PENNONI ASSOCIATES INC.
CONSULTING ENGINEERS

March 27, 2015

Design Level Inspection Report
I-95 Wilmington Viaduct

Re: Concrete Coring and Testing Services
Bridge I-748 North and South Bound
I-95 Viaduct, Wilmington, DE

Pennoni Associates (Pennoni) visited the above referenced structure on the nights of November 19, 2014 and December 10, 11, 15, 17, 18 and 21, 2014 to drill and extract concrete core samples and perform overlay pull testing. A total of twenty two (22) concrete cores were extracted and transported to our laboratory where they were documented and tested for thickness, compressive strength and water soluble chloride ions. Eight (8) cores, 4 from each direction of the structure, were sent to Highbridge Materials, Inc. for petrography and air voids testing. Table 1 below summarizes the physical dimensions, locations and selected testing for each of the concrete cores extracted from Bridge I-748.

Table 1 - Core Locations, Dimensions and Prescribed Testing

Bridge	Core ID	Core Location				Core Diameter (in)	Core Thickness		Laboratory Testing
		Span	Lane	Distance from Joint (X) (ft)	Distance from Lane Line (Y) (Ft)		Overlay (in)	Structural (in)	
I-748 (NB)	748NB-1C	4	R	10.0	5.0	3.25	2.50	5.25	Compression
	748NB-2C	5	L	88.0	10.0	3.25	1.50	4.50	Compression
	748NB-3C	8	C	66.0	11.0	3.25	3.00	5.00	Compression
	748NB-4C	12	R	28.0	7.0	3.25	2.00	5.50	Compression Water Soluble Chloride
	748NB-5C	19	L	11.0	4.5	3.25	1.25	6.25	Compression Water Soluble Chloride
	748NB-6C	22	R	50.0	9.0	3.25	3.00	4.50	Compression
	748NB-7C	24	C	17.0	7.0	3.25	3.13	4.88	Compression
	748NB-1P	5	L	84.0	6.0	3.25	1.25	5.50	Petrography & Air Voids
	748NB-2P	8	C	82.0	1.0	3.25	3.00	5.00	Petrography & Air Voids
	748NB-3P	11	R	89.0	5.0	3.25	2.00	6.00	Petrography & Air Voids
	748NB-4P	24	C	52.0	8.0	3.25	3.00	4.50	Petrography & Air Voids
I-748 (SB)	748SB-1C	25	R	30.0	10.0	3.25	2.50	5.00	Compression
	748SB-2C	22	L	116.0	3.0	3.25	1.00	6.50	Compression Water Soluble Chloride
	748SB-3C	16	C	59.0	3.0	3.25	3.00	4.75	Compression
	748SB-4C	11	R	21.0	8.0	3.25	2.50	4.00	Compression
	748SB-5C	10	L	125.0	8.0	3.25	1.19	6.25	Compression
	748SB-6C	6	C	72.0	7.0	3.25	3.00	4.50	Compression Water Soluble Chloride
	748SB-7C	2	C	110.0	10.0	3.25	3.00	4.50	Compression
	748SB-1P	24	L	27.0	10.0	3.25	1.50	4.50	Petrography & Air Voids
	748SB-2P	13	L	53.0	1.0	3.25	1.50	5.50	Petrography & Air Voids
	748SB-3P	12	C	111.0	3.0	3.25	3.00	4.50	Petrography & Air Voids
	748SB-4P	2	R	78.0	8.0	3.25	2.13	5.88	Petrography & Air Voids

Pull testing was performed at fourteen (14) locations. Seven (7) tests were performed adjacent to the compression core locations on both the northbound and southbound sides of the bridge.

As-Received Core Conditions

The following concrete core photographs were taken as they were received in the laboratory prior to testing.

Core 748NB-1C (As-Received)

Core 748NB-2C (As-Received)

Core 748NB-3C (As-Received)

Core 748NB-4C (As-Received)

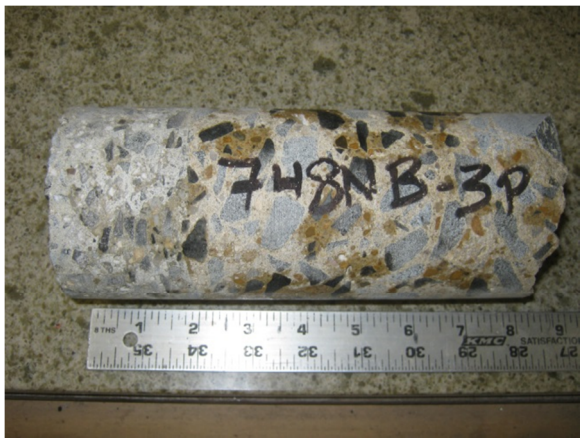
Core 748NB-5C (As-Received)

Core 748NB-6C (As-Received)

Core 748NB-7C (As-Received)

Core 748NB-1P (As-Received)

Core 748NB-2P (As-Received)



Core 748NB-3P (As-Received)

Core 748NB-4P (As-Received)

Core 748SB-1C (As-Received)

Core 748SB-2C (As-Received)

Core 748SB-3C (As-Received)

Core 748SB-4C (As-Received)

Core 748SB-5C (As-Received)

Core 748SB-6C (As-Received)

Core 748SB-7C (As-Received)

Core 748SB-1P (As-Received)

Core 748SB-2P (As-Received)

Core 748SB-3P (As-Received)

Core 748SB-4P (As-Received)

<u>As-Prepared and Tested</u>

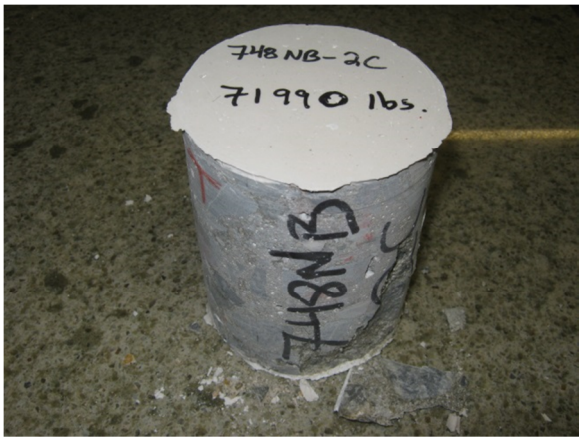
The cores were sawn cut to achieve the maximum length to diameter ratios and placed in non-absorptive bags for a minimum of 5 days prior to testing. At the date of testing the ends concrete cores were capped using a high strength hydro-stone capping compound to further level the ends of the cores.

The failures are highlighted in the "tested" photographs for clarity

Core 748NB-1C (As-Prepared)

Core 748NB-1C (Tested)

Core 748NB-2C (As-Prepared)

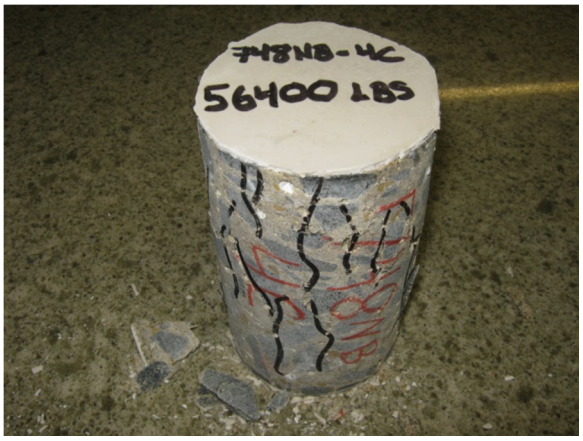


Core 748NB-2C (Tested)

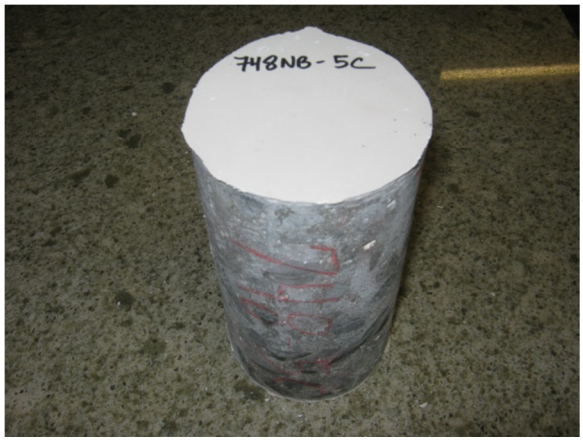
Core 748NB-3C (As-Prepared)

Core 748NB-3C (Tested)

