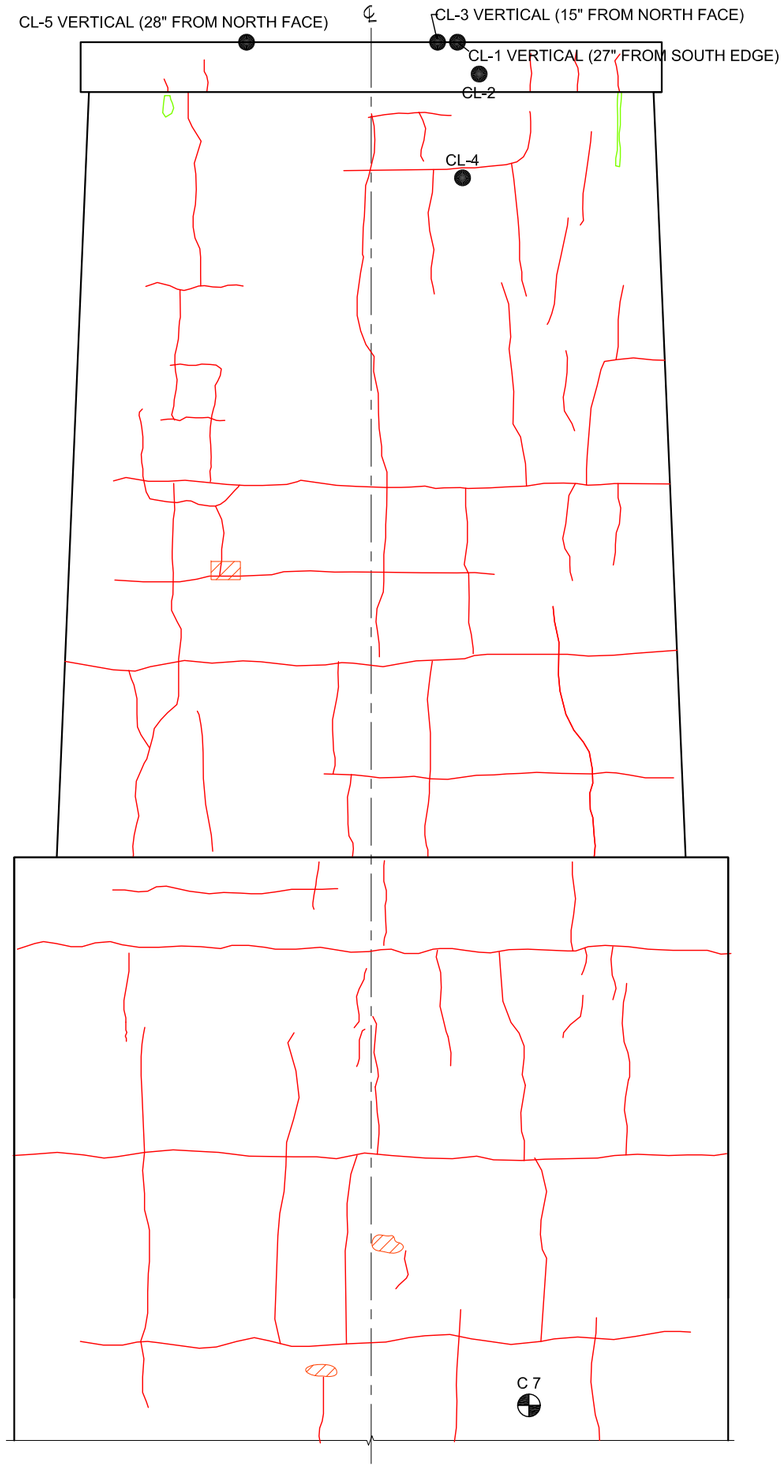
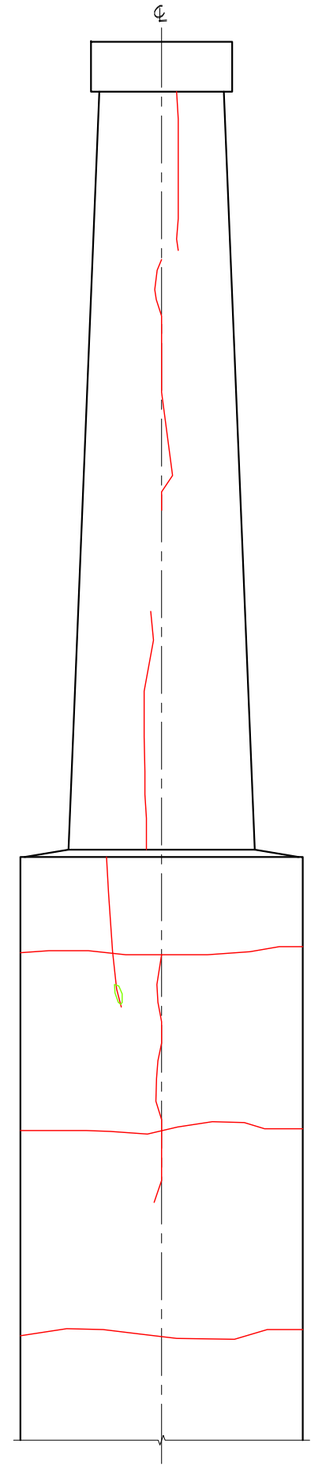


1 PIER 7 NORTH FACE
NTS



2 PIER 7 WEST FACE
NTS

Pier 7 North Face

sample no	Depth(in.)			
	0.5-1.5	1.5-2.5	2.5-3.5	3.5-4.5
1	0.005	0.004	0.011	0.010
2	0.010	0.004	0.006	0.004
4	0.004	0.004	0.005	0.007
5	0.009	0.004	0.004	0.009

LEGEND:

- CRACK
- DELAMINATION
- SPALL
- EFFLORECENCE
- CL-# CHLORIDE SAMPLE LOCATION
- C# CORE LOCATION
- C# CORE LOCATION ON CRACK OR LIFT LINE

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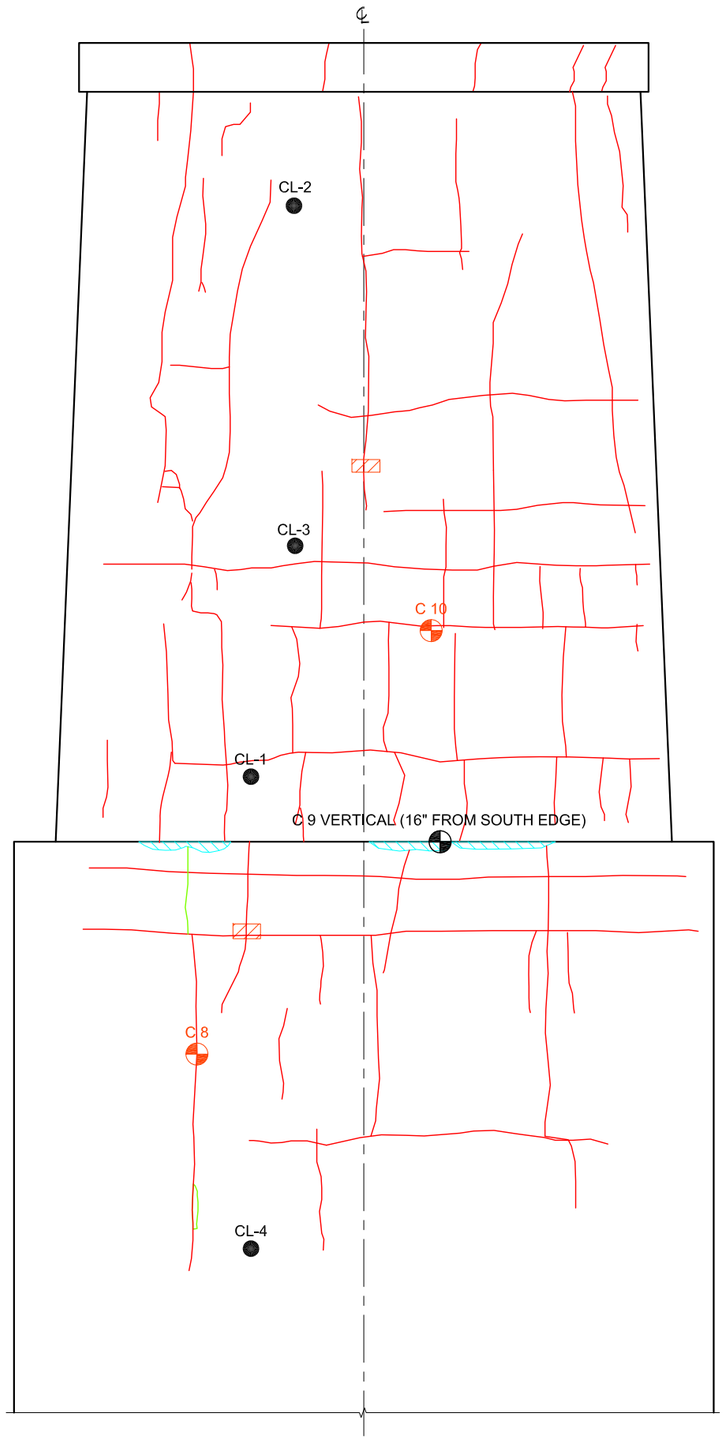
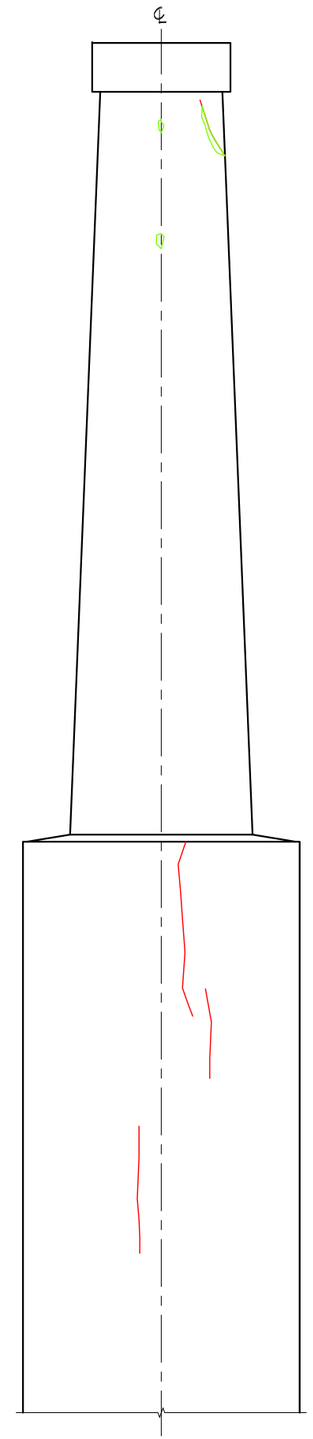


1 PIER 7 SOUTH FACE
NTS



2 PIER 7 EAST FACE
NTS

Pier 7 South Face

sample no	Depth(in.)			
	0.5-1.5	1.5-2.5	2.5-3.5	3.5-4.5
1	0.019	0.004	0.001	0.007
2	0.002	0.002	0.006	0.002
3	0.002	0.002	0.003	0.006
	Depth(in.)			
	0.0-1.0	1.0-2.0	2.0-3.0	3.0-4.0
C-9	0.131	0.081	0.02	0.011

LEGEND:

- CRACK
- DELAMINATION
- SPALL
- EFFLORECENCE
- FREEZE/THAW DAMAGE
- ## CHLORIDE CORE
- C# CORE LOCATION
- C# CORE LOCATION ON CRACK OR LIFT LINE

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Evaluation of Milton Madison Bridge Substructures

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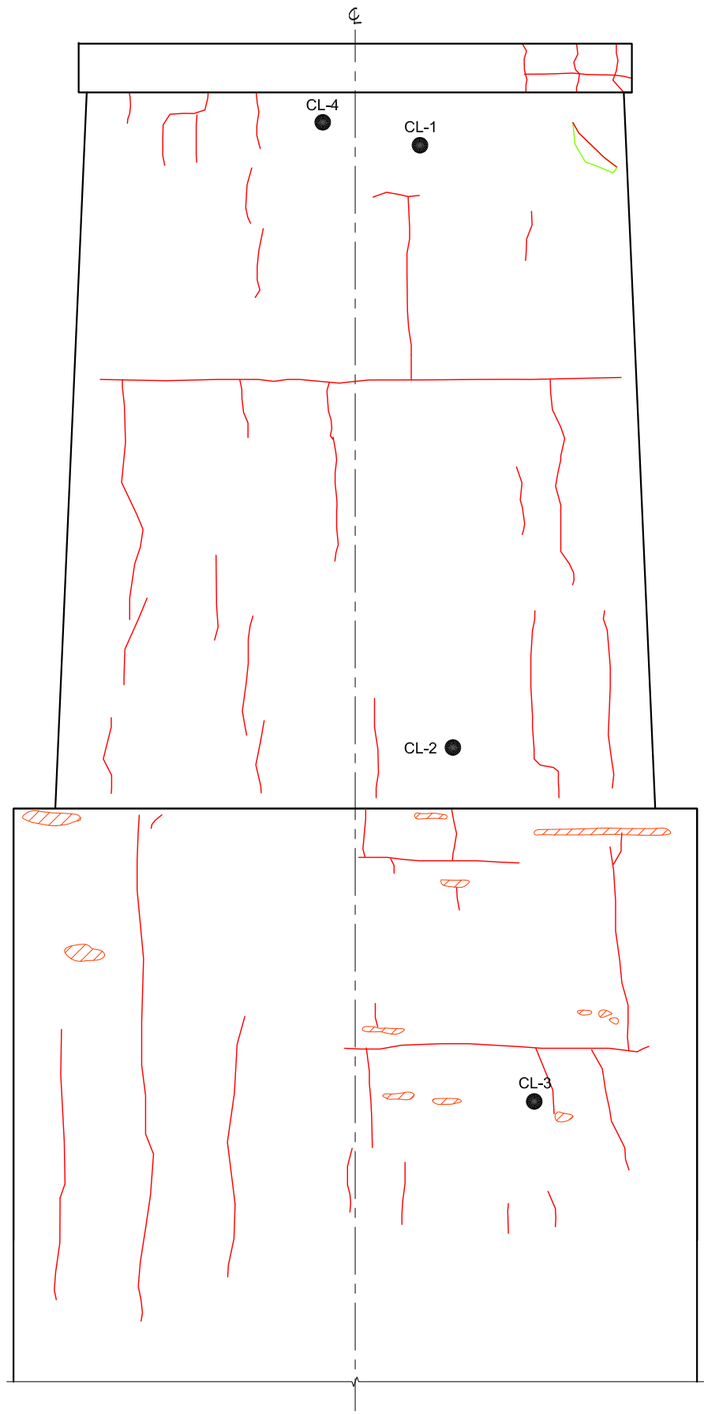
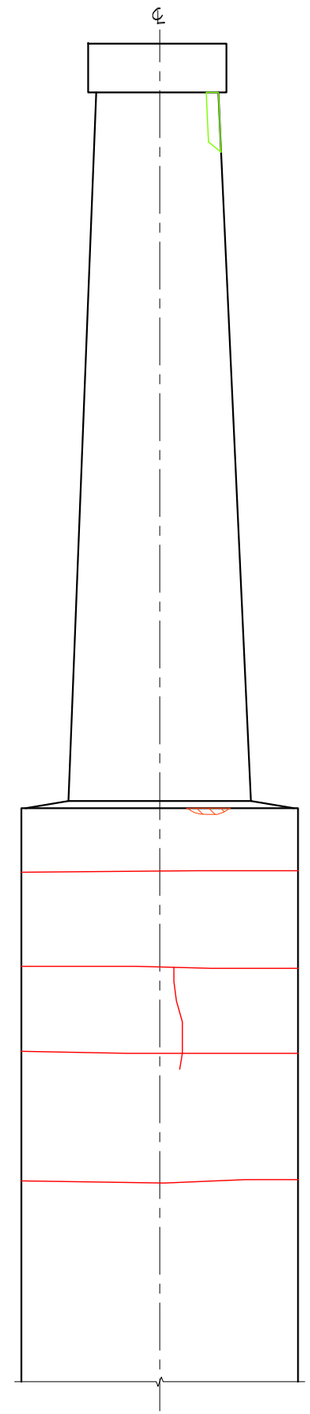


1 PIER 8 NORTH FACE
NTS



2 PIER 8 WEST FACE
NTS

Pier 8 North Face

sample no	Depth(in.)			
	0.5-1.5	1.5-2.5	2.5-3.5	3.5-4.5
1	0.006	0.012	0.010	0.003
2	0.010	0.006	0.003	
3	0.013	0.010	0.003	0.005
4	0.011	0.006	0.005	0.006

LEGEND:

- CRACK
- DELAMINATION
- SPALL
- EFFLORECENCE
- CL-# CHLORIDE SAMPLE LOCATION
- C# CORE LOCATION
- C# CORE LOCATION ON CRACK OR LIFT LINE

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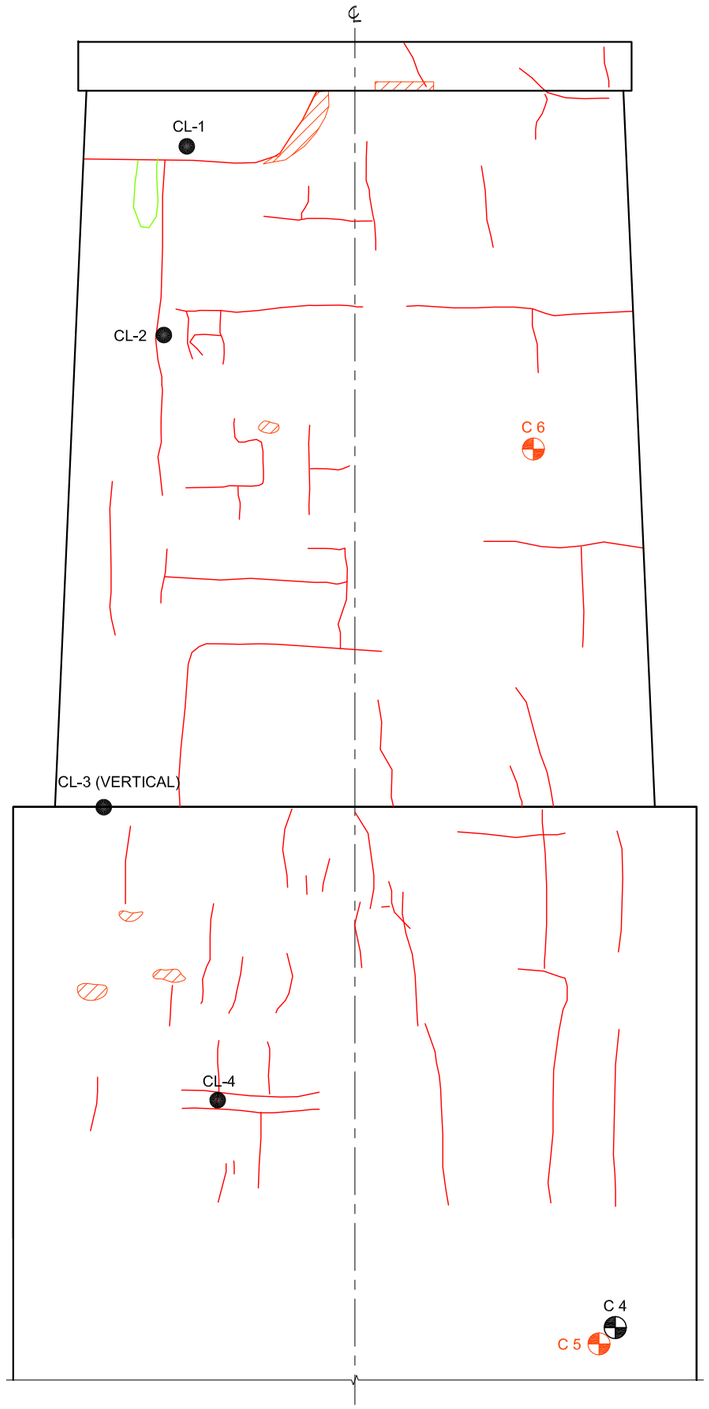
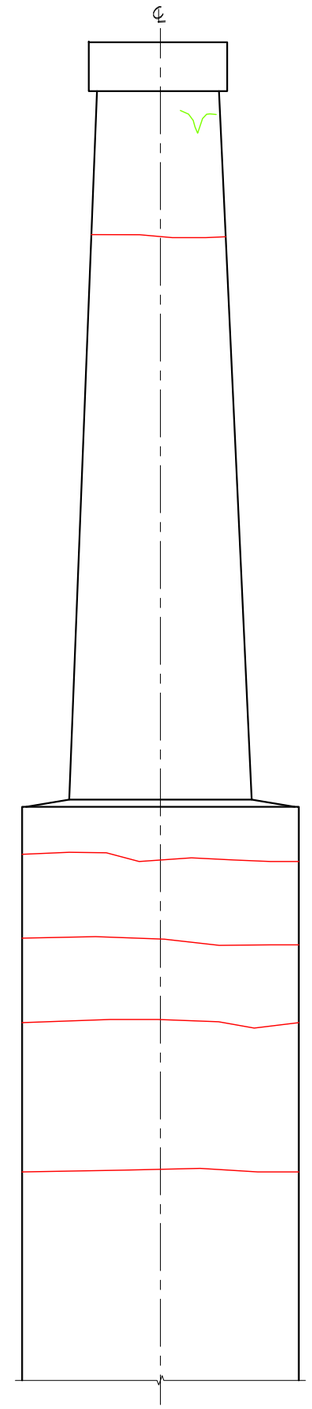
7



1 PIER 8 SOUTH FACE
NTS



2 PIER 8 EAST FACE
NTS

Pier 8 South Face

sample no	Depth(in.)			
	0.5-1.5	1.5-2.5	2.5-3.5	3.5-4.5
1	0.019	0.013	0.012	0.004
2	0.005	0.005	0.006	0.001
3	0.014	0.004	0.001	0.016
4	0.002	0.003	0.010	0.001

LEGEND:
- CRACK
- DELAMINATION
- SPALL
- EFFLORECENCE
- ## CHLORIDE CORE
- C# CORE LOCATION
- C# CORE LOCATION ON CRACK OR LIFT LINE

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Evaluation of Milton Madison Bridge Substructures

Sheet No.:

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APPENDIX C

Non Destructive Testing (NDT)

- **APPENDIX C.1 – NDT Test Methodologies**
- **APPENDIX C.2 – Impulse Response Test Results (Sheets IR-1 through IR-4)**
- **APPENDIX C.3 – Ground Penetrating Radar (Sheets GPR-1 through GPR-8)**
- **APPENDIX C.4 – Half Cell Potentials (Sheets HC-1 through HC-8)**

APPENDIX C.1

NDT Test Methodologies

- **Impulse Response**
- **Ground Penetrating Radar**
- **Half Cell Potential**

IMPULSE RESPONSE (IR) TEST METHOD

The nondestructive Impulse Response (IR) method was used to evaluate bridge concrete piers. This technique is fully described in the American Concrete Institute Report, ACI 228.2R-98 *"Nondestructive Test Methods for Evaluation of Concrete in Structures"*.

Prior to the test, a grid system of 2 ft x 2 ft in both longitudinal and transverse directions was mapped out on the vertical surface of the piers. The IR test was performed at the intersections of the gridlines.

The IR test produces two principal parameters: Average Mobility and Dynamic Stiffness. The average mobility is defined as the structural surface velocity responding to the impact divided by the force input [(m/s)/N]. The mean mobility value over the 0.1-1 kHz range is directly related to the modules, density and the effective thickness of a plate element, for example. In general, any presence of internally delaminated layer, weakened layer, cracking or unconsolidated concrete will result in an increased average mobility value. On the contrary, a sound concrete element without distress will reduce the average mobility value. The Dynamic Stiffness is a function of concrete quality, thickness and more important, the support condition. In general, a weaker support condition will reduce the dynamic stiffness value of the element, assuming other influence factors remain the same.

Values of the two parameters from the test can be analyzed and presented in the form of contour plots. The relatively weaker areas can be identified through a scaled color scheme.

GROUND PENETRATING RADAR TEST

The Impulse Radar (Ground Penetrating Radar or GPR) technique employs high-frequency electromagnetic energy waves for rapidly and continuously assessing a variety of characteristics of concrete structures. The principle of operation is based on reflection of electromagnetic waves from varying dielectric constant boundaries in the material being probed.

A contacting transducer (antenna) transmits and receives radar signals. High frequency, short pulse electromagnetic energy is transmitted into the element under test (concrete, sub-base). Each transmitted pulse travels through the material, and is partially reflected when it encounters a change in dielectric constant. The receiving section of the transducer detects reflected pulses. The location and depth of the dielectric constant boundary is evaluated by using recorded transit time from start of pulse to reception of reflected pulse and the velocity of wave propagation. Boundary depth is proportional to transit time. Since concrete to air, water, and/or backfill interfaces are electronically detected by the instrument as dielectric constant boundaries, the Impulse Radar method is capable of assessing a variety of reinforced concrete, masonry and environmental characteristics. The Impulse Radar equipment is self-contained, compact, and portable. The system consists of the main radar unit, antenna and transducer cable. All data is stored in the main radar unit, by means of a computer hard drive (ACI 228, 1998).

Impulse Radar has been successfully used in a variety of civil and structural engineering applications, including evaluation of embedded reinforcement locations, evaluation of grouted and ungrouted cells in masonry block walls, locating embedded foreign objects (clay balls) in concrete pavements, evaluation of dowel bars alignment and the consolidation of concrete, etc.

Half-Cell Potential Measurements

This method is described in ASTM C876 “Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete”. This test allows the plotting of an equipotential contour map of the concrete element under test. The value of the potential measured is used to estimate the likelihood of corrosion, as follows:

- If potentials over an area are more positive than -0.20 V, there is a greater than 90% probability that no steel reinforcement corrosion is occurring,
- If potentials over an area are in the range -0.20 to -0.35 V, corrosion activity of the reinforcing steel in that area is uncertain,
- If potentials in any area are more negative than -0.35 V, then there is a greater than 90% probability that reinforcing steel corrosion is occurring in that area.

The equipment usually consists of a saturated copper/copper sulfate (CSE) electrode, a electrical junction device, a voltmeter and lead wires. Electrical connection is made to the reinforcement in the concrete using a clamping pliers. The electric potentials are measured between the CSE at the concrete surface and the embedded steel. The surface of the concrete is maintained in a moist condition during testing. The surface of the concrete is divided into a grid system, enabling the plotting of results as a contour map.

