Appendix C. Substructure Evaluation and Remaining Life Report

(Complete report prepared by KPFF Consulting Engineers including Appendixes A thru D)

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Substructure Evaluation

Route 19 Bridges over Current River and Spring Valley

MoDOT Structure Nos.: G0804 / J0420

Inspection Report

October 2019

kpff Consulting Engineers

Inspection Report

October 2019

Prepared for:

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Executive Summary

As part of the Shannon County, Route 19 Arch Bridge Rehabilitation Study Project, KPFF Consulting Engineers, Inc. (KPFF) was retained by HDR Engineering, Inc. to perform an evaluation of the concrete materials of the Route 19 bridges over Spring Valley and Current River, in Shannon County, MO. Field work was completed August 6 and 7, 2019.

Our evaluation work included limited, hands-on inspection, with hammer sounding of accessible portions of the bridges, Non-Destructive Testing (NDT) including half-cell potential testing in select areas and representative impulse radar scans, and materials sampling and testing. Due to project constraints, inspections were limited to arch abutments and other areas accessible by foot.

Route 19 over Current River, Bridge No. G0804

The concrete at the Current River Bridge is in fair to poor condition, with widespread deteriorated concrete, including cracking, and spalling along the vertical corners of the piers and abutments and moderate cracking and spalling along the edges of the arches. Additionally, petrographic evaluation of two cores taken from the edges of the arches in spans 2 and 5 indicated significant, internal, freeze-thaw damage. Freeze-thaw damage is typically associated with saturated, non-air entrained concrete and is likely due to the poor drainage of the earth fill above the arch.

Chloride levels in the cores taken from the edges of the arch were also high, exceeding corrosion initiation thresholds at depths greater than 5-inches, indicating that chlorides may be carried by drainage in the earth fill. Although there were no observations of chloride induced corrosion damage, half-cell potential measurements indicate that corrosion is likely in 2 of six locations tested and possible in 3 other locations.

The combination of freeze-thaw damage due to saturated conditions and elevated chloride levels represent a significant durability issue. The arches are likely nearing the end of their service life and significant rehabilitation will required if this concrete is to remain in service. Although testing was limited to the lower arches, similar deterioration is likely present in the fascia walls.

Rehabilitation options could include removal and replacement of chloride contaminated concrete as well as spalled and delaminated concrete, epoxy injection of cracks, installation of transverse ties perpendicular to the arch surface, and or implementation of cathodic protection. Additionally, removal of earth fill and sealing the top surface of the arches and inside surfaces of the walls will reduce future freeze-thaw damage.

Route 19 over Spring Valley, Bridge No. J0420

The Spring Valley Bridge concrete is in good to fair condition with isolated areas of deterioration, including cracks, delaminations and spalls with exposed reinforcement. Deterioration is more prevalent in the pier columns.

Although deterioration is isolated, future durability of the concrete is a concern, because measured chloride ion content exceeds corrosion initiation thresholds at the depth of the reinforcement in two out of three locations sampled and half cell potential measurements indicate that corrosion is likely in 2 out of 6 locations tested. Additionally, petrographic evaluation indicated that concrete carbonation depths are approaching the average measured cover thickness of the pier columns

To enhance the durability of these elements, limited rehabilitation, including installation of passive cathodic protection, removal and replacement of chloride contaminated concrete; sealing the concrete surface; and/or limiting exposure to deicing solutions by eliminating the open transverse superstructure joints is recommended. However, it should be noted that testing was very limited and additional testing and modeling are required to better establish remaining service life of the bridge. It is possible that chloride levels are higher in pier cap beams and portions of the arches at higher elevation and closer to the underside of the deck and associated run-off of deicing solutions.

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Appendices

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1. Background

KPFF Consulting Engineers, Inc. (KPFF) was retained by HDR Engineering, Inc. (HDR) for the evaluation of the concrete substructures of the Route 19 Bridges over Spring Valley and the Current River, in Shannon County, MO as part of the Missouri Department of Transportation (MoDOT) Route 19 Arch Bridge Rehabilitation Study Project.

The Route 19 Bridge over the Current River, shown in Photo 1, was originally constructed in 1924. The 5 span, filled spandrel arch structure has a length of 602 ft, comprised of three 130 ft arch spans, flanked on either end by 60 ft arch spans. An 18 ft wide roadway is carried across the bridge.

The Route 19 Bridge over Spring Valley, shown in Photo 5, was originally constructed in 1930. The bridge is 523 ft long with a 20 ft wide deck, carrying two lanes of traffic. The 150 foot main span is supported by a two rib open spandrel arch with 3 concrete deck girder approach spans to the north of the main span and 4 to the south. The approach spans are supported by reinforced concrete piers.

2. Scope of Work

The objective of our work was to investigate the concrete materials, including durability evaluation. Our work was limited to portions of the bridges accessible by foot, with a single day available at each bridge.

KPFF's scope of work included:

1. Representative radar scans of accessible areas to determine reinforcement cover depth variation.
2. Half-cell potential testing in select areas to determine corrosion potential levels.
3. Concrete material sampling and testing, as detailed below. A total of 7 cores were collected from the bridges and the following testing was performed on the samples:
    a. Concrete strength testing to verify concrete strength.
    b. Petrographic examination to evaluate overall concrete quality and determine air content, w/c ratio, depth of carbonation, and to identify micro-cracking and/or potential aggregate reactivity.
    c. Water-soluble chloride content testing to determine chloride content profiles.

3. Field Evaluation

3.1 SUMMARY

The field testing and concrete material sampling occurred on August 6th and 7th, 2019. Weather was seasonally hot and humid, with some passing rain over the inspection period. Access was by foot to the bottoms of the arches and arch abutments and bottoms of the pier columns.

In general the arches and piers of the Current River bridge are in fair condition with moderate cracking and spalling along the vertical corners of the pier pilasters and abutments and moderate cracking and spalling along the edges of the arches, see photo 2. Significant leakage was observed from the vertical joints in the fascia walls and the drains located near the base of the arches, as shown in Photos 3 and 4.

The arches and piers of the Spring Valley Bridge (SVB) are in good condition, with isolated areas of delaminated concrete and limited cracking observed in the pier columns, Photo 6

3.2 NON-DESTRUCTIVE TESTING

3.2.1 Ground-Penetrating Radar

The Ground-Penetrating Radar (GPR) method was used to conduct a concrete cover survey of steel reinforcement. The 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. 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 and antenna in a single unit. All data is stored in the main radar unit, for future processing. GPR is widely accepted as a reliable and rapid means for detecting rebar position and measuring approximate concrete cover depth.

Test locations were selected to capture a representative sampling of as-built reinforcement position and depth and generally included primary and secondary reinforcement of arches, columns, and pier pilasters. GPR measurements were calibrated on exposed bars throughout.

Statistical data, including number of bars, maximum cover, minimum cover, and average cover, were tabulated for each bridge, and these are summarized in Tables 3-1 and 3-2. The orientation of the reinforcing steel documented in a given scan is orthogonal to the direction of the scan.

Plan-specified cover for each set of bars is also shown in Tables 3-1 and 3-2. In general, the average cover was approximately 2-inches, in general agreement with plan-specified cover.

Table 3-1: Summary of Concrete Cover Data, Route 19 over Current River

Element	Bar Direct.	No. Scans	No. Bars Meas.	Average Cover (in.)	Min. Cover (in.)	Max. Cover (in.)	Plan Cover (in.)
Short Span Arch (Bottom)	Longitudinal	4	56	1.95	1.14	3.78	2
Long Span Arch (Bottom)	Longitudinal	4	70	2.37	1.54	3.82	2
Arch (Bottom)	Transverse	6	14	2.76	1.69	5.08	
Pier Pilaster	Vertical	3	37	4.27	2.83	5.39	4

Table 3-2: Summary of Concrete Cover Data, Route 19 over Spring Valley

Element	Bar Direct.	No. Scans	No. Bars Meas.	Average Cover (in.)	Min. Cover (in.)	Max. Cover (in.)	Plan Cover (in.)
Arch	Longitudinal	7	82	1.72	0.51	3.11	2
	Transverse	3	8	2.85	1.77	3.66	
Pier Column	Vertical	6	15	2.22	0.71	3.23	2
	Horizontal	6	27	1.33	0.59	2.52	

3.2.2 Half-cell Potential Measurements

Half-cell potential measurements using a copper/copper sulfate reference half-cell were performed in accordance with ASTM C876-09, “Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete.” Measurements were taken at select locations throughout both bridges, as shown in Photo 7.

Corrosion, which is an electrochemical process, occurs in concrete when oxygen and moisture are present. The actual corrosion is an exchange of energy within different sections of the uncoated reinforcing steel. The relative energy levels can be determined in relation to a reference electrode with a stable electrochemical potential. By connecting a high impedance voltmeter between the reinforcing steel and a reference electrode placed on the concrete surface, a measurement can be made for the half-cell potential at the location of the reference cell. This then is a measurement of the probability of corrosion activity in the steel in the vicinity of the reference cell. The reference cell is copper in a copper/sulphate solution. By taking half-cell potential measurements a fixed distance apart, a grid of half-cell potentials can be quickly made, and therefore areas delineated with a high probability of corrosion of the reinforcing steel. It should be noted that factors like cover depth, moisture content, concrete resistivity, location of the reference electrode during testing, and chloride concentration of the concrete, among other factors, may influence results.