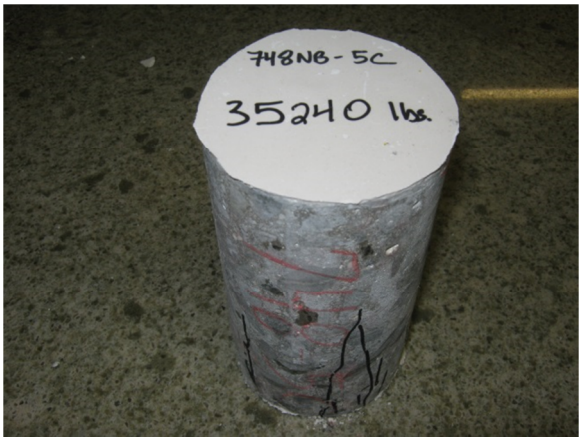
Core 748NB-4C (As-Prepared)



Core 748NB-4C (Tested)

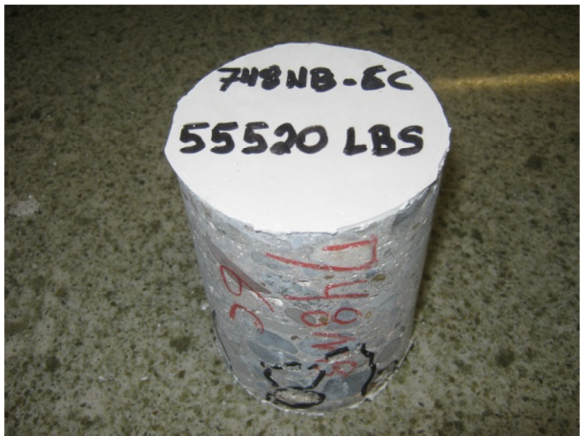


Core 748NB-5C (As-Prepared)



Core 748NB-5C (Tested)

Core 748NB-6C (As-Prepared)



Core 748NB-6C (Tested)

Core 748NB-7C (As-Prepared)

Core 748NB-7C (Tested)

Core 748SB-1C (As-Prepared)

Core 748SB-1C (Tested)

Core 748SB-2C (As-Prepared)

Core 748SB-2C (Tested)

Core 748SB-3C (As-Prepared)

Core 748SB-3C (Tested)

Core 748SB-4C (As-Prepared)

Core 748SB-4C (Tested)

NO PHOTO

Core 748SB-5C (As-Prepared)

Core 748SB-5C (Tested)

Core 748SB-6C (As-Prepared)

Core 748SB-6C (Tested)

Core 748SB-7C (As-Prepared)

Core 748SB-7C (Tested)

Compression Results

Table 2 summarizes the compression testing results of the concrete cores.

Table 2: Compression Testing Summary							
Core ID	Diameter (in)	As-Prepared Length (in)	Cross Sectional Area (in^2)	Ultimate Load (lbs.)	L/D Ratio	Correction Factor	Compressive Strength (psi)
748NB-1C	3.25	4.58	8.30	59,560	1.41	0.949	6,810
748NB-2C	3.25	4.07	8.30	71,990	1.25	0.930	8,070
748NB-3C	3.25	4.46	8.30	57,020	1.37	0.945	6,490
748NB-4C	3.25	5.48	8.30	56,400	1.69	0.975	6,630
748NB-5C	3.25	5.90	8.30	35,240	1.82	0.987	4,190
748NB-6C	3.25	4.50	8.30	55,520	1.38	0.946	6,330
748NB-7C	3.25	4.10	8.30	67,340	1.26	0.931	7,560
748SB-1C	3.25	4.51	8.30	62,500	1.39	0.947	7,130
748SB-2C	3.25	6.26	8.30	31,590	1.93	0.999	3,800
748SB-3C	3.25	4.45	8.30	42,580	1.37	0.944	4,850
748SB-4C	3.25	3.66	8.30	51,450	1.13	0.900	5,580
748SB-5C	3.25	5.93	8.30	58,020	1.82	0.988	6,910
748SB-6C	3.25	3.62	8.30	50,180	1.11	0.897	5,430
748SB-7C	3.25	4.59	8.30	44,160	1.41	0.950	5,050
Average Compression Strength (psi)							6,060

The failure mode of the tested cores was generally consistent with a Type 1 fracture pattern. A Type 1 fracture pattern is defined in ASTM C39 as having reasonably well-formed cones on both ends with less than 1 inch of cracking through the capped ends.

The average compressive strength of the cores extracted from the northbound sections of structure 748 was 6,580psi. The average compressive strength of the cores extracted from the southbound sections of structure 748 was 5,540 psi. There were two (2) cores 748NB-5C and 748SB-2C that were significantly less than 5000 psi. Due to the lower strength of these test results, Pennoni recommends impact echo testing results be reviewed.

Water Soluble Chloride Ion Testing

Cores 748NB-4C, 748NB-5C, 748SB-2C and 748SB-6C were randomly selected for water soluble chloride ion testing. Testing was performed at three depths from the surface of the structural concrete; 0.5 inch, 1 inch and 2 inch. The thickness of the concrete overlay wearing surface at locations 748NB-4C and 748NB-5C were 2.00 inches and 1.25 inches respectively. The thickness of the concrete overlay wearing surface at locations 748SB-2C and 748SB-6C were 1.00 inch and 3.00 inches respectively. Table 3 summarizes the concentrations of water soluble chloride ions for each tested core.

Table 3 - Water Soluble Chloride Ion Test Results						
Bridge	Core ID	Depth (in)	Cl- (%wt)	Cl- (ppm)	Cl- (lbs/yrd^3)	Cl- (% cement)
I-748	748NB-4C	-0.50	0.00046	5	0.02	0.00
	748NB-4C	-1.00	0.00023	2	0.01	0.00
	748NB-4C	-2.00	0.00014	1	0.01	0.00
	748NB-5C	-0.50	0.00140	14	0.05	0.01
	748NB-5C	-1.00	0.00084	8	0.03	0.01
	748NB-5C	-2.00	0.00059	6	0.02	0.00
	748SB-2C	-0.50	0.01332	133	0.52	0.10
	748SB-2C	-1.00	0.00449	45	0.18	0.03
	748SB-2C	-2.00	0.00215	21	0.08	0.02
	748SB-6C	-0.50	0.00986	99	0.39	0.07
	748SB-6C	-1.00	0.00526	53	0.21	0.04
	748SB-6C	-2.00	0.00174	17	0.07	0.01

The following assumptions were used in order to estimate the water soluble chloride concentrations as a function of pound per cubic yard of concrete and as a percent of cement mass.

1. The air dry density of normal weight concrete is 3915 pounds per cubic yard (145 pounds per cubic foot).
2. The cement content is assumed as 14% for normal weight concrete.

ACI 318 Chapter 4 Table 4.3.1 provides requirements for maximum concentrations of water soluble chlorides for C2 structures as 0.15. C2 structures are defined as structures exposed to external sources of moisture and chlorides from deicing chemicals. The results listed in Table 3 indicate that the concentrations of water soluble chlorides are lower than this limit and are practically nonexistent at the depth of the top layer of reinforcing steel (i.e. 2 inches from the surface). These results indicate that the reinforcing steel within this structure is not in a corrosive environment and should be in as good a condition as originally placed. These data also indicates that the concrete overlay wearing surface is providing adequate protection to the concrete structural slab at most of the locations. The chloride concentration is slightly high at the top of the structural slab at location 748SB-2C. This could be due to the overlay thickness at this location was only 1 inch.

Pull Testing of Overlay Wearing Surface

Pull testing of the concrete overlay wearing surface was performed at core locations 748NB-1C to 748NB-7C and 748SB-1C to 748SB-7C. The overlay thickness at these locations varied from 1.00 inches to 3.13 inches. The pull testing was performed in general compliance with ASTM C1583. A 3 inch diameter cored hole was drilled through the overlay wearing surface and into the underlying concrete slab by approximately 0.5 inches. A 3 inch diameter steel disk was then epoxied to the surface of the overlay and pulled at a constant rate until failure. The application of tensile load was monitored using an inline dynamometer. Table 4 summarizes the results from the overlay pull testing.