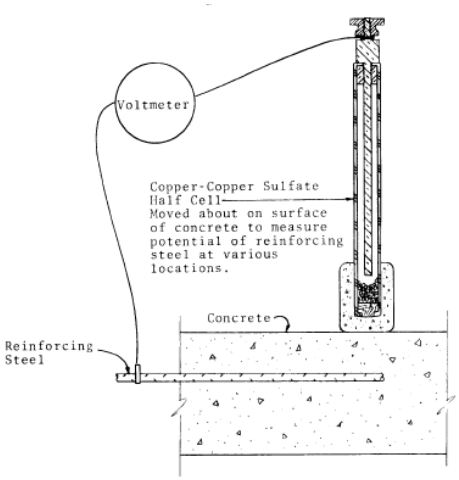
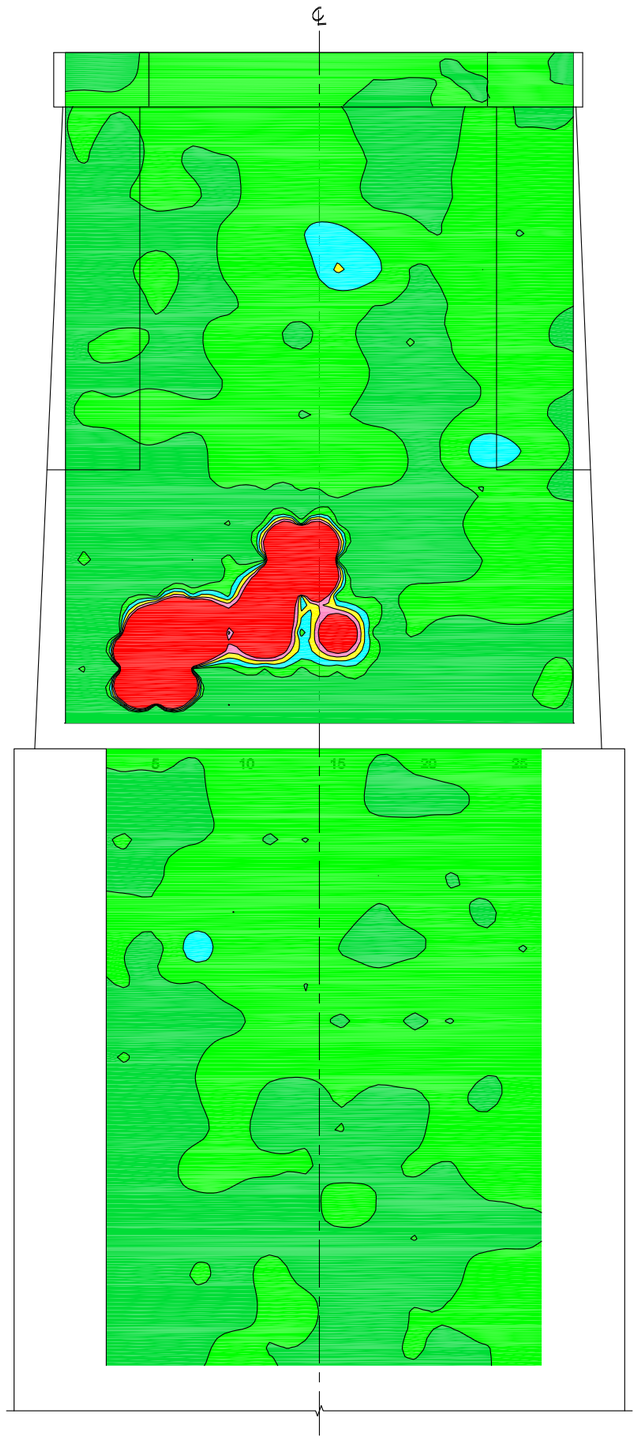


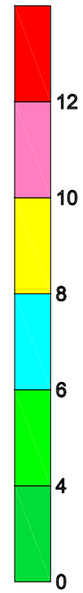
FIG. 1 Copper-Copper Sulfate Half Cell Circuitry

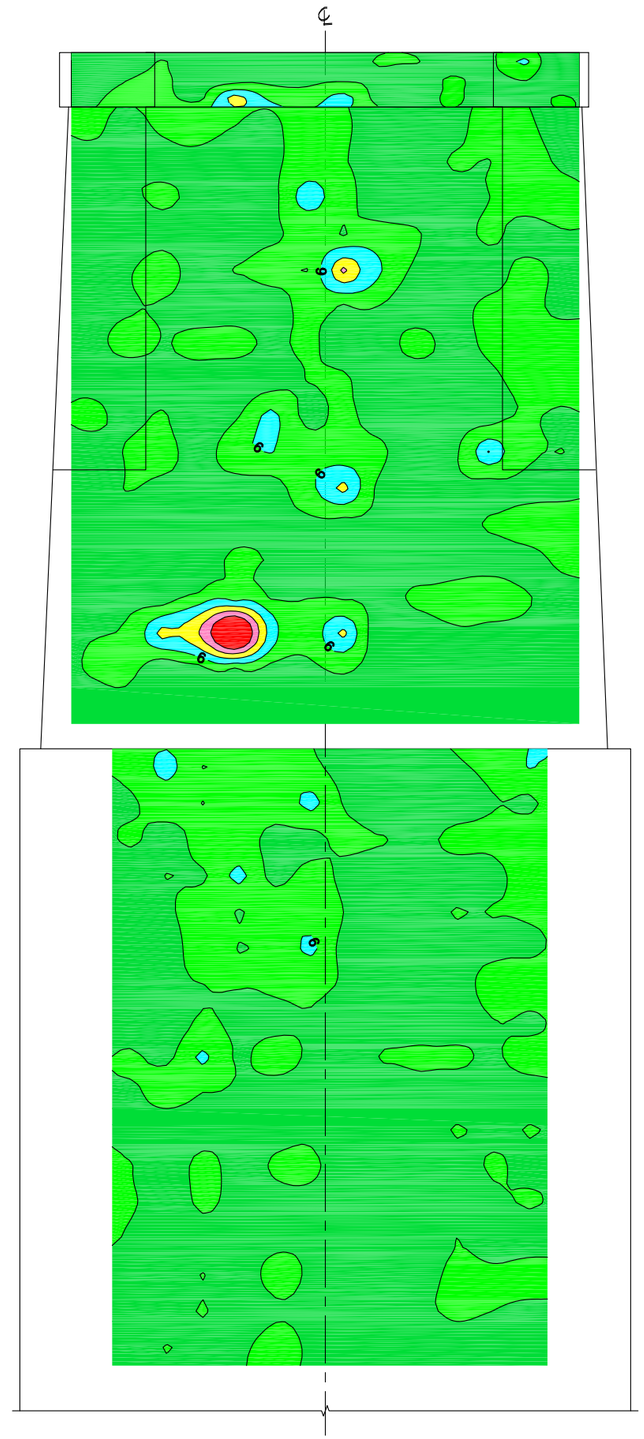
APPENDIX C.2

Impulse Response Test Results

- **Sheets IR-1 through IR-4**







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2 PIER 5 NORTH FACE MOBILITY SLOPE
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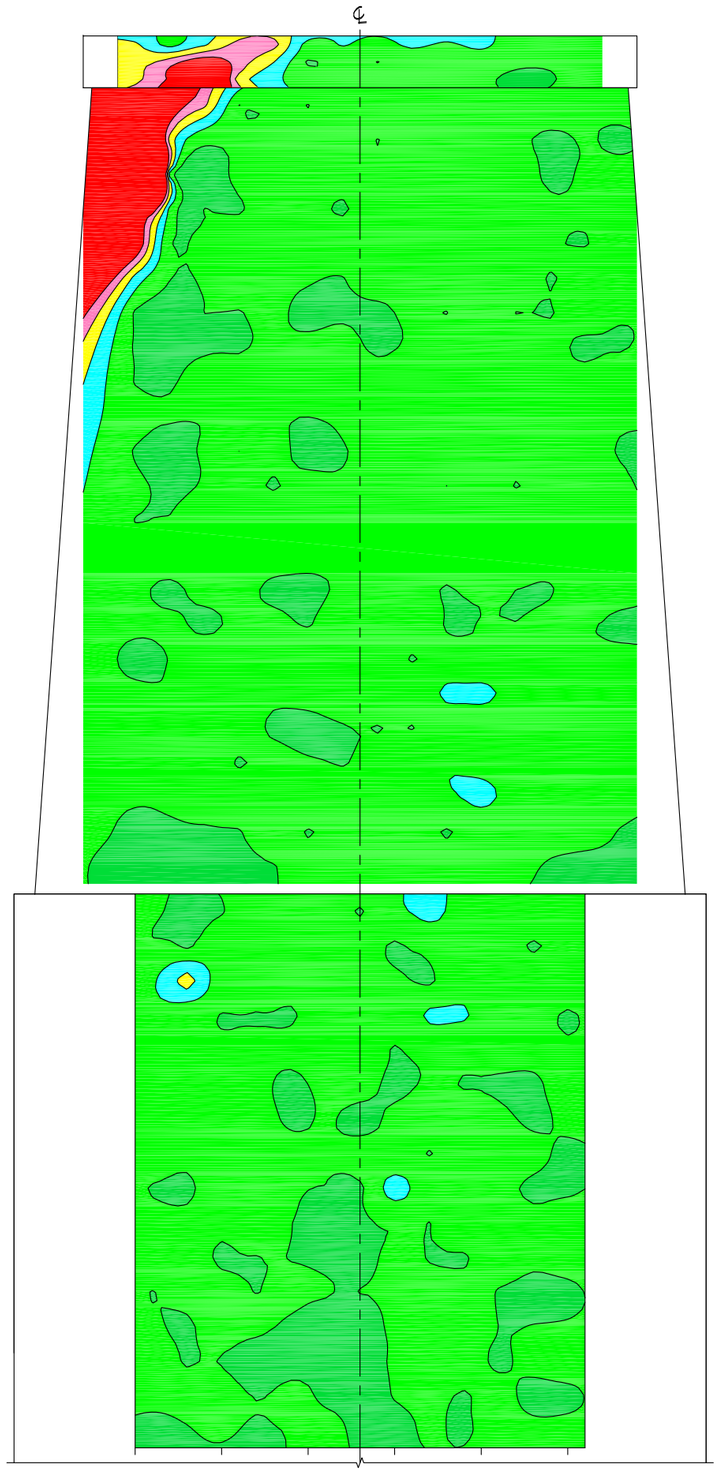
IR-1



1 **PIER 6 SOUTH FACE MOBILITY**
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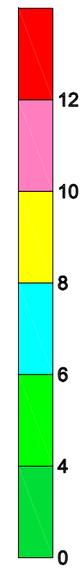

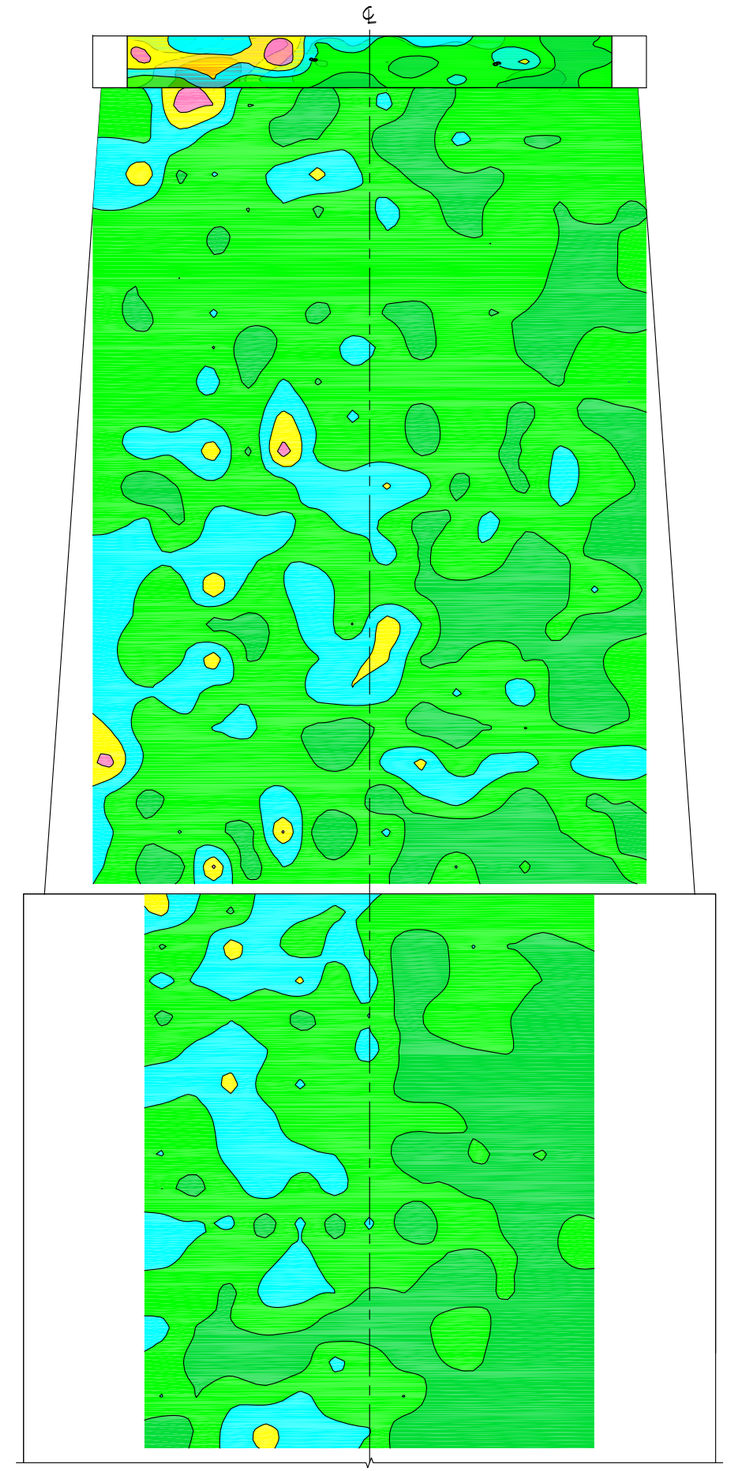

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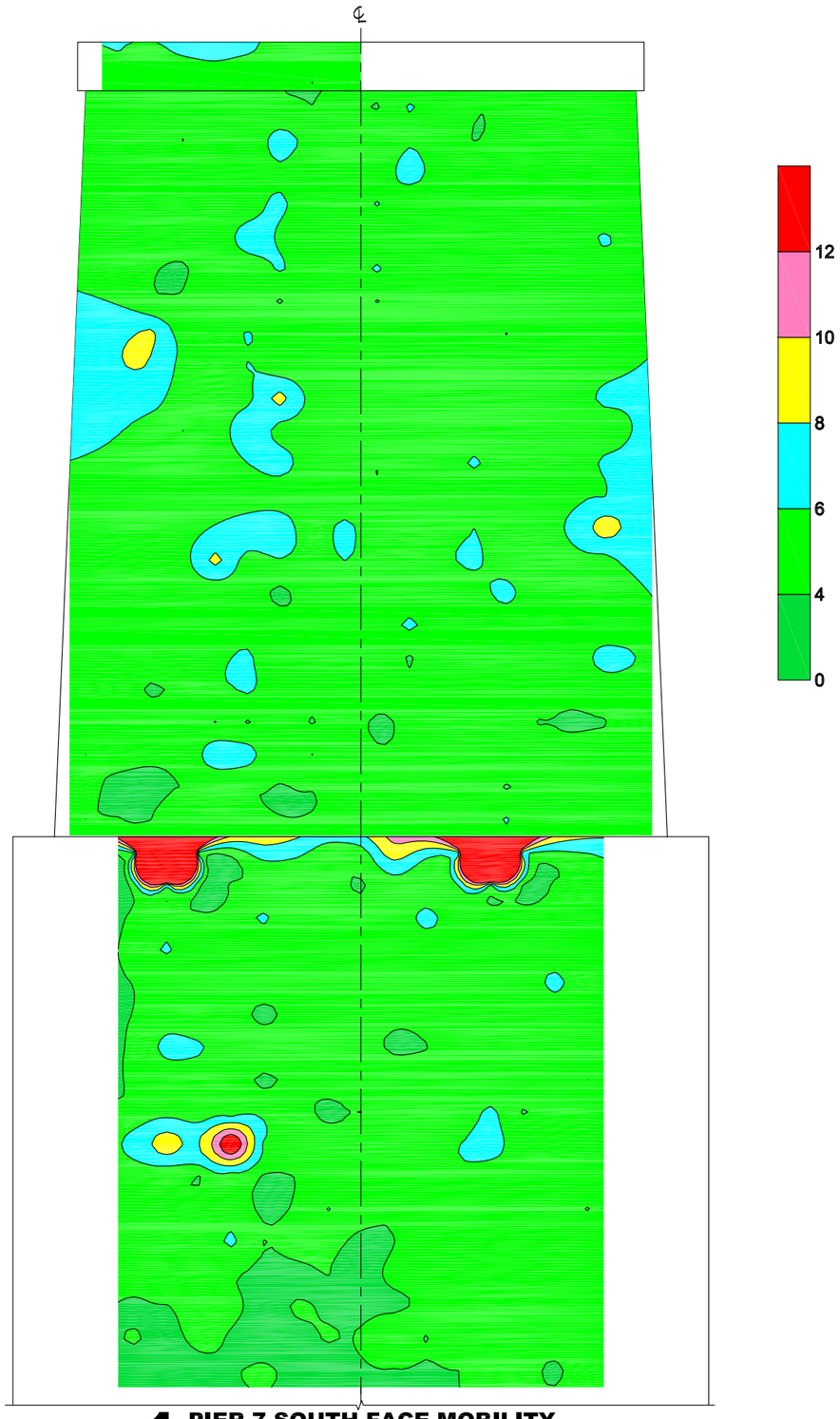
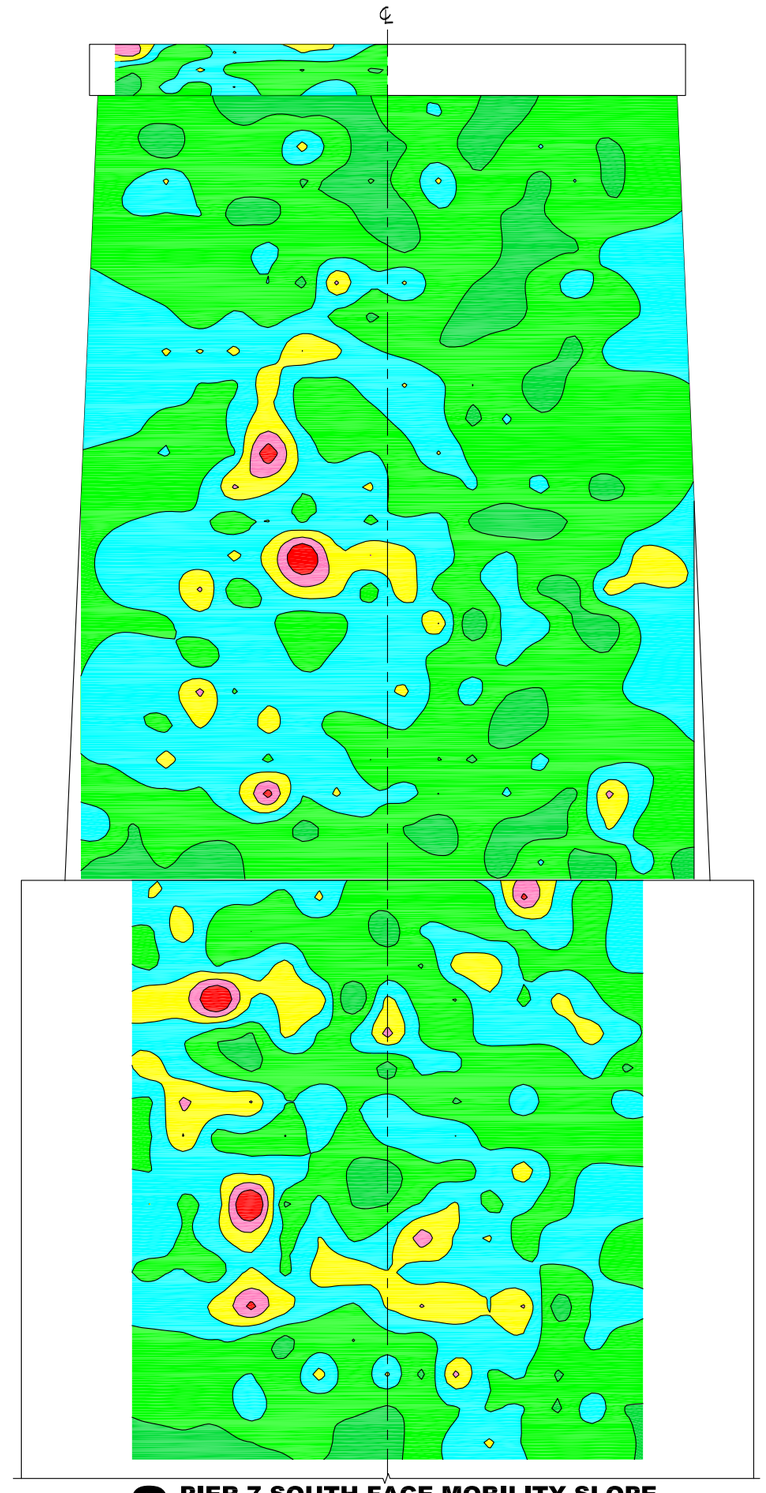
Sheet No.:

IR-2



1 PIER 7 SOUTH FACE MOBILITY
NTS



2 PIER 7 SOUTH FACE MOBILITY SLOPE
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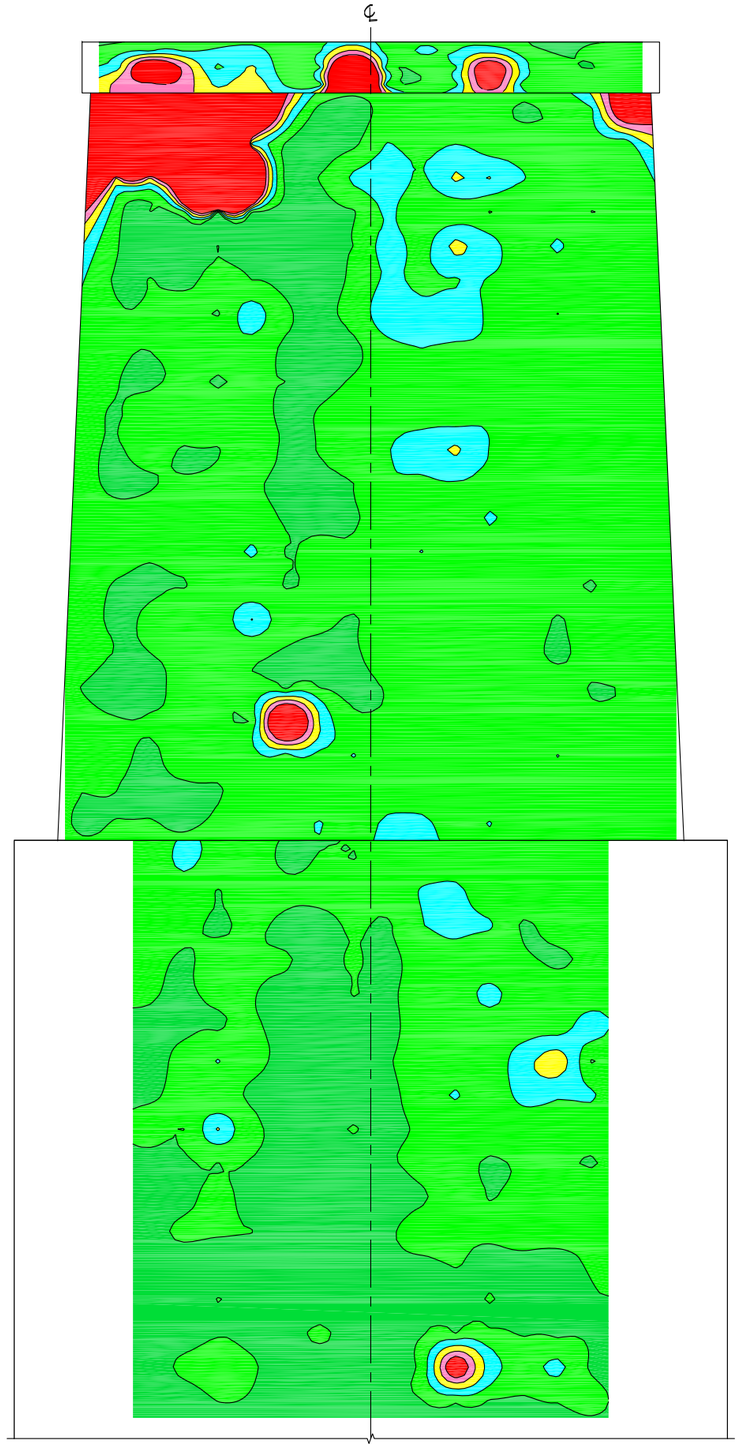
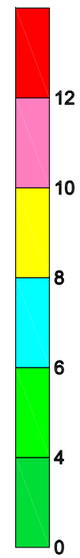
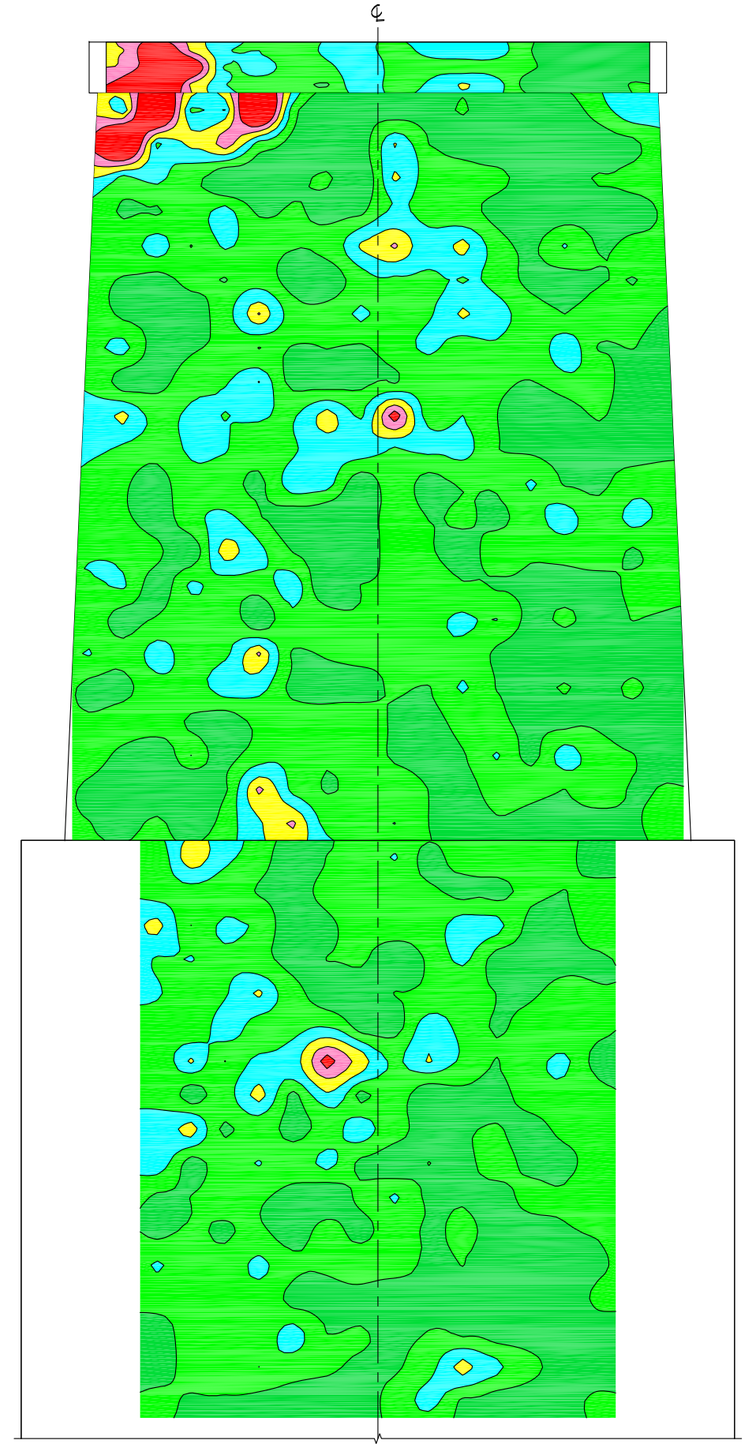
Sheet No.:

IR-3







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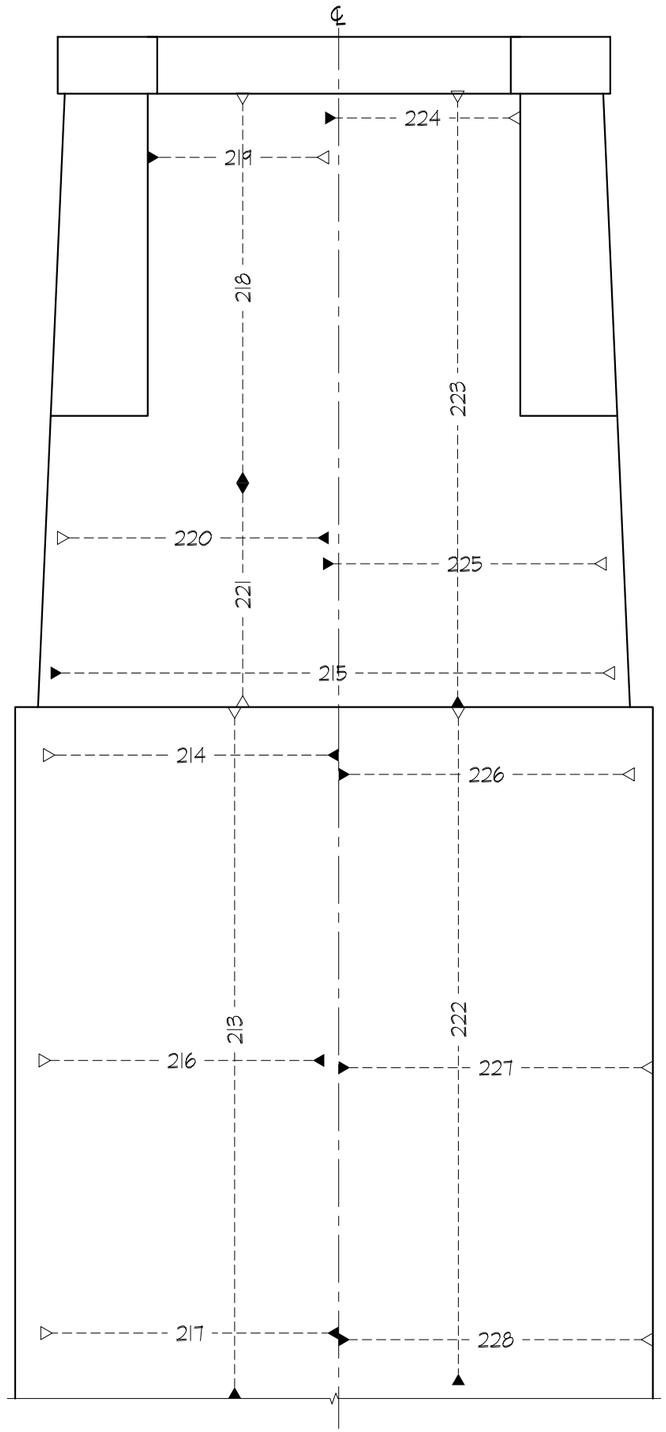
IR-4

APPENDIX C.3

Ground Penetrating Radar.