The appendix of the ASTM standard indicates that if the electrical potential values obtained are more positive than 200mV, there is a greater than 90 percent probability that no corrosion of the steel reinforcement is occurring. If potential measurements are in the range of -200 to -350 mV, corrosion activity of the reinforcing steel in that area is uncertain. If the potential measurements are more negative than -350mV, there is a greater than 90 percent probability that corrosion is occurring.

In general, the readings indicate a range of potential for corrosion of the pier reinforcement throughout the bridges, with areas of increased potential noted in Table 3-3. Half-cell results are presented in Appendix B.

Table 3-3: Summary of Half cell potential measurements

Bridge	Location	Approximate Area	Condition
Current River	Bottom surface arch, Span 1 at Abutment 1	8 ft x 14 ft	Corrosion likely on outer 1/3's of surface, along edge of arch
	Bottom surface arch, Span 2 at Pier 2	8 ft x 14 ft	Corrosion not likely over east half of surface, possible over west half
	West face, Pier 2 Pilaster	6 ft by 6 ft	Corrosion likely
	Bottom surface arch, Span 5 at Pier 5	8 ft x 14 ft	Corrosion not likely
	East face, Abutment 6	7 ft x 5 ft	Corrosion possible over half of surface
	North face, East side of arch, Abutment 6	6 ft x 4 ft	Corrosion possible over half of surface
Spring Valley	Top surface, West arch at Pier 5	10 ft x 5 ft	Corrosion not likely
	South and East face, East Column, Pier 6	7 ft x 2.5 ft and 7 ft x 4 ft	Corrosion not likely
	South and West face, West Column, Pier 6	7 ft x 2.5 ft and 7 ft x 4 ft	Corrosion not likely
	West face, West Column, Pier 7	7 ft x 4 ft	Corrosion not likely
	West face, East Column, Pier 7	7 ft x 4 ft	Corrosion likely
	North and West face, West Column, Pier 8	7 ft x 2.5 ft and 7 ft x 4 ft	Corrosion likely

3.3 CONCRETE MATERIAL SAMPLING

A total of seven, 4-inch diameter cores were removed from the bridges. Cores were extracted using a standard water-cooled core drill, as shown in Photo 8. Sample locations and observations are summarized in Table 3-4 below.

Table 3-4: Concrete Core Sample Summary

Bridge	Core ID	Location	Exposure	Notes
Current River	CR-1	Edge of Arch, Span 2 at Pier 2	West	Several Delaminations in Core and Core hole
	CR-2	Pier 2	East	No Delaminations
	CR-3	Arch Bottom, Span 1 at Abut 1	South	No delaminations
	CR-4	Edge of arch, Span 5 at Abut 6	East	Several Delaminations in Core and Core hole
Spring Valley	SV-1	West Column, Pier 6	West	No Delaminations
	SV-2	West Arch at Pier 5	East	No Delaminations
	SV-3	East Arch Abut. at Pier 5	South	No Delaminations

KPFF provided onsite supervision during coring operations, including determination of core locations, onsite inspection, and documentation of core samples and sample locations. Coring was completed by Coring and Cutting - Springfield. All core holes were filled using a pre-bagged grout mix.

4. Materials Testing and Evaluation

Laboratory testing of concrete core samples was performed by Universal Construction Testing (UCT) to evaluate compressive strength and chloride ion concentrations in the concrete. Additionally, petrographic examination was performed to evaluate general concrete quality and document the properties of the material. The following sections detail the testing methods and results.

4.1 COMPRESSIVE STRENGTH TESTING

Compressive strength testing was performed on four 4-inch-nominal-diameter concrete core samples, in accordance with ASTM C-42, "Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete." Cores were tested in the air-dry condition.

Compressive strengths are shown in Table 4-1 below. The full test report is included in Appendix D.

Table 4-1: Summary of Concrete Compressive Strength Test Results

Bridge	Core ID	Member Type	Measured Compressive Strength, f'c (psi)
Current River	CR-2	Pier	8470
	CR-3	Arch	4050
Spring Valley	SV-1	Column	8230
	SV-2	Arch	4820

4.2 CHLORIDE ION CONCENTRATION TESTING

Water-soluble chloride ion concentration testing was performed on a total of 30 samples, obtained from 6 cores.

Water-soluble (available) chloride content test results were used to evaluate the chloride levels in the concrete at various depths measured from the exposed surface. Testing was performed in accordance with AASHTO T260-97 (2001), “Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials.” A summary of the test results is included in Table 4-2 below. Individual laboratory test results are included in Appendix D. Chloride ion concentration test results are reported as percentage of the total sample weight and include both paste and aggregate.

Table 4-2: Summary of Chloride Content Profiles

Bridge	Sample ID	Member	Face	Water Soluble Chloride Ion Content[1] (% by weight of sample)				
				Depth 0-1 in.	Depth 1-2 in.	Depth 2-3 in.	Depth 3-4 in.	Depth 4-5 in.
Current River	CR-1	Arch	West	**0.099**	**0.083**	**0.062**	**0.056**	**0.046**
	CR-2	Pier	East	**0.041**	**0.004**	**0.003**	**0.003**	**0.002**
	CR-4	Arch	East	**0.063**	**0.063**	**0.046**	**0.035**	**0.028**
Spring Valley	SV-1	W. Column	West	**0.035**	**0.012**	**0.003**	**0.003**	**0.003**
	SV-2	W. Arch	East	**0.094**	**0.054**	**0.025**	**0.005**	**0.003**
	SV-3	E. Arch Abut	South	**0.141**	**0.097**	**0.086**	**0.055**	**0.013**

[1] Values displayed in red exceed corrosion initiation threshold, 0.024% by weight of sample.

General observations about these test results include the following:

- Higher concentrations of chloride ions near the surface of the concrete and a decreasing gradient of the chloride content with depth of sample indicate that the concrete has been exposed to an external source of chlorides.
- Chloride levels are high, exceeding corrosion initiation threshold to depths of 1 inch at all locations and up to 5 inches at some locations.
- High Chloride levels at depths exceeding 5-inches for cores CR-1 and CR-4 may be a result of delamination cracks in these locations.
- Elevated chloride levels represent a significant durability issue.

4.3 PETROGRAPHIC EXAMINATION

Petrographic examination was performed on a total of 3 cores, shown in Table 4-3, in accordance with ASTM C856-04 “Standard Practice for Petrographic Examination of Hardened Concrete.” This procedure evaluates the overall concrete quality, air content, w/c ratio, and depth of carbonation and identifies micro-cracking and/or potential aggregate reactivity. The complete petrographic report is included in Appendix D.

Table 4-3: Summary of Petrographic Analysis

Bridge	Core ID	General Condition	Carbonation Depth (mm)	Estimated W/C	Air Content (%)
Current River	CR-1	Heavily Fractured	5	0.35 to 0.45	2 to 3%
	CR-4	Heavily Fractured	12	0.35 to 0.45	2 to 3%
Spring Valley	SV-3	Good	33	0.35 to 0.45	3 to 4%

Findings of the petrographic examination include the following:

- Aggregates are sound and stable with no evidence of ASR, AAR, or other aggregate reactivity. Aggregates are well graded with no evidence of segregation.
- Concrete is not air-entrained with entrapped air content between 2 and 4%.
- Carbonation depths ranged from 5 to 12 mm in the current river bridge and up to 33 mm in the Spring Valley Bridge.
- Cement paste was hard with good paste to aggregate bond in all cores. Water to cement ratio is estimated at 0.35 to 0.45 for all three cores. No supplemental cementitious materials, such as fly-ash, were observed. Cement content is estimated at 5 to 6 bags per cubic yard.
- Cores CR-1 and CR-4 exhibited significant fractures, oriented sub-parallel to the core surface. Fractures pass both through and around aggregate particles. Cracking was consistent with freeze-thaw damage in concrete with saturated service exposure.

5. Discussion of Inspection Findings

In general, compressive strength testing and petrographic examination indicate that the concrete is generally fair quality with damage consistent with concrete in service for nearly 100 years. Given the overall quality of the concrete, service life of the piers is controlled by a combination of chloride-induced corrosion of embedded reinforcement, carbonation, and freeze-thaw damage.

5.1 CURRENT RIVER BRIDGE

The concrete at the Current River Bridge is in fair to poor condition with significant internal, freeze-thaw damage observed.

The earth fill within the concrete arches is likely saturated, resulting in saturation of the concrete in the arches. This saturated condition has resulted in freeze-thaw damage to the non-air-entrained concrete in the arches that will continue. Although this damage may be limited to the lower portion of the arches, additional testing would be required to verify.

Additionally, chloride contents are also high, exceeding corrosion initiation thresholds at depths greater than 5 inches in two out of three locations tested. These high chloride levels will result in corrosion of reinforcement and ongoing deterioration.

The combination of freeze-thaw damage due to saturated conditions and elevated chloride levels represent a significant durability issue for this bridge. The arches are likely near the end of their service life and significant rehabilitation will required if this concrete is to remain in service. Although testing was limited to the arches, similar deterioration is likely present in the fascia walls.

Rehabilitation options could include removal and replacement of chloride contaminated concrete as well as spalled and delaminated concrete, epoxy injection of cracks, installation of transverse ties perpendicular to the arch surface, and or implementation of passive cathodic protection. Additionally, removal of earth fill and sealing the top surface of the arches and inside surfaces of the walls will reduce future freeze-thaw damage.

5.2 SPRING VALLEY BRIDGE

In general, the Spring Valley Bridge concrete is in good to fair condition, with isolated areas of delaminated and spalled concrete, and with some minor areas of exposed rebar in the piers. The arches and arch abutments were in good condition with no damage noted.