Table 4 - Pull Test Results of Concrete Overlay Wearing Surface					
Bridge	Core ID	Load Area (in^2)	Tensile Load (lbs)	Bond Strength (psi)	Failure Type
I-748	748NB-1C	7.07	100	14	Bond Fail
	748NB-2C	7.07	750	106	Bond Fail
	748NB-3C	7.07	100	14	Bond Fail
	748NB-4C	7.07	100	14	Bond Fail
	748NB-5C	7.07	750	106	Bond Fail
	748NB-6C	7.07	750	106	Bond Fail
	748NB-7C	7.07	1000	141	Bond Fail
	748SB-1C	7.07	1000	141	Bond Fail
	748SB-2C	7.07	1500	212	Bond Fail
	748SB-3C	7.07	1000	141	Bond Fail
	748SB-4C	7.07	250	35	Bond Fail
	748SB-5C	7.07	2000	283	Bond Fail
	748SB-6C	7.07	100	14	Bond Fail
	748SB-7C	7.07	1200	170	Bond Fail

The bond strengths listed in Table 4 have a wide range of results ranging from 14 psi to 283 psi. ACI 345 – Concrete Highway Bridge Deck Construction does not list values for the bond strength between the substructure and the concrete wearing surface. However, developing a good bond between the two surfaces is a fundamental requirement for most concrete overlay wearing surfaces. Without an adequate bond, the overlay wearing surface is susceptible to delamination which can range from localized minor spalling or the removal of extensive sections. In both cases, the removal of the wearing surface allows the infiltration of various chemicals and weather conditions to attack the underlying structure. The concrete repair institute (ICRI) generally notes that bond strengths should not be below 100 psi. Locations with very low bond strengths should be investigated further, possibly in companion with the results from the impulse echo testing to confirm possible delamination of the overlay surface.

Petrography and Air Voids

Cores 748NB-1P – 748NB-4P and 748SB-1P – 748SB-4P were sent to Highbridge Materials Consulting, Inc. for petrography and air voids. The following is a summary of the test results, for further information; please reference *"Petrographic Examination Report"*, prepared by Highbridge Materials Consulting, Inc. dated March 22, 2015.

The total air voids observed in cores 748NB-1P, 748NB-2P, 748NB-3P and 748NB-4P was 5.2%, 5.1%, 5.1% and 6.8% respectively. The total air voids observed in cores 748SB-1P, 748SB-2P, 748SB-3P and 748SB-4P was 8.7%, 5.6%, 5.6% and 9.1% respectively. The air contents for cores 748SS-1P and 748SB-4P exceed modern specifications for concrete that is exposed to freezing and thawing. The air contents for the remaining cores are within modern specifications. Current specifications for concrete exposed to freezing and thawing cycles is 3.5% to 6.5% per ACI 318 Chapter 4 Section 4. Concrete with high air content may have lower compressive strengths. There were two instances where the compressive strengths of the cores were significantly lower than the other tested cores; these lower compressive strengths could be the result of higher air void contents.

It was also noted that the air void structures in cores 748NB-2P, 748NB-3P and 748SB-3P had high spacing factors. Concrete with poorly developed air structures tend to have durability issues due to the imbalance of correctly sized voids to accommodate water infiltration and expansion during freezing events.

The petrographic analysis of the cores indicated that the concrete materials were well mixed, cast and consolidated. There were no obvious signs of workmanship deficiencies. The water is cement ratio for the core is estimated to be in the mid to high 0.40's. All eight (8) cores had trace to early stages of ASR present primarily in the fine chert particles. Cores 748NB-1P, 748NB-4P and 748SB-3P had evidence of mild dedolomitization (corrosion) in the dolostone grains. All of the cores had very minor and early stage micro cracking extending from the effected grains. Trace evidence of ASR gel was found in a few of these micro cracks.

We thank you for the opportunity to assist you with this project. If you have any questions, or if you need any further assistance with this project, please contact me at your earliest convenience.

Sincerely,

PENNONI ASSOCIATES INC.

Michael A. Padula
Senior Engineer/Division Manager
Inspection & Testing Technology

PENNONI ASSOCIATES INC.
CONSULTING ENGINEERS

March 27, 2015

Design Level Inspection Report
I-95 Wilmington Viaduct

Re: Concrete Coring and Testing Services
Bridge I-748N Northbound
I-95 Viaduct, Wilmington, DE

Pennoni Associates (Pennoni) visited the above referenced structure on the nights of November 19, 2014, December 17 and 21, 2014 and January 11, 2015 to drill and extract concrete core samples and perform overlay pull testing. A total of nine (9) concrete cores were extracted and transported to our laboratory where they were documented and tested for thickness, compressive strength and water soluble chloride ions. Three (3) cores, 2 from the 2 lane segment and 1 from the 3 lane segment of the structure, were sent to Highbridge Materials, Inc. for petrography and air voids. Table 1 below summarizes the physical dimensions, locations and selected testing for each of the concrete cores extracted from Bridge I-748N.

Table 1 - Core Locations, Dimensions and Prescribed Testing

Bridge	Core ID	Core Location				Core Diameter (in)	Core Thickness		Laboratory Testing
		Span	Lane	Distance from Joint (X) (ft)	Distance from Lane Line (Y) (Ft)		Overlay (in)	Structural (in)	
I-748 (N2)	748N2-1C	29	R	67.0	6.0	3.25	3.00	4.75	Compression
	748N2-2C	37	L	46.0	2.5	3.25	2.25	4.88	Compression Water Soluble Chloride
	748N2-3C	45	L	52	7.5	3.25	2.75	4.25	Compression
	748N2-1P	32	R	19.0	6.0	3.25	2.00	5.50	Petrography & Air Voids
	748N2-2P	45	L	67.0	5.5	3.25	2.50	3.75	Petrography & Air Voids
I-748 (N3)	748N3-1C	52	L	12.0	5.0	3.25	2.25	4.50	Compression Water Soluble Chloride
	748N3-2C	55	R	23.5	5.5	3.25	2.75	3.25	Compression
	748N3-3C	58	C	15.0	7.0	3.25	2.00	6.00	Compression
	748N3-1P	57	R	21.0	11.0	3.25	2.75	5.00	Petrography & Air Voids

Pull testing was performed at six (6) locations. Three (3) tests were performed adjacent to the compression core locations on both the two lane and three lane segments of the structure.

As-Received Core Conditions

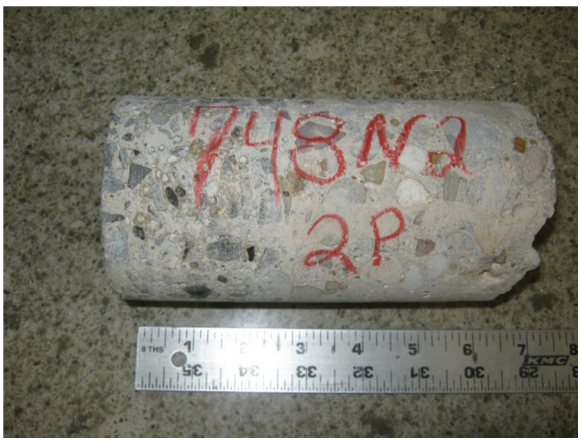
The following concrete core photographs were taken as they were received in the laboratory prior to testing.

Core 748N2-1C (As-Received)

Core 748N2-2C (As-Received)

Core 748N2-3C (As-Received)

Core 748N2-1P (As-Received)

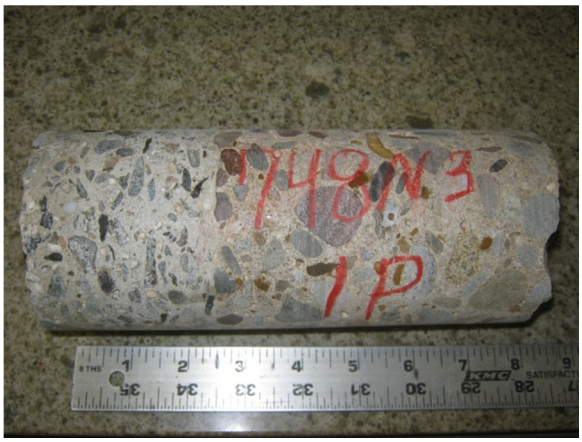


Core 748N2-2P (As-Received)

Core 748N3-1C (As-Received)

Core 748N3-2C (As-Received)

Core 748N3-3C (As-Received)

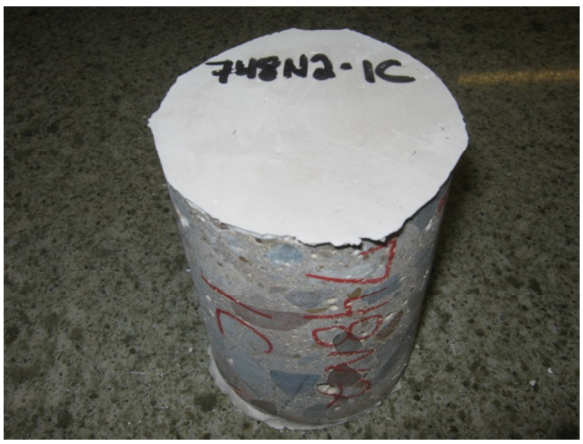


Core 748N3-1P (As-Received)

As-Prepared and Tested

The cores were sawn cut to achieve the maximum length to diameter ratios and placed in non-absorptive bags for a minimum of 5 days prior to testing. At the date of testing the ends concrete cores were capped using a high strength hydro-stone capping compound to further level the ends of the cores.