- **Sheets GPR-1 through GPR-8**



1 PIER 5 NORTH FACE
NTS

Top Portion of Pier 5- North Face

Scan No.	Rebar Orientation	Cover (in.)		
		max	min	Average
215	Verical	3.5	2.0	2.6
219		4.1	3.2	3.5
220		3.3	2.1	2.5
224		3.9	3.1	3.4
225		4.1	2.1	2.8
218	Horizontal	3.8	2.6	3.2
221		3.8	1.6	2.5
223		3.9	2.5	3.0

Bottom Portion of Pier 5- North Face

Scan No.	Rebar Orientation	Cover (in.)		
		max	min	Average
214	Vertical	4.8	3.6	4.2
216		4.1	3.4	3.8
217		3.8	3.1	3.5
226		4.3	3.1	3.8
227		4.7	3.7	4.2
228		4.2	2.4	3.6
213	Horizontal	4.0	2.7	3.1
222		3.7	2.0	2.9

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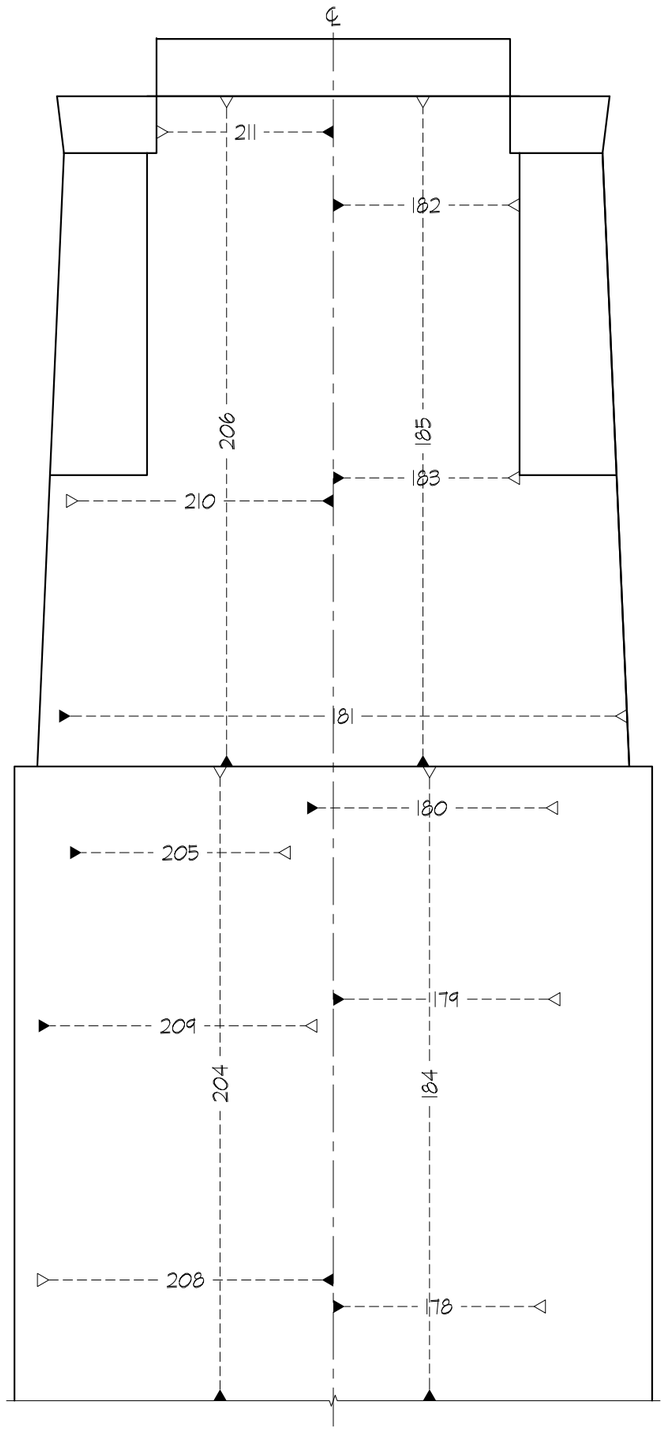
Sheet No.:

GPR-1



1 PIER 5 SOUTH FACE
NTS

Top Portion of Pier 5-South Face

Scan No.	Rebar Orientation	Cover (in.)		
		max	min	Average
181	Vertical	3.9	2.4	3.1
183		5.7	2.3	4.2
182		4.4	3.9	4.2
210		4.4	1.8	3.3
211		2.7	2.3	2.5
185	Horizonal	4.8	2.2	3.8
206		5.0	2.6	3.7

Bottom Portion of Pier 5-South Face

Scan No.	Rebar Orientation	Cover (in.)		
		max	min	Average
209	Vertical	4.3	3.8	4.0
208		4.1	3.0	3.6
205		4.7	3.6	4.1
178		3.8	2.8	3.4
179		4.1	3.6	3.8
180		6.0	3.4	4.4
184	Horizontal	3.5	2.4	3.1
204		3.6	2.5	3.1

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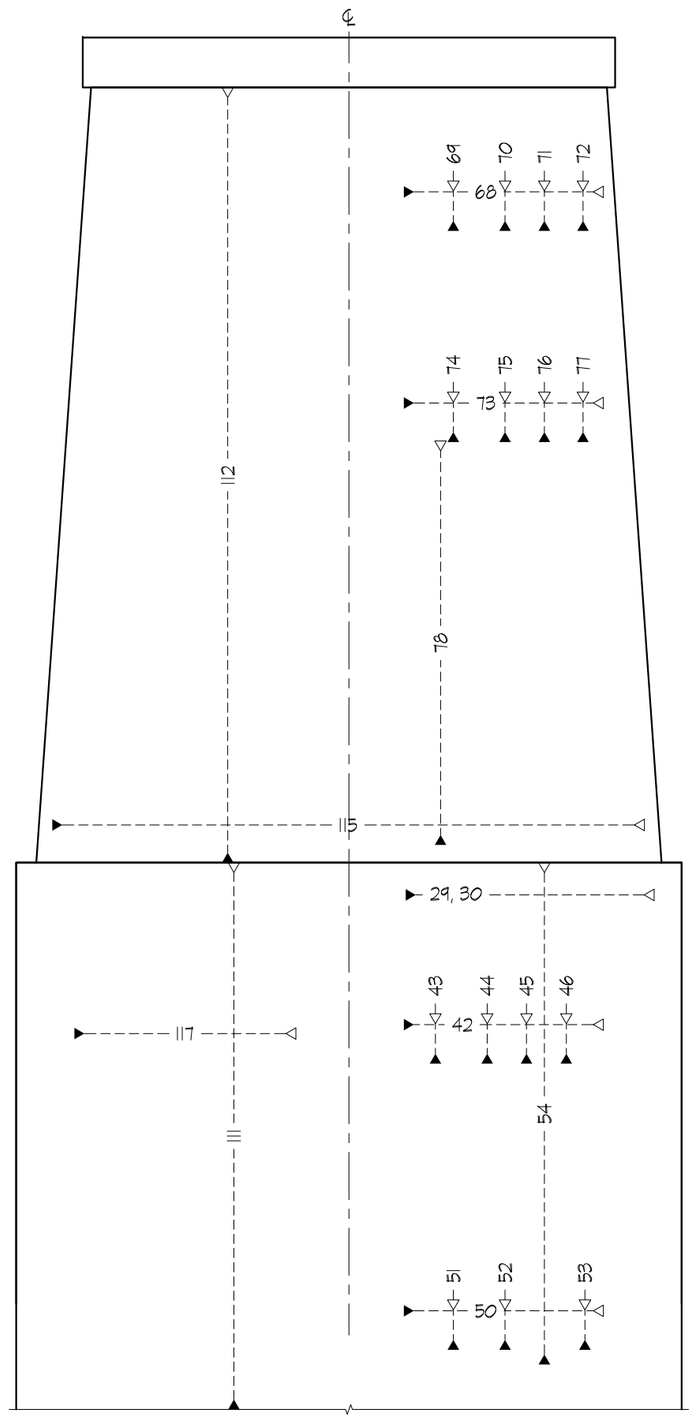
Sheet No.:

GPR-2



1 **PIER 6 NORTH FACE**
NTS

Top Portion of Pier 6 - North Face

Scan No.	Rebar Orientation	Cover (in.)		
		max	min	Average
73	Vertical	3.6	2.7	3.2
115		3.9	3.0	3.5
68		4.6	4.0	4.3
74, 75, 76, 77	Horizontal	2.9	2.5	2.7
69-72		3.6	3.2	3.5
78		3.1	2.5	2.8
112		3.7	2.5	3.1

Bottom Prtion of Pier 6 - North Face

Scan No.	Rebar Orientation	Cover (in.)		
		max	min	Average
29	Vertical	3.4	3.1	3.3
42		4.6	4.0	4.3
50		5.0	3.8	4.4
117		5.1	4.6	4.8
51,52,53	Horizontal	4.1	3.4	3.7
43,44,45,46		3.8	2.7	3.3
54		3.5	2.5	3.1

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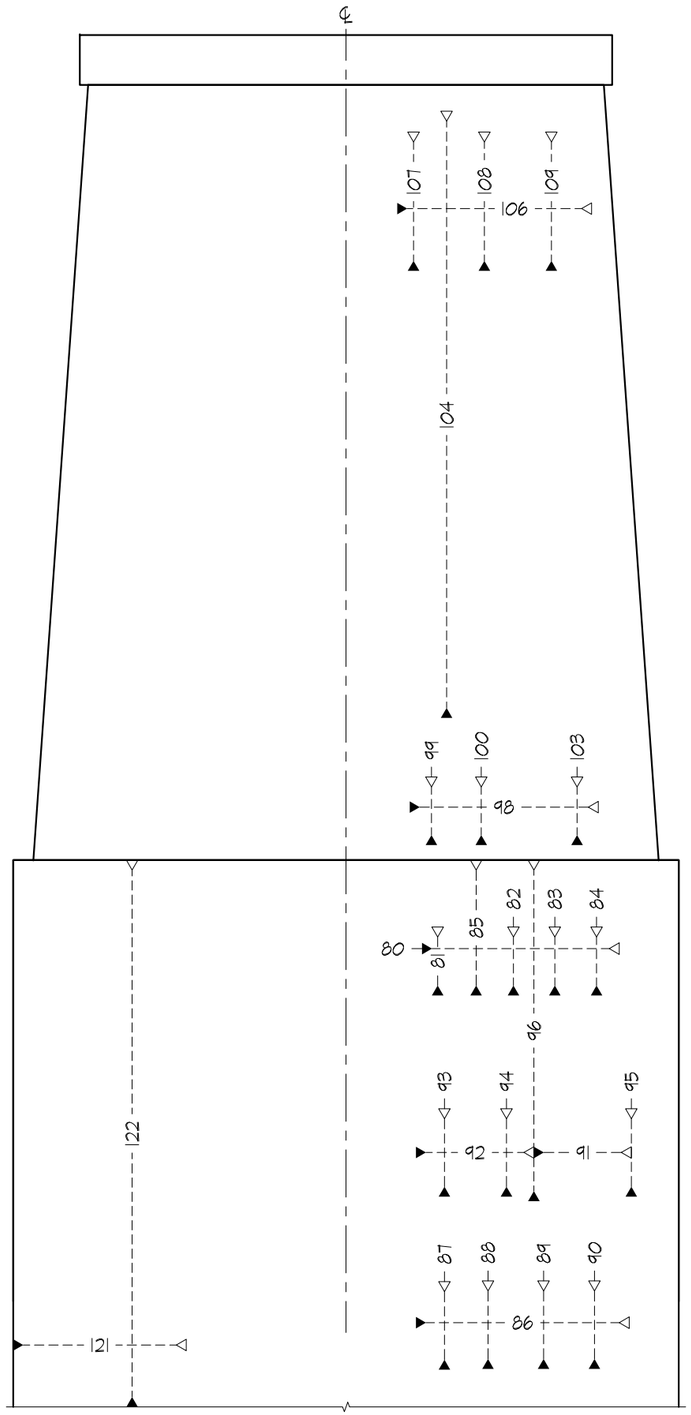
Sheet No.:

GPR-3



1 **PIER 6 SOUTH FACE**
NTS

Top Portion of Pier 6-South Face

Scan No.	Rebar Orientation	Cover (in.)		
		max	min	Average
98	Vertical	4.4	3.5	3.9
106		4.0	3.4	3.6
99,100,103	Horizontal	5.7	2.7	4.0
107,108,109		3.5	2.7	2.9
104		3.5	2.6	3.0

Bottom Portion of Pier 6-South Face

Scan No.	Rebar Orientation	Cover (in.)		
		max	min	Average
80	Vertical	3.8	3.2	3.6
91, 92		3.4	2.5	2.9
86		5.1	3.9	4.2
121		4.8	3.7	4.3
81,82,83,84	Horizontal	3.3	3.1	3.2
93, 94, 95		3.1	2.4	2.8
87, 88, 89, 90		3.7	2.8	3.3
122		3.6	2.7	3.1
96		3.0	2.6	2.8
85		3.0	2.9	3.0

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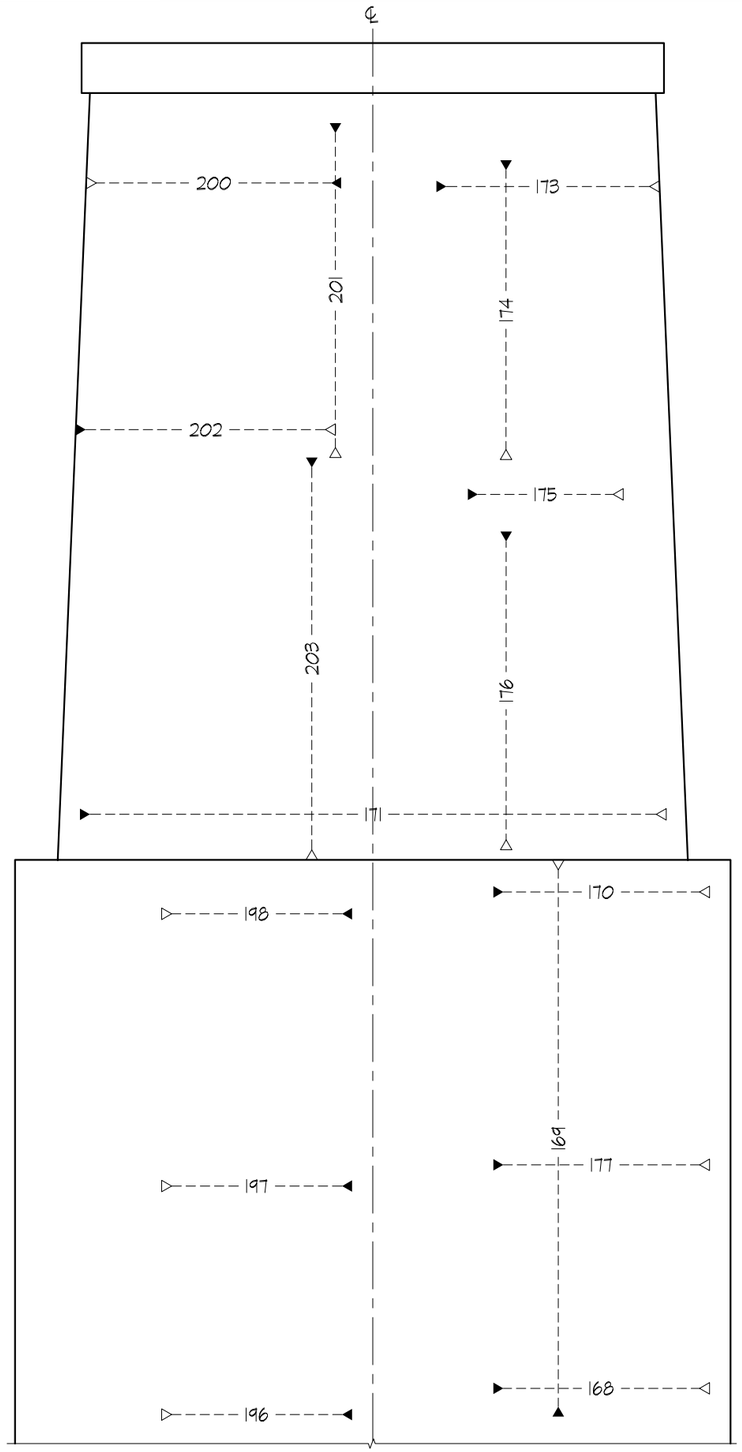
Sheet No.:

GPR-4



1 PIER 7 NORTH FACE
NTS

Top Portion of Pier 7- North Face

Scan No.	Rebar Orientation	Cover (in.)		
		max	min	Average
171	Vertical	5.8	4.0	4.8
173		6.1	3.3	4.5
175		4.0	2.9	3.3
200		5.3	4.1	4.5
202		4.1	3.6	3.8
174	Horizontal	4.4	3.8	4.0
176		4.4	2.7	3.8
201		4.0	2.5	3.5
203		3.8	2.5	3.0

Bottom Portion of Pier 7- North Face

Scan No.	Rebar Orientation	Cover (in.)		
		max	min	Average
168	Vertical	4.3	3.4	3.8
170		4.4	1.8	3.5
177		4.0	3.2	3.5
196		4.4	3.6	3.9
197		4.9	3.3	3.9
198		4.8	3.6	4.0
169	Horizontal	3.8	2.4	3.1

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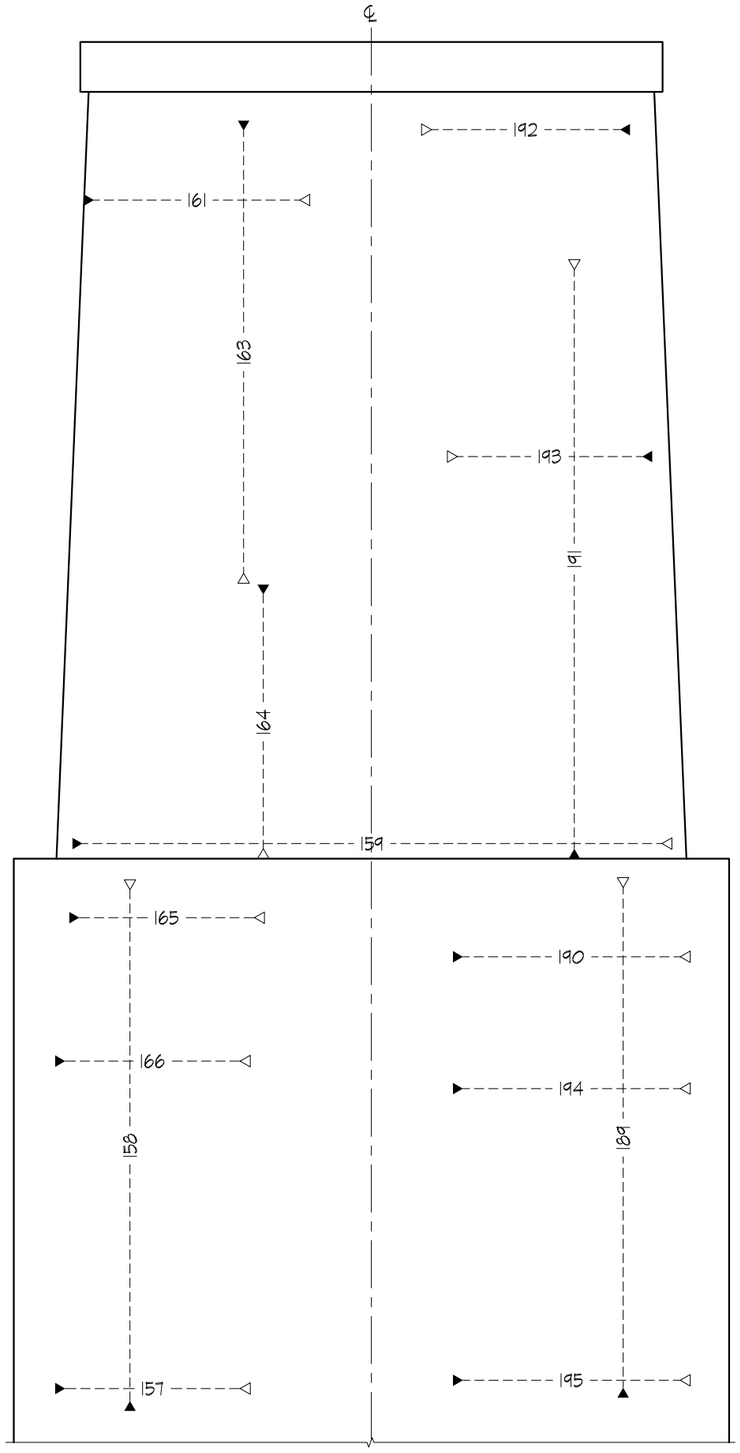
GPR-5



1 **PIER 7 SOUTH FACE**
NTS

Top Portion of Pier 7- South Face

Scan No.	Rebar Orientation	Cover (in.)		
		max	min	Average
159	Vertical	4.4	2.4	3.4
161		5.0	4.4	4.7
192		5.4	4.0	4.6
193		4.6	2.7	3.4
163	Horizontal	3.7	3.2	3.3
164		3.7	2.4	3.2
191		4.3	2.6	3.6

Bottom Portion of Pier 7- South Face

Scan No.	Rebar Orientation	Cover (in.)		
		max	min	Average
157	Vertical	4.6	3.8	4.1
165		5.5	3.7	4.3
166		4.9	3.8	4.2
190		4.4	3.7	3.9
194		4.7	2.7	3.4
195		4.8	3.8	4.1
158	Horizontal	4.1	3.4	3.8
189		3.9	3.0	3.3

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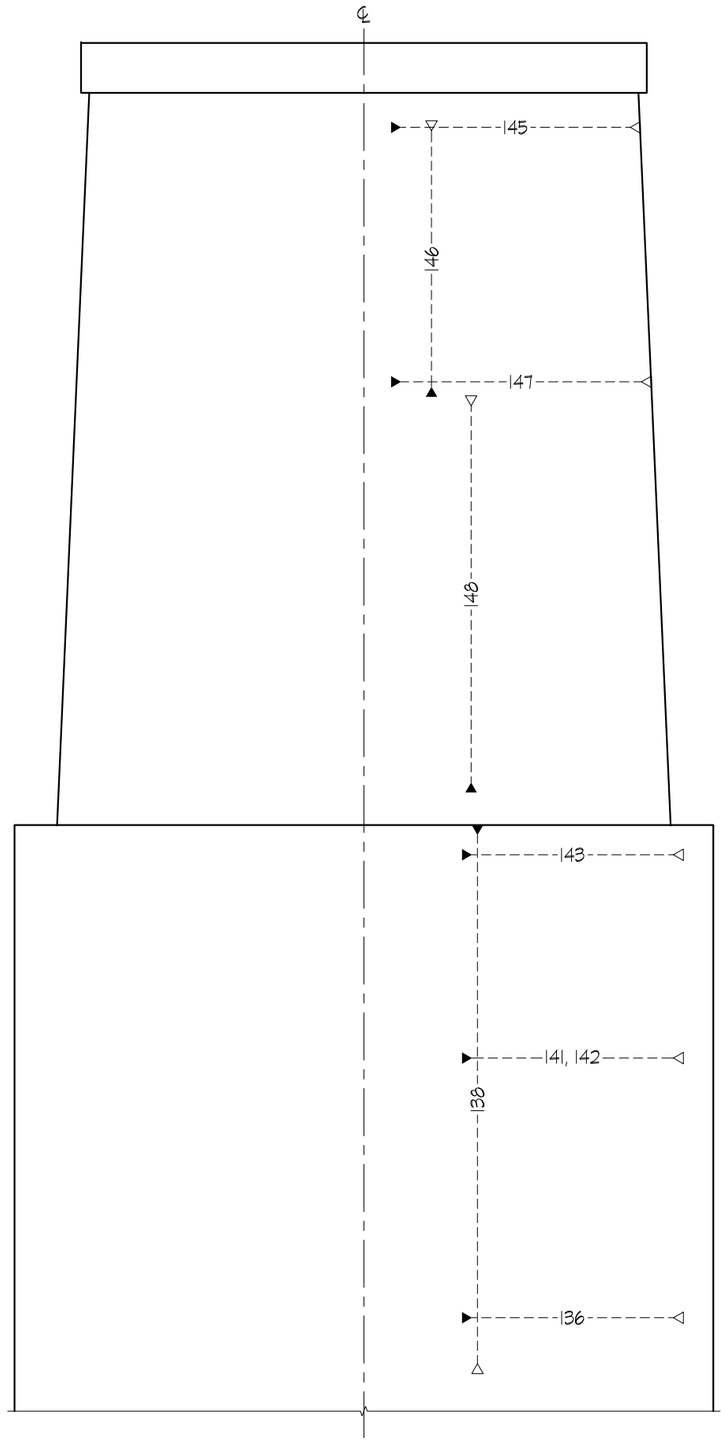
GPR-6



1 **PIER 8 NORTH FACE**
NTS

Top Portion of Pier 8 - North face

Scan No.	Rebar Orientation	Cover (in.)		
		max	min	Average
147	Vertical	5.1	3.1	3.9
145		5.0	4.0	4.6
146	Horizontal	3.4	2.8	3.0
148		3.6	2.2	2.9

Bottom Portion of Pier 8 - North face

Scan No.	Rebar Orientation	Cover (in.)		
		max	min	Average
136	Vertcal	4.3	3.2	3.8
141		4.8	4.0	4.3
143		4.2	3.1	3.8
138	Horizontal	3.4	2.7	3.1

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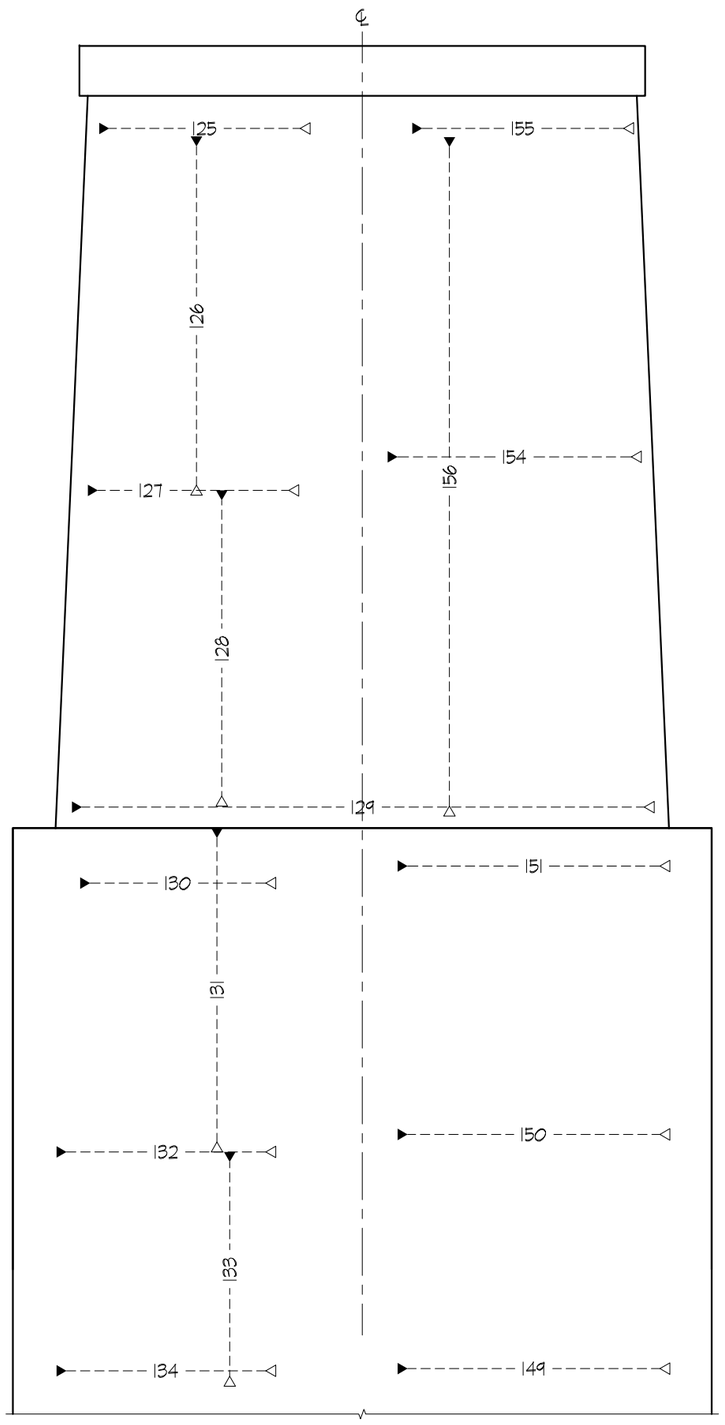
GPR-7



1 PIER 8 SOUTH FACE
NTS

Top Portion of Pier 8 - South Face

Scan No.	Rebar Orientation	Cover (in.)		
		max	min	Average
125	Vertical	5.3	4.6	5.0
127		5.5	3.6	4.4
129		5.5	2.8	3.9
155		5.3	4.3	4.7
154		4.6	3.6	4.0
126	Horizontal	4.6	3.6	3.9
128		3.4	2.6	2.9
156		3.8	2.7	3.2

Bottom Portion of Pier 8 - South Face

Scan No.	Rebar Orientation	Cover (in.)		
		max	min	Average
130	Vertical	5.8	3.9	5.1
132		6.3	3.2	4.4
134		4.1	3.3	3.8
151		5.8	3.3	5.2
150		4.4	3.5	4.0
149		4.6	3.5	4.0
131	Horizontal	5.1	3.5	4.0
133		3.7	2.9	3.3

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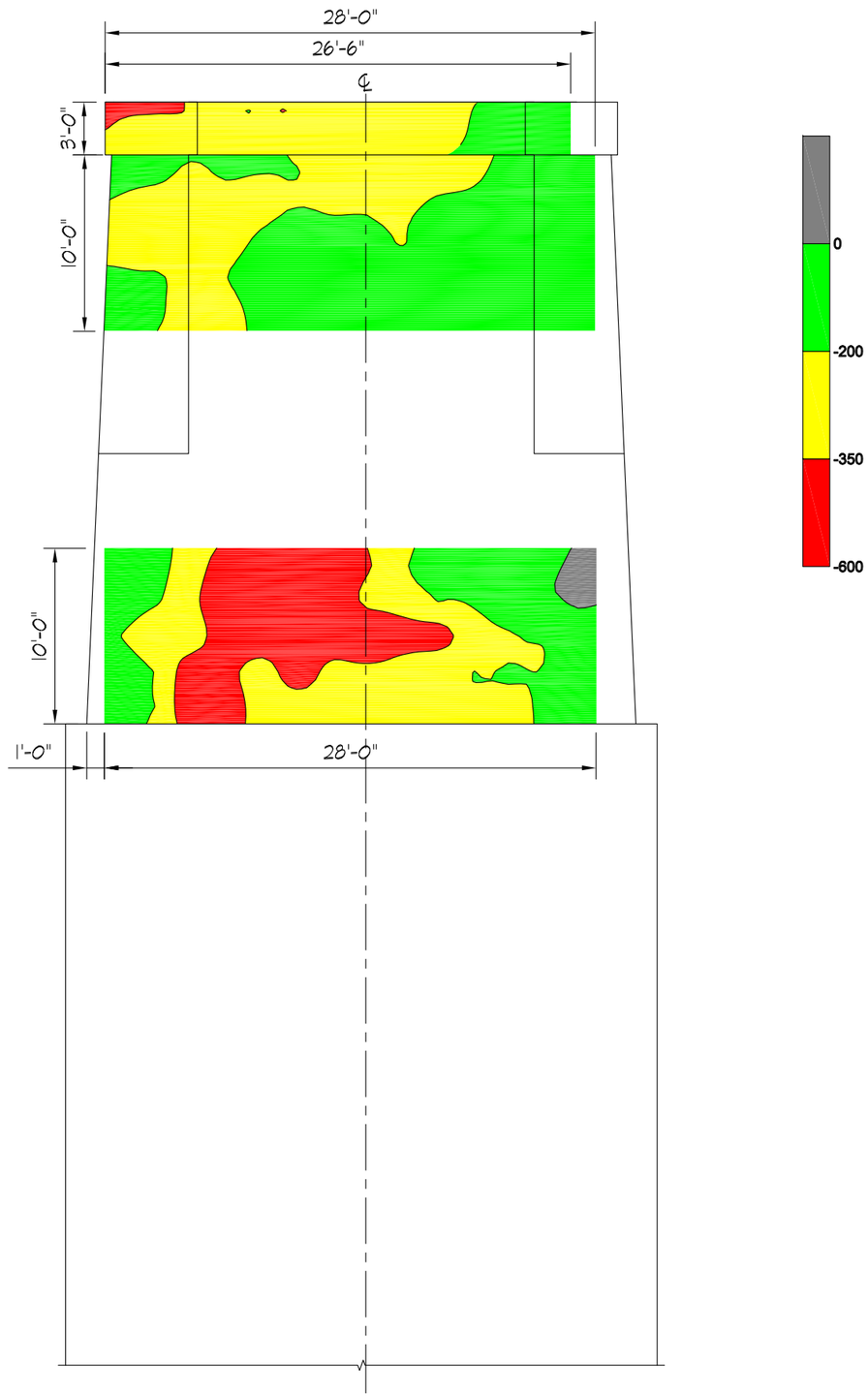
GPR-8