Average measured cover on the arches was in close agreement with the 2-inch minimum specified by the plans. Average measured cover on the pier columns was more shallow, with many bars measuring less than 1.5 inches. Cover is a concern, as carbonation depth was measured at just over 1-1/4 inch. Additionally, chloride contents exceeded the corrosion initiation thresholds at depths exceeding 2-inches in 2 out of the three locations tested.

Half-cell potential measurements indicated a 90 percent probability that corrosion is occurring in 33% of 6 locations evaluated.

Although damage was isolated, the combination of relatively shallow cover and high chloride content are a durability concern that may limit remaining service life of the concrete. Additional testing and service life modeling is necessary to better establish likely remaining service life. It should also be noted that concrete sampling and test locations were limited to areas close to the ground. It is anticipated that corrosion is more severe in areas closer to the underside of the deck, especially near joints, due to higher chloride exposure from deicing solutions. These areas include pier cap beams and the center portions of the arch.

To enhance the durability of these elements, limited rehabilitation, including installation of passive cathodic protection, removal and replacement of chloride contaminated concrete; sealing the concrete surface; and/or limiting exposure to deicing solutions by eliminating the open transverse superstructure joints is recommended.

Appendix A

Photo Log

List of Photos

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Photo 1: Current River Bridge, Downstream Fascia, looking south

Photo 2: CRB, Typical spalling and deterioration along vertical corners of pier and edge of arch, West Face, pier 2 shown.


Photo 3: CRB, Typical Leakage from vertical joints in fascia walls

Photo 4: CRB, Typical leakage from drains at base of arch

Photo 5: Spring Valley Bridge, East Fascia, looking north

Photo 6: SVB, Typical Cracking and exposed reinforcement,
Pier 7, North Face, east column and Pier 6, East Face, east column shown

Photo 7: Half Cell Potential Testing

Photo 8: Concrete Coring

Appendix B

Half-Cell Potential Test Results

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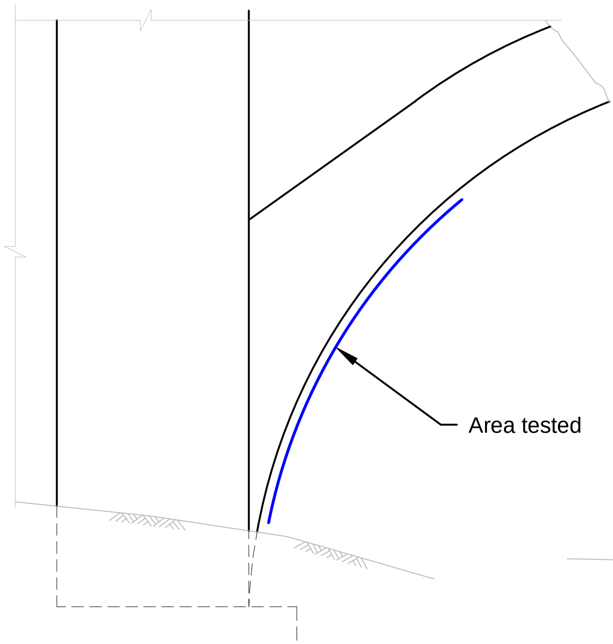
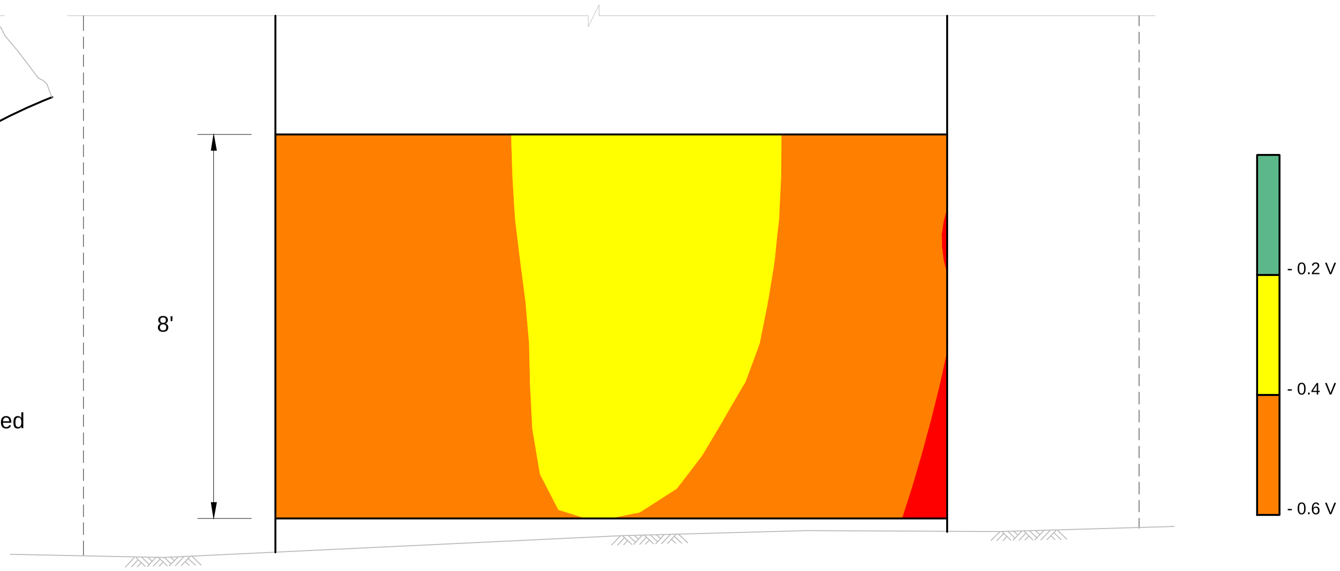


Abut. 1
Partial West Elevation



South Face, Under Arch

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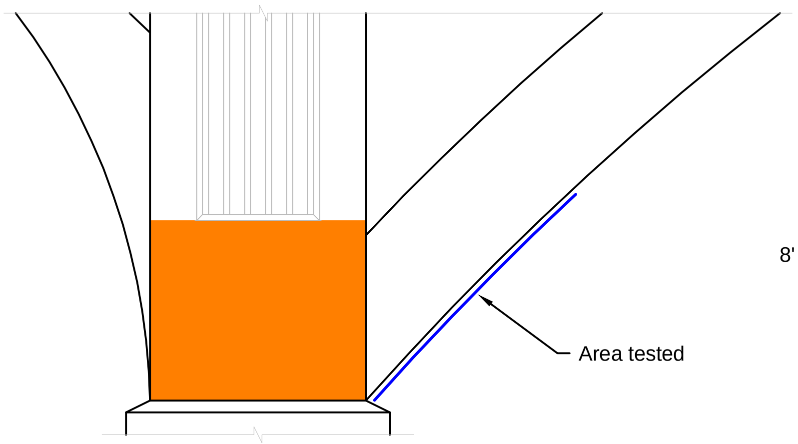
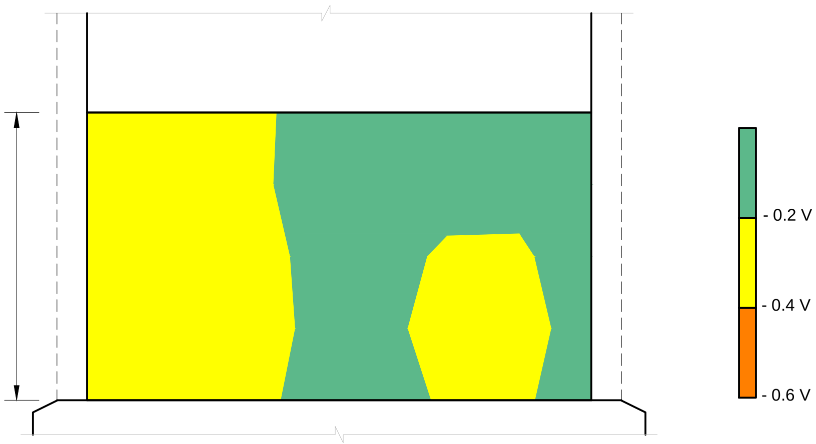
Date: Sept. 2019	
KPFF Proj: 10041900532	



Pier2
Partial West Elevation



South Face, Under Arch

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Date: Sept. 2019	
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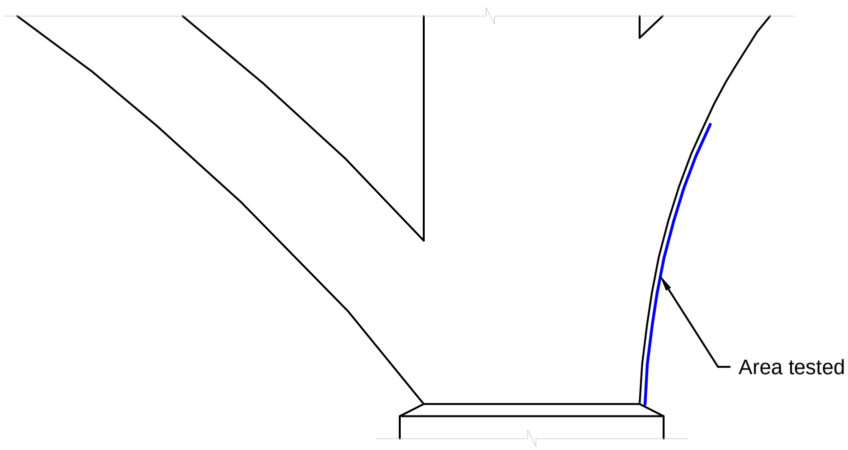