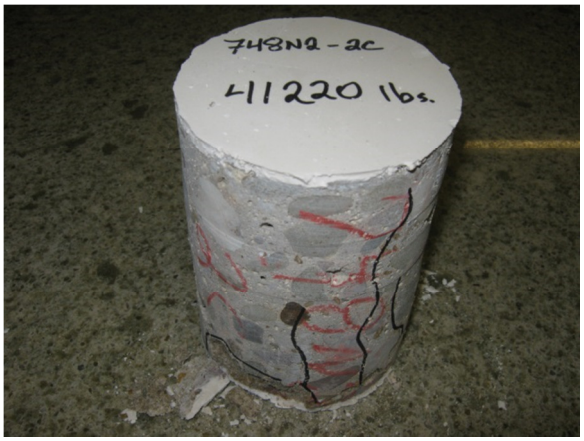
The failures are highlighted in the "tested" photographs for clarity.



Core 748N2-1C (As-Prepared)

Core 748N2-1C (Tested)

Core 748N2-2C (As-Prepared)



Core 748N2-2C (Tested)

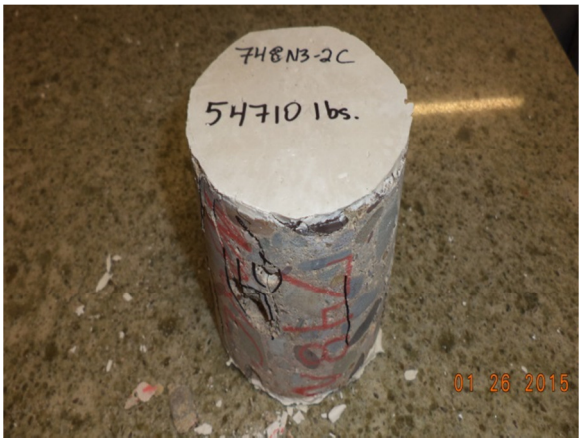
Core 744N2-3C (As-Prepared)

Core 744N2-3C (Tested)

Core 748N3-1C (As-Prepared)

Core 748N3-1C (Tested)

Core 748N3-2C (As-Prepared)



Core 748N3-2C (Tested)

Core 748N3-3C (As-Prepared)

Core 748N3-3C (Tested)

Compression Results

Table 2 summarizes the compression testing results of the concrete cores.

Table 2: Compression Testing Summary							
Core ID	Diameter (in)	As-Prepared Length (in)	Cross Sectional Area (in^2)	Ultimate Load (lbs.)	L/D Ratio	Correction Factor	Compressive Strength (psi)
748N2-1C	3.25	4.58	8.30	52,990	1.41	0.949	6,060
748N2-2C	3.25	4.58	8.30	41,220	1.41	0.949	4,720
748N2-3C	3.25	3.66	8.30	48,520	1.13	0.900	5,270
748N3-1C	3.25	3.92	8.30	41,380	1.21	0.920	4,590
748N3-2C	3.25	3.47	8.30	54,710	1.07	0.886	5,840
748N3-3C	3.25	5.49	8.30	52,570	1.69	0.975	6,180
Average Compression Strength (psi)							5,440

The failure mode of the tested cores was generally consistent with a Type 1 fracture pattern. A Type 1 fracture pattern is defined in ASTM C39 as having reasonably well-formed cones on both ends with less than 1 inch of cracking through the capped ends.

Water Soluble Chloride Ion Testing

Cores 748-N2-2C and 748-N3-1C were randomly selected for water soluble chloride ion testing. Testing was performed at three depths from the surface of the structural concrete; 0.5 inch, 1 inch and 2 inch. Both core locations 748-N2-2C and 748-N3-1C had a 2.25 inch thick concrete overlay wearing surface. Table 3 below summarizes the concentrations of water soluble chloride ions for each tested core.

Table 3 - Water Soluble Chloride Ion Test Results						
Bridge	Core ID	Depth (in)	Cl- (%wt)	Cl- (ppm)	Cl- (lbs/yrd^3)	Cl- (% cement)
I-748(N2)	748-N2-2C	-0.50	0.00353	35	0.14	0.03
	748-N2-2C	-1.00	0.00156	16	0.06	0.01
	748-N2-2C	-2.00	0.00039	4	0.02	0.00
I-748(N3)	748-N3-1C	-0.50	0.00026	3	0.01	0.00
	748-N3-1C	-1.00	0.00013	1	0.01	0.00
	748-N3-1C	-2.00	0.00009	1	0.00	0.00

The following assumptions were used in order to estimate the water soluble chloride concentrations as a function of pound per cubic yard of concrete and as a percent of cement mass.

1. The air dry density of normal weight concrete is 3915 pounds per cubic yard (145 pounds per cubic foot).
2. The cement content is assumed as 14% for normal weight concrete.

ACI 318 Chapter 4 Table 4.3.1 provides requirements for maximum concentrations of water soluble chlorides for C2 structures as 0.15. C2 structures are defined as structures exposed to external sources of moisture and chlorides from deicing chemicals. The results listed IN Table 3 indicate that the concentrations of water soluble chlorides are lower than this limit and are practically nonexistent at the depth of the top layer of reinforcing steel (i.e. 2 inches from the surface). These results indicate that the reinforcing steel within this structure is not in a corrosive environment and should be in as good a condition as originally placed. This data also indicates that the concrete overlay wearing surface is providing adequate protection to the concrete structural slab.

Pull Testing of Overlay Wearing Surface

Pull testing of the concrete overlay wearing surface was performed at core locations 748-N2-1C to 748-N2-3C and 748-N3-1C to 748-N3-3C. The overlay thickness at these locations varied from 2.00 inches to 3.00 inches. The pull testing was performed in general compliance with ASTM C1583. A 3inch diameter cored hole was drilled through the overlay wearing surface and into the underlying concrete slab by approximately 0.5 inches. A 3 inch diameter steel disk was then epoxied to the surface of the overlay and pulled at a constant rate until failure. The application of tensile load was monitored using an inline dynamometer. Table 4 below summarizes the results from the overlay pull testing.

Table 4 - Pull Test Results of Concrete Overlay Wearing Surface

Bridge	Core ID	Load Area (in^2)	Tensile Load (lbs)	Bond Strength (psi)	Failure Type
I-748(N2)	748-N2-1C	7.07	1000	141	Bond Fail
	748-N2-2C	7.07	750	106	Bond Fail
	748-N2-3C	7.07	1500	212	Bond Fail
I-748(N3)	748-N3-1C	7.07	1000	141	Bond Fail
	748-N3-2C	7.07	1000	141	Bond Fail
	748-N3-3C	7.07	1200	170	Bond Fail

The bond strengths listed in Table 4 have fairly consistent results ranging from 106 psi to 212 psi. ACI 345 – Concrete Highway Bridge Deck Construction does not list an actual value for the bond strength between the substructure and the concrete wearing surface. However, developing a good bond between the two surfaces is a fundamental requirement for most concrete overlay wearing surfaces. Without an adequate bond, the overlay wearing surface is susceptible to delamination which can range from localized minor spalling or the removal of extensive sections. In both cases, the removal of the wearing surface allows the infiltration of various chemicals and weather conditions to attack the underlying structure. The concrete repair institute (ICRI) generally notes bond strengths should not be below 100 psi.

Petrography and Air Voids

Cores 748N2-1P, 748N2-2P and 748N3-1P were sent to Highbridge Materials Consulting, Inc. for petrography and air voids. The following is a summary of the test results, for further information; please reference *"Petrographic Examination Report"*, prepared by Highbridge Materials Consulting, Inc. dated March 22, 2015.

The total air voids observed in cores 748N2-1P, 748N2-2P and 748N3-1P was 8.1%, 7.5% and 5.2% respectively. The air contents for cores 748N2-1P and 748N2-2P exceed modern specifications for concrete that is exposed to freezing and thawing. The air content for core 748N3-1P was within modern specifications. Current specifications for concrete exposed to freezing and thawing cycles is 3.5% to 6.5% per ACI 318 Chapter 4 Section 4. Concrete with high air content may have lower compressive strengths. The compressive

strength data for the cores extracted from this structure did not indicate a reduction in strength due to this higher air content.

The petrographic analysis of the cores indicated that the concrete materials were well mixed, cast and consolidated. There were no obvious signs of workmanship deficiencies. The water is cement ratio for the core is estimated to be in the mid to high 0.40's. Cores 748N2-1P and 748N3-1P had trace amounts of ASR present in the chert fine aggregate with no evidence of ASR in the cut thin sections. Core 748N2-2P had no evidence of ASR reactions.

We thank you for the opportunity to assist you with this project. If you have any questions, or if you need any further assistance with this project, please contact me at your earliest convenience.

Sincerely,

PENNONI ASSOCIATES INC.