APPENDIX C.4

Half Cell Potentials

- **Sheets HC-1 through HC-8**



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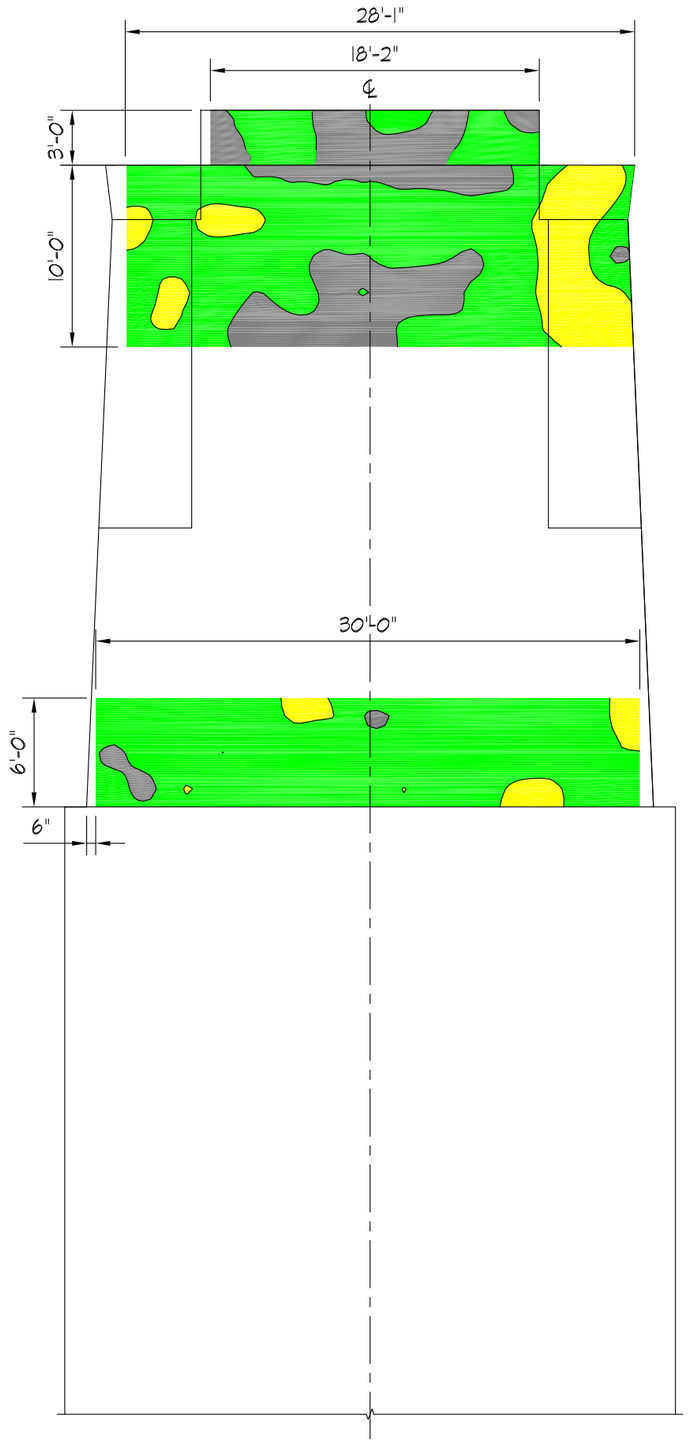
NTS



2 PIER 5 SOUTH FACE
NTS

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No.	Description	Date

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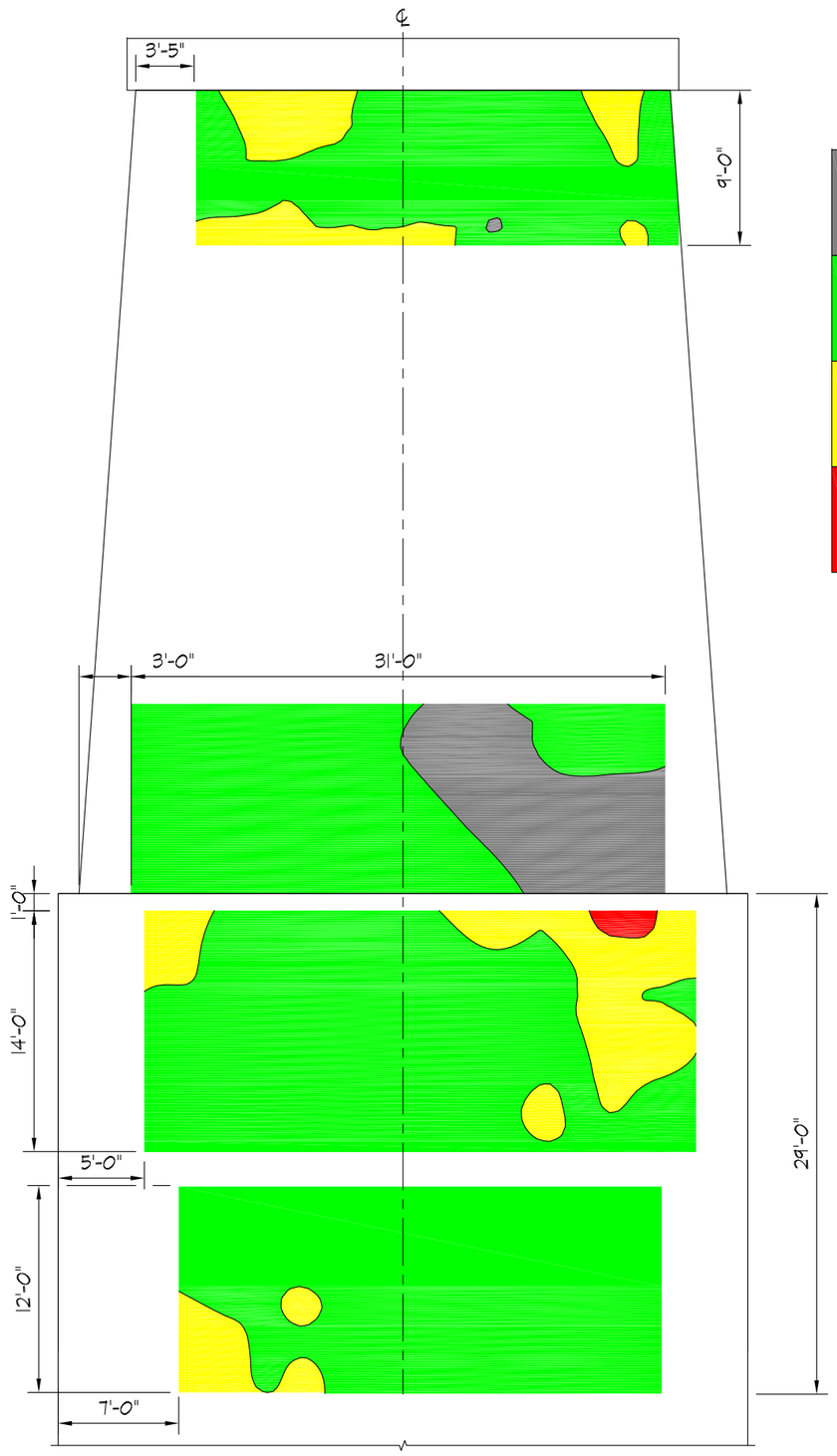
Date: **10JUNJ09**
Scale: **NTS**

Evaluation of Milton Madison Bridge Substructures

Sheet No.:

HC-1



1 **PIER 6 NORTH FACE**
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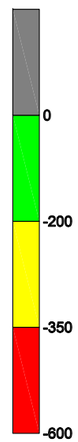

2 **PIER 6 SOUTH FACE**
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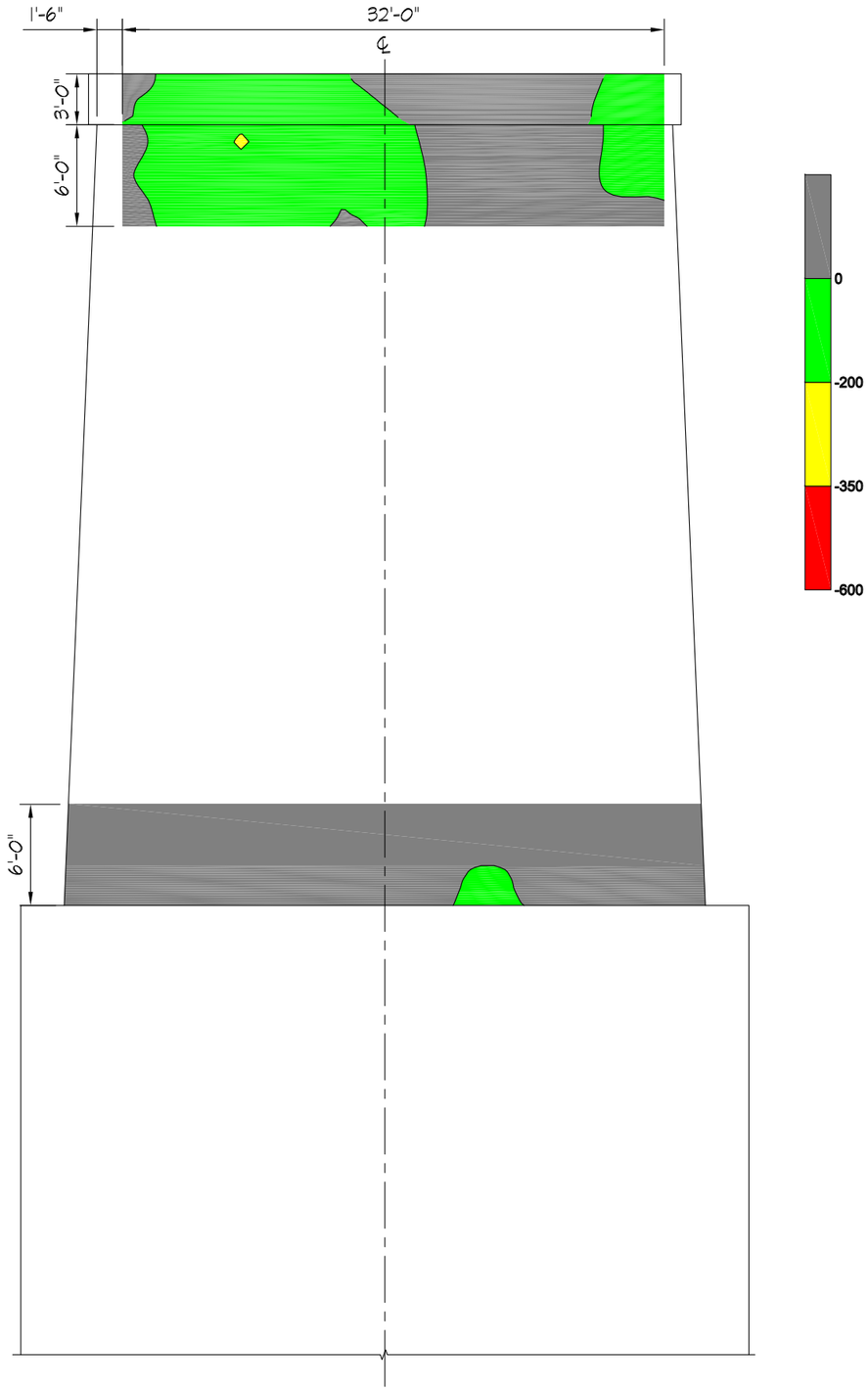
Evaluation of Milton Madison Bridge Substructures

Sheet No.:

HC-2



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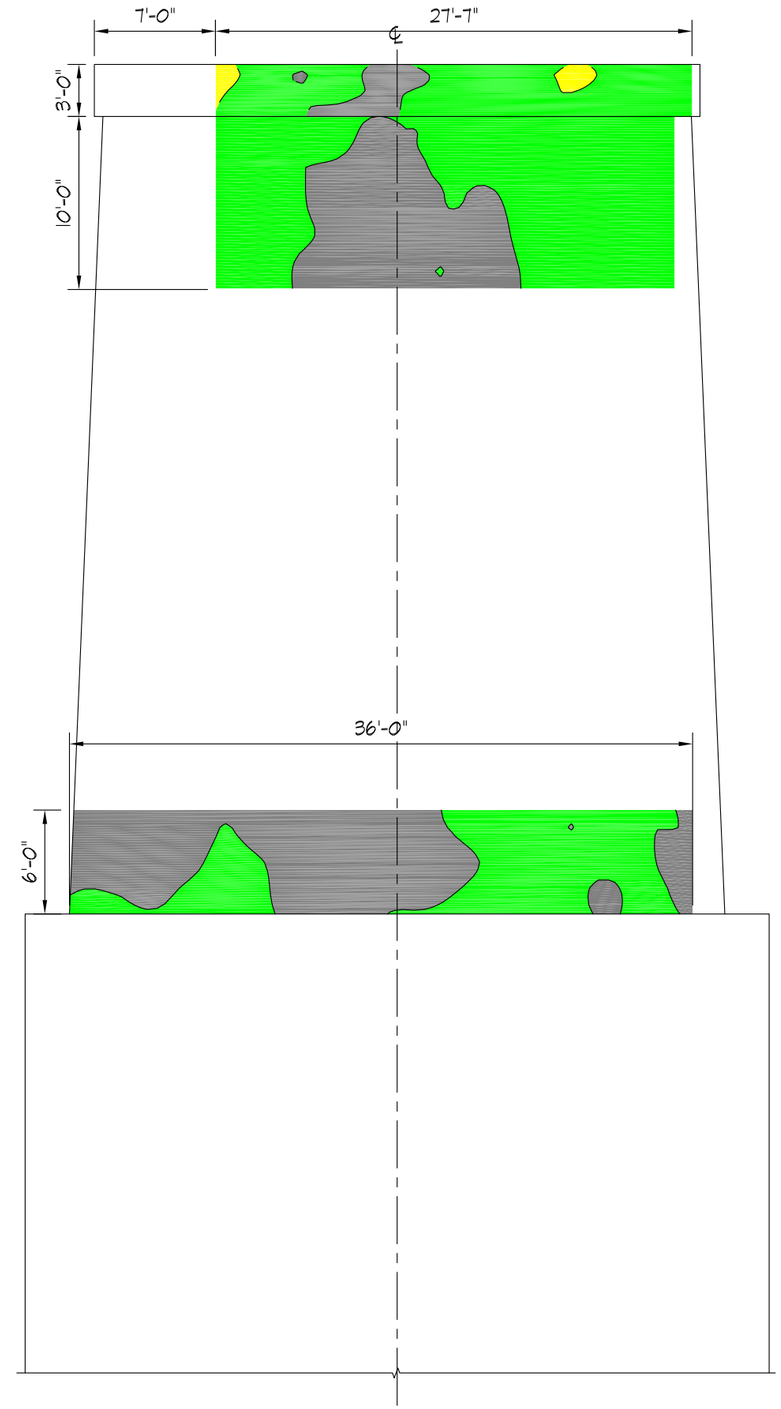

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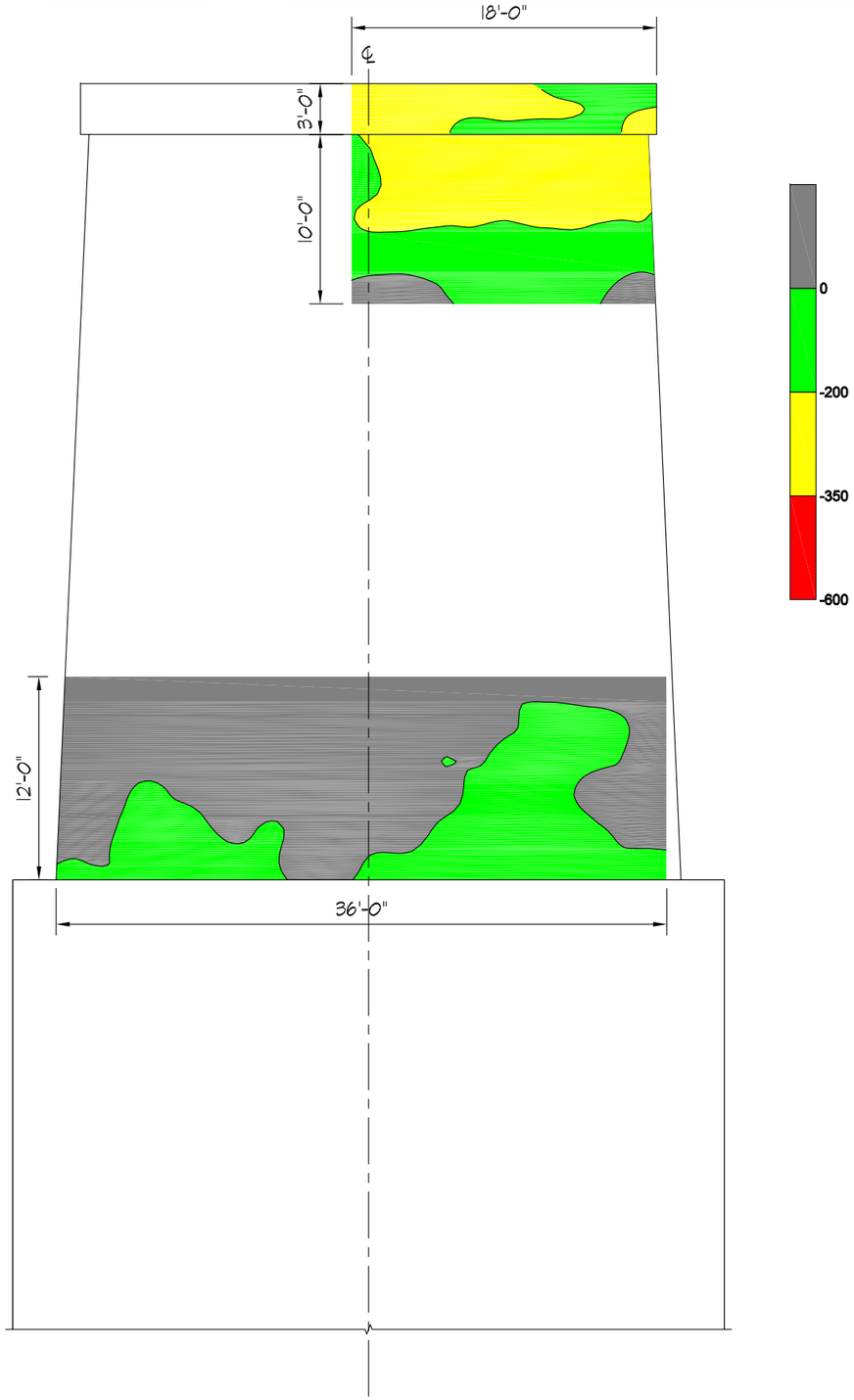
Evaluation of Milton Madison Bridge Substructures

Sheet No.:

HC-3



1 PIER 8 NORTH FACE
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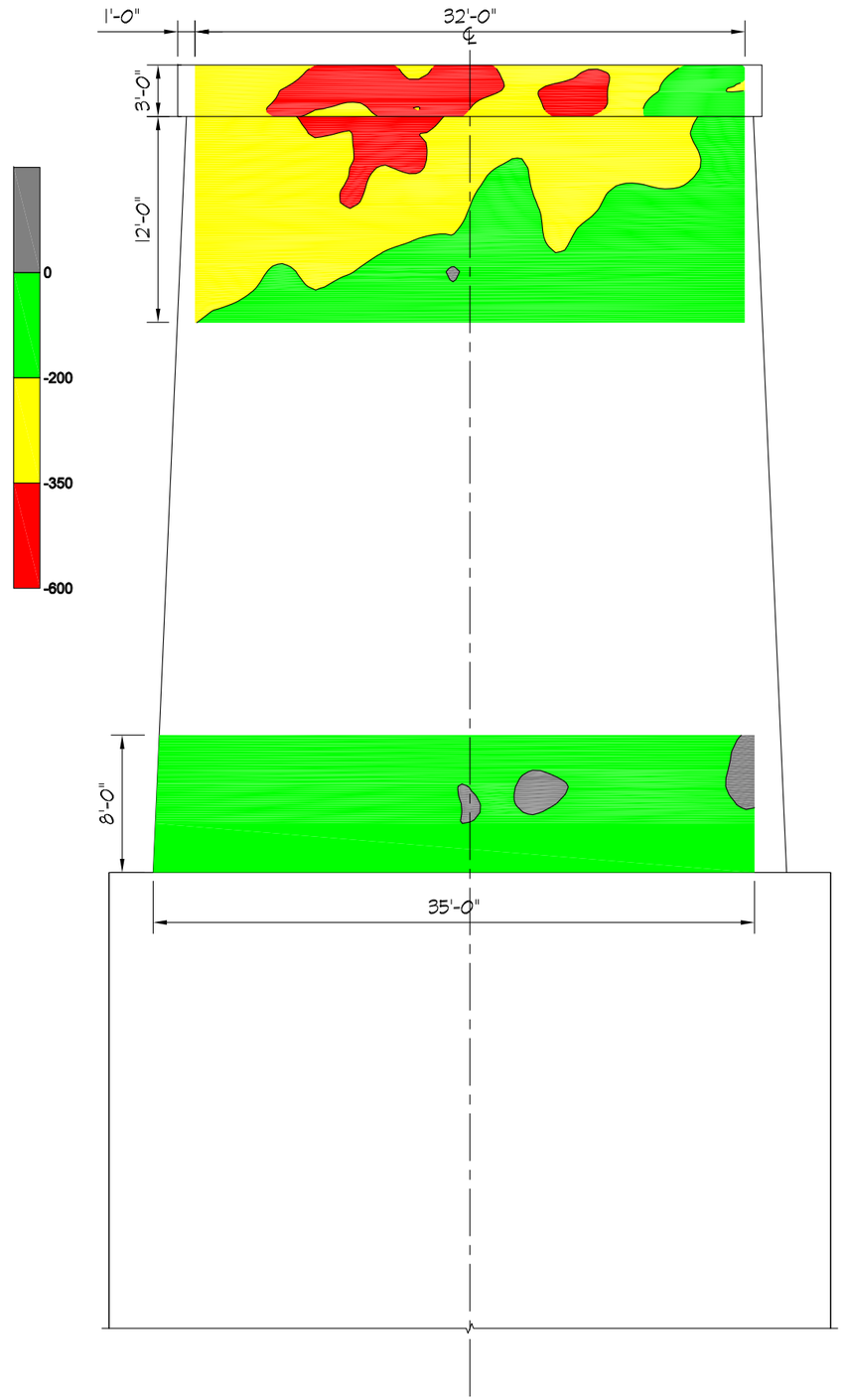

2 PIER 8 SOUTH FACE
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Evaluation of Milton Madison Bridge Substructures

Sheet No.:

HC-4

APPENDIX D

Concrete Material Testing

- **D.1 – Compressive Strength Testing**
- **D.2 – Static Modulus of Elasticity Testing**
- **D.3 – Acid Soluble Chloride Ion Concentration Testing**
- **D.4 – Petrographic Examination**
    - **D.4.1 Cores extracted from face of piers**
    - **D.4.2 Vertical cores-previous visits**

APPENDIX D.1

Compressive Strength Testing

- **Test Results of ASTM C 42/C 42M-04, "Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete"**

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Client: Wilbur Smith Associates
Project: Milton Madison Bridge Substructures
Contact: Mr. John L. Carr, PE
Submitter: S. Wyatt, CTLGroup

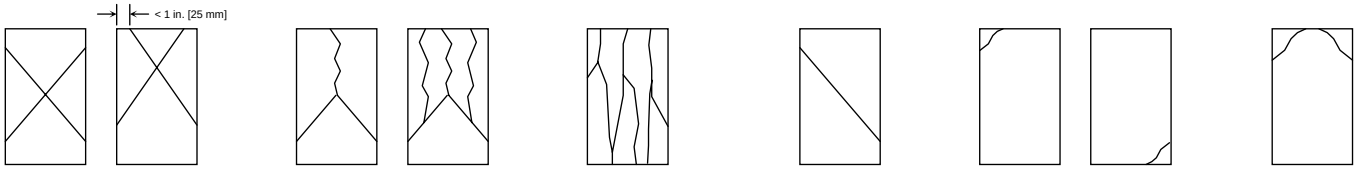
CTLGroup Project No.: 210727
CTLGroup Project Mgr.: C. Ligozio
Technician: P. Brindise
Approved: W. Morrison
Date: March 30, 2009

ASTM C 42 / C 42M - 04
Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

Specimen Identification	C - 1	C - 3B
Nominal Maximum Aggregate Size, in.	1 ½	1 ½
Concrete Age at Test, days	Not Stated	Not Stated
Moisture Condition at Test	Dry as received	Dry as received
Orientation of Core Axis in Structure	Not Stated	Not Stated
Diameter 1, in.	3.80	3.81
Diameter 2, in.	3.81	3.81
Average Diameter, in.	3.81	3.81
Cross-Sectional Area, sq in.	11.37	11.40
Length Trimmed, in.	7.18	4.30
Length Capped, in.	7.36	4.46
Weight in Air, lbs.	7.25	4.21
Immersed Weight in Water, lbs.	4.32	2.45
Calculated Unit Weight, pcf	154.4	149.3
Maximum Load, lb	118,000	87,600
Uncorrected Compressive Strength, psi	10,380	7,680
Ratio of Capped Length to Diameter	1.93	1.17
Correction Factor	1.00	0.91
Corrected Compressive Strength, psi	**10,380**	**7,000**
Fracture Pattern	Type 1	Type 4

Notes:

Schematic of Typical Fracture Patterns



Type 1
Reasonable well-formed cones on both ends, less than 1 in. [25 mm] of cracking through caps

Type 2
Well-formed cone on one end, vertical cracks running through caps, no well-defined cone on other end

Type 3
Columnar vertical cracking through both ends, no well-formed cones

Type 4
Diagonal fracture with no cracking through ends; tap with hammer to distinguish from Type I

Type 5
Side fractures at top or bottom (occur commonly with unbonded caps)

Type 6
Similar to Type 5 but end of cylinder is pointed

Test Machine No. 400BTE/15-0054

Corporate Office 5400 Old Orchard Road Skokie, Illinois 60077-1030 Phone 847-965-7500 Fax 847-965-6541
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Client: Wilbur Smith Associates
Project: Milton Madison Bridge Substructures
Contact: Mr. John L. Carr, PE
Submitter: S. Wyatt, CTLGroup

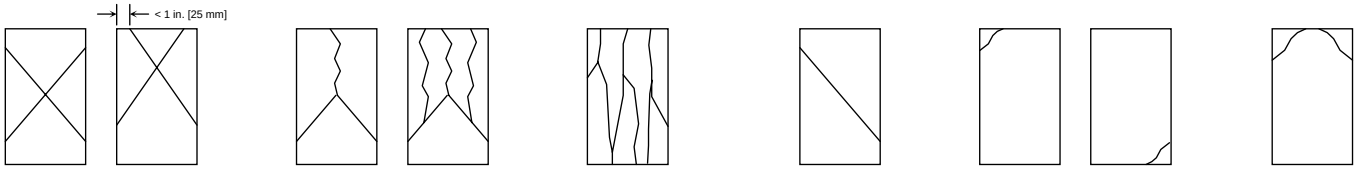
CTLGroup Project No.: 210727
CTLGroup Project Mgr.: C. Ligozio
Technician: P. Brindise
Approved: W. Morrison
Date: March 30, 2009

ASTM C 42 / C 42M - 04
Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

Specimen Identification	C - 7	C - 11A
Nominal Maximum Aggregate Size, in.	1 ½	1 ½
Concrete Age at Test, days	Not Stated	Not Stated
Moisture Condition at Test	Dry as received	Dry as received
Orientation of Core Axis in Structure	Not Stated	Not Stated
Diameter 1, in.	3.83	3.26
Diameter 2, in.	3.83	3.26
Average Diameter, in.	3.83	3.26
Cross-Sectional Area, sq in.	11.52	8.35
Length Trimmed, in.	5.73	5.01
Length Capped, in.	6.04	5.15
Weight in Air, lbs.	5.76	3.79
Immersed Weight in Water, lbs.	3.39	2.30
Calculated Unit Weight, pcf	151.7	158.7
Maximum Load, lb	97,600	117,200
Uncorrected Compressive Strength, psi	8,470	14,040
Ratio of Capped Length to Diameter	1.58	1.58
Correction Factor	0.97	0.97
Corrected Compressive Strength, psi	**8,180**	**13,570**
Fracture Pattern	Type 4	Type 1

Notes:

Schematic of Typical Fracture Patterns



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Type 3
Columnar vertical cracking through both ends, no well-formed cones

Type 4
Diagonal fracture with no cracking through ends; tap with hammer to distinguish from Type I

Type 5
Side fractures at top or bottom (occur commonly with unbonded caps)

Type 6
Similar to Type 5 but end of cylinder is pointed

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Contact: Mr. John L. Carr, PE
Submitter: S. Wyatt, CTLGroup

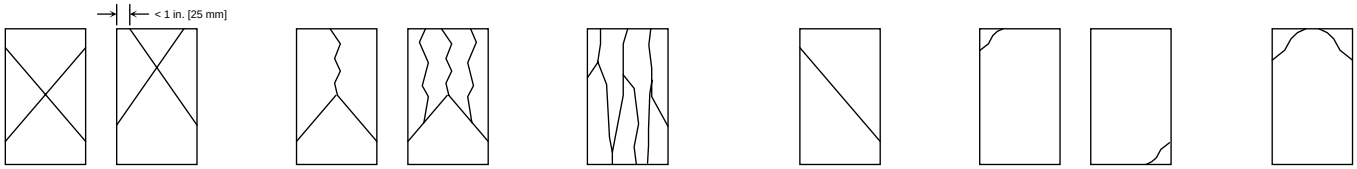
CTLGroup Project No.: 210727
CTLGroup Project Mgr.: C. Ligozio
Technician: P. Brindise
Approved: W. Morrison
Date: March 30, 2009

ASTM C 42 / C 42M - 04
Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

Specimen Identification	C - 2	C - 4
Nominal Maximum Aggregate Size, in.	1 ½	1 ½
Concrete Age at Test, days	Not Stated	Not Stated
Moisture Condition at Test	Dry as received	Dry as received
Orientation of Core Axis in Structure	Not Stated	Not Stated
Diameter 1, in.	3.80	3.81
Diameter 2, in.	3.81	3.83
Average Diameter, in.	3.81	3.82
Cross-Sectional Area, sq in.	11.37	11.46
Length Trimmed, in.	7.24	7.28
Length Capped, in.	7.24	7.28
Weight in Air, lbs.	7.27	7.33
Immersed Weight in Water, lbs.	4.32	4.36
Calculated Unit Weight, pcf	153.8	154.0
Maximum Load, lb	126,800	131,800
Uncorrected Compressive Strength, psi	11,150	11,500
Ratio of Capped Length to Diameter	1.90	1.90
Correction Factor	1.00	1.00
Corrected Compressive Strength, psi	**11,150**	**11,500**
Fracture Pattern	Type 4	Type 1

Notes:

Schematic of Typical Fracture Patterns



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Type 3
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Diagonal fracture with no cracking through ends; tap with hammer to distinguish from Type I

Type 5
Side fractures at top or bottom (occur commonly with unbonded caps)

Type 6
Similar to Type 5 but end of cylinder is pointed

Test Machine No. 400BTE/15-0054

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APPENDIX D.2

Modulus of Elasticity Testing

- **Results of ASTM C 469-02, "Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression."**

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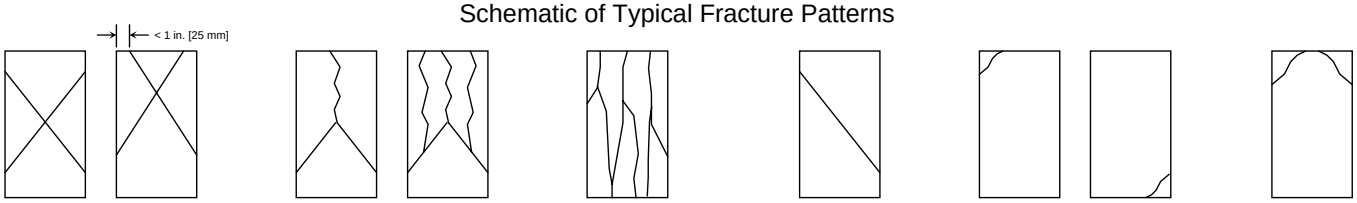
Project: Milton Madison Bridge Substructures	CTLGroup Project Mgr.: C. Ligozio
	Technician: P. Brindise
Contact: Mr. John L. Carr, PE	Approved: W. Morrison
Submitter: S. Wyatt, CTLGroup	Date: March 31, 2009

ASTM C 42 COMPRESSIVE STRENGTH OF CYLINDRICAL CONCRETE CORE SPECIMENS
ASTM C 469 STATIC MODULUS OF ELASTICITY OF CYLINDRICAL CONCRETE CORE SPECIMENS

Specimen Identification	C-2	C-4
Date Tested	03/30/09	03/30/09
Age at Test	Not Stated	Not Stated
Cure Condition	Dry As Received	Dry As Received
Diameter 1, in.	3.80	3.81
Diameter 2, in.	3.81	3.83
Average Diameter, in.	3.81	3.82
Cross-Section Area, sq in.	11.40	11.46
Length, in.	7.24	7.28
Maximum Load, lb	126,800	131,800
Compressive Strength, psi	11,120	11,500
Chord Modulus of Elasticity, ksi	6,000	6,300
Fracture Pattern	Type 4	Type 1

Notes:
* Cylinder cores taken from the same area were used to determine the compressive strength in accordance with ASTM C 42 prior to the test for modulus of elasticity.