Pier 5
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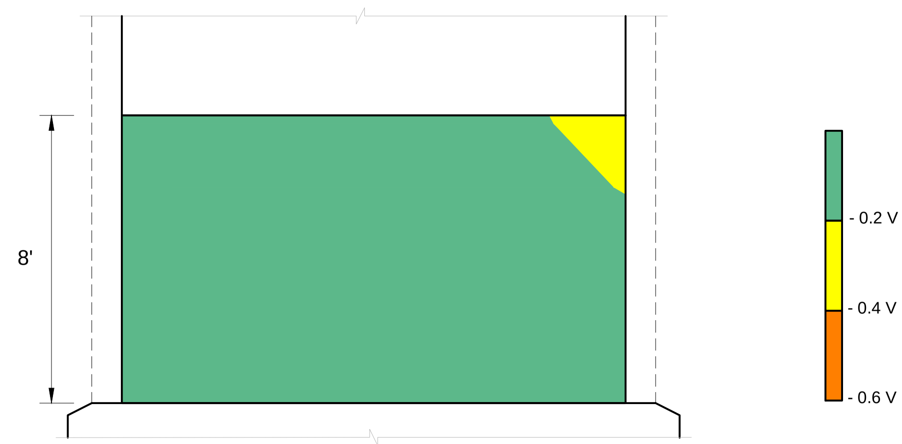

South Face, Under Arch

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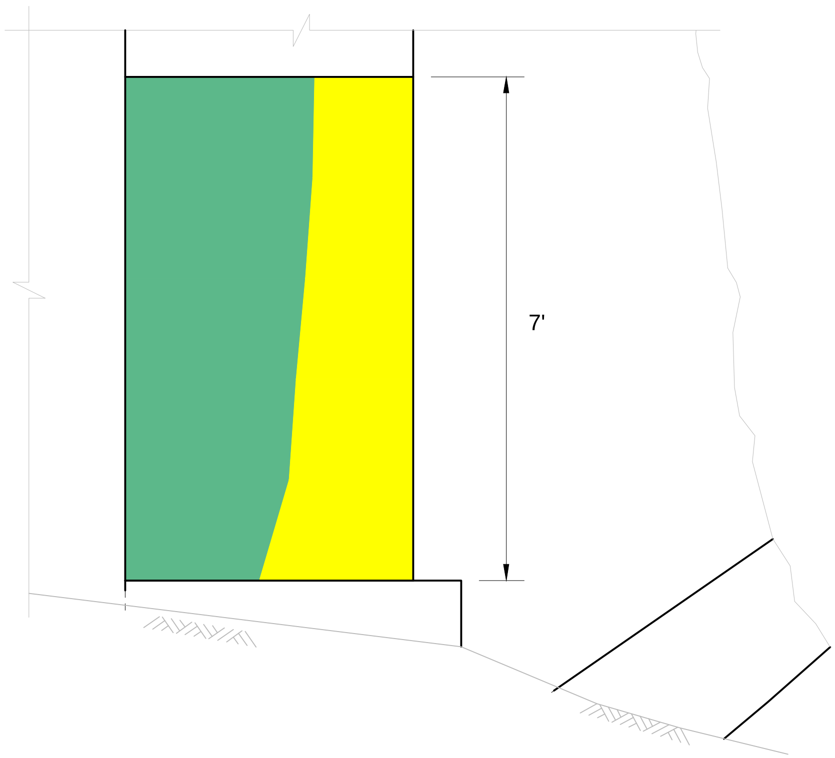
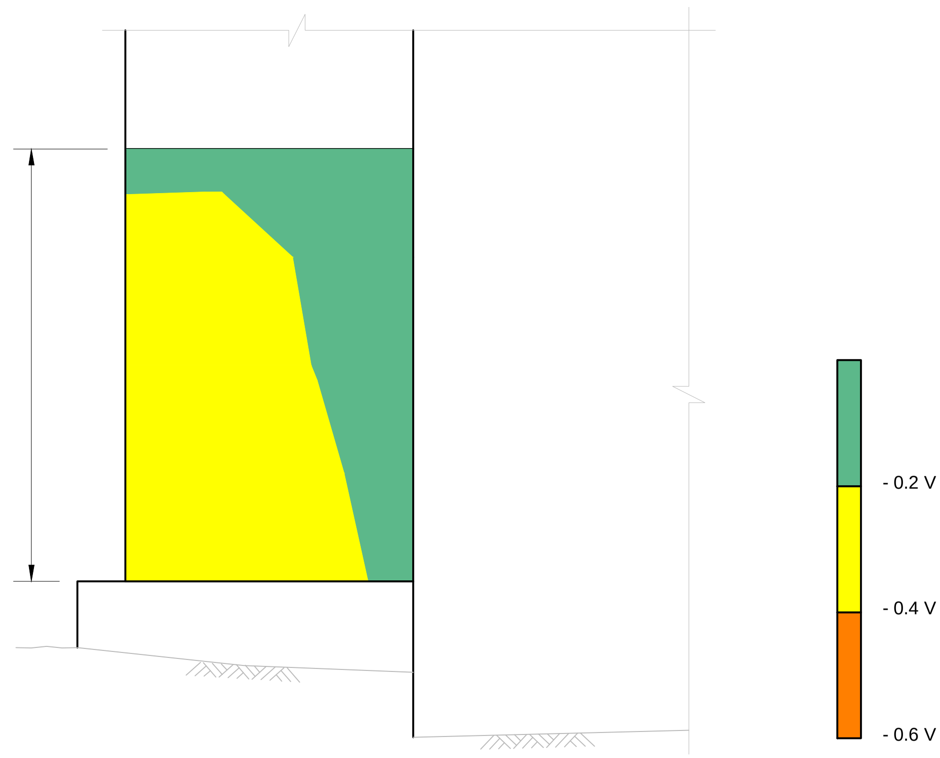


Abut. 6, East Face



Abut. 6, North Face

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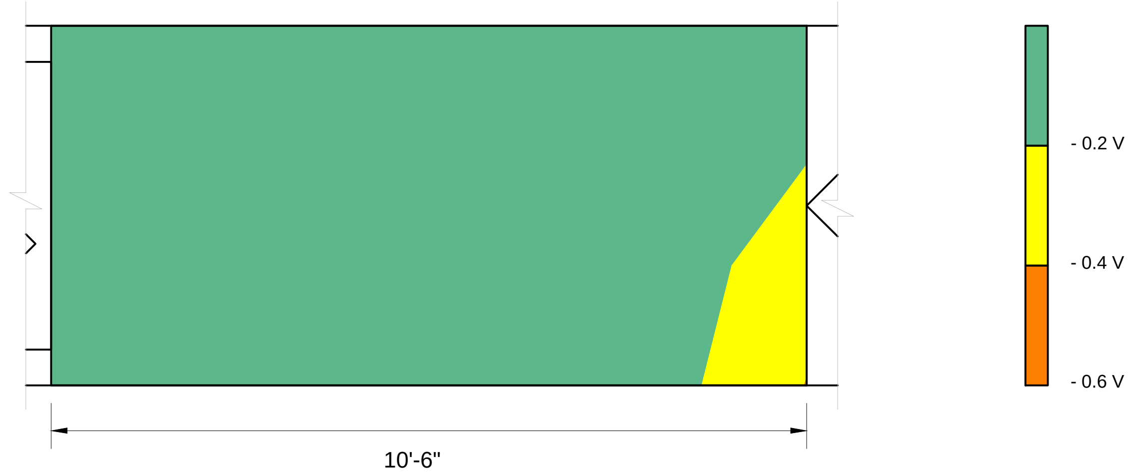
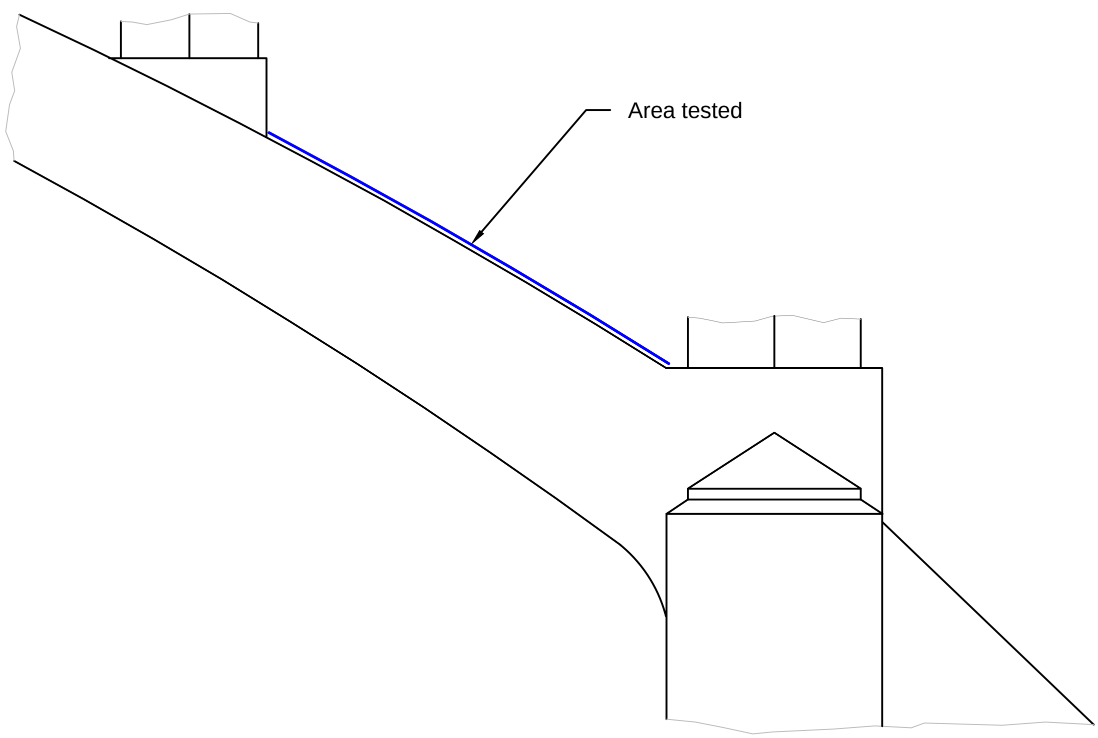