Michael A. Padula
Senior Engineer/Division Manager
Inspection & Testing Technology

PENNONI ASSOCIATES INC.
CONSULTING ENGINEERS

March 27, 2015

Design Level Inspection Report
I-95 Wilmington Viaduct

Re: Concrete Coring and Testing Services
Bridge I-748S Southbound
I-95 Viaduct, Wilmington, DE

Pennoni Associates (Pennoni) visited the above referenced bridge on the nights of December 7, 10, 11 and 18, 2014 to drill and extract concrete core samples and perform overlay pull testing. A total of nine (9) concrete cores were extracted and transported to our laboratory where they were documented and tested for thickness, compressive strength and water soluble chloride ions. Three (3) cores were sent to Highbridge Materials, Inc. for petrography and air voids. Table 1 below summarizes the physical dimensions, locations and selected testing for each of the concrete cores extracted from Structure I-748S.

Table 1 - Core Locations, Dimensions and Prescribed Testing

Bridge	Core ID	Core Location				Core Diameter (in)	Core Thickness		Laboratory Testing
		Span	Lane	Distance from Joint (X) (ft)	Distance from Lane Line (Y) (Ft)		Overlay (in)	Structural (in)	
I-748S	748S-1C	27	L	43.0	2.5	3.25	2.25	5.25	Compression Water Soluble Chloride
	748S-2C	35	L	21.0	10.0	3.25	1.50	4.50	Compression
	748S-3C	39	L	60.0	1.0	3.25	2.00	6.00	Compression Water Soluble Chloride
	748S-4C	44	L	64.0	3.0	3.25	2.25	6.25	Compression
	748S-5C	53	L	22.0	8.0	3.25	2.00	6.25	Compression
	748S-6C	54	R	64.0	8.0	3.25	2.00	5.00	Compression
	748S-1P	27	L	10.0	7.0	3.25	2.25	5.75	Petrography & Air Voids
	748S-2P	45	R	31.0	3.0	3.25	2.00	6.00	Petrography & Air Voids
	748S-3P	57	L	44.0	10.0	3.25	1.50	6.75	Petrography & Air Voids

Pull testing was performed at six (6) locations. The locations selected for the pull testing were directly adjacent to the compression core locations for this structure.

As-Received Core Conditions

The following concrete core photographs were taken as they were received in the laboratory prior to testing.

Core 748S-1C (As-Received)

Core 748S -2C (As-Received)

Core 748S -3C (As-Received)

Core 748S -4C (As-Received)

Core 748S -5C (As-Received)

Core 748S -6C (As-Received)

Core 748S -1P (As-Received)

Core 748S -2P (As-Received)

Core 748S -3P (As-Received)

As-Prepared and Tested

The cores were sawn cut to achieve the maximum length to diameter ratios and placed in non-absorptive bags for a minimum of 5 days prior to testing. At the date of testing the ends concrete cores were capped using a high strength hydro-stone capping compound to further level the ends of the cores.

The failures are highlighted in the "tested" photographs for clarity.

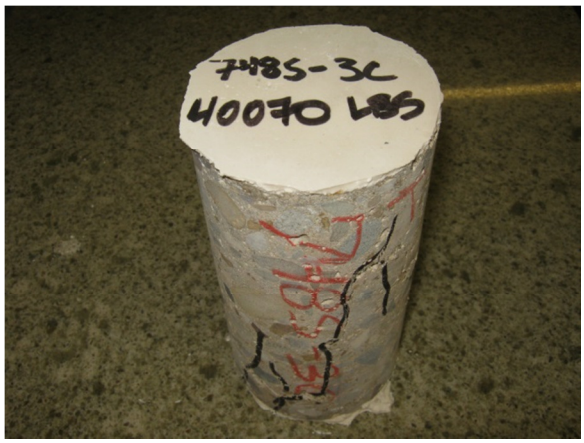
Core 748S -1C (As-Prepared)

Core 748S -1C (Tested)

Core 748S -2C (As-Prepared)

Core 748S -2C (Tested)

Core 748S -3C (As-Prepared)

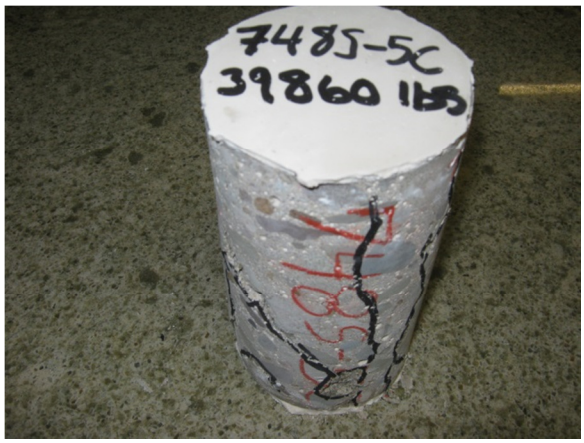


Core 748S -3C (Tested)

Core 748S -4C (As-Prepared)

Core 748S -4C (Tested)

Core 748S -5C (As-Prepared)



Core 748S -5C (Tested)

Core 748S -6C (As-Prepared)

Core 748S -6C (Tested)

Compression Results

Table 2 summarizes the compression testing results of the concrete cores.

Table 2: Compression Testing Summary							
Core ID	Diameter (in)	As-Prepared Length (in)	Cross Sectional Area (in^2)	Ultimate Load (lbs.)	L/D Ratio	Correction Factor	Compressive Strength (psi)
748S-1C	3.25	4.88	8.30	45,860	1.50	0.960	5,310
748S-2C	3.25	3.92	8.30	55,460	1.21	0.920	6,150
748S-3C	3.25	6.28	8.30	40,070	1.93	0.999	4,830
748S-4C	3.25	6.41	8.30	47,950	1.97	1.000	5,780
748S-5C	3.25	6.10	8.30	39,860	1.88	0.993	4,770
748S-6C	3.25	4.49	8.30	55,100	1.38	0.946	6,280
Average Compression Strength (psi)							5,520

The failure mode of the tested cores was generally consistent with a Type 1 fracture pattern. A Type 1 fracture pattern is defined in ASTM C39 as having reasonably well-formed cones on both ends with less than 1 inch of cracking through the capped ends.

Water Soluble Chloride Ion Testing

Cores 748S-1C and 748S-3C were randomly selected for water soluble chloride ion testing. Testing was performed at three depths from the surface of the structural concrete; 0.5 inch, 1 inch and 2 inch. The core at location 748S-1C had a 2.25 inch thick concrete overlay wearing surface. The core at location 748-3C had a 2.00 inch thick concrete overlay wearing surface. Table 3 summarizes the concentrations of water soluble chloride ions for each tested core.

Table 3 - Water Soluble Chloride Ion Test Results						
Bridge	Core ID	Depth (in)	Cl- (%wt)	Cl- (ppm)	Cl- (lbs/yrd^3)	Cl- (% cement)
I-748S	748S-1C	-0.50	0.00125	13	0.05	0.01
	748S-1C	-1.00	0.00105	10	0.04	0.01
	748S-1C	-2.00	0.00039	4	0.02	0.00
	748S-3C	-0.50	0.00084	8	0.03	0.01
	748S-3C	-1.00	0.00044	4	0.02	0.00
	748S-3C	-2.00	0.00026	3	0.01	0.00

The following assumptions were used in order to estimate the water soluble chloride concentrations as a function of pound per cubic yard of concrete and as a percent of cement mass.

1. The air dry density of normal weight concrete is 3915 pounds per cubic yard (145 pounds per cubic foot).
2. The cement content is assumed as 14% for normal weight concrete.

ACI 318 Chapter 4 Table 4.3.1 provides requirements for maximum concentrations of water soluble chlorides for C2 structures as 0.15. C2 structures are defined as structures exposed to external sources of moisture and chlorides from deicing chemicals. The results listed In Table 3 indicate that the concentrations of water soluble chlorides are lower than this limit and are practically nonexistent at the depth of the top layer of reinforcing steel (i.e. 2 inches from the surface). These results indicate that the reinforcing steel within this structure is not in a corrosive environment and should be in as good a condition as originally placed. This data also indicates that the concrete overlay wearing surface is providing adequate protection to the concrete structural slab.

Pull Testing of Overlay Wearing Surface

Pull testing of the concrete overlay wearing surface was performed at core locations 748S-1C to 748S-6C. The overlay thickness at these locations varied from 1.50 inches to 2.25 inches. The pull testing was performed in general compliance with ASTM C1583. A 3inch diameter cored hole was drilled through the overlay wearing surface and into the underlying concrete slab by approximately 0.5 inches. A 3 inch diameter steel disk was then epoxied to the surface of the overlay and pulled at a constant rate until failure. The application of tensile load was monitored using an inline dynamometer. Table 4 summarizes the results from the overlay pull testing.