Schematic of Typical Fracture Patterns



Type 1
Reasonable well-formed cones on both ends, less than 1 in. [25 mm] of cracking through caps

Type 2
Well-formed cone on one end, vertical cracks running through caps, no well-defined cone on other end

Type 3
Columnar vertical cracking through both ends, no well-formed cones

Type 4
Diagonal fracture with no cracking through ends; tap with hammer to distinguish from Type I

Type 5
Side fractures at top or bottom (occur commonly with unbonded caps)

Type 6
Similar to Type 5 but end of cylinder is pointed

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APPENDIX D.3

Acid Soluble Chloride Ion Concentration Testing

- **Results of ASTM C1152/C1152M-04 "Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete."**

Client:	**Wilbur Smith Associates**	CTL Project No:	**210727**
Project:	**Chloride Analysis**	CTL Project Mgr.:	**Chris Ligozio**
		Analyst:	**R. Naamane**
Contact:	**John L. Carr, P.E.**	Approved:	
Submitter:	**Scott Wyatt, CTLGroup**	Date Analyzed:	**Various**
Date Received:	**March 23, 2009**	Date Reported:	**April 2, 2009**

REPORT of ACID-SOLUBLE CHLORIDE

Sample Identification CTL ID	Client ID	Description	Determined Chloride (wt% sample)
2306001	Pier 5 North #1 (0.5-1.5”)	Concrete	0.071
2306002	Pier 5 North #1 (1.5-2.5”)	Concrete	0.033
2306003	Pier 5 North #1 (2.5-3.5”)	Concrete	0.014
2306004	Pier 5 North #1 (3.5-4.5”)	Concrete	0.007
2306005	Pier 5 North #2 (0.5-1.5”)	Concrete	0.015
2306006	Pier 5 North #2 (1.5-2.5”)	Concrete	0.012
2306007	Pier 5 North #2 (2.5-3.5”)	Concrete	0.009
2306008	Pier 5 North #2 (3.5-4.5”)	Concrete	0.006
2306009	Pier 5 North #3 (0.5-1.5”)	Concrete	0.070
2306010	Pier 5 North #3 (1.5-2.5”)	Concrete	0.022
2306012	Pier 5 North #3 (2.5-3.5”)	Concrete	0.021
2306011	Pier 5 North #3 (3.5-4.5”)	Concrete	0.006
2306013	Pier 5 North #4 (0.5-1.5”)	Concrete	0.074
2306014	Pier 5 North #4 (1.5-2.5”)	Concrete	0.006
2306015	Pier 5 North #4 (2.5-3.5”)	Concrete	0.004
2306016	Pier 5 North #4 (3.5-4.5”)	Concrete	0.007

Notes:
1. This analysis represents specifically the samples submitted as received.
2. Analysis by potentiometric titration with silver nitrate. (AASHTO T 260-97 (2001))
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Project:	**Chloride Analysis**	CTL Project Mgr.:	**Chris Ligozio**
		Analyst:	**R. Naamane**
Contact:	**John L. Carr, P.E.**	Approved:	
Submitter:	**Scott Wyatt, CTLGroup**	Date Analyzed:	**Various**
Date Received:	**March 23, 2009**	Date Reported:	**April 2, 2009**

REPORT of ACID-SOLUBLE CHLORIDE

Sample Identification CTL ID	Client ID	Description	Determined Chloride (wt% sample)
2306017	Pier 5 South #1 (0.5-1.5”)	Concrete	0.051
2306018	Pier 5 South #1 (1.5-2.5”)	Concrete	0.016
2306019	Pier 5 South #1 (2.5-3.5”)	Concrete	0.010
2306020	Pier 5 South #1 (3.5-4.5”)	Concrete	0.008
2306021	Pier 5 South #2 (0.5-1.5”)	Concrete	0.039
2306022	Pier 5 South #2 (2.5-3.5”)	Concrete	0.017
2306023	Pier 5 South #2 (3.5-4.5”)	Concrete	0.010
2306024	Pier 5 South #3 (0.5-1.5”)	Concrete	0.116
2306025	Pier 5 South #3 (1.5-2.5”)	Concrete	0.078
2306026	Pier 5 South #3 (2.5-3.5”)	Concrete	0.048
2306027	Pier 5 South #3 (3.5-4.5”)	Concrete	0.049
2306028	Pier 5 South #4 (0.5-1.5”)	Concrete	0.062
2306029	Pier 5 South #4 (1.5-2.5”)	Concrete	0.061
2306030	Pier 5 South #4 (2.5-3.5”)	Concrete	0.025
2306031	Pier 5 South #4 (3.5-4.5”)	Concrete	0.015
2306032	Pier 5 South #5 (0.5-1.5”)	Concrete	0.025
2306033	Pier 5 South #5 (1.5-2.5”)	Concrete	0.007
2306034	Pier 5 South #5 (2.5-3.5”)	Concrete	0.009
2306035	Pier 5 South #5 (3.5-4.5”)	Concrete	0.008

Notes:
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Project:	**Chloride Analysis**	CTL Project Mgr.:	**Chris Ligozio**
		Analyst:	**R. Naamane**
Contact:	**John L. Carr, P.E.**	Approved:	
Submitter:	**Scott Wyatt, CTLGroup**	Date Analyzed:	**Various**
Date Received:	**March 23, 2009**	Date Reported:	**April 2, 2009**

REPORT of ACID-SOLUBLE CHLORIDE

Sample Identification CTL ID	Client ID	Description	Determined Chloride (wt% sample)
2306036	Pier 6 North #1 (1-2")	Concrete	0.006
2306037	Pier 6 North #1 (2-3")	Concrete	0.014
2306038	Pier 6 North #1 (3-4")	Concrete	0.005
2306045	Pier 6 North #4 (1-2")	Concrete	0.005
2306046	Pier 6 North #4 (2-3")	Concrete	0.009
2306047	Pier 6 North #4 (3-4")	Concrete	0.008
2306048	Pier 6 North #5 (1-2")	Concrete	0.007
2306049	Pier 6 North #5 (2-3")	Concrete	0.008
2306050	Pier 6 North #5 (3-4")	Concrete	0.007
2306051	Pier 6 South #1 (1-2")	Concrete	0.004
2306052	Pier 6 South #1 (2-3")	Concrete	0.006
2306053	Pier 6 South #1 (3-4")	Concrete	0.005
2306059	Pier 6 South #4 (1-2")	Concrete	0.007
2306060	Pier 6 South #4 (2-3")	Concrete	0.006
2306061	Pier 6 South #4 (3-4")	Concrete	0.004
2306062	Pier 6 South #5 (1-2")	Concrete	0.007
2306063	Pier 6 South #5 (2-3")	Concrete	0.003
2306064	Pier 6 South #5 (3-4")	Concrete	0.013
2306065	Pier 6 South #6 (1-2")	Concrete	0.004
2306066	Pier 6 South #6 (2-3")	Concrete	0.005
2306067	Pier 6 South #6 (3-4")	Concrete	0.004

Notes:
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Contact:	**John L. Carr, P.E.**	Approved:	
Submitter:	**Scott Wyatt, CTLGroup**	Date Analyzed:	**Various**
Date Received:	**March 23, 2009**	Date Reported:	**April 2, 2009**

REPORT of ACID-SOLUBLE CHLORIDE

Sample Identification CTL ID	Client ID	Description	Determined Chloride (wt% sample)
2306401	Pier 7 North #1 (0.5-1.5”)	Concrete	0.005
2306402	Pier 7 North #1 (1.5-2.5”)	Concrete	0.004
2306403	Pier 7 North #1 (2.5-3.5”)	Concrete	0.011
2306404	Pier 7 North #1 (3.5-4.5”)	Concrete	0.010
2306405	Pier 7 North #2 (0.5-1.5”)	Concrete	0.010
2306406	Pier 7 North #2 (1.5-2.5”)	Concrete	0.004
2306407	Pier 7 North #2 (2.5-3.5”)	Concrete	0.006
2306408	Pier 7 North #2 (3.5-4.5”)	Concrete	0.004
2306413	Pier 7 North #4 (0.5-1.5”)	Concrete	0.004
2306414	Pier 7 North #4 (1.5-2.5”)	Concrete	0.004
2306415	Pier 7 North #4 (2.5-3.5”)	Concrete	0.005
2306416	Pier 7 North #4 (3.5-4.5”)	Concrete	0.007
2306417	Pier 7 North #5 (0.5-1.5”)	Concrete	0.009
2306418	Pier 7 North #5 (1.5-2.5”)	Concrete	0.004
2306419	Pier 7 North #5 (2.5-3.5”)	Concrete	0.004
2306420	Pier 7 North #5 (3.5-4.5”)	Concrete	0.009

Notes:
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Client:	**Wilbur Smith Associates**	CTL Project No:	**210727**
Project:	**Chloride Analysis**	CTL Project Mgr.:	**Chris Ligozio**
		Analyst:	**R. Naamane**
Contact:	**John L. Carr, P.E.**	Approved:	
Submitter:	**Scott Wyatt, CTLGroup**	Date Analyzed:	**Various**
Date Received:	**March 23, 2009**	Date Reported:	**April 2, 2009**

REPORT of ACID-SOLUBLE CHLORIDE

Sample Identification CTL ID	Client ID	Description	Determined Chloride (wt% sample)
2306421	Pier 7 South #1 (0.5-1.5”)	Concrete	0.019
2306422	Pier 7 South #1 (1.5-2.5”)	Concrete	0.004
2306423	Pier 7 South #1 (2.5-3.5”)	Concrete	0.001
2306424	Pier 7 South #1 (3.5-4.5”)	Concrete	0.007
2306425	Pier 7 South #2 (0.5-1.5”)	Concrete	0.002
2306426	Pier 7 South #2 (1.5-2.5”)	Concrete	0.002
2306427	Pier 7 South #2 (2.5-3.5”)	Concrete	0.006
2306428	Pier 7 South #2 (3.5-4.5”)	Concrete	0.002
2306429	Pier 7 South #3 (0.5-1.5”)	Concrete	0.002
2306430	Pier 7 South #3 (1.5-2.5”)	Concrete	0.002
2306431	Pier 7 South #3 (2.5-3.5”)	Concrete	0.003
2306432	Pier 7 South #3 (3.5-4.5)	Concrete	0.006

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Client:	**Wilbur Smith Associates**	CTL Project No:	**210727**
Project:	**Chloride Analysis**	CTL Project Mgr.:	**Chris Ligozio**
		Analyst:	**R. Naamane**
Contact:	**John L. Carr, P.E.**	Approved:	
Submitter:	**Scott Wyatt, CTLGroup**	Date Analyzed:	**Various**
Date Received:	**March 23, 2009**	Date Reported:	**April 2, 2009**

REPORT of ACID-SOLUBLE CHLORIDE

Sample Identification CTL ID	Client ID	Description	Determined Chloride (wt% sample)
2306441	Pier 8 North #1 (0.5-1.5”)	Concrete	0.006
2306442	Pier 8 North #1 (1.5-2.5”)	Concrete	0.012
2306443	Pier 8 North #1 (2.5-3.5”)	Concrete	0.010
2306444	Pier 8 North #1 (3.5-4.5”)	Concrete	0.003
2306445	Pier 8 North #2 (0.5-1.5”)	Concrete	0.010
2306446	Pier 8 North #2 (1.5-2.5”)	Concrete	0.006
2306447	Pier 8 North #2 (2.5-3.5”)	Concrete	0.003
2306448	Pier 8 North #3 (0.5-1.5”)	Concrete	0.013
2306449	Pier 8 North #3 (1.5-2.5”)	Concrete	0.010
2306450	Pier 8 North #3 (2.5-3.5”)	Concrete	0.003
2306451	Pier 8 North #3 (3.5-4.5”)	Concrete	0.005
2306452	Pier 8 North #4 (0.5-1.5”)	Concrete	0.011
2306453	Pier 8 North #4 (1.5-2.5”)	Concrete	0.006
2306454	Pier 8 North #4 (2.5-3.5”)	Concrete	0.005
2306455	Pier 8 North #4 (3.5-4.5”)	Concrete	0.006

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Client:	**Wilbur Smith Associates**	CTL Project No:	**210727**
Project:	**Chloride Analysis**	CTL Project Mgr.:	**Rick Stevenson**
		Analyst:	**R. Naamane**
Contact:	**John L. Carr, P.E.**	Approved:	
Submitter:	**Scott Wyatt, CTLGroup**	Date Analyzed:	**March 24, 2009**
Date Received:	**March 23, 2009**	Date Reported:	**March 27, 2009**

REPORT of ACID-SOLUBLE CHLORIDE

Sample Identification CTL ID	Client ID	Description	Determined Chloride (wt% sample)
2306456	Pier 8 South #1 (0.5-1.5”)	Concrete	0.019
2306457	Pier 8 South #1 (1.5-2.5”)	Concrete	0.013
2306458	Pier 8 South #1 (2.5-3.5”)	Concrete	0.012
2306459	Pier 8 South #1 (3.5-4.5”)	Concrete	0.004
2306460	Pier 8 South #2 (0.5-1.5”)	Concrete	0.005
2306461	Pier 8 South #2 (1.5-2.5”)	Concrete	0.005
2306462	Pier 8 South #2 (2.5-3.5”)	Concrete	0.006
2306463	Pier 8 South #2 (3.5-4.5”)	Concrete	0.001
2306464	Pier 8 South #3 (0.5-1.5”)	Concrete	0.014
2306465	Pier 8 South #3 (1.5-2.5”)	Concrete	0.004
2306466	Pier 8 South #3 (2.5-3.5”)	Concrete	0.001
2306467	Pier 8 South #3 (3.5-4.5”)	Concrete	0.016
2306468	Pier 8 South #4 (0.5-1.5”)	Concrete	0.002
2306469	Pier 8 South #4 (1.5-2.5”)	Concrete	0.003
2306470	Pier 8 South #4 (2.5-3.5”)	Concrete	0.010
2306471	Pier 8 South #4 (3.5-4.5”)	Concrete	0.001

Notes:
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2. Analysis by potentiometric titration with silver nitrate. (AASHTO T 260-97 (2001))
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Client:	**Wilbur Smith Associates**	CTL Project No:	**210727**
Project:	**Chloride Analysis**	CTL Project Mgr.:	**Chris Ligozio**
		Analyst:	**Dombroski**
Contact:	**John L. Carr, P.E.**	Approved:	
Submitter:	**Scott Wyatt, CTLGroup**	Date Analyzed:	**April 3, 2009**
Date Received:	**March 27, 2009**	Date Reported:	**April 3, 2009**

REPORT of ACID-SOLUBLE CHLORIDE

Sample Identification CTL ID	Client ID	Description	Determined Chloride (wt% sample)
2309101	C-9 0-1”	Concrete	0.131
2309102	C-9 1-2”	Concrete	0.081
2309103	C-9 2-3”	Concrete	0.020
2309104	C-9 3-4”	Concrete	0.011

Notes:
1. This analysis represents specifically the samples submitted on a dry (105°C) basis.
2. Analysis by potentiometric titration with silver nitrate. (AASHTO T 260-97 (2001))
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APPENDIX D.4

Petrographic Examination

- **Report of ASTM C856-04, "Standard Practice for Petrographic Examination of Hardened Concrete."**
    - **D.4.1 Cores extracted from face of piers**
    - **D.4.2 Vertical cores-previous visits**

APPENDIX D.4.1

Cores Extracted From Face Of Piers

- **Report Dated April 27, 2009**

Copy No. 1

Wilbur Smith Associates

Project Number 210727

Petrographic Examination of Concrete Cores from Milton-Madison Bridge – Second Core Set Submission

Date:
April 27, 2009

Submitted by:
Hugh (Xiaoqiang) Hou

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REPORT OF PETROGRAPHIC EXAMINATION

Date: April 27, 2009

www.CTLGroup.com

CTLGroup Project No.: 210727

Petrographic Examination of Concrete Cores from Milton-Madison Bridge – Second Core Set Submission

Six concrete cores were received on March 17, 2009 and three additional cores were received on March 26, 2009 from Mr. Scott Wyatt, CTLGroup Senior Engineer. Reportedly, the submitted cores were extracted either horizontally or vertically from different elevations of existing piers for the US 421 Bridge over the Ohio River between Milton, Kentucky and Madison, Indiana, as part of continued evaluation of the structure condition to determine the feasibility for reusing the piers to support a replacement superstructure. Core “C4-ER to C4-ES” was reportedly extracted vertically during an earlier field visit performed on Feb. 5th and 6th 2009 from the top deck of the bridge drilling along the vertical direction of the pier. Other submitted cores were extracted horizontally in March 2009, except Core C-9 that was extracted vertically from a step top. Reportedly, the bridge is approximately 80 years old.

Table 1 provides a list of sample identifications, core locations, and descriptions of the core location relative to water line. As-received photographs of the cores are provided in Figures 1 through 9.

Petrographic examination (ASTM C 856) of the submitted core samples was requested to assess the material properties and condition of the concrete. Cores from the same bridge and extracted during the same visit as Core C4-ER to C4-ES had also been submitted earlier for petrographic examination, and a report dated February 18, 2009 was released summarizing findings based on those cores from the previous petrographic examination.

TABLE 1 CORE SEGMENTS FROM MILTON/MADISON BRIDGE FOR PETROGRAPHIC EXAMINATION

Core Identification	Location Pier No.	Vertical Location	Comments	Core Photographs
C-11	5	Lower wall, 34.5' below step	Approximately 1.5' above waterline	Fig. 1
C-12	5	Upper wall, 43.5' below top	Taken at a horizontal lift line	Fig. 2
C-7	7	Lower wall, 33' below step	Approximately 2' above waterline	Fig. 3
C-8	7	Lower wall, 13' below step	Taken at a vertical crack	Fig. 4
C-9 [a]	7	Lower wall, at step	Near area of delamination	Fig. 5
C-10	7	Upper wall, 36' below top	Horizontal lift line	Fig. 6
C-5	8	Lower wall, 33' below step	Horizontal lift line	Fig. 7
C-6	8	Upper wall, 27' below top	Horizontal lift line	Fig. 8
C4-ER to C4-ES [a,b]	9	Footing, approx. 137' from top	Cored vertically from the top along the length of the pier	Fig. 9

[a] C-9 and C4-ER to C4-ES were extracted vertically; horizontally for all of the rest cores.

[b] C4-ER to C4-ES extracted during the February 5th and 6th 2009.

FINDINGS AND CONCLUSIONS

Based on results of the petrographic examination, the concrete represented by the provided cores appears to be overall in fairly good condition, although some localized deterioration is observed along exposed outer surfaces. Aside from the lack of air-entrainment in the body of the represented concrete, concrete is judged to be of fairly good quality. Lack of air entrainment does not appear to have compromised its long-term durability though; no substantial microcracking, scaling, or paste softening is noted in the near-surface concrete represented by the core samples, except for surface erosion.

Summary of Concrete Characteristics

Concrete in all core segments contains similar constituents and exhibits roughly similar properties. Each consists of natural gravel and sand distributed in a moderately hard to hard, non-air entrained, portland cement paste (Figs. 10 through 18), and each exhibiting a

moderately tight or moderately tight to tight past-aggregate bond. Concrete represented in each core appears well consolidated.

Deterioration in each concrete appears to be mainly in the form of surface erosion, except C4-ER to C4-ES that does not exhibit a surface directly exposed to weathering conditions. Exposed surfaces of concrete represented by the other cores exhibit surficial erosions from severe to minor. This surface erosion is mainly manifested as paste loss that exposes aggregate with variable relief (Figs. 1 through 8). Concrete cores extracted from the lower pier wall and adjacent to the water line generally exhibit the most severe erosion (Figs. 1, 3, and 7). However, the erosion appears to be mainly of physical or mechanical nature rather than chemical alteration, as the existing near-surface paste still remains moderately hard to hard and is comparable in quality to paste at greater depth in the concrete.

Concrete in several cores, namely C-12, C-10, C-5, C-6 and C4-ER to C4-ES, exhibits a discontinuity, either distinct and abrupt or barely visible in appearance that likely represents a cold joint or a lift line. Typically, no significant difference in paste properties was noted in concrete above and below the lift line, except that: 1) the paste immediately below and above the horizontal line may be locally different in color, and 2) Core C-12 and Core C4-ER to C4-ES exhibit locally moderately soft paste near the discontinuity (Figs. 11 and 18). Many of these cores were received cracked or fractured along or near the lift line.

The concrete is not air entrained. Air content in most of the cores is estimated 1 to 2%.

Carbonation of paste was generally minor along the exposed core end surfaces, typically less than 2 to 3 mm (0.08 to 0.12 in.), but locally up to 25 mm (1.0 in.) in Core C-12. Localized carbonation is also observed near the lift line, even in portions where concrete did not fracture along the discontinuity (Fig. 19).

A major, full-length crack is observed in Core C-8 (Figs. 4 and 13). The crack extends through very small amounts of aggregate particles. In contrast, fresh fractures produced in laboratory examination extend through significantly more aggregate particles than the full-length crack. The full-length crack may have formed very early, before concrete completely set and gained full strength. Other than the major crack and microcracks near it, the concrete in Core C-8 does not exhibit other apparent distress or abnormalities.

The following additional findings and descriptions of the concrete are based on results of the petrographic examination, details of which are provided in the attached data sheets.

1. Aggregate characteristics differ somewhat among the group of core segments. Although the overall composition of the natural gravel and sand aggregate is generally similar, some differences are observed in aggregate gradation and top size, and possibly aggregate volume. Maximum observed aggregate size ranges from 27 to 42 mm (1.1 to 1.7 in.) among the examined core segments. Visible characteristics of the aggregate are illustrated in Figs. 10 through 18. Constituents of both coarse and fine aggregates are generally hard and dense. Coarse aggregate is comprised mainly of granite, sandstone, limestone, quartzite and chert. Fine aggregate is comprised mainly of quartz/quartzite, limestone, granite, chert, feldspar, and sandstone. Both coarse and fine aggregate contain trace to minor amounts of shale, argillaceous rock and coal. Aggregate distribution within individual core section is generally uniform.

2. Concrete properties do not vary significantly among the core segments. In general the paste is mottled medium gray in color (Figs. 10 through 18), moderately hard to hard, subvitreous to dull in luster, and moderately low to moderate in water absorbency. Paste-aggregate bond is moderately tight or moderately tight to tight.

3. Core C4-ER to C4-ES and portions of Core C-12 exhibit slightly reduced paste quality compared to concrete in the other cores, as indicated by their overall or localized lighter color, weaker paste that is moderately hard to locally moderately soft and exhibits slightly greater water absorbency. Core C4-ER to C4-ES also appears to contain slightly low volume of paste.

4. No supplementary cementitious materials are observed in the hardened paste.

5. No steel reinforcement is noted in any of the provided core segments. An imprint of a reinforcing bar is observed along the fractured top end of Core C4-ER to C4-ES. No corrosion products were observed on the imprint surfaces; however, the segment of steel bar was not included for examination and no interpretation of its condition could be rendered.

6. The concrete exhibits evidence of prolonged or periodic exposure to moisture-saturated conditions over the life of the structure. Relics of in-situ hydrated portland cement clinker

particles are common and unhydrated clinker particles are scarce in the paste, which indicates an advanced degree of cement hydration.

ADDITIONAL COMMENTS

The findings of the petrographic examination were inconclusive as to how much the discontinuity could affect the structural integrity and performance of the concrete. The discontinuities, however, are likely old, pre-existing features, and are oriented horizontally (perpendicular to the structural loading direction).

Concrete contains potentially deleterious alkali-silica reactive aggregates; however, no evidence of significant alkali-silica reactions or associated distress is observed in the examined cores. Considering the old age and exposure conditions the concrete has undergone to date, as well as its relatively good condition, possibility of deleterious reactions in the future is judged to be minimal.

METHODS OF TEST

Petrographic examination of the provided samples was performed in accordance with ASTM C 856-04, "Standard Practice for Petrographic Examination of Hardened Concrete." Each core was visually inspected and photographed as received. For some longer cores, the sample was first saw-cut transversely near mid-length to facilitate subsequent preparation and handling**.** A slice was cut longitudinally from each core or core segment and one of the resulting sides of each slice was ground (lapped) to produce a smooth, flat, semi-polished surface. Lapped and freshly broken surfaces of the concrete were examined using a stereomicroscope at magnifications up to 45X.

For thin-section study, a small rectangular block was cut from each core, and one side of each block was lapped to produce a smooth, flat surface. Each block was cleaned and dried, and the prepared surface was mounted on a separate ground glass microscope slide with epoxy resin. After the epoxy hardened, the thickness of each mounted block was reduced to approximately 20 μm (0.0008 in.). The resulting thin sections were examined using a polarized-light (petrographic) microscope at magnifications up to 400X to study aggregate and paste mineralogy and microstructure.

Depth and pattern of paste carbonation was initially determined by application of a pH indicator solution (phenolphthalein) to freshly cut or fractured concrete surfaces. The solution is expected to impart a deep magenta stain to high pH, non-carbonated paste. Carbonated paste does not change color. The extent of paste carbonation was confirmed in thin-section.

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Notes: 1. Results refer specifically to the samples submitted.
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1a. Exterior end. Note the exposed and protruding aggregate particles.

1b. Side view of the core. Exterior end facing up.

1c. Interior end of the core.

Fig. 1 Core C-11, as received for examination.

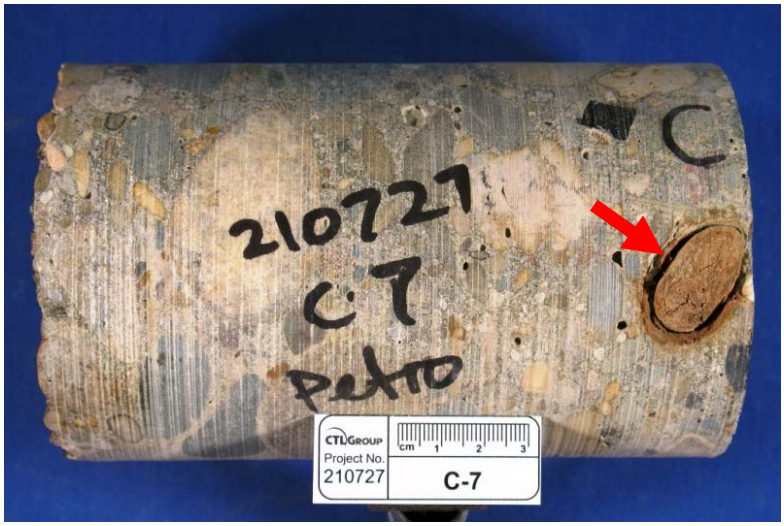
2a. Exterior end.

2b. Side view of the core. Exterior end to the left. Note that the core was cracked (red arrows) as received, along a suspected cold joint or lift line, further shown in Fig. 11.

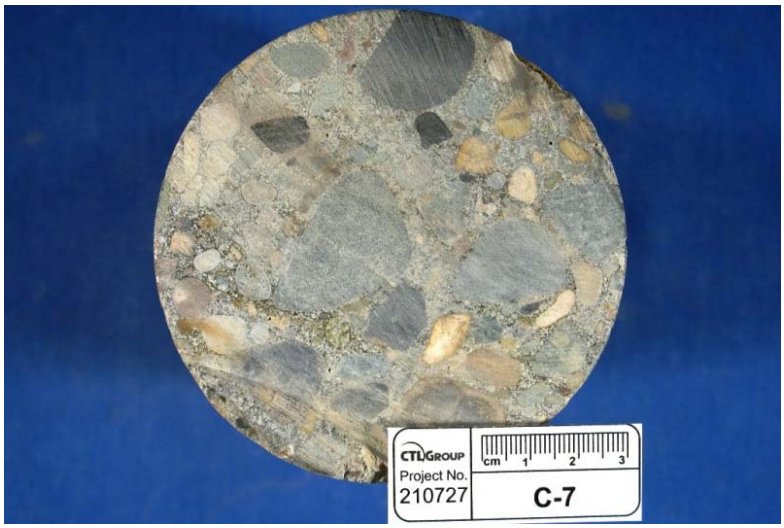
2c. Interior end of the core.

Fig. 2 Core C-12, as received for examination.

3a. Exterior end. Note the exposed and protruding aggregate particles.