Top Surface of Arch



West Arch @ Pier 5
Partial West Elevation

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Date: Sept. 2019		
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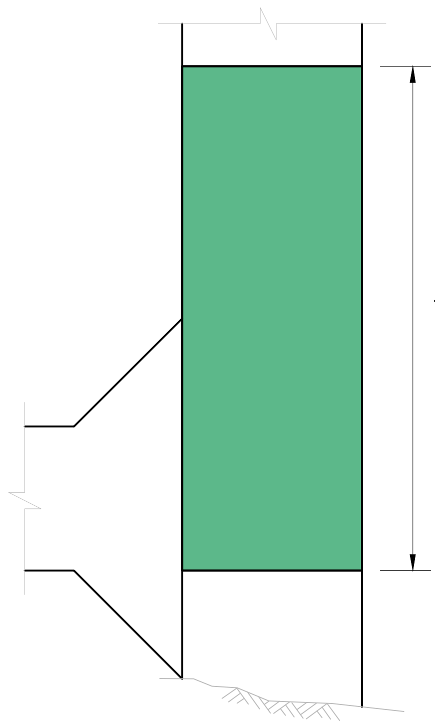
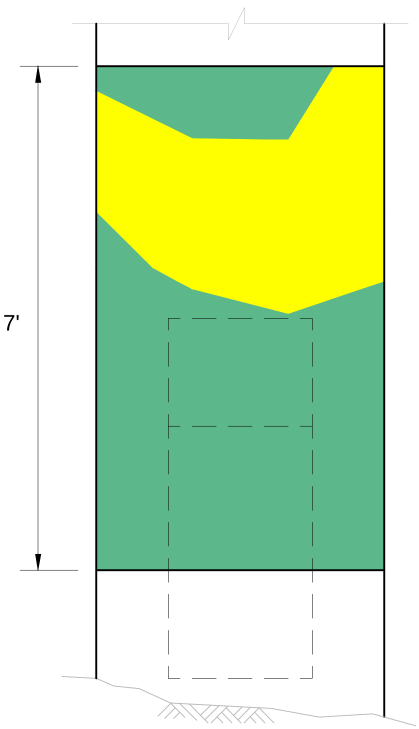
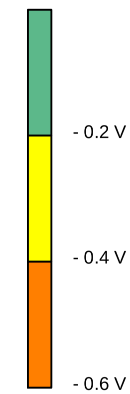


Pier 6, East Column
South Face



Pier 6 , East Column
East Face



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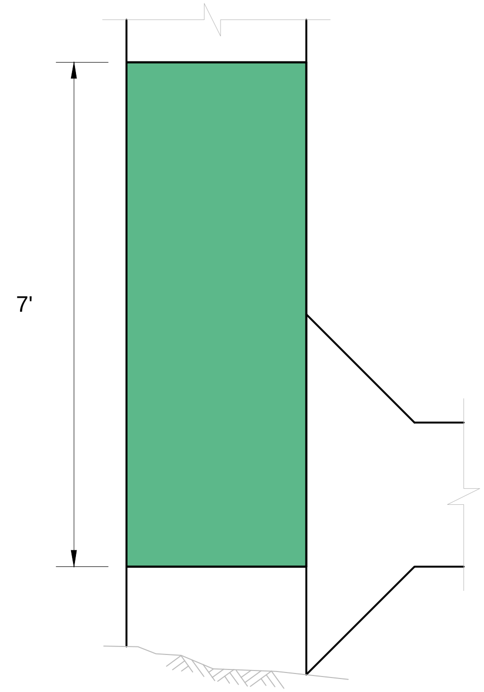
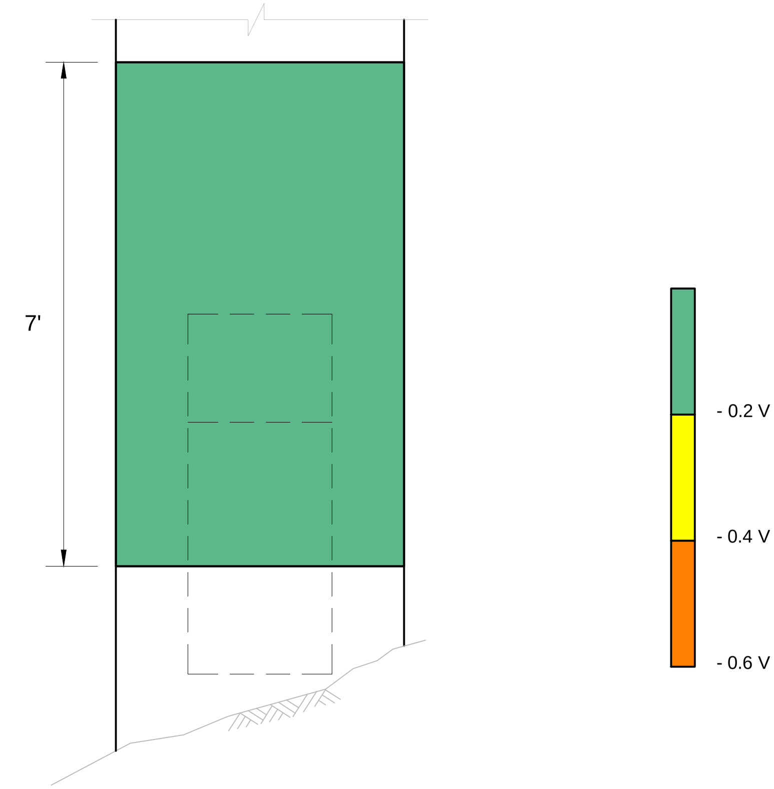


Pier 6, West Column
South Face



Pier 6, West Column
West Face

Route 16 Bridges, Spring Valley Bridge	
Half Cell Potential Test Results	
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Date: Sept. 2019	
KPFF Proj: 10041900532	

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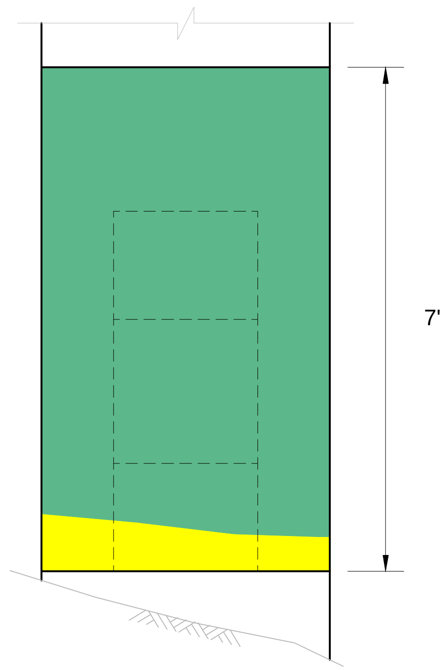
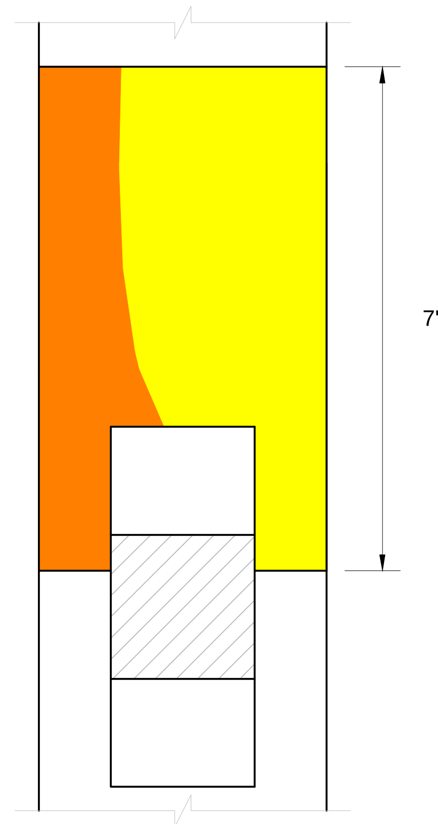
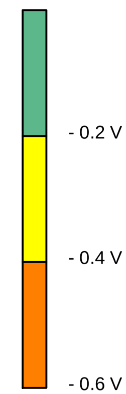