Table 4 - Pull Test Results of Concrete Overlay Wearing Surface

Bridge	Core ID	Load Area (in^2)	Tensile Load (lbs)	Bond Strength (psi)	Failure Type
I-748S	748S-1C	7.07	750	106	Bond Fail
	748S-2C	7.07	1200	170	Bond Fail
	748S-3C	7.07	500	71	Bond Fail
	748S-4C	7.07	750	106	Bond Fail
	748S-5C	7.07	750	106	Bond Fail
	748S-6C	7.07	1200	170	Bond Fail

The bond strengths listed in Table 4 had fairly consistent results ranging from 71 psi to 170 psi. ACI 345 – Concrete Highway Bridge Deck Construction does not list values for the bond strength between the substructure and the concrete wearing surface. However, developing a good bond between the two surfaces is a fundamental requirement for most concrete overlay wearing surfaces. Without an adequate bond, the overlay wearing surface is susceptible to delamination which can range from localized minor spalling or the removal of extensive sections. In both cases, the removal of the wearing surface allows the infiltration of various chemicals and weather conditions to attack the underlying structure. The concrete repair institute (ICRI) generally notes bond strengths should not be below 100 psi.

Petrography and Air Voids

Cores 748S-1P, 748S-2P and 748S-3P were sent to Highbridge Materials Consulting, Inc. for petrography and air voids. The following is a summary of the test results, for further information; please reference *"Petrographic Examination Report"*, prepared by Highbridge Materials Consulting, Inc. dated March 22, 2015.

The total air voids observed in cores 748S-1P, 748S-2P and 748S-3P was 5.0%, 7.8% and 9.6% respectively. The air contents for cores 748S-2P and 748S-3P exceed modern specifications for concrete that is exposed to freezing and thawing. The air content for core 748S-1P was within modern specifications. Current specifications for concrete exposed to freezing and thawing cycles is 3.5% to 6.5% per ACI 318 Chapter 4 Section 4. Concrete with high air content may have lower compressive strengths. The compressive strength data for the cores extracted from this structure did not indicate a reduction in strength due to this higher air content. It was also noted that the air void structures in cores 748S-1P and 748S-3P had low specific surface characteristics and 748S-1P had a high spacing factor. Concrete with poorly developed air structures tend to have durability issues due to the imbalance of correctly sized voids to accommodate water infiltration and expansion during freezing events.

The petrographic analysis of the cores indicated that the concrete materials were well mixed, cast and consolidated. There were no obvious signs of workmanship deficiencies. The water is cement ratio for the core is estimated to be in the mid to high 0.40's. All three (3) of the cores had trace amounts of ASR present in the chert fine aggregate with no evidence of ASR in the cut thin sections for cores 748S-1P and 748S-3P. Core 748S-2P had one local indication of micro-cracking with gel pockets identified in the cut thin section.

We thank you for the opportunity to assist you with this project. If you have any questions, or if you need any further assistance with this project, please contact me at your earliest convenience.

Sincerely,

PENNONI ASSOCIATES INC.

Michael A. Padula
Senior Engineer/Division Manager
Inspection & Testing Technology

PENNONI ASSOCIATES INC.
CONSULTING ENGINEERS

March 27, 2015

Design Level Inspection Report
I-95 Wilmington Viaduct

Re: Concrete Coring and Testing Services
Bridge I-749 North and South Bound
I-95 Viaduct, Wilmington, DE

Pennoni Associates (Pennoni) visited the above referenced structure on the night of January 5, 2015 to drill and extract concrete core samples and perform overlay pull testing. A total of four (4) concrete cores were extracted and transported to our laboratory where they were documented and tested for thickness, compressive strength and water soluble chloride ions. One (1) core was sent to Highbridge Materials, Inc. for petrography and air voids testing. Table 1 summarizes the physical dimensions, locations and selected testing for each of the concrete cores extracted from Bridge I-749.

Table 1 - Core Locations, Dimensions and Prescribed Testing									
Bridge	Core ID	Core Location				Core Diameter (in)	Core Thickness		Laboratory Testing
		Span	Lane	Distance from Joint (X) (ft)	Distance from Lane Line (Y) (Ft)		Overlay (in)	Structural (in)	
I-749	749-1C	2	R	33.0	3.0	3.25	1.75	5.25	Compression
	749-2C	1	R	77.0	7.0	3.25	3.00	4.50	Compression
	749-3C	4	R	50.0	11.0	3.25	1.50	5.50	Compression
	749-1P	3	R	109.0	8.0	3.25	2.00	6.00	Petrography & Air Voids

Pull testing was performed at three (3) locations. The locations selected for the pull testing were directly adjacent to the compression core locations for this bridge.

As-Received Core Conditions

The following concrete core photographs were taken as they were received in the laboratory prior to testing.

Core 749-1C (As-Received)

Core 749-2C (As-Received)

Core 749-3C (As-Received)

Core 749-1P (As-Received)

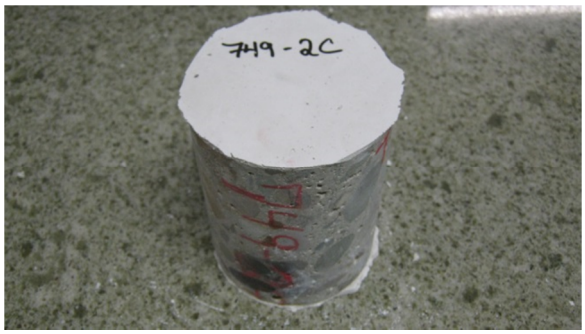
As-Prepared and Tested

The cores were sawn cut to achieve the maximum length to diameter ratios and placed in non-absorptive bags for a minimum of 5 days prior to testing. At the date of testing the ends concrete cores were capped using a high strength hydro-stone capping compound to further level the ends of the cores.

The failures are highlighted in the “tested” photographs for clarity.

Core 749-1C (As-Prepared)

Core 749-1C (Tested)



Core 749-2C (As-Prepared)

Core 749-2C (Tested)

Core 749-3C (As-Prepared)

Core 749-3C (Tested)

Compression Results

Table 2 summarizes the compression testing results of the concrete cores.

Table 2: Compression Testing Summary							
Core ID	Diameter (in)	As-Prepared Length (in)	Cross Sectional Area (in^2)	Ultimate Load (lbs.)	L/D Ratio	Correction Factor	Compressive Strength (psi)
749-1C	3.25	5.30	8.30	45,410	1.63	0.971	5,310
749-2C	3.25	4.42	8.30	52,320	1.36	0.943	5,950
749-3C	3.25	5.85	8.30	40,830	1.80	0.985	4,850
Average Compression Strength (psi)							5,370

The failure mode of the tested cores was generally consistent with a Type 1 fracture pattern. A Type 1 fracture pattern is defined in ASTM C39 as having reasonably well-formed cones on both ends with less than 1 inch of cracking through the capped ends.

Water Soluble Chloride Ion Testing

Core 749-1C was randomly selected for water soluble chloride ion testing. Testing was performed at three (3) depths from the surface of the structural concrete surface; 0.5 inch, 1 inch and 2 inches. The core at this location had a 1.75 inch thick concrete overlay wearing surface. Table 3 summarizes the concentrations of water soluble chloride ions for each tested core.

Table 3 - Water Soluble Chloride Ion Test Results						
Bridge	Core ID	Depth (in)	Cl- (%wt)	Cl- (ppm)	Cl- (lbs/yrd^3)	Cl- (% cement)
I-749	749-1C	-0.50	0.00244	24	0.10	0.02
	749-1C	-1.00	0.00012	1	0.00	0.00
	749-1C	-2.00	0.00010	1	0.00	0.00

The following assumptions were used in order to estimate the water soluble chloride concentrations as a function of pound per cubic yard of concrete and as a percent of cement mass.

1. The air dry density of normal weight concrete is 3915 pounds per cubic yard (145 pounds per cubic foot).
2. The cement content is assumed as 14% for normal weight concrete.

ACI 318 Chapter 4 Table 4.3.1 provides requirements for maximum concentrations of water soluble chlorides for C2 structures as 0.15. C2 structures are defined as structures that are exposed to external sources of moisture and chlorides from deicing chemicals. The results listed above indicate that the concentrations of water soluble chlorides are lower than this limit and are practically nonexistent at the depth of the top layer of reinforcing steel (i.e. 2 inches from the surface). These results indicate that the reinforcing steel within this structure is not in a corrosive environment and should be in as good a condition as originally placed.

Pull Testing of Overlay Wearing Surface

Pull testing of the concrete overlay wearing surface was performed at core locations 749-1C, 749-2C and 749-3C. The overlay thickness at these locations varied from 1.50 inches to 3.00 inches. The pull testing was performed in general compliance with ASTM C1583. A 3inch diameter cored hole was drilled through the overlay wearing surface and into the underlying concrete slab by approximately 0.5 inches. A 3 inch diameter steel disk was then epoxied to the surface of the overlay and pulled at a constant rate until failure. The application of tensile load was monitored using an inline dynamometer. Table 4 below summarizes the results from the overlay pull testing.