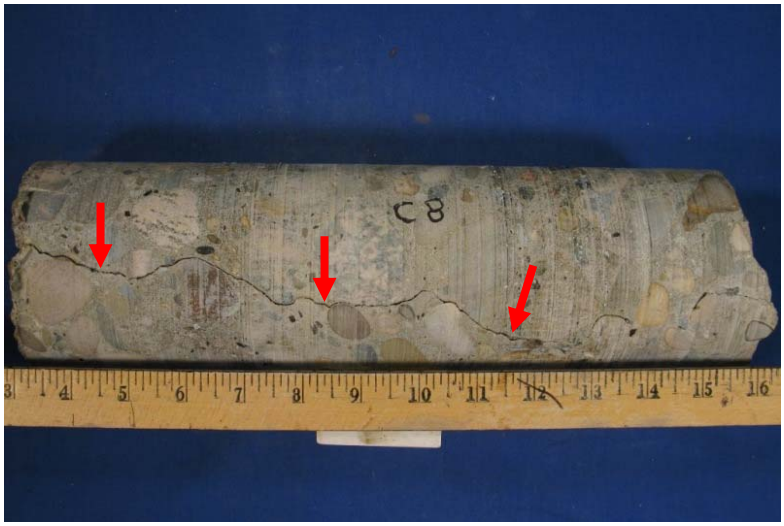
3b. Side view of the core. A short wood stick (red arrow) is observed at the interior end of the core. Exterior end to the left.



3c. Interior end of the core.

Fig. 3 Core C-7, as received for examination.

4a. Exterior end. Note the exposed and slightly protruding aggregate particles.



4b. Side view of the core. Exterior end to the left. Note the cracking (red arrows) that is further illustrated in Fig. 13.

4c. Interior end of the core.

Fig. 4 Core C-8, as received for examination.

5a. Top end.

5b. Side view of the core. Top end placed to the left.

5c. Bottom end of the core.

Fig. 5 Core C-9, as received for examination.

6a. Exterior end.

6b. Side view of the core. Exterior end to the left. Note the crack (red arrows) along a suspected cold joint or lift line that is further shown in Fig. 15.

6c. Interior end of the core.

Fig. 6 Core C-10, as received for examination.

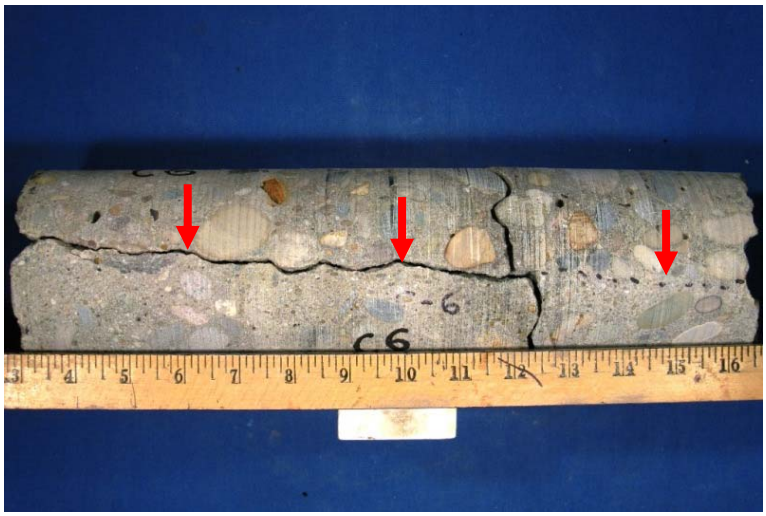
7a. Exterior end. Note the exposed and protruding aggregate particles.

7b. Side view of the core. Exterior end to the left.

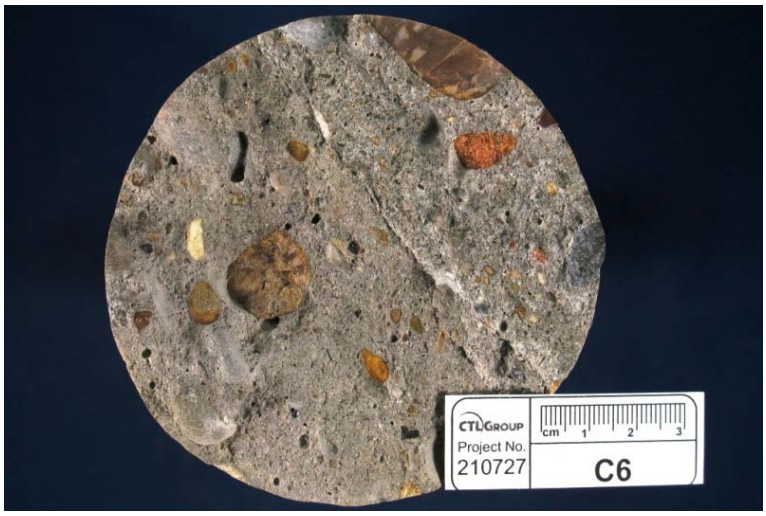
7c. Interior end of the core.

Fig. 7 Core C-5, as received for examination.

8a. Exterior end.



8b. Side view of the core. Exterior end to the left. Note that the core was fractured (red arrows) and partially opened along a suspected cold joint or lift line that is further shown in Fig. 17.



8c. Interior end of the core.

Fig. 8 Core C-6, as received for examination.

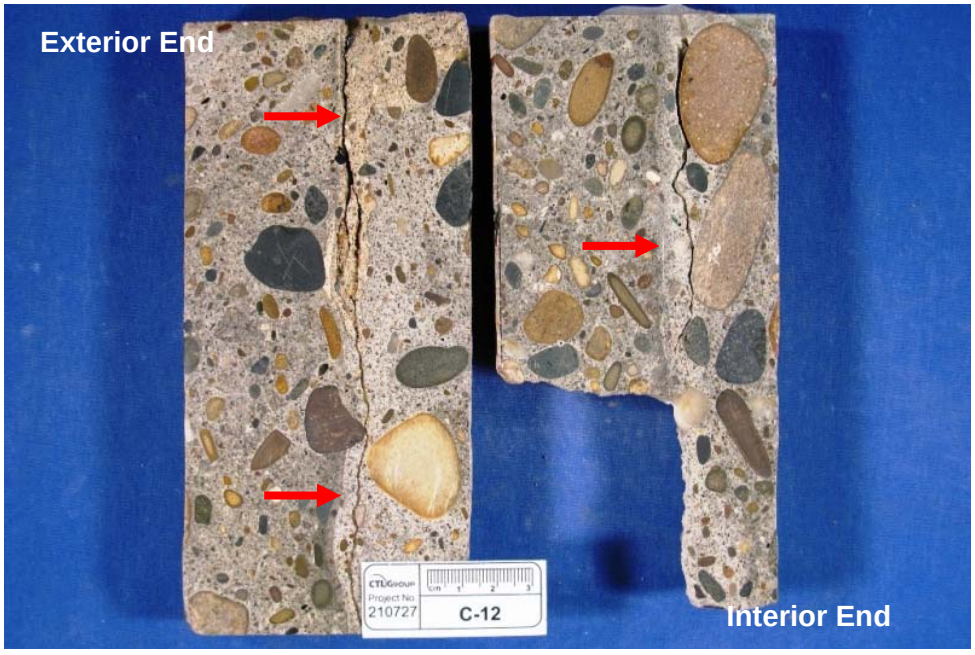
9a. Top end. Note the reprint of a reinforcing bar (red arrows).

9b. Side view of the core. Top end placed to the left. A suspected cold joint or lift line, oriented horizontally in structure but perpendicular to the core length, as shown (red arrow), is observed, and further shown in Fig. 18.

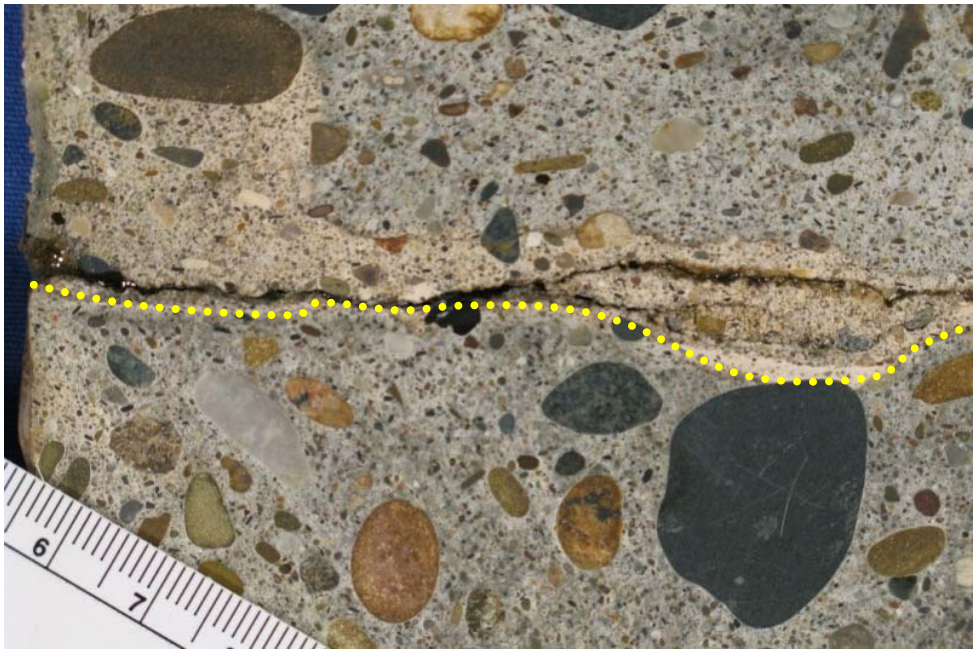
9c. Bottom end of the core.

Fig. 9 Core C4-ER to C4-ES, as received for examination.

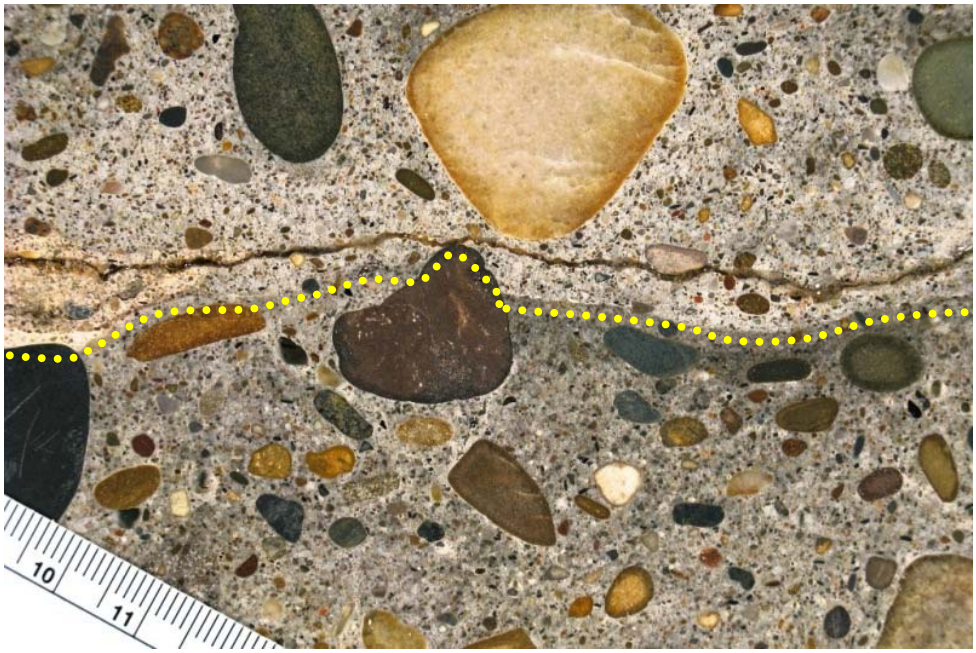
Fig. 10 Lapped longitudinal cross-section of Core C-11 illustrating its constituents and general condition. Exterior end facing up.



11a. Full cross section of core, saw-cut transversely at mid-length. Regions near the lift line or cold joint (red arrows) are further illustrated in 11b and 11c below.



11b. Close-up view of the lift line or cold joint near the exterior end of core.



11c. Close-up view of the lift line or cold joint region at greater depth.

Fig. 11 Closer view of the lapped longitudinal cross-section of Core C-12, previously depicted in Fig. 11a, exterior end to the left, further illustrating a discontinuity (yellow lines) likely representing a cold joint or lift line. Paste immediately above the lift line exhibits localized reduced qualities. The core cracked along or above the discontinuity line.

Fig. 12 Lapped longitudinal cross-section of Core C-7 illustrating its constituents and general condition. Exterior end placed to the left.

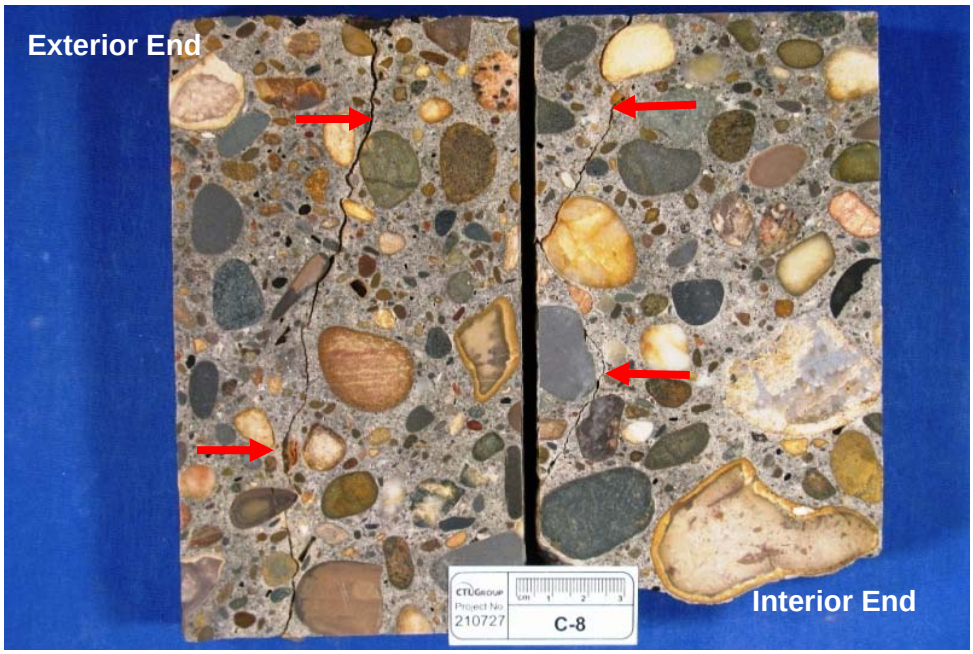


Fig. 13 Lapped longitudinal cross-section of Core C-8 illustrating its constituents and general condition. Full cross section of core, saw-cut transversely near mid-length. Note the full-length crack (marked with red arrows).

Fig. 14 Lapped longitudinal cross-section of Core C-9 illustrating its constituents and general condition. Full cross section of core, saw-cut transversely near mid-length.

Fig. 15 Lapped longitudinal cross-section of Core C-10 illustrating its constituents and general condition. Note a discontinuity is present and likely indicates a cold joint. Exterior end placed to the left.

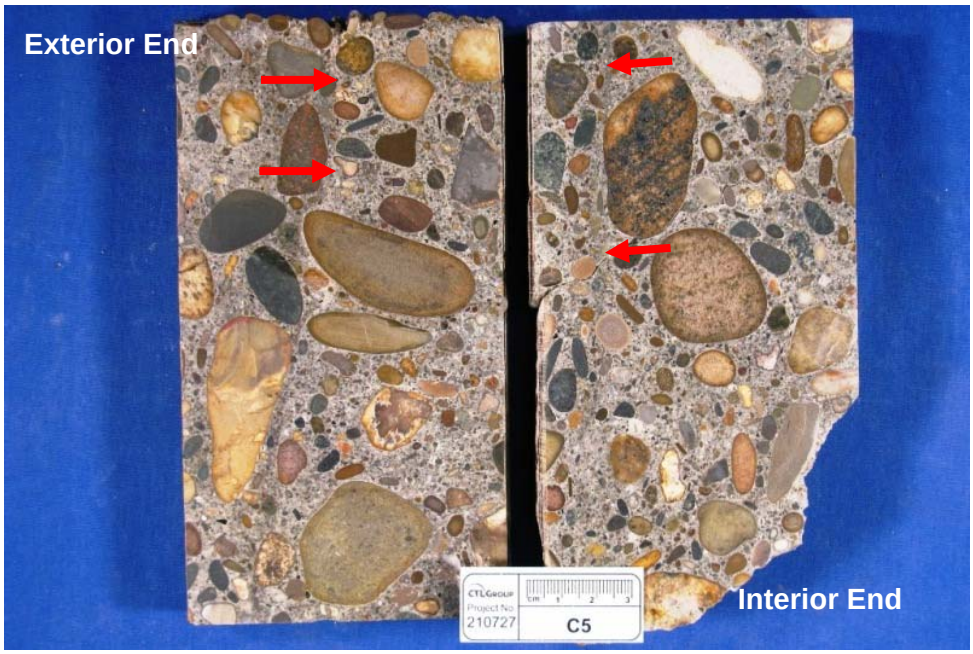
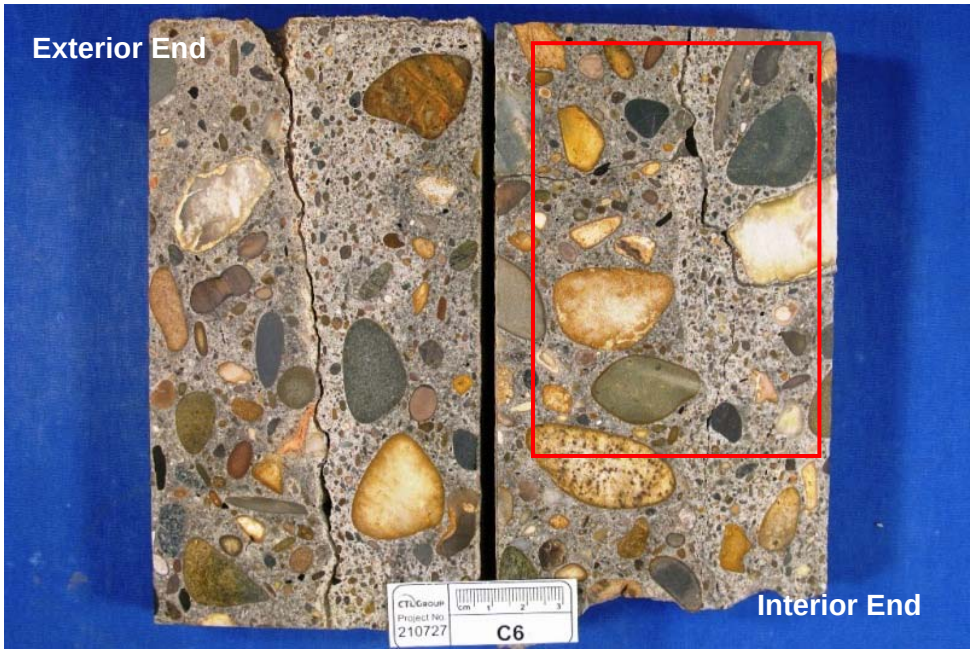
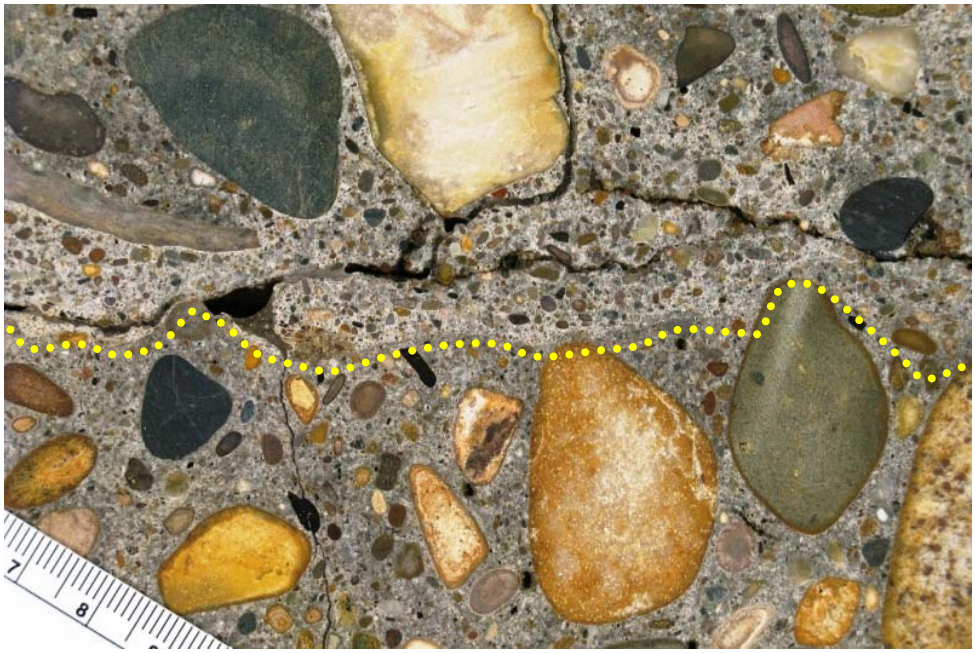


Fig. 16 Lapped longitudinal cross-section of Core C-5 illustrating its constituents and general condition. Note a weak and barely visible discontinuity (marked with red arrows), likely indicates a lift line or cold joint. Full-length cross section of core, saw-cut transversely near mid-length.



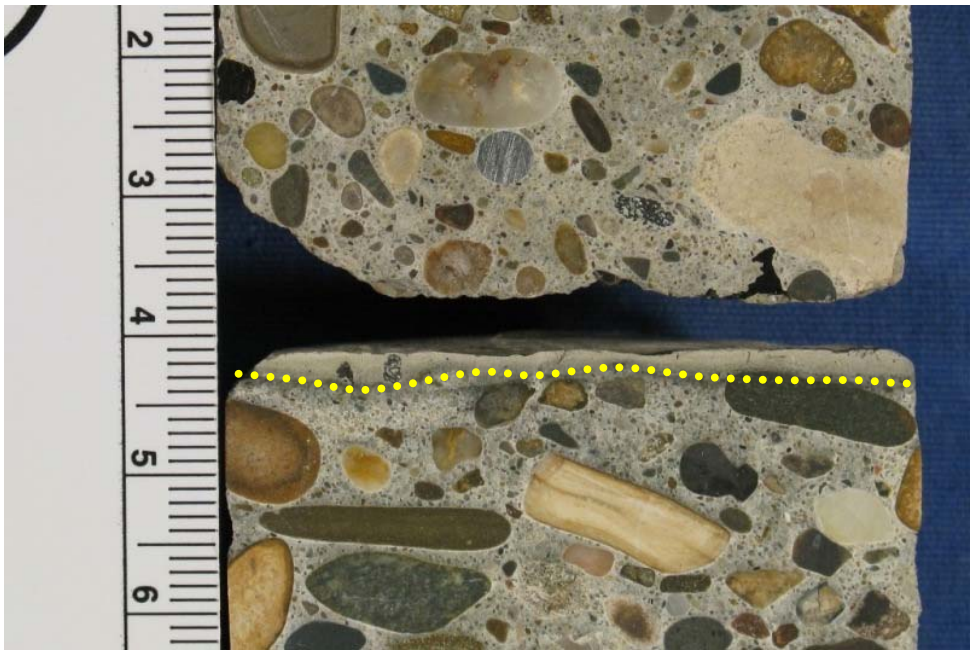
17a. Full-length cross section of Core C-6, saw-cut transversely at mid-length. Area in red rectangle is further illustrated below.



17b. Area in 17a, rotated 90° counter clockwise.

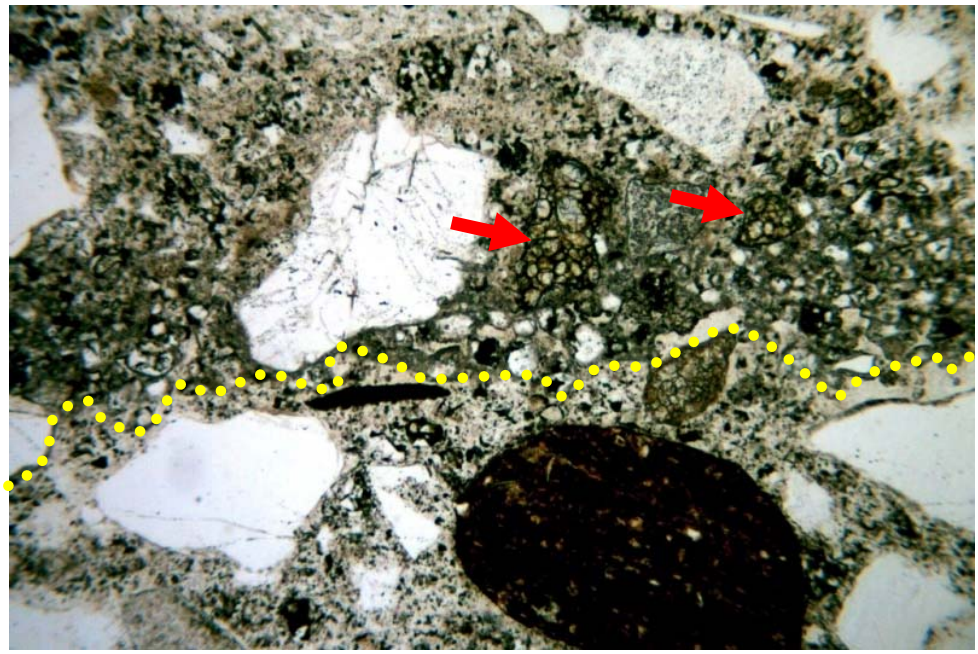
Fig. 17 Lapped longitudinal cross-section of Core C-6 illustrating its constituents and general condition. Note a discontinuity (yellow line) is present and likely indicates a cold joint. The core cracked and opened up along or above the discontinuity line.

18a. Full-length cross section of Core C4-ER to C4-ES, saw-cut transversely at depth of about 11 in. from top. Area in red rectangle is further illustrated below.

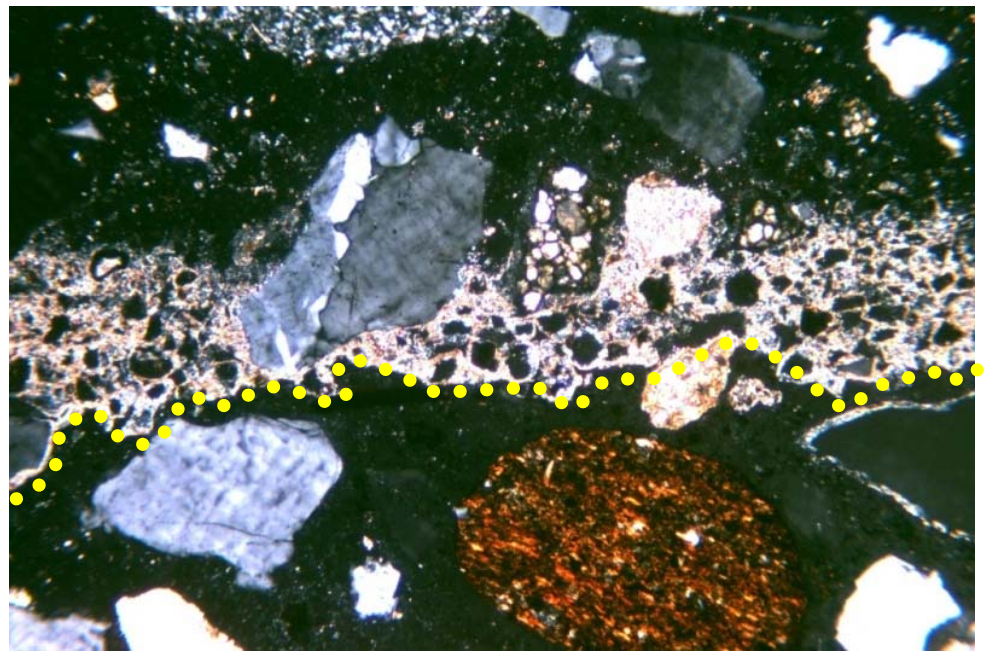


18b. Area in 18a, rotated 90° clockwise.

Fig. 18 Lapped longitudinal cross-section of Core C4 ER to C4-ES illustrating its constituents and general condition. Note a discontinuity (yellow line) is present and likely indicates a cold joint. The core broke above the discontinuity line during coring.



19a. Plane-polarized light.



19b. Same area as above, viewed with cross-polarized light.

Fig. 19 Thin-section photomicrographs of cement paste in a region along a lift line or cold joint in Core C-12. Yellow dotted line indicates the slightly carbonated lift line or cold joint boundary. Red arrows mark residual cement clinker particles. Field of view approximately 1.4 mm (0.06 in.) across.

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

STRUCTURE: Bridge pier wall

DATE RECEIVED: March 26, 2009

LOCATION: US 421 Bridge over Ohio River between Milton, KY and Madison, IN

EXAMINED BY: Hugh X. Hou

SAMPLE (FIG. 1)

Client Identification: C-11.

Dimensions: Core diameter = 82 mm (3.2 in.). Core length = 69 mm (2.7 in.); partial pier wall thickness.

Exterior End: Deeply eroded, rough concrete surface exhibits exposed, protruding coarse aggregate particles.

Interior End: Flat saw-cut surface.

Cracks, Joints, Large Voids: None observed in the core segment.

Reinforcement: None observed in the core segment.

AGGREGATES (FIG. 10)

Coarse: Natural gravel composed mainly of granite, sandstone, chert, quartzite and limestone with smaller amounts of volcanic rocks and other rock types.

Fine: Natural sand composed mainly of quartz/quartzite, limestone, granite, chert, sandstone, siltstone, with smaller amounts of volcanic rocks and other rock types.

Gradation & Top Size: Visually appears evenly graded to an observed top size of 27 mm (1.1 in.).

Shape, Texture, Distribution: Coarse – mostly rounded to sub-rounded and equant to slightly elongate. Fine – rounded to angular and equant to slightly elongate. Distribution of aggregates is fairly uniform.

PASTE (FIG. 10)

Color: Mottled medium gray.

Hardness: Moderately soft along exterior end to a depth of approximately 1 mm (0.04 in.); moderately hard to hard in body.

Luster: Subvitreous to dull.

Paste-Aggregate Bond: Moderately tight to tight.

Air Content: Estimated 1 to 2%. Concrete is not air entrained.

Depth of Carbonation: Approximately 1 mm (0.04 in.) from the existing exterior surface of exposed mortar (excluding protruded coarse aggregate); locally deeper to 5 mm (0.2 in.).

Calcium Hydroxide*: Estimated 7 to 12%, non-uniform.

Residual Portland Cement Clinker Particles*: Sparse; “ghost” relics of in-situ hydrated cement clinker are common.

Supplementary Cementitious Materials*: None observed.

Secondary Deposits: None observed.

MICROCRACKING: Sparse.

ESTIMATED WATER-CEMENT RATIO: Not provided, due to the old age of the concrete.

MISCELLANEOUS: Paste absorbency is moderately low.

---

* % by volume of paste

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

STRUCTURE: Bridge pier wall

DATE RECEIVED: March 17, 2009

LOCATION: US 421 Bridge over Ohio River between Milton, KY and Madison, IN

EXAMINED BY: Hugh X. Hou

SAMPLE (FIG. 2)

Client Identification: C-12.