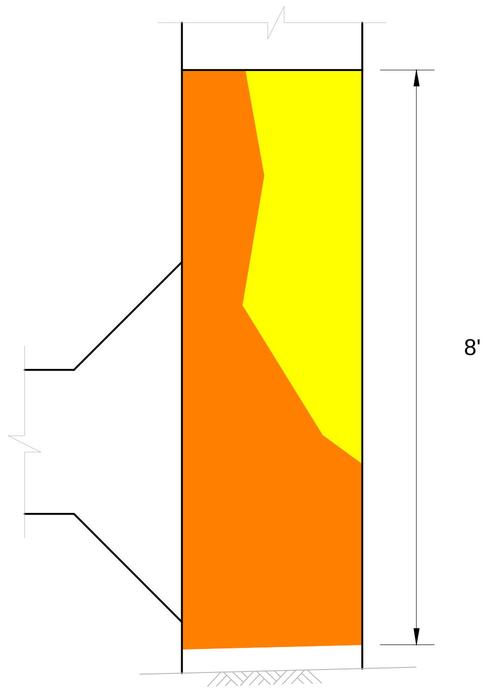
Pier 7, West Column
West Face



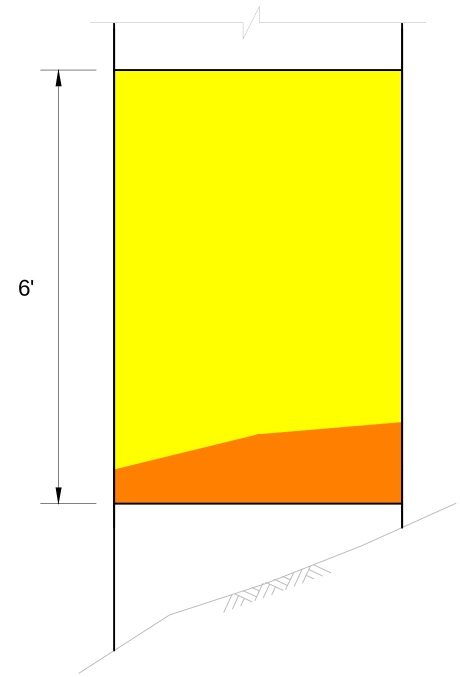
Pier 7, East Column
West Face



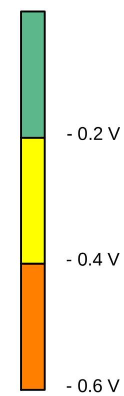
Route 16 Bridges, Spring Valley Bridge	
Half Cell Potential Test Results	
by: MI	ckd: CAL
Date: Sept. 2019	
KPFF Proj: 10041900532	



Pier 8, West Column
North Face



Pier 8, West Column
West Face



Route 16 Bridges, Spring Valley Bridge	
Half Cell Potential Test Results	
by: MI	ckd: CAL
Date: Sept. 2019	
KPFF Proj: 10041900532	

kpff Consulting Engineers

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Appendix C

Concrete Material Sampling

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Core CR-1

- Edge of Arch, Span B @ Pier 2
- West Exposure
- 4 x 10, extracted in two pieces
- Several delaminations noted in core and core hole
- Cracks through and around aggregate with cracks in aggregate

Testing

- Petrographic Examination
- Water soluble chloride, 0 to 5-in depths in 1-inch increments

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Core CR-2:

- East Face of Pier 2
- 4 x 10
- No delaminations noted
- Some cracking in Aggregates

Testing

- Compressive Strength?
- Water soluble chloride, 0 to 5-in depths in 1-inch increments

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 	**Core CR-3:** • Underside of Arch, Span A @ Abutment 1, near center of bridge • South Exposure, under bridge • 4 x 10 • No delaminations noted • Some cracking in Aggregates Testing • Compressive Strength?
 	**Core CR-4** • Edge of Arch, Span A @ Abut. 6 • East Exposure • Drilled 4 x 10, extracted length ~ 7 inch. • Several delaminations noted in core and core hole • Cracks through and around aggregate with cracks in aggregate Testing • Petrographic Examination • Water soluble chloride, 0 to 5-in depths in 1-inch increments

Core SV-1

- Pier 6, West Column, West Face
- 4 x 10
- No delaminations noted

Testing

- Compressive Strength?
- Water soluble chloride, 0 to 5-in depths in 1-inch increments

Core SV-2

- West Arch @ Pier 5, East Face
- 4 x 10
- No delaminations noted

Testing

- Compressive Strength?
- Water soluble chloride, 0 to 5-in depths in 1-inch increments

Core SV-3

- East Arch Abutment @ Pier 5, South Face
- 4 x 10
- No delaminations noted

Testing

- Petrographic Examination
- Water soluble chloride, 0 to 5-in depths in 1-inch increments

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Appendix D

Materials Test Reports

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Mr. Chris Ligozio
Senior Engineer – Bridges and Infrastructure
KPFF
140 A Metro Park
Rochester, NY 14623

chris.ligozio@kpff.com
PH: 585.465.5092

Re: Laboratory Studies of Concrete Core Samples
Route 19 Bridges
Winona, Missouri
KPFF Project No. 10041900532

Dear Mr. Ligozio:

Universal Construction Testing, Ltd. (UCT) has completed laboratory studies of seven (7) concrete core samples excised by others from the referenced project and delivered to our laboratories on September 9, 2019.

The cores were reportedly taken from a century-old arch bridge in Missouri. Four (4) core samples were tested for compression strength, six (6) core samples were analyzed chemically for chloride ion content profile, and three (3) core samples were subjected to petrographic examination as directed by you. The purpose of the testing was to evaluate the concrete properties and to determine the general quality, serviceability characteristics, and to identify if any, the presence of deleterious materials.

Table 1 – Sample Identification and Test Program

Sample ID	**Location in the Structure**	**Compressive Strength** (ASTM C42)	**Chloride Content Analysis** (ASTM C1218)	**Petrographic Examination** (ASTM C856)
CR-1	Arch Edge, Span B at Pier 2	--	X	X
CR-2	East Face of Pier 2	X	X	--
CR-3	Arch Underside Span A at Abut. 6	X	--	--
CR-4	Arch Edge, Span A, Abut. 6	--	X	X
SV-1	Pier 6, West Face of West Column	X	X	--
SV-2	West Arch, East Face of Pier 5	X	X	--
SV-3	East Arch Abut., South Face of Pier 5	--	X	X

SUMMARY OF FINDINGS

Compressive Strength: The compressive strength of the concrete represented by the designated cores is in the 4,000-8,000-psi range.

Chloride Content Analysis: According to the American Concrete Institute, 0.15% maximum water-soluble chloride content expressed by weight of cement is the suggested threshold to minimize the risk of chloride-induced corrosion in conventionally reinforced concrete.

The results of the chemical analysis are shown in Table 3 below.

The chloride content profile of the samples analyzed suggests an external source of chloride ingress, such as deicing salts.

Petrographic Examination: The concrete represented by all the cores is well consolidated. The concrete in Cores CR-1 and CR-4 is heavily fractured with fractures oriented sub-parallel to the outer surface of each core.

The coarse aggregate is fairly well graded and has a 1.25-in. (32-mm) maximum size. The coarse aggregate is natural gravel composed primarily of chert with minor amounts of sandstone and dolomite. The fine aggregate is a calcareous and siliceous natural sand, which is uniformly dispersed in a hardened Portland-cement based paste matrix.

The paste in all three cores is moderately well bond to aggregate, hard, and dense. Freshly fractured surfaces have a dull to subvitreous luster.
The cement paste is carbonated to a depth of approximately 0.20 to 1.30-in. (5 to 33-mm) below the outer surfaces of Cores CR-1, Cr-4, and SV-3.

Cement paste properties reported above are used to interpret the estimated water-to-cement ratio. The water-to-cement ratio is estimated to be in the range of *0.35 to 0.45* in all three cores.

The concrete of the three cores is not intentionally air-entrained, based on the lack of small, spherical air-voids, with an estimated entrapped air-content between **2.0 to 4.0%**.

Multiple cracks are present in the outer sections of Cores CR-1 and CR-4 and pass through and around aggregate particles.

There is no evidence of alkali-aggregate reaction associated with the aggregate.

Discussion

The cores are not air-entrained, as air-entrained admixtures were not discovered until about 20 or more years after this concrete was cast. Therefore, the samples contain low estimated air contents, significantly lower than the 4% recommended by ACI 318 for air-entrained concrete to protect against freeze-thaw damage.

The lack of an intentionally developed air-void system imparted by intentional air-entrainment has rendered this concrete highly susceptible to freeze-thaw damage. Cracking oriented subparallel to the outer surface of the concrete and in the outer regions of the concrete members in cores CR-1 and CR-4 is characteristic of bulk freeze-thaw damage that usually occurs in a non-air-entrained concrete subjected to saturated service exposure. Therefore, bulk freeze-thaw damage is the most likely cause of the cracking in Core CR-1 and CR-4.

LABORATORY STUDIES

Compressive Strength: The compression testing was performed in general accordance with applicable provisions of ASTM Standard C42 - *Standard Test Method for Obtaining and Testing Drilled Cores of Concrete*. Refer to Table 2 below for the results of compression testing. Samples were tested in an air-dry condition.

Table 2 - Compressive Strength Test Results

Core ID	Tested Height L (in)	Diam. D (in)	L/D Ratio K	Total Load (lbs.)	Uncorrected Compressive Strength (psi)	**Corrected Compressive Strength (psi)**
CR-2	7.46	3.73	2.00 1.00	92,470	8,470	**8,470**
CR-3	7.46	3.73	2.00 1.00	45,240	4,050	**4,050**
SV-1	7.45	3.73	2.00 1.00	89,840	8,230	**8,230**
SV-2	7.46	3.73	2.00 1.00	52,610	4,820	**4,820**
Remarks: The cores were tested in air-dry conditions.						

Chloride Content Analysis was performed in accordance with the applicable provisions of ASTM Standard C1218 - *Standard Test Method for Water-Soluble Chloride in Mortar and Concrete*. Refer to Table 3 below for the summary of the results obtained.