Table 4 - Pull Test Results of Concrete Overlay Wearing Surface

Bridge	Core ID	Load Area (in^2)	Tensile Load (lbs)	Bond Strength (psi)	Failure Type
I-749	749-1C	7.07	2400	340	Bond Fail
	749-2C	7.07	200	28	Bond Fail
	749-3C	7.07	750	106	Bond Fail

The bond strengths listed in Table 4 had high variability ranging from 28 psi to 141 psi. ACI 345 – Concrete Highway Bridge Deck Construction does not list values for the bond strength between the substructure and the concrete wearing surface. However, developing a good bond between the two surfaces is a fundamental requirement for most concrete overlay wearing surfaces. Without an adequate bond, the overlay wearing surface is susceptible to delamination which can range from localized minor spalling or the removal of extensive sections. In both cases, the removal of the wearing surface allows the infiltration of various chemicals and weather conditions to attack the underlying structure. The concrete repair institute (ICRI) generally notes bond strengths should not be below 100 psi.

Petrography and Air Voids

Core 749-1P was sent to Highbridge Materials Consulting, Inc. for petrography and air voids. The following is a summary of the test results, for further information; please reference *"Petrographic Examination Report"*, prepared by Highbridge Materials Consulting, Inc. dated March 22, 2015.

The total air voids observed in core 749-1P was 5.8%. This value is within the range of modern specifications for concrete that is exposed to freezing and thawing. Current specifications for concrete exposed to freezing and thawing cycles is 3.5% to 6.5% per ACI 318 Chapter 4 Section 4.

The petrographic analysis of the cores indicated that the concrete materials were well mixed, cast and consolidated. There were no obvious signs of workmanship deficiencies. The water is cement ratio for the core is estimated to be in the high 0.40's. Core 749-1P had evidence of early stage alkali-silica reactions in the form of axial micro-cracking primarily in the upper 2 inches of the core. The reactions have not compromised the integrity of the concrete below the upper 2 inches and no imminent threat is suggested by the existing conditions. However, the ASR reactions could continue to advance if there is a moisture source for this concrete.

We thank you for the opportunity to assist you with this project. If you have any questions, or if you need any further assistance with this project, please contact me at your earliest convenience.

Sincerely,

PENNONI ASSOCIATES INC.

Michael A. Padula, P.E.
Senior Engineer/Division Manager
Inspection & Testing Technology

PENNONI ASSOCIATES INC.
CONSULTING ENGINEERS

March 27, 2015

Design Level Inspection Report
I-95 Wilmington Viaduct

Re: Concrete Coring and Testing Services
Bridge I-750 North and South Bound
I-95 Viaduct, Wilmington, DE

Pennoni Associates (Pennoni) visited the above referenced structure on the night of January 8, 2015 to drill and extract concrete core samples from the structure. A total of four (4) concrete cores were extracted and transported to our laboratory where they were documented and tested for thickness, compressive strength and water soluble chloride ions. One (1) core was sent to Highbridge Materials, Inc. for petrography and air voids testing. Table 1 below summarizes the physical dimensions, locations and selected testing for each of the concrete cores extracted from Bridge I-750.

Table 1 - Core Locations, Dimensions and Prescribed Testing

Bridge	Core ID	Core Location				Core Diameter (in)	Core Thickness		Laboratory Testing
		Span	Lane	Distance from Joint (X) (ft)	Distance from Lane Line (Y) (Ft)		Overlay (in)	Structural (in)	
I-750	750-1C	1	R	20.0	11.0	3.25	3.00	3.50	Compression
	750-2C	2	R	75.0	8.0	3.25	2.00	4.50	Compression
	750-3C	3	R	16.0	11.0	3.25	2.00	5.25	Compression Water Soluble Chloride
	750-1P	3	R	25.0	3.0	3.25	1.75	5.75	Petrography & Air Voids

Pull testing of the overlay wearing surface was not performed on this structure.

As-Received Core Conditions

The following concrete core photographs were taken as they were received in the laboratory prior to testing.

Core 750-1C (As-Received)

Core 750-2C (As-Received)

Core 750-3C (As-Received)

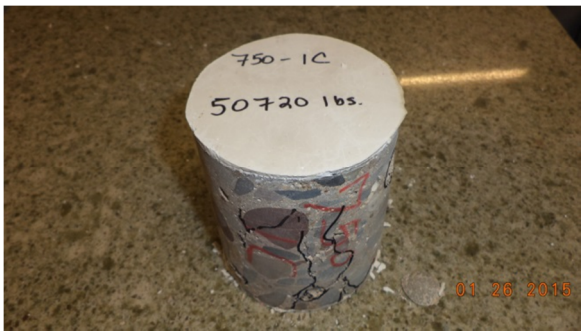
Core 750-1P (As-Received)

As-Prepared and Tested

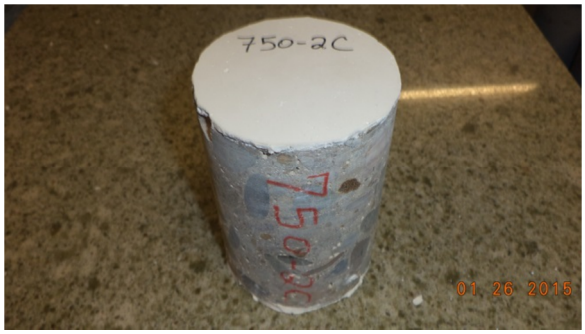
The cores were sawn cut to achieve the maximum length to diameter ratios and placed in non-absorptive bags for a minimum of 5 days prior to testing. At the date of testing the ends concrete cores were capped using a high strength hydro-stone capping compound to further level the ends of the cores.

The failures are highlighted in the “tested” photographs for clarity.

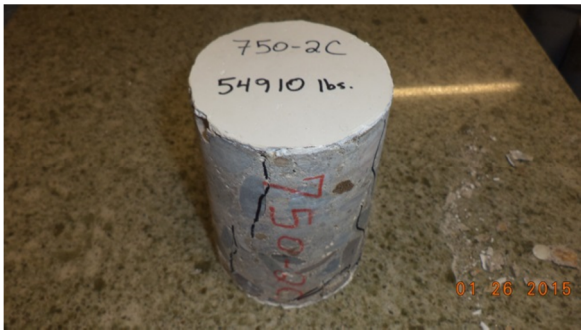
Core 750-1C (As-Prepared)



Core 750-1C (Tested)

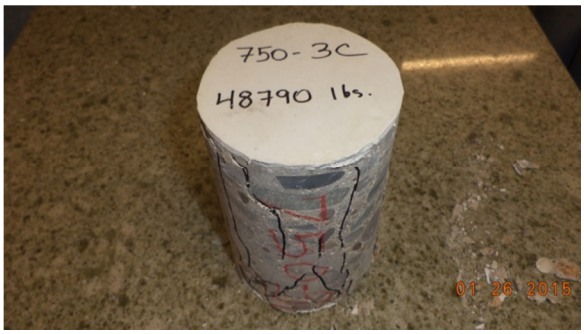


Core 750-2C (As-Prepared)



Core 750-2C (Tested)

Core 750-3C (As-Prepared)



Core 750-3C (Tested)

Compression Results

Table 2 summarizes the compression testing results of the concrete cores.

Table 2: Compression Testing Summary							
Core ID	Diameter (in)	As-Prepared Length (in)	Cross Sectional Area (in^2)	Ultimate Load (lbs.)	L/D Ratio	Correction Factor	Compressive Strength (psi)
750-1C	3.25	3.77	8.30	50,720	1.16	0.908	5,550
750-2C	3.25	4.50	8.30	54,910	1.38	0.946	6,260
750-3C	3.25	4.99	8.30	48,790	1.54	0.963	5,660
Average Compression Strength (psi)							5,820

The failure mode of the tested cores was generally consistent with a Type 1 fracture pattern. A Type 1 fracture pattern is defined in ASTM C39 as having reasonably well-formed cones on both ends with less than 1 inch of cracking through the capped ends.

Water Soluble Chloride Ion Testing

Core 750-3C was randomly selected for water soluble chloride ion testing. Testing was performed at three depths from the surface of the structural concrete; 0.5 inch, 1 inch and 2 inch. The core at this location had a 2 inch thick concrete overlay wearing surface. Table 3 below summarizes the concentrations of water soluble chloride ions for each tested core.