Dimensions: Core diameter = 81 mm (3.2 in.). Core length = 280 to 350 mm (11.0 to 13.8 in.); partial pier thickness.

Exterior End: Moderately eroded, generally flat concrete surface exhibits some exposed fine aggregate particles and a gap or crack that is slightly off-center along core exterior surface. The crack extends to the core interior end. Reportedly it is oriented horizontally in the pier in field.

Interior End: Irregular fractured surface extends both through and around aggregate particles. A portion of concrete in the most interior 70 mm (2.8 in.) of concrete and below the discontinuity was not included.

Cracks, Joints, Large Voids: The core exhibits a major crack along full depth. However, the crack does not exactly coincide with a discontinuity seam of paste, instead, it occurs 1 to 10 mm (0.04 to 0.40 in.) above the discontinuity seam (in the lighter concrete portion) and runs overall parallel to the seam, as observed in the lapped, lengthwise cross section of the core (Fig. 11). The discontinuity seam appears to represent a horizontal lift line. A few short cracks, parallel to and near the discontinuity are observed. No major cracks or unusually large voids are observed in the remaining portion of core segment.

Reinforcement: None observed in the core segment.

AGGREGATES (FIG. 11)

Coarse: Natural gravel composed mainly of sandstone, quartzite, volcanic rocks, limestone and chert with smaller amounts of other rock types.

Fine: Natural sand composed mainly of quartz/quartzite, limestone, granite, chert, sandstone, siltstone, with smaller amounts of volcanic rocks and other rock types.

Gradation & Top Size: Visually appears evenly graded to an observed top size of 30 mm (1.2 in.).

Shape, Texture, Distribution: Coarse – mostly rounded to sub-rounded and equant to occasionally elongate. Fine – rounded to angular and equant to slightly elongate. Distribution of aggregates is fairly uniform.

PASTE (FIGS. 11 AND 19)

Color: Mottled medium gray in concrete below the discontinuity seam, light-medium gray in concrete above the discontinuity seam; locally beige in carbonated portions.

Hardness: Moderately hard to hard. Locally moderately soft near portions of the discontinuity or near the exterior surface.

Luster: Subvitreous to dull.

Paste-Aggregate Bond: Moderately tight.

Air Content: Estimated 1 to 2%. Concrete is not air entrained.

Depth of Carbonation: Typically 2 to 3 mm (0.08 to 0.12 in.), locally up to 25 mm (1.0 in.) from the exterior surface. Carbonation is also locally observed near the lift line.

Calcium Hydroxide*: Sparse in the examined thin section.

Residual Portland Cement Clinker Particles*: Typically sparse in body; abundant near the lift line. “Ghost” relics of in-site hydrated cement clinker are common in concrete away from discontinuity.

Supplementary Cementitious Materials*: None observed.

Secondary Deposits: Carbonate deposits are observed along the lift line discontinuity and along the fracture surface. Fractured surface of a chert aggregate particle at the interior end exhibits minor ASR gel.

MICROCRACKING: Microcracks are frequently observed adjacent to the discontinuity and mainly in the upper, lighter concrete portion; frequency of microcracks decreases away from the discontinuity.

ESTIMATED WATER-CEMENT RATIO: Not provided, due to the old age of the concrete.

MISCELLANEOUS:

1. Paste absorbency is moderately low.
2. Volume of coarse aggregate appears to be slightly lower than in the other submitted core samples.

---

* % by volume of paste

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

STRUCTURE: Bridge pier wall

DATE RECEIVED: March 26, 2009

LOCATION: US 421 Bridge over Ohio River between Milton, KY and Madison, IN

EXAMINED BY: Hugh X. Hou

SAMPLE (FIG. 3)

Client Identification: C-7.

Dimensions: Core diameter = 97 mm (3.8 in.). Core length = 160 mm (6.3 in.); partial pier wall thickness.

Exterior End: Deeply eroded, somewhat rough concrete surface exhibits exposed, protruding coarse and fine aggregate particles.

Interior End: Flat saw-cut surface.

Cracks, Joints, Large Voids: None observed in the core segment.

Reinforcement: None observed in the core segment.

AGGREGATES (Fig. 12)

Coarse: Natural gravel composed mainly of granite, sandstone, limestone, quartzite and chert with smaller amounts of volcanic rocks and other rock types.

Fine: Natural sand composed mainly of quartz/quartzite, limestone, granite, chert, sandstone, siltstone, with smaller amounts of volcanic rocks and other rock types.

Gradation & Top Size: Visually appears evenly graded to an observed top size of 33 mm (1.3 in.).

Shape, Texture, Distribution: Coarse – mostly rounded to sub-rounded and equant to slightly elongate. Fine – rounded to angular and equant to slightly elongate. Distribution of aggregates is fairly uniform.

PASTE (FIG. 12)

Color: Mottled medium gray.

Hardness: Moderately hard to hard.

Luster: Subvitreous to dull.

Paste-Aggregate Bond: Moderately tight to tight.

Air Content: Estimated 1 to 2%. Concrete is not air entrained.

Depth of Carbonation: Approximately 1 to 2 mm (0.04 to 0.08 in.) from existing exterior surface.

Calcium Hydroxide*: Estimated 7 to 11%, slightly non-uniform and locally lower.

Residual Portland Cement Clinker Particles*: Sparse; “ghost” relics of in-site hydrated cement clinker particles are common.

Supplementary Cementitious Materials*: None observed.

Secondary Deposits: None observed.

MICROCRACKING: Sparse.

ESTIMATED WATER-CEMENT RATIO: Not provided, due to the old age of the concrete.

MISCELLANEOUS: Paste absorbency is moderately low.

---

* % by volume of paste

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

STRUCTURE: Bridge pier wall

DATE RECEIVED: March 17, 2009

LOCATION: US 421 Bridge over Ohio River between Milton, KY and Madison, IN

EXAMINED BY: Hugh X. Hou

SAMPLE (FIG. 4)

Client Identification: C-8.

Dimensions: Core diameter = 97 mm (3.8 in.). Core length = 325 mm (12.8 in.); partial pier wall thickness.

Exterior End: Moderately to severely eroded, though otherwise generally flat concrete surface. The exterior surface exhibits some exposed coarse and fine aggregate particles and a crack, which is slightly off-center of core exterior surface and extends nearly to the core interior end. Reportedly the crack is oriented vertically in the pier wall in field.

Interior End: Irregular fractured surface extends both through and around aggregate particles.

Cracks, Joints, Large Voids: The crack throughout the core depth is locally curved, though overall straight. It extends around a majority of aggregate particles but through a few. No other major cracks, joints, or unusually large voids are observed in the core segment.

Reinforcement: None observed in the core segment.

AGGREGATES (FIG. 13)

Coarse: Natural gravel composed mainly of granite, sandstone, limestone, quartzite and chert with smaller amounts of volcanic rocks and other rock types.

Fine: Natural sand composed mainly of quartz/quartzite, limestone, granite, chert, sandstone, siltstone, with smaller amounts of volcanic rocks and other rock types.

Gradation & Top Size: Visually appears fairly evenly graded to an observed top size of 35 mm (1.4 in.).

Shape, Texture, Distribution: Coarse – mostly rounded to sub-rounded and equant to slightly elongate. Fine – rounded to angular and equant to slightly elongate. Distribution of aggregates is fairly uniform.

PASTE (FIG. 13)

Color: Mottled medium gray.

Hardness: Moderately hard to hard.

Luster: Subvitreous to dull.

Paste-Aggregate Bond: Moderately tight to tight.

Air Content: Estimated 1 to 2%. Concrete is not air entrained.

Depth of Carbonation: Approximately 2 mm (0.08 in.) from the exterior end.

Calcium Hydroxide*: Estimated 5 to 8%; not uniform and locally lower.

Residual Portland Cement Clinker Particles*: Sparse; “ghost” relics of in-site hydrated cement clinker particles are common.

Supplementary Cementitious Materials*: None observed.

Secondary Deposits: Carbonate crystals line portions of cracking faces. Carbonate deposits are observed around the periphery of some limestone or dolomitic limestone aggregate particles.

MICROCRACKING: Microcracks are frequently observed adjacent to the major crack; frequency of microcracks decreases away from the crack.

ESTIMATED WATER-CEMENT RATIO: Not provided, due to the old age of the concrete.

MISCELLANEOUS: Paste absorbency is generally moderately low.

---

* % by volume of paste

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

STRUCTURE: Bridge pier wall

DATE RECEIVED: March 17, 2009

LOCATION: US 421 Bridge over Ohio River between Milton, KY and Madison, IN

EXAMINED BY: Hugh X. Hou

SAMPLE (FIG. 5)

Client Identification: C-9.

Dimensions: Core diameter = 50 mm (2.0 in.). Core length = 315 to 330 mm (12.4 to 13.0 in.); partial pier depth.

Top End: Moderately eroded, uneven concrete surface exhibits some exposed coarse and fine aggregate particles.

Bottom End: Irregular fractured surface extends both through and around aggregate particles.

Cracks, Joints, Large Voids: No major cracks, joints, or unusually large voids are observed in the core segment.

Reinforcement: None observed in the core segment.

AGGREGATES (FIG. 14)

Coarse: Natural gravel composed mainly of granite, sandstone, limestone, quartzite and chert with smaller amounts of volcanic rocks and other rock types.

Fine: Natural sand composed mainly of quartz/quartzite, limestone, granite, chert, sandstone, siltstone, with smaller amounts of volcanic rocks and other rock types.

Gradation & Top Size: Visually appears fairly evenly graded to an observed top size of 42 mm (1.7 in.).

Shape, Texture, Distribution: Coarse – mostly rounded to sub-rounded and equant to occasionally slightly elongate. Fine – rounded to angular and equant to slightly elongate. Distribution of aggregates is fairly uniform.

PASTE (FIG. 14)

Color: Light-medium gray in upper 40 mm (1.6 in.) gradually changing to mottled medium gray in body.

Hardness: Moderately hard to hard.

Luster: Subvitreous to dull.

Paste-Aggregate Bond: Moderately tight.

Air Content: Estimated 2 to 3%. Concrete is not air entrained.

Depth of Carbonation: Typically 2 to 3 mm (0.08 to 0.12 in.); locally up to 18 mm (0.7 in.) from the top surface.

Calcium Hydroxide*: Estimated 6 to 9%.

Residual Portland Cement Clinker Particles*: Sparse; “ghost” relics of in-site hydrated cement clinker particles are common.

Supplementary Cementitious Materials*: None observed.

Secondary Deposits: None observed.

MICROCRACKING: Generally sparse.

ESTIMATED WATER-CEMENT RATIO: Not provided, due to the old age of the concrete.

MISCELLANEOUS: Paste absorbency is moderately low.

---

* % by volume of paste

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

STRUCTURE: Bridge pier wall

DATE RECEIVED: March 17, 2009

LOCATION: US 421 Bridge over Ohio River between Milton, KY and Madison, IN

EXAMINED BY: Hugh X. Hou

SAMPLE (FIG. 6)

Client Identification: C-10.

Dimensions: Core diameter = 96 mm (3.8 in.). Core length = 130 to 140 mm (5.1 to 5.5 in.); partial pier wall thickness.

Exterior End: Slightly eroded, generally flat concrete surface exhibits a straight discontinuity or crack that is slightly off-center along core exterior surface and extends to the core interior end. Reportedly the discontinuity or crack is oriented horizontally in the pier wall in field.

Interior End: Irregular fractured surface extends both through and around aggregate particles. The discontinuity is observed on the interior end surface.

Cracks, Joints, Large Voids: The core opened up longitudinally into two pieces along the discontinuity during sample preparation (Fig. 15). The discontinuity generally does not extend through aggregate particles throughout the core length, and appears to represent a horizontal lift line or very early age crack. No other major cracks or unusually large voids are observed in the core segment.

Reinforcement: None observed in the core segment.

AGGREGATES (FIG. 15)

Coarse: Natural gravel composed mainly of quartzite, sandstone, chert, limestone, and granite with smaller amounts of volcanic rocks and other rock types.

Fine: Natural sand composed mainly of quartz/quartzite, limestone, granite, chert, sandstone, siltstone, with smaller amounts of volcanic rocks and other rock types.

Gradation & Top Size: Visually appears fairly evenly graded to an observed top size of 30 mm (1.2 in.).

Shape, Texture, Distribution: Coarse – mostly rounded to sub-rounded and equant to occasionally slightly elongate. Fine – rounded to angular and equant to slightly elongate. Distribution of aggregates is fairly uniform.

PASTE (FIG. 15)

Color: Mottled medium gray.

Hardness: Moderately hard to hard.

Luster: Subvitreous to dull.

Paste-Aggregate Bond: Moderately tight.

Air Content: Estimated 1 to 2%. Concrete is not air entrained.

Depth of Carbonation: 2 to 5 mm (0.08 to 0.20 in.) from existing exterior surface.

Calcium Hydroxide*: Estimated 6 to 9%.

Residual Portland Cement Clinker Particles*: Sparse; “ghost” relics of in-site hydrated cement clinker particles are common.

Supplementary Cementitious Materials*: None observed.

Secondary Deposits: A thin layer of carbonate deposits is observed along the lift line discontinuity.

MICROCRACKING: Generally sparse.

ESTIMATED WATER-CEMENT RATIO: Not provided, due to the old age of the concrete.

MISCELLANEOUS: Paste absorbency is moderately low.

---

* % by volume of paste

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

STRUCTURE: Bridge pier wall

DATE RECEIVED: March 17, 2009

LOCATION: US 421 Bridge over Ohio River between Milton, KY and Madison, IN

EXAMINED BY: Hugh X. Hou

SAMPLE (FIG. 7)

Client Identification: C-5.

Dimensions: Core diameter = 96 mm (3.8 in.). Core length = 240 to 360 mm (9.4 to 14.2 in.); partial pier wall thickness.

Exterior End: Deeply eroded, generally flat but rough concrete surface exhibits exposed coarse aggregate particles. A straight discontinuity line or crack crosses the exterior surface center**.**

Interior End: Irregular fractured surface extends both through and around aggregate particles.

Cracks, Joints, Large Voids: The core was received transversely fractured at depths from 210 to 260 mm (8.3 to 10.2 in.) from the exterior end. A 20-mm (0.8-in.) diameter coal particle is observed on the fracture surface. The discontinuity described along exterior end becomes less apparent with increasing depth and barely visible near the core interior end (Fig. 16). Reportedly the discontinuity line or crack is oriented horizontally in the pier in field. It generally does not extend through aggregate particles and appears to represent a horizontal lift line or a very early-age crack. No other major cracks or unusually large voids are observed in the core segment.

Reinforcement: None observed in the core segment.

AGGREGATES (FIG. 16)

Coarse: Natural gravel composed mainly of quartzite, sandstone, chert, limestone, and granite with smaller amounts of volcanic rocks and other rock types.

Fine: Natural sand composed mainly of quartz/quartzite, limestone, granite, chert, sandstone, siltstone, with smaller amounts of volcanic rocks and other rock types.

Gradation & Top Size: Visually appears fairly evenly graded to an observed top size of 38 mm (1.5 in.).

Shape, Texture, Distribution: Coarse – mostly rounded to sub-rounded and equant to occasionally slightly elongate. Fine – rounded to angular and equant to slightly elongate. Distribution of aggregates is fairly uniform.

PASTE (FIG. 16)

Color: Mottled medium gray, locally slightly lighter in concrete below the discontinuity.

Hardness: Moderately hard to hard.

Luster: Subvitreous to dull.

Paste-Aggregate Bond: Moderately tight.

Air Content: Estimated 1 to 2%. Concrete is not air entrained.

Depth of Carbonation: Approximately 2 mm (0.08 in.) from existing exterior surface. Carbonation is also observed near the lift line.

Calcium Hydroxide*: Estimated 6 to 9%; non-uniform and locally lower.

Residual Portland Cement Clinker Particles*: Sparse; “ghost” relics of in-site hydrated cement clinker particles are common.

Supplementary Cementitious Materials*: None observed.

Secondary Deposits: Carbonate deposits are observed around the periphery of some limestone or dolomitic limestone aggregate particles. A thin layer of carbonate deposits was also observed along the discontinuity line. Minor amounts of ettringite is observed in the interfacial transition zone between a few aggregate particles and the surrounding paste.

MICROCRACKING: Microcracks are frequently observed. Some microcracks extend from aggregate particles into surrounding paste.

ESTIMATED WATER-CEMENT RATIO: Not provided, due to the old age of the concrete.

MISCELLANEOUS: Paste absorbency is moderately low.

---

* % by volume of paste

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

STRUCTURE: Bridge pier

DATE RECEIVED: March 17, 2009

LOCATION: US 421 Bridge over Ohio River between Milton, KY and Madison, IN

EXAMINED BY: Hugh X. Hou

SAMPLE (FIG. 8)

Client Identification: C-6.

Dimensions: Core diameter = 96 mm (3.8 in.). Core length = 350 mm (17.8 in.); partial pier thickness.

Exterior End: Moderately to slightly eroded, generally flat, though somewhat rough concrete surface exhibits some exposed fine aggregate particles and a separation gap that is slightly off center along core exterior surface.

Interior End: Irregular fractured surface extends both through and around aggregate particles.

Cracks, Joints, Large Voids: The core exhibits a major separation gap or fracture along full depth. The gap or fracture locally does not coincide with a discontinuity seam of paste, instead, it occurs 10 to 20 mm (0.4 to 0.8 in.) above the discontinuity seam and runs overall parallel to the seam, as observed in the lapped, lengthwise cross section of the core (Fig. 17). The discontinuity seam appears to represent a horizontal lift line. The core was received fractured into two segments at depth of 210 to 245 mm (8.3 to 9.6 in.). The exterior segment opens up along the lift line into two pieces. The interior segment remains intact along the lift line. A few short cracks, parallel to and near the discontinuity are observed. No major cracks or unusually large voids are observed in the core segment.

Reinforcement: None observed in the core segment.

AGGREGATES (FIG. 17)

Coarse: Natural gravel composed mainly of quartzite, sandstone, chert, limestone, and granite with smaller amounts of volcanic rocks and other rock types.

Fine: Natural sand composed mainly of quartz/quartzite, limestone, granite, chert, sandstone, siltstone, with smaller amounts of volcanic rocks and other rock types.

Gradation & Top Size: Visually appears fairly evenly graded to an observed top size of 29 mm (1.1 in.).

Shape, Texture, Distribution: Coarse – mostly rounded to sub-rounded and equant to occasionally slightly elongate. Fine – rounded to angular and equant to slightly elongate. Distribution of aggregates is fairly uniform.

PASTE (FIG. 17)

Color: Mottled medium gray; overall slightly lighter in concrete above the discontinuity.

Hardness: Moderately hard to hard.

Luster: Subvitreous to dull.

Paste-Aggregate Bond: Moderately tight.

Air Content: Estimated 1 to 2%. Concrete is not air entrained.

Depth of Carbonation: Approximately 2 mm (0.08 in.) from existing exterior surface. Carbonation is also observed near the lift line even in the portions where concrete did not fracture.

Calcium Hydroxide*: Estimated 6 to 10%; non-uniform and locally lower.

Residual Portland Cement Clinker Particles*: Sparse; “ghost” relics of in-site hydrated cement clinker particles are common.

Supplementary Cementitious Materials*: None observed.

Secondary Deposits: None observed.

MICROCRACKING: Microcracks are occasionally observed.

ESTIMATED WATER-CEMENT RATIO: Not provided, due to the old age of the concrete.

MISCELLANEOUS: Paste absorbency is moderately low.

---

* % by volume of paste

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

STRUCTURE: Bridge pier footing

DATE RECEIVED: March 26, 2009

LOCATION: US 421 Bridge over Ohio River between Milton, KY and Madison, IN

EXAMINED BY: Hugh X. Hou

SAMPLE (FIG. 9)

Client Identification: C4-ER to C4-ES.

Dimensions: Core diameter = 50 mm (2.0 in.). Core length = 480 mm (18.9 in.); partial footing depth.

Top End: Uneven fractured concrete surface exhibits an imprint of a reinforcing bar.

Bottom End: Irregular fractured surface extends both through and around aggregate particles.

Cracks, Joints, Large Voids: The core was received transversely fractured into 3 segments at depths of 60 and 165 mm (2.4 and 6.5 in.). The upper fracture occurs at an apparent lift line or joint, where a flat surface composed of a 2-mm (0.08 in.) thick cementitious-rich layer is observed. The other fracture occurs at the interface of a large aggregate particle. No other major cracks or unusually large voids are observed in the core segment.

Reinforcement: Two steel wires of 4 mm (0.16 in.) diameter are observed near the lift line of joint. Minor corrosion stains were observed on the wire ends.

AGGREGATES (FIG. 18)

Coarse: Natural gravel composed mainly of sandstone, quartzite, chert, limestone, and granite with smaller amounts of volcanic rocks and other rock types.

Fine: Natural sand composed mainly of quartz/quartzite, limestone, granite, chert, sandstone, siltstone, with smaller amounts of volcanic rocks and other rock types.

Gradation & Top Size: Visually appears fairly evenly graded to an observed top size of 30 mm (1.2 in.).

Shape, Texture, Distribution: Coarse – mostly rounded to sub-rounded and equant to occasionally slightly elongate. Fine – rounded to angular and equant to slightly elongate. Distribution of aggregates is fairly uniform.

PASTE (FIG. 18)

Color: Mottled light to medium gray.

Hardness: Moderately hard to locally moderately soft; locally moderately soft near the lift line.

Luster: Subvitreous to dull.

Paste-Aggregate Bond: Moderately tight to moderately weak.

Air Content: Estimated 1 to 2%. Concrete is not air entrained.

Depth of Carbonation: None observed along the core top surface; carbonation is also observed near the lift line.

Calcium Hydroxide*: Estimated 6 to 10%; non-uniform and locally sparse in the examined thin section.

Residual Portland Cement Clinker Particles*: Sparse; "ghost" relics of in-site hydrated cement clinker particles are common.

Supplementary Cementitious Materials*: None observed.

Secondary Deposits: Minor amounts of white deposits, suspected ettringite, are observed lining a few voids and around the peripheries of a few aggregate particles.

MICROCRACKING: Microcracks are sparse.

ESTIMATED WATER-CEMENT RATIO: Not provided, due to the old age of the concrete.

MISCELLANEOUS:

1. Paste absorbency is moderate.
2. No significant difference is noted between concrete above and below the discontinuity line.
3. Volume of paste appears to be lower than observed in other cores.

---

* % by volume of paste

APPENDIX D.4.2

Vertical Cores – Previous Visits

- **Report Dated February 18, 2009**

Copy No. 1

Wilbur Smith Associates

Project Number 210727

Petrographic Examination of Concrete Cores from Milton-Madison Bridge

Date:
February 18, 2009

Submitted by:
Hugh (Xiaoqiang) Hou

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REPORT OF PETROGRAPHIC EXAMINATION

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Date: February 18, 2009

CTLGroup Project No.: 210727

Petrographic Examination of Concrete Cores from Milton-Madison Bridge

Four concrete cores were received on January 27, 2009 from Mr. Salvador Villalobos-Chapa, CTLGroup Associate II, on behalf of Mr. Christopher Ligozio, CTLGroup Senior Engineer and Project Manager. Two additional cores were received on February 12, 2009 from Mr. Scott Wyatt, CTLGroup Senior Engineer. Reportedly, the submitted cores were extracted vertically from different elevations of existing piers for the US 421 Bridge over the Ohio River between Milton, Kentucky and Madison, Indiana, as part of an evaluation of the structure condition to determine the feasibility for reusing the piers to support a replacement superstructure. Reportedly, the bridge is approximately 80 years old. Table 1 provides a list of sample identifications, core elevations, and descriptions of the core location relative to water line. As-received photographs of the cores are provided in Figures 1 through 6.

TABLE 1 CORE SEGMENTS FROM MILTON/MADISON BRIDGE FOR PETROGRAPHIC EXAMINATION

Core Identification	Location Pier No.	Approx. Elevation (ft)*		Comments	Core Photographs
		from	to		
C1-CR (2)	8	99.0	99.7	Near/below waterline	Fig. 1
C1-EW (2)	8	165.4	166.1	Near bottom of pier	Fig. 2
C2-CQ	7	101.9	102.8	Near/below waterline	Fig. 3
C2-GR & C2-GS	7	168.1	169.2	Near bottom of pier	Fig. 4
C3-CS	6	97.7	98.8	Near waterline	Fig. 5
C4-CM	9	73.9	74.8	Near waterline	Fig. 6

* Depth from top of pier

Full petrographic examination (ASTM C 856) of the early provided core samples C1-CR (2), C1-EW (2), C2-CQ, and C2-GR & C2-GS, and brief petrographic examination of the later provided core samples C3-CS and C4-CM, were requested to assess the material properties and condition of the concrete.

FINDINGS AND CONCLUSIONS

Based on results of the petrographic examination, concrete represented by the provided core segments is judged to be of generally good quality and appears to be overall in good condition. Concrete in all core segments contains similar constituents, each consisting of natural gravel and sand distributed in a hardened, non-air entrained portland cement paste (Figs. 7 through 12). The following additional findings and descriptions of the concrete are based on results of the petrographic examination, details of which are provided in the attached data sheets.

1. Aggregate characteristics differ somewhat among the group of core segments. Although the overall composition of the natural gravel and sand aggregate is generally similar, some differences are observed in aggregate gradation and top size, and possibly aggregate volume. Visible characteristics of the aggregate are illustrated in Figs. 7 through 12. Constituents of both coarse and fine aggregates are generally hard and dense. Coarse aggregate is comprised mainly of granite, sandstone, limestone, quartzite and chert. Fine aggregate is comprised mainly of quartz/quartzite, limestone, granite, chert, and sandstone. Maximum observed aggregate size ranges from 20 to 30 mm (0.8 to 1.2 in.) among the examined core segments. Aggregate distribution within individual core section is generally uniform.

2. While concrete properties vary somewhat among the core segments, in general the paste is medium-dark or medium gray in color (Figs. 7 through 12), moderately hard to hard, exhibits subvitreous to dull luster, and moderately low to moderate in water absorbency. Paste-aggregate bond is moderately tight to tight. Selected major concrete properties of the core segments are summarized in Table 2.

3. No supplementary cementitious materials are observed in the hardened paste.

4. No major cracks or excessive microcracks are observed in the cores.

5. Concrete represented in each core appears well consolidated.

TABLE 2 SUMMARY OF PASTE PROPERTIES IN CORE SEGMENTS FROM MILTON-MADISON BRIDGE

Core	Color	Hardness	Luster	Absorbency	Paste-Aggregate Bond
C1-CR (2)	Mottled medium-dark gray	Hard	Subvitreous	Moderately low	Tight to moderately tight
C1-EW (2)	Mottled medium gray	Moderately hard to hard	Subvitreous to dull	Moderate to moderately low	Moderately tight
C2-CQ	Medium to medium-dark gray	Hard	Subvitreous	Moderately low	Tight to moderately tight
C2-GR & C2-GS	Light to medium-dark gray, non-uniform (see datasheets for details)	Generally moderately hard to hard	Subvitreous to dull	Moderate to moderately low	Moderately tight
C3-CS	Dark-medium gray	Hard	Subvitreous	Moderately low to low	Tight to moderately tight
C4-CM	Mottled medium gray	Moderately hard to hard	Subvitreous to dull	Moderately low	Moderately tight

6. No reinforcement is noted in the core segments.

7. Concrete represented by core segments is not air entrained based on the scarcity of small, spherical voids in the hardened cement paste. Air content in most of the cores is estimated 1 to 2%.

8. The concrete exhibits evidence of prolonged or periodic exposure to moisture-saturated conditions over the life of the structure. Relics of in-situ hydrated portland cement clinker particles are common and unhydrated clinker particles are scarce in the paste (Figs. 13, 14, and 15), which indicates an advanced degree of cement hydration. Furthermore, secondary deposits of ettringite, and locally some portlandite (calcium hydroxide), line or partially fill some air voids and microcracks within the concrete (Fig. 13). Formation of such deposits is further indications of exposure of the concrete to moisture or moisture-saturated conditions.

9. Concrete in Core C2-GR & C2-GS exhibits an abrupt discontinuity in appearance that likely represents a lift line or cold joint. A distinct boundary is observed at a depth of

approximately 130 mm (5.1 in.) from the top end of the core (Figs. 10 and 13). Concrete immediately above and below the joint exhibits somewhat contrasting paste properties, with noticeably reduced paste quality below the discontinuity and improved paste quality above, due probably to localized variations in original water-to-cement ratios.

10. Carbonation of paste was generally not observed near the core end surfaces as the submitted core segments were taken from the interior of piers, away from surfaces exposed to air. However, minor secondary carbonate deposits are observed along the periphery of some dolomitic limestone aggregate in the concrete (Figs. 15 and 16), a feature probably related to the aggregate.

ADDITIONAL COMMENTS

Since the concrete is not air entrained, its durability may be compromised if exposed to freeze-thaw cycles when moisture saturated. As concrete near the exposed, outer surfaces of the pier was not provided for examination, evaluation of frost damage to the concrete could not be addressed by this petrographic study.

Concrete contains potentially deleterious alkali-aggregate reactive components; however, no evidence of significant alkali-aggregate reactions or associated distress is observed. Considering the old age and the exposure conditions the concrete to date, as well as its relatively good condition, possibility of deleterious reactions in the future is judged to be minimal.

METHODS OF TEST

Petrographic examination of the provided samples was performed in accordance with ASTM C 856-04, "Standard Practice for Petrographic Examination of Hardened Concrete." Each core was visually inspected and photographed as received. A slice was cut longitudinally from each core and one of the resulting sides of each slice was ground (lapped) to produce a smooth, flat, semi-polished surface. Lapped and freshly broken surfaces of the concrete were examined using a stereomicroscope at magnifications up to 45X.

For thin-section study of the cores requested for full petrographic examination, a small rectangular block was cut from each core, and one side of each block was lapped to produce a smooth, flat surface. Each block was cleaned and dried, and the prepared surface was mounted on a separate ground glass microscope slide with epoxy resin. After the epoxy hardened, the thickness of each mounted block was reduced to approximately 20 μm (0.0008 in.). The resulting thin sections were examined using a polarized-light (petrographic) microscope at magnifications up to 400X to study aggregate and paste mineralogy and microstructure.

Depth and pattern of paste carbonation was initially determined by application of a pH indicator solution (phenolphthalein) to freshly cut or fractured concrete surfaces. The solution is expected to impart a deep magenta stain to high pH, non-carbonated paste. Carbonated paste does not change color. The extent of paste carbonation was confirmed in thin-section.

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Notes: 1. Results refer specifically to the samples submitted.
2. This report may not be reproduced except in its entirety.

1a. Core top end.

1b. Core side view. Top end placed to the left.

Fig. 1 Core C1-CR (2), as received for examination.

2a. Core top end.