Table 3 - Results of Chloride Content Analysis

Core ID	**Level Tested from Top**	**Chloride (CL^-) Content**		
		CL^- by weight of concrete (PPM)*	CL^- by weight of concrete (%)	**CL^- by weight of cement (%) ***
CR-1	0 to 1 in. (0-25 mm)	990	0.099	**0.64**
	1 to 2 in. (25-51 mm)	830	0.083	**0.54**
	2 to 3 in. (51-76 mm)	620	0.062	**0.40**
	3 to 4 in. (77-100 mm)	560	0.056	**0.37**
	4 to 5 in. (100-125 mm)	460	0.046	**0.30**
CR-2	0 to 1 in. (0-25 mm)	410	0.041	**0.27**
	1 to 2 in. (25-51 mm)	40	0.004	**0.03**
	2 to 3 in. (51-76 mm)	30	0.003	**0.02**
	3 to 4 in. (77-100 mm)	30	0.003	**0.02**
	4 to 5 in. (100-125 mm)	20	0.002	**0.01**
CR-4	0 to 1 in. (0-25 mm)	630	0.063	**0.41**
	1 to 2 in. (25-51 mm)	630	0.063	**0.41**
	2 to 3 in. (51-76 mm)	460	0.046	**0.30**
	3 to 4 in. (77-100 mm)	350	0.035	**0.23**
	4 to 5 in. (100-125 mm)	280	0.028	**0.18**
SV-1	0 to 1 in. (0-25 mm)	350	0.035	**0.23**
	1 to 2 in. (25-51 mm)	120	0.012	**0.08**
	2 to 3 in. (51-76 mm)	30	0.003	**0.02**
	3 to 4 in. (77-100 mm)	30	0.003	**0.02**
	4 to 5 in. (100-125 mm)	30	0.003	**0.02**
SV-2	0 to 1 in. (0-25 mm)	940	0.094	**0.61**
	1 to 2 in. (25-51 mm)	540	0.054	**0.35**
	2 to 3 in. (51-76 mm)	250	0.025	**0.16**
	3 to 4 in. (77-100 mm)	50	0.005	**0.04**
	4 to 5 in. (100-125 mm)	30	0.003	**0.02**

Table 3 - Results of Chloride Content Analysis (Cont'd).

Core ID	**Level Tested from Top**	**Chloride (CL^-) Content**		
		CL^- by weight of concrete (PPM)*	CL^- by weight of concrete (%)	**CL^- by weight of cement (%) ***
SV-3	0 to 1 in. (0-25 mm)	1410	0.141	**0.92**
	1 to 2 in. (25-51 mm)	970	0.097	**0.63**
	2 to 3 in. (51-76 mm)	860	0.086	**0.56**
	3 to 4 in. (77-100 mm)	550	0.055	**0.36**
	4 to 5 in. (100-125 mm)	130	0.013	**0.09**
Remarks: *) Assumed cement content 600 lbs./cu.yd. and U.W. = 3900 pcy.				

PETROGRAPHIC EXAMINATION

CR-1 (Pier 2 Arch)

General

The core is 3.75-in. (95-mm) in diameter, 9.25-in. (235-mm) long and represents a partial member thickness (Figure 1). The outer surface has a smooth imprint of a formed surface (Figure 1). The inner surface is an irregular fracture surface (Figure 1). The concrete is well consolidated and shows no signs of segregation.

Figure 1: *Top:* **Core CR-1 (outer surface oriented to the left).** *Bottom:* **Outer (left) and inner (right) surfaces of the Core CR-1.**

Cracks

Multiple, interlaced cracks, oriented subparallel to the outer surface of the core, are present through the length of the core and have a range of widths from 0.1 to 6.0 mm. The cracks pass around and through aggregate particles. Cracks are depicted in Figure 2 below (red arrows).

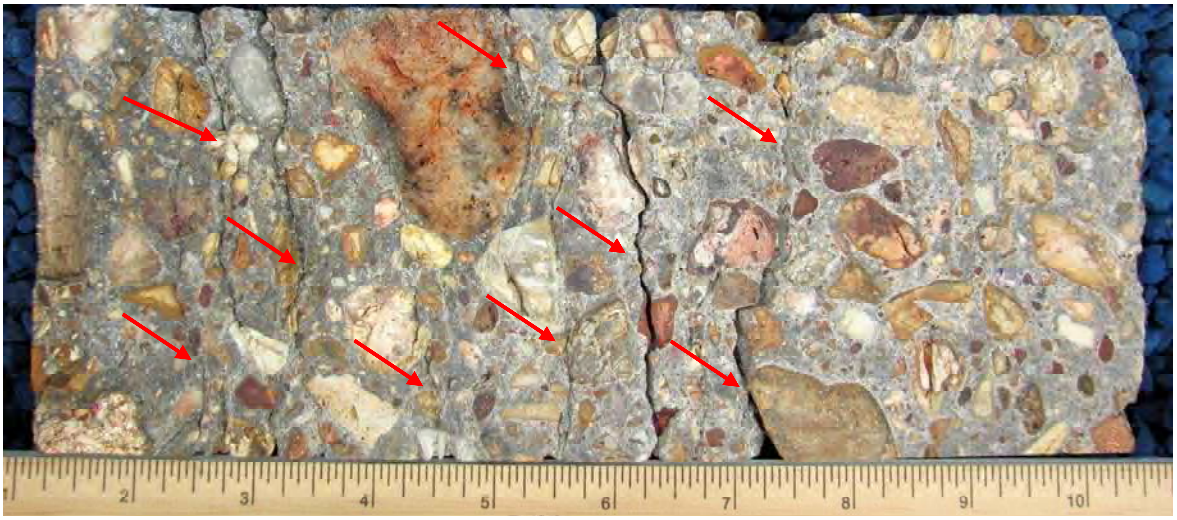

Figure 2: Photograph showing the cracks in Core CR-1. The outer surface is to the left. Scale in inches.

Unit Weight

The unit weight of the concrete sample, as received, is approximately **143.0 lbs./cf**.

Air Content

The concrete has an estimated air content between **2.0 and 3.0%.**

Carbonation

The depth of paste carbonation, measured from the outer surface of the core is approximately 5-mm (0.20-in.).

Reinforcement

Reinforcement is not present in the core.

Water-to-Cement Ratio

The water-to-cement ratio is estimated to be between 0.35 and 0.45.

Paste-Aggregate Bond

The paste-aggregate bond is moderately tight throughout the core, as fractures created in the laboratory pass through and around coarse aggregate particles.

Paste

The cement paste is dark gray, dense, and hard. Freshly fractured surfaces have a dull to subvitreous luster.

Aggregate

The aggregate is fairly well graded and uniformly distributed. There is no evidence of deleterious alkali-aggregate reactions.

The coarse aggregate consists of natural gravel composed primarily of chert with minor amounts of sandstone and dolomite with a 1.25-in. (32-mm) top size. The coarse aggregate particles are rounded to subangular with a blocky to elongate sphericity.

The fine aggregate is natural sand composed primarily of quartz, limestone, feldspar, sandstone and other minerals and rocks. Individual sand grains are subrounded and range from elongated to blocky shape.

Core Sample CR-4 (Abutment 6 Arch)

General

The core is 3.75-in. (95-mm) in diameter, 7.5-in. (191-mm) long and represents a partial member thickness (Figure 3). The outer surface has a smooth imprint of a formed surface (Figure 3). The inner surface is an irregular fracture surface (Figure 3). The concrete is well consolidated and shows no signs of segregation.

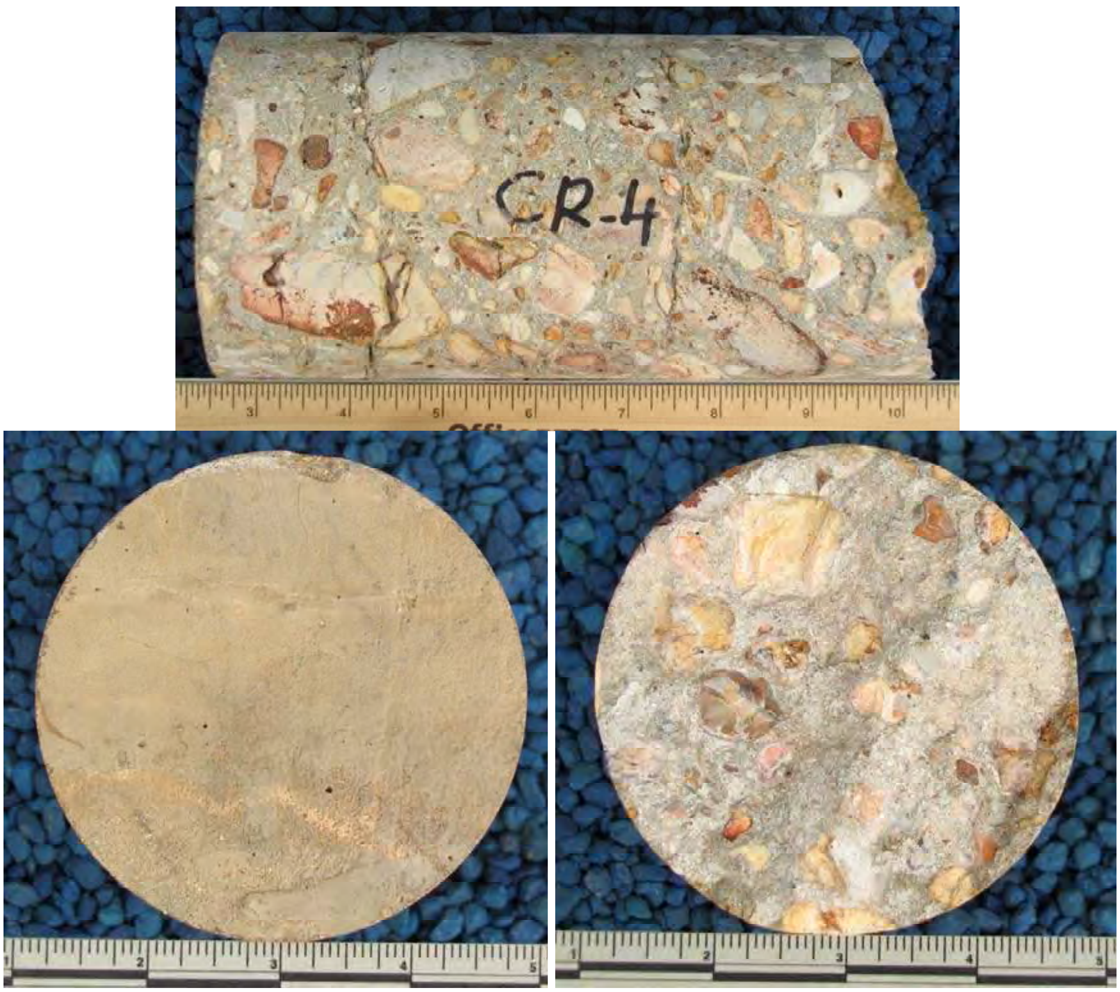

Figure 3: *Top:* **Core CR-4 (outer surface oriented to the left).** *Bottom:* **Outer (left) and inner (right) surfaces of Core CR-4.**

Cracks

Multiple, interlaced cracks, oriented subparallel to the outer surface of the core, are present through the length of the core and have a range of widths from 0.1 to 1.0-mm. The cracks pass around and through aggregate particles. Cracks are depicted in Figure 4 below (red arrows).

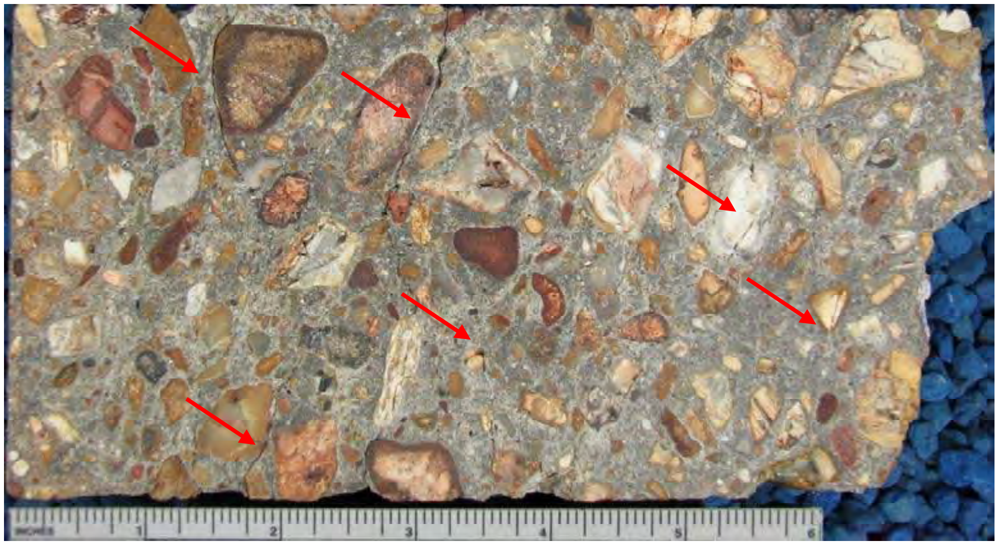

Figure 4: Photograph showing the cracks in Core CR-4. The outer surface is to the left. Scale in inches.

Unit Weight

The unit weight of the concrete sample, as received, is approximately **144.0 lbs./cf**.

Air Content

The concrete has an estimated air content between **2.0 and 3.0%.** Figure 5 is a photomicrograph depicting the low air content.

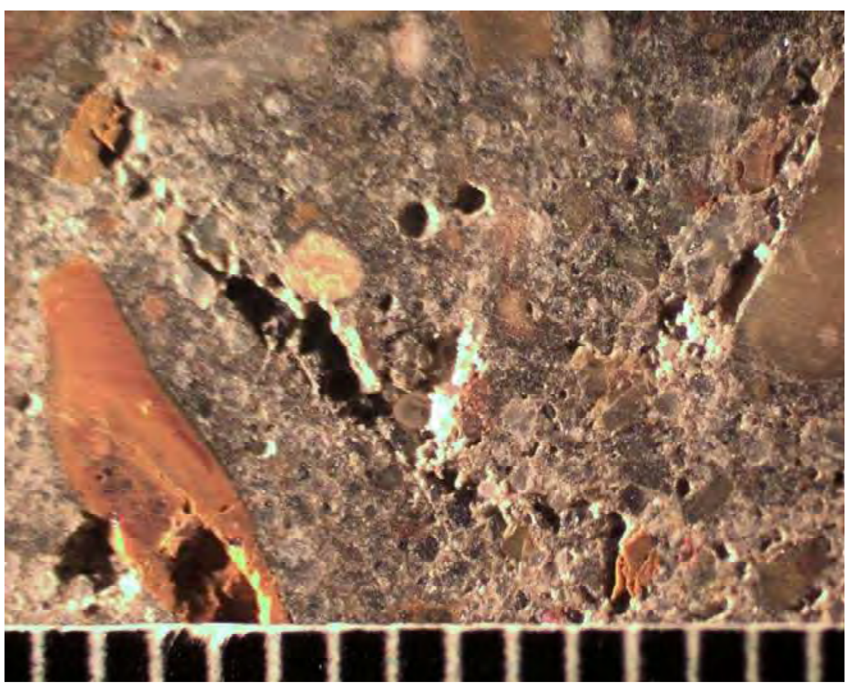

Figure 5: Photomicrograph showing the low air content in Sample CR-4. Scale in millimeters.

Carbonation

Depth of paste carbonation, measured from the top surface of the core, is approximately 12-mm (0.47-in).

Reinforcement

Reinforcement is not present in the core.

Water-to-Cement Ratio

The water-to-cement ratio is estimated to be between 0.35 and 0.45.

Paste-Aggregate Bond

The paste-aggregate bond is moderately tight throughout the core, as fractures created in the laboratory pass through and around coarse aggregate particles.

Paste

The cement paste is dark gray, dense, and hard. Freshly fractured surfaces have a dull to subvitreous luster.

Aggregate

The aggregate is fairly well graded and uniformly distributed. There is no evidence of deleterious alkali-aggregate reactions.

The coarse aggregate consists of natural gravel composed primarily of chert with minor amounts of sandstone and dolomite with a 1.25-in. (32-mm) top size. The coarse aggregate particles are rounded to subangular with a blocky to elongate sphericity.

The fine aggregate is natural sand composed primarily of quartz, limestone, feldspar, sandstone and other minerals and rocks. Individual sand grains are subrounded and range from elongated to blocky shape.

Core Sample SV-3 (South Face of Pier 5)

General

The core is 3.7-in. (95-mm) in diameter, 10.0-in. (254-mm) long and represents a partial member thickness (Figure 6). The outer surface has a smooth imprint of a formed surface (Figure 6). The inner surface is an irregular fracture surface (Figure 6). The concrete is well consolidated and shows no signs of segregation (Figure 7).

Figure 6: *Top:* **Core SV-3 (outer surface oriented to the left).** *Bottom:* **Outer (left) and inner (right) surfaces of Core SV-3.**

Cracks

No cracks or microcracks are present in the core, as shown in Figure 7 below.

Figure 7: Photograph showing the good condition of Core SV-3. The outer surface is to the left. Scale in inches.

Unit Weight

The unit weight of the concrete sample, as received, is approximately **143.0 lbs./cf**.

Air Content

The concrete has an estimated air content between **3.0 and 4.0%.**

Carbonation

Depth of paste carbonation, measured from the top surface of the core, is approximately 33-mm (1.3-in).

Reinforcement

Reinforcement is not present in the core.

Water-to-Cement Ratio

The water-to-cement ratio is estimated to be between 0.35 and 0.45.

Paste-Aggregate Bond

The paste-aggregate bond is moderately tight throughout the core, as fractures created in the laboratory pass through and around coarse aggregate particles.

Paste

The cement paste is gray, dense, and hard. Freshly fractured surfaces have a dull to subvitreous luster.

Aggregate

The aggregate is fairly well graded and uniformly distributed. The aggregate appears sound. There is no evidence of deleterious alkali-aggregate reactions.

The coarse aggregate consists of natural gravel composed primarily of chert with minor amounts of sandstone and dolomite with a 1.25-inch (32-mm) top size. The coarse aggregate particles are round to subangular with a blocky to elongate sphericity.

The fine aggregate is natural sand composed primarily of quartz, limestone, feldspar, sandstone and other minerals and rocks. Individual sand grains are subrounded and range from elongated to blocky shape.

****

We appreciate the opportunity to be of continued service to you. Should you have any questions or require additional information, please feel free to contact us at your convenience.

Sincerely yours,
Universal Construction Testing, Ltd.

Mitchell McCarthy
Junior Petrographer

Elena I. Emerson
Operations Manager

Reviewed by James W. Schmitt, P.G (IL, IN, WI).

Sample(s) will be discarded after ninety (90) days unless another disposition is requested by you.