2b. Core side view. Top end placed to the left.

Fig. 2 Core C1-EW (2), as received for examination.

3a. Core top end.

3b. Core side view. Top end placed to the left.

Fig. 3 Core C2-CQ, as received for examination.

4a. Core top end.

4b. Core side view. Top end placed to the left.

Fig. 4 Core C2-GR & C2-GS, as received for examination. Note in the lower image that the core was fractured (red arrows) as received, with upper portion labeled as C2-GR and lower as C2-GS. A suspected cold joint is indicated with blue arrows, and further shown in Fig. 10.

5a. Core top end.

5b. Core side view. Top end placed to the left.

Fig. 5 Core C3-CS, as received for examination.

6a. Core top end.

6b. Core side view. Top end placed to the left.

Fig. 6 Core C4-CM, as received for examination.

Fig. 7 Lapped longitudinal cross-section of Core C1-CR (2) illustrating its constituents and general condition.

Fig. 8 Lapped longitudinal cross-section of lower 8 in. of Core C1-EW (2) illustrating its constituents and general condition.

Fig. 9 Lapped longitudinal cross-section of lower 8 in. of Core C2-CQ illustrating its constituents and general condition.

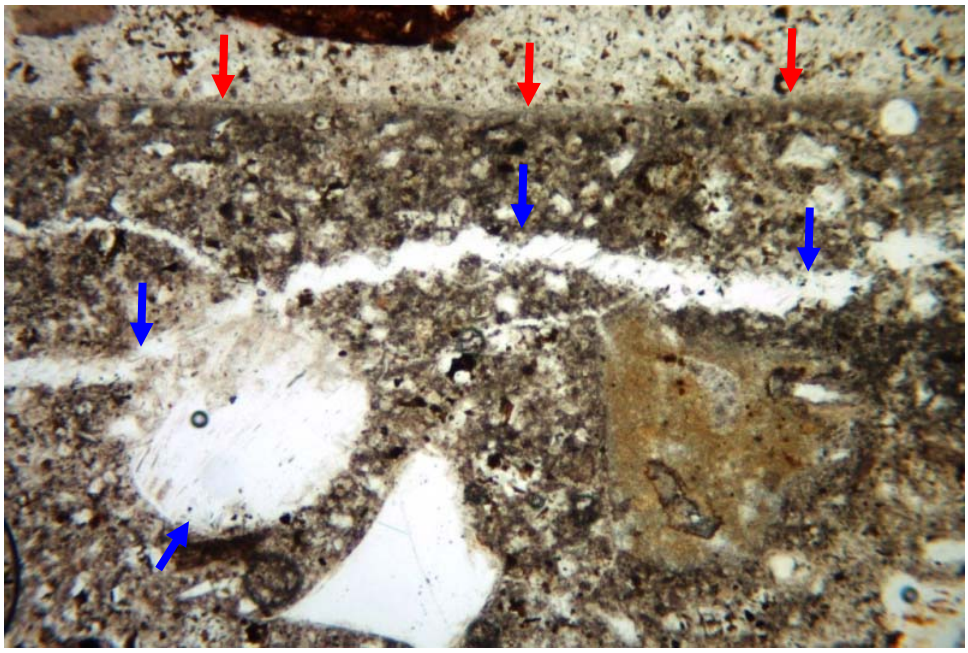
10a. Full cross section of core, saw-cut transversely at mid-length.

10b. Close-up view of the cold joint region.

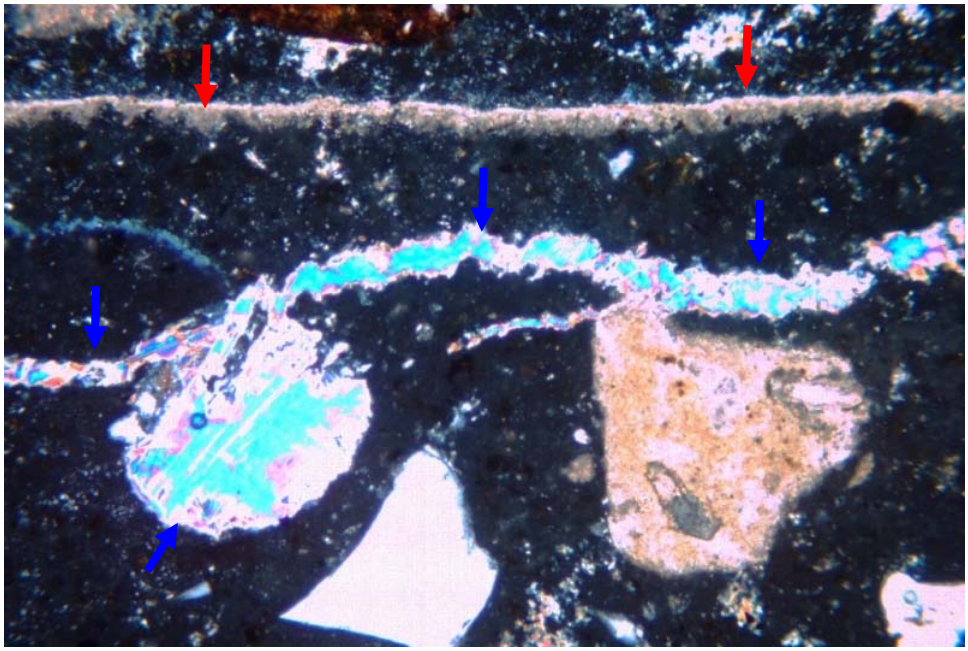
Fig. 10 Lapped longitudinal cross-section of Core C2-GR & C2-GS illustrating its constituents and general condition. Note a distinct transverse boundary (red arrows) is present and likely indicates a cold joint. Microscopic features near the joint are documented in Fig. 13 below.

Fig. 11 Lapped longitudinal cross-section of lower 8 in. of Core C3-CS illustrating its constituents and general condition.

Fig. 12 Lapped longitudinal cross-section of Core C4-CM illustrating its constituents and general condition.

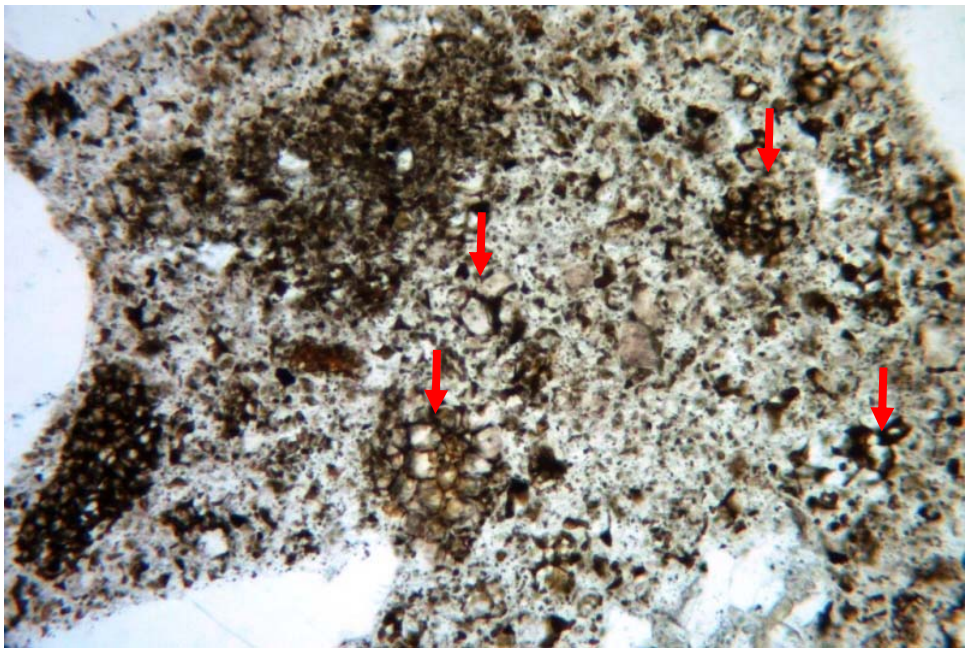


13a. Plane-polarized light.

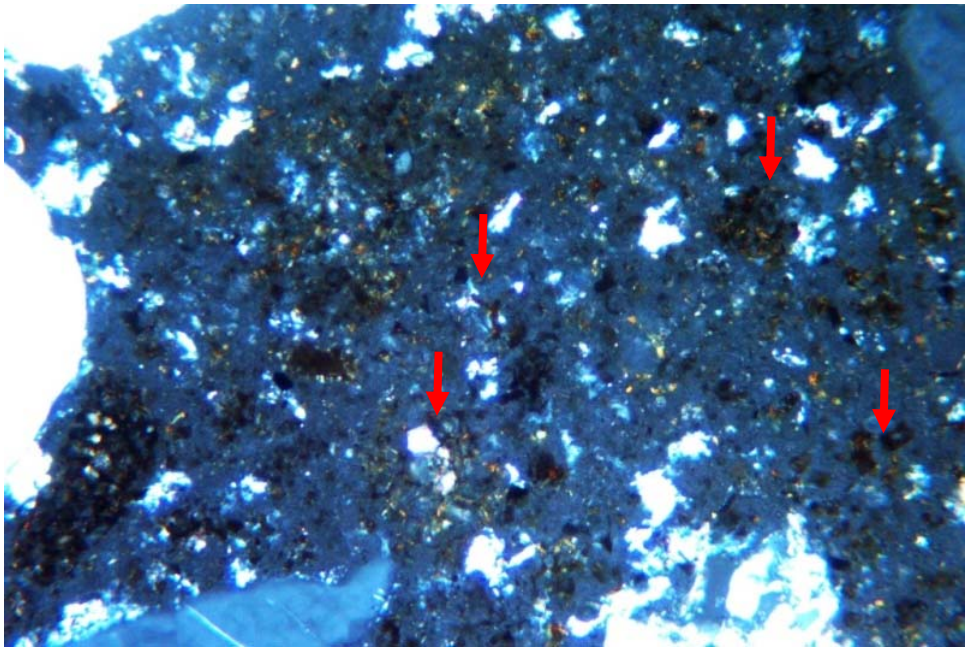


13b. Same area as above, viewed with cross-polarized light.

Fig. 13 Thin-section photomicrographs of cement paste in the region near a cold joint in Core C2-GR & C2-GS. Red arrows indicate a slightly carbonated lift line surface or cold joint. Blue arrows mark a relic horizontal tear and void filled with portlandite calcium. Field of view approximately 1.4 mm (0.06 in.) across.

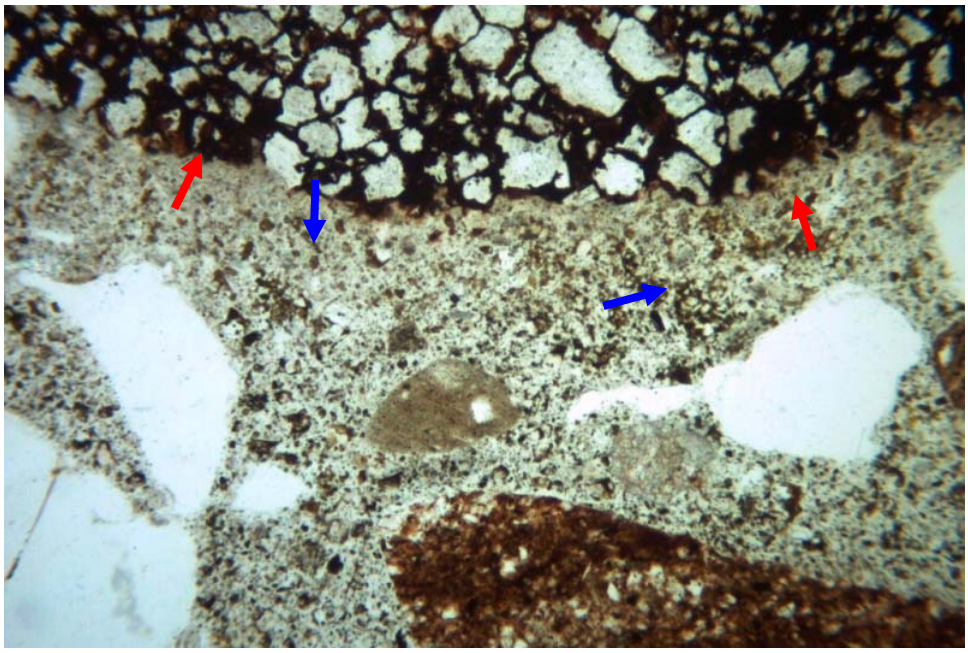


14a. Plane-polarized light.

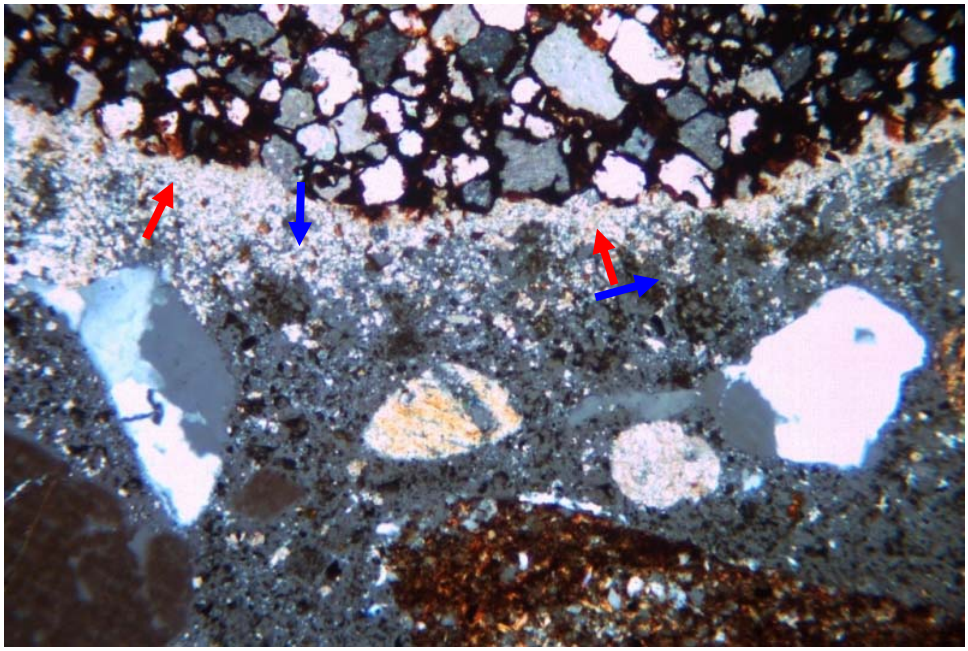


14b. Same area as above, viewed with cross-polarized light.

Fig. 14 Thin-section photomicrographs of cement paste in body of Core C1-CR (2). Red arrows indicate portland cement clinker particles that are in an advanced hydration stage. Field of view approximately 0.7 mm (0.03 in.) across.



15a. Plane-polarized light.



15b. Same area as above, viewed with partially cross-polarized light.

Fig. 15 Thin-section photomicrographs of cement paste in Core C1-EW (2). Blue arrows indicate portland cement clinker particles that are in an advanced state of hydration. Red arrows indicate carbonate deposits around periphery of a dolomitic limestone particle. Field of view approximately 1.4 mm (0.06 in.) across.

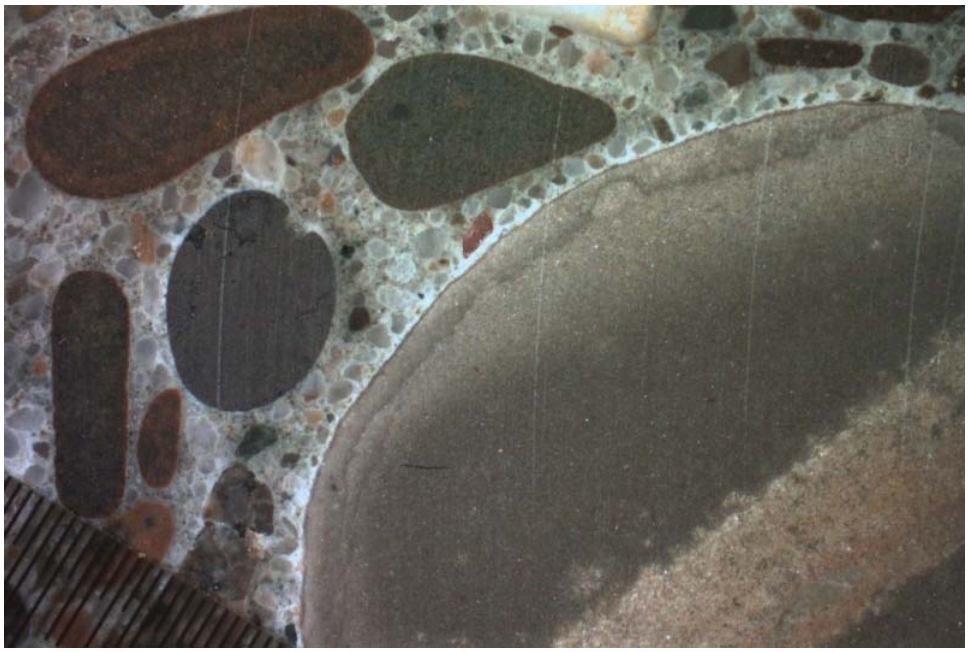


Fig. 16 Stereo-photomicrograph of the lapped surface of Core C2-GS illustrating white, carbonate deposits around periphery of a dolomitic limestone particle. Scale shown at bottom-left is marked in 0.01 in. increments.

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

STRUCTURE: Bridge pier

DATE RECEIVED: January 27, 2009

LOCATION: US 421 Bridge over Ohio River between Milton, KY and Madison, IN

EXAMINED BY: Hugh X. Hou

SAMPLE

Client Identification: C1-CR (2).

Dimensions: Core diameter = 50 mm (2.0 in.). Core length = 225 to 240 mm (8.9 to 9.4 in.); partial pier depth.

Top End: Irregular fractured surface extends both through and around aggregate particles.

Bottom End: Somewhat flat, fractured surface extends both through and around aggregate particles.

Cracks, Joints, Large Voids: None observed in the core segment.

Reinforcement: None observed in the core segment.

AGGREGATES

Coarse: Natural gravel composed mainly of granite, sandstone, limestone, quartzite and chert with smaller amounts of volcanic rocks, siltstone, and other rock types.

Fine: Natural sand composed mainly of quartz/quartzite, limestone, granite, chert, sandstone, siltstone, with smaller amounts of volcanic rocks and other rock types.

Gradation & Top Size: Visually appears evenly graded to an observed top size of 20 mm (0.8 in.).

Shape, Texture, Distribution: Coarse – mostly rounded to sub-rounded and equant to slightly elongate. Fine – rounded to angular and equant to slightly elongate.

PASTE

Color: Mottled medium-dark gray.

Hardness: Hard.

Luster: Subvitreous.

Paste-Aggregate Bond: Tight to moderately tight.

Air Content: Estimated 1 to 2%. Concrete is not air entrained.

Depth of Carbonation: None observed in the core segment.

Calcium Hydroxide*: Estimated 4 to 7%, non-uniform.

Residual Portland Cement Clinker Particles*: Estimated less than 1%, “ghost” relics are common.

Supplementary Cementitious Materials*: None observed.

Secondary Deposits: Carbonate deposits are observed around the periphery of some limestone or dolomitic limestone aggregate particles; ettringite lines some voids.

MICROCRACKING: Sparse.

ESTIMATED WATER-CEMENT RATIO: Not provided, due to the old age of the concrete.

MISCELLANEOUS: Paste absorbency is moderately low.

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

STRUCTURE: Bridge pier

DATE RECEIVED: January 27, 2009

LOCATION: US 421 Bridge over Ohio River between Milton, KY and Madison, IN

EXAMINED BY: Hugh X. Hou

SAMPLE

Client Identification: C1-EW (2).

Dimensions: Core diameter = 50 mm (2.0 in.). Core length = 265 to 280 mm (10.4 to 11.0 in.); partial pier depth.

Top End: Irregular fractured surface extends both through and around aggregate particles.

Bottom End: Irregular fractured surface extends both through and around aggregate particles.

Cracks, Joints, Large Voids: None observed in the core segment.

Reinforcement: None observed in the core segment.

AGGREGATES

Coarse: Natural gravel composed mainly of granite, sandstone, limestone, quartzite and chert with smaller amounts of volcanic rocks and other rock types.

Fine: Natural sand composed mainly of quartz/quartzite, limestone, granite, chert, sandstone, siltstone, with smaller amounts of volcanic rocks and other rock types.

Gradation & Top Size: Visually appears evenly graded to an observed top size of 30 mm (1.2 in.).

Shape, Texture, Distribution: Coarse – mostly rounded to sub-rounded and equant to slightly elongate. Fine – rounded to angular and equant to slightly elongate.

PASTE

Color: Mottled medium gray.

Hardness: Moderately hard to hard.

Luster: Subvitreous to dull.

Paste-Aggregate Bond: Moderately tight.

Air Content: Estimated 1 to 2%. Concrete is not air entrained.

Depth of Carbonation: None observed in the core segment.

Calcium Hydroxide*: Estimated 3 to 6%, non-uniform.

Residual Portland Cement Clinker Particles*: Rarely observed, “ghost” relics are common.

Supplementary Cementitious Materials*: None observed.

Secondary Deposits: The surface of a chert coarse aggregate particle at the bottom end exhibits minor ASR gel. Carbonate deposits are observed around the periphery of some limestone or dolomitic limestone aggregate particles; ettringite lines some voids.

MICROCRACKING: Sparse.

ESTIMATED WATER-CEMENT RATIO: Not provided, due to the old age of the concrete.

MISCELLANEOUS: Paste absorbency is moderate to moderately low.

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* % by volume of paste

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

STRUCTURE: Bridge pier

DATE RECEIVED: January 27, 2009

LOCATION: US 421 Bridge over Ohio River between Milton, KY and Madison, IN

EXAMINED BY: Hugh X. Hou

SAMPLE

Client Identification: C2-CQ.

Dimensions: Core diameter = 50 mm (2.0 in.). Core length = 275 mm (10.8 in.); partial pier depth.

Top End: Somewhat flat and rough fractured surface extends both through and around aggregate particles.

Bottom End: Somewhat flat surface exhibits some small wooden fragments and generally intact aggregate particles.

Cracks, Joints, Large Voids: None observed in the core segment.

Reinforcement: None observed in the core segment.

AGGREGATES

Coarse: Natural gravel composed mainly of granite, sandstone, limestone, quartzite and chert with smaller amounts of volcanic rocks and other rock types.

Fine: Natural sand composed mainly of quartz/quartzite, limestone, granite, chert, sandstone, siltstone, with smaller amounts of volcanic rocks and other rock types.

Gradation & Top Size: Visually appears evenly graded to an observed top size of 25 mm (1.0 in.).

Shape, Texture, Distribution: Coarse – mostly rounded to sub-rounded and equant to slightly elongate. Fine – rounded to angular and equant to slightly elongate.

PASTE

Color: Medium-dark gray in upper approximately 9 in; medium gray in lower 2 in.

Hardness: Hard.

Luster: Subvitreous.

Paste-Aggregate Bond: Tight to moderately tight.

Air Content: Estimated 1 to 2%. Concrete is not air entrained.

Depth of Carbonation: None observed in the core segment.

Calcium Hydroxide*: Estimated 7 to 11%, non-uniform.

Residual Portland Cement Clinker Particles*: Rarely observed, “ghost” relics are common.

Supplementary Cementitious Materials*: None observed.

Secondary Deposits: Carbonate deposits are observed around the periphery of some limestone or dolomitic limestone aggregate particles; ettringite lines some voids.

MICROCRACKING: Sparse.

ESTIMATED WATER-CEMENT RATIO: Not provided, due to the old age of the concrete.

MISCELLANEOUS: Paste absorbency is moderately low.

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* % by volume of paste

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

STRUCTURE: Bridge pier

DATE RECEIVED: January 27, 2009

LOCATION: US 421 Bridge over Ohio River between Milton, KY and Madison, IN

EXAMINED BY: Hugh X. Hou

SAMPLE

Client Identification: C2-GR & C2-GS.

Dimensions: Core diameter = 50 mm (2.0 in.). Core length = 350 to 365 mm (13.8 to 14.4 in.), reassembled; partial pier depth.

Top End: Irregular fractured surface extends mainly around aggregate particles and exhibits white deposits in aggregate sockets and air voids.

Bottom End: Irregular fractured surface extends mainly around aggregate particles.

Cracks, Joints, Large Voids: The core was received fractured at a depth of 80 mm (3.1 in.) from top end into two segments, labeled as C2-GR (smaller, upper segment) and C2-GS (larger, lower segment), respectively. A distinct boundary suggesting a lift line and cold joint is observed at a depth of approximately 130 mm (5.1 in.) from the top end. No unusually large voids were observed in the core.

Reinforcement: None observed in the core segment.

AGGREGATES

Coarse: Natural gravel composed mainly of granite, sandstone, limestone, quartzite and chert with smaller amounts of volcanic rocks and other rock types.

Fine: Natural sand composed mainly of quartz/quartzite, limestone, granite, chert, sandstone, siltstone, with smaller amounts of volcanic rocks and other rock types.

Gradation & Top Size: Visually appears fairly evenly graded to an observed top size of 27 mm (1.1 in.).

Shape, Texture, Distribution: Coarse – mostly rounded to sub-rounded and equant to slightly elongate. Fine – rounded to angular and equant to slightly elongate.

PASTE

Color: Non-uniform across the core depth profile. Light gray in upper approximately 100 mm (3.9 in.), darkening into medium-dark gray to the cold joint at depth of ~130 mm (5.1 in.) from top end; light gray immediately underneath the cold joint, darkening into medium gray.

Hardness: Typically moderately hard to hard; locally hard in the medium-dark gray portion, and moderately soft in the light gray portion near the cold joint.

Luster: Subvitreous to dull.

Paste-Aggregate Bond: Moderately tight.

Air Content: Estimated 1 to 2%. Concrete is not air entrained.

Depth of Carbonation: None observed in the core segment.

Calcium Hydroxide*: Estimated 9 to 15%; not uniform and locally higher or lower.

Residual Portland Cement Clinker Particles*: Estimated less than 1% in a majority of the paste; locally higher in the medium-dark gray portion near the cold joint.

Supplementary Cementitious Materials*: None observed.

Secondary Deposits: Ettringite many voids near the cold joint. Calcium hydroxide crystals line a tear in the concrete just below the cold joint. Carbonate deposits are observed around the periphery of some limestone or dolomitic limestone aggregate particles;

MICROCRACKING: Generally sparse; a few microcracks or relic micro-tears near and parallel to the cold joint surface are observed.

ESTIMATED WATER-CEMENT RATIO: Not provided, due to the old age of the concrete.

MISCELLANEOUS: Paste absorbency is generally moderate to moderately low; locally moderately high under the cold joint lift line.

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* % by volume of paste

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

STRUCTURE: Bridge pier

DATE RECEIVED: February 12, 2009

LOCATION: US 421 Bridge over Ohio River between Milton, KY and Madison, IN

EXAMINED BY: Hugh X. Hou

SAMPLE

Client Identification: C3-CS.

Dimensions: Core diameter = 50 mm (2.0 in.). Core length = 315 to 330 mm (12.4 to 13.0 in.); partial pier depth.

Top End: Irregular fractured surface extends both around and through aggregate particles and exhibits white deposits in some air voids.

Bottom End: Irregular fractured surface extends both around and through aggregate particles.

Cracks, Joints, Large Voids: Some entrapped air voids, one up to 20 mm diameter, are observed. No joints or cracks are observed in the core segment.

Reinforcement: None observed in the core segment.

AGGREGATES

Coarse: Natural gravel composed mainly of granite, sandstone, limestone, quartzite and chert with smaller amounts of volcanic rocks and other rock types.

Fine: Natural sand composed mainly of quartz/quartzite, limestone, granite, chert, sandstone, siltstone, with smaller amounts of volcanic rocks and other rock types.

Gradation & Top Size: Visually appears fairly evenly graded to an observed top size of 26 mm (1.0 in.).

Shape, Texture, Distribution: Coarse – mostly rounded to sub-rounded and equant to occasionally slightly elongate. Fine – rounded to angular and equant to slightly elongate.

PASTE

Color: Dark-medium gray.

Hardness: Hard.

Luster: Subvitreous.

Paste-Aggregate Bond: Tight to moderately tight.

Air Content: Estimated 2 to 3%. Concrete is not air entrained.

Depth of Carbonation: None observed in the core segment.

Secondary Deposits: Minor amounts of white deposits suspected ettringite, are observed lining a few voids. ASR gel is observed in voids near two chert coarse aggregate particles.

MICROCRACKING: Generally sparse.

ESTIMATED WATER-CEMENT RATIO: Not provided, due to the old age of the concrete.

MISCELLANEOUS:

1. Paste absorbency is low to moderately low.

2. Relatively large, irregular air voids are frequently observed in the core segment; however, the voids do not appear to indicate significant under-consolidation.

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

STRUCTURE: Bridge pier

DATE RECEIVED: February 12, 2009

LOCATION: US 421 Bridge over Ohio River between Milton, KY and Madison, IN

EXAMINED BY: Hugh X. Hou

SAMPLE

Client Identification: C4-CM.

Dimensions: Core diameter = 50 mm (2.0 in.). Core length = 270 to 280 mm (10.6 to 11.0 in.); partial pier depth.

Top End: Irregular fractured surface extends both around and through aggregate particles.

Bottom End: Irregular fractured surface extends both around and through aggregate particles.

Cracks, Joints, Large Voids: A few entrapped air voids, one up to 12 mm diameter, are observed. No joints or cracks are observed in the core segment.

Reinforcement: None observed in the core segment.

AGGREGATES

Coarse: Natural gravel composed mainly of quartzite, sandstone, chert, limestone, and granite with smaller amounts of volcanic rocks and other rock types.

Fine: Natural sand composed mainly of quartz/quartzite, limestone, granite, chert, sandstone, siltstone, with smaller amounts of volcanic rocks and other rock types.

Gradation & Top Size: Visually appears fairly evenly graded to an observed top size of 30 mm (1.2 in.).

Shape, Texture, Distribution: Coarse – mostly rounded to sub-rounded and equant to occasionally slightly elongate. Fine – rounded to angular and equant to slightly elongate.

PASTE

Color: Mottled medium gray.

Hardness: Moderately hard to hard.

Luster: Subvitreous to dull.

Paste-Aggregate Bond: Moderately tight.

Air Content: Estimated 1 to 2%. Concrete is not air entrained.

Depth of Carbonation: None observed in the core segment.

Secondary Deposits: Minor amounts of white deposits suspected ettringite, are observed lining a few voids.

MICROCRACKING: Generally sparse.

ESTIMATED WATER-CEMENT RATIO: Not provided, due to the old age of the concrete.

MISCELLANEOUS: Paste absorbency is moderately low.