Table 3 - Water Soluble Chloride Ion Test Results						
Bridge	Core ID	Depth (in)	Cl- (%wt)	Cl- (ppm)	Cl- (lbs/yrd^3)	Cl- (% cement)
I-750	750-3C	-0.50	0.00123	12	0.05	0.01
	750-3C	-1.00	0.00009	1	0.00	0.00
	750-3C	-2.00	0.00003	0	0.00	0.00

The following assumptions were used in order to estimate the water soluble chloride concentrations as a function of pound per cubic yard of concrete and as a percent of cement mass.

1. The air dry density of normal weight concrete is 3915 pounds per cubic yard (145 pounds per cubic foot).
2. The cement content is assumed as 14% for normal weight concrete.

ACI 318 Chapter 4 Table 4.3.1 provides requirements for maximum concentrations of water soluble chlorides for C2 structures as 0.15. C2 structures are defined as structures that are exposed to external sources of moisture and chlorides from deicing chemicals. The results listed above indicate that the concentrations of water soluble chlorides are lower than this limit and are practically nonexistent at the depth of the top layer of reinforcing steel (i.e. 2 inches from the surface). These results indicate that the reinforcing steel within this structure is not in a corrosive environment and should be in as good as condition as originally placed.

Air Voids and Petrography

Core 750-1P was sent to Highbridge Materials Consulting, Inc. for petrography and air voids. The following is a summary of the test results, for further information; please reference *"Petrographic Examination Report"*, prepared by Highbridge Materials Consulting, Inc. dated March 22, 2015.

The total air voids observed in core 750-1P was 8.5%. This value exceeds modern specifications for concrete that is exposed to freezing and thawing. Current specifications for concrete exposed to freezing and thawing cycles is 3.5% to 6.5% per ACI 318 Chapter 4 Section 4. Concrete with high air content may have lower compressive strengths. The compressive strength data for the cores extracted from this structure did not indicate a reduction in strength due to this higher air content.

The petrographic analysis of the cores indicated that the concrete materials were well mixed, cast and consolidated. There were no obvious signs of workmanship deficiencies. The water is cement ratio for the core is estimated to be in the mid to high 0.40's. Core 750-1P had trace levels of incipient scaling within the uppermost millimeter of the core. This scaling may have been the result from the scarification process used prior to the application of the overlay. There was no evidence of ASR present in the core sample.

We thank you for the opportunity to assist you with this project. If you have any questions, or if you need any further assistance with this project, please contact me at your earliest convenience.

Sincerely,

PENNONI ASSOCIATES INC.

Michael A. Padula
Senior Engineer/Division Manager
Inspection & Testing Technology

PENNONI ASSOCIATES INC.
CONSULTING ENGINEERS

March 27, 2015

Design Level Inspection Report
I-95 Wilmington Viaduct

Re: Concrete Coring and Testing Services
Bridge I-758 North and South Bound
I-95 Viaduct, Wilmington, DE

Pennoni Associates (Pennoni) visited the above referenced bridge on the night of January 8, 2015 to drill and extract concrete core samples. A total of four (4) concrete cores were extracted and transported to our laboratory where they were documented and tested for thickness, compressive strength and water soluble chloride ions. One (1) core was sent to Highbridge Materials, Inc. for petrography and air voids testing. Table 1 below summarizes the physical dimensions, locations and selected testing for each of the concrete cores extracted from Bridge I-758.

Table 1 - Core Locations, Dimensions and Prescribed Testing

Bridge	Core ID	Core Location				Core Diameter (in)	Core Thickness		Laboratory Testing
		Span	Lane	Distance from Joint (X) (ft)	Distance from Lane Line (Y) (Ft)		Overlay (in)	Structural (in)	
I-758	758-1C	2	R	13.0	4.0	3.25	2.00	7.00	Compression
	758-2C	4	R	72.0	8.0	3.25	2.50	3.50	Compression Water Soluble Chloride
	758-3C	6	R	22.0	8.0	3.25	3.00	4.75	Compression
	758-1P	7	R	45.0	9.0	3.25	3.00	4.50	Petrography & Air Voids

Pull testing of the overlay wearing surface was not performed on this bridge.

As-Received Core Conditions

The following concrete core photographs were taken as they were received in the laboratory prior to testing.

Core 758-1C (As-Received)

Core 758-2C (As-Received)

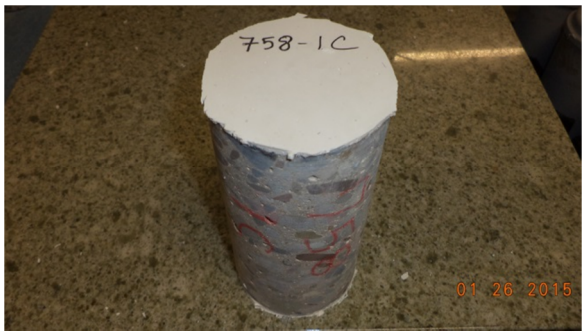
Core 758-3C (As-Received)

Core 758-1P (As-Received)

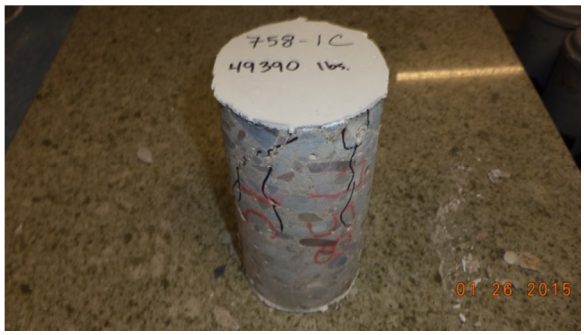
As-Prepared and Tested

The cores were sawn cut to achieve the maximum length to diameter ratios and placed in non-absorptive bags for a minimum of 5 days prior to testing. At the date of testing the ends concrete cores were capped using a high strength hydro-stone capping compound to further level the ends of the cores.

The failures are highlighted in the “tested” photographs for clarity.

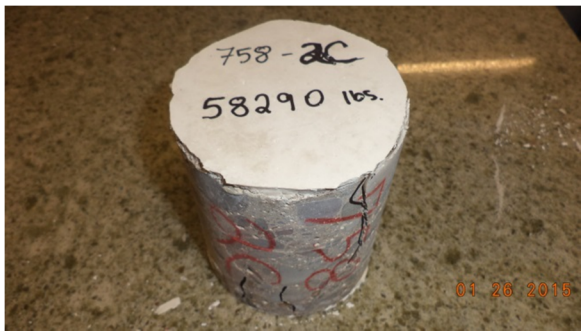


Core 758-1C (As-Prepared)



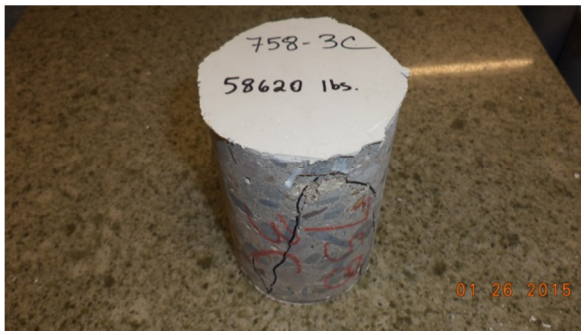
Core 758-1C (Tested)

Core 758-2C (As-Prepared)



Core 758-2C (Tested)

Core 758-3C (As-Prepared)



Core 758-3C (Tested)

Compression Results

Table 2 summarizes the compression testing results of the concrete cores.

Table 2: Compression Testing Summary							
Core ID	Diameter (in)	As-Prepared Length (in)	Cross Sectional Area (in^2)	Ultimate Load (lbs.)	L/D Ratio	Correction Factor	Compressive Strength (psi)
758-1C	3.25	6.18	8.30	49,390	1.90	0.996	5,930
758-2C	3.25	3.80	8.30	58,290	1.17	0.911	6,400
758-3C	3.25	4.76	8.30	58,620	1.46	0.956	6,750
Average Compression Strength (psi)							6,360

The failure mode of the tested cores was generally consistent with a Type 1 fracture pattern. A Type 1 fracture pattern is defined in ASTM C39 as having reasonably well-formed cones on both ends with less than 1 inch of cracking through the capped ends.

Water Soluble Chloride Ion Testing

Core 758-2C was randomly selected for water soluble chloride ion testing. Testing was performed at three depths from the surface of the structural concrete; 0.5 inch, 1 inch and 2 inch. The core at this location had a 2.5 inch thick concrete overlay wearing surface. Table 3 below summarizes the concentrations of water soluble chloride ions for each tested core.

Table 3 - Water Soluble Chloride Ion Test Results						
Bridge	Core ID	Depth (in)	Cl- (%wt)	Cl- (ppm)	Cl- (lbs/yrd^3)	Cl- (% cement)
I-758	758-2C	-0.50	0.00091	9	0.04	0.01
	758-2C	-1.00	0.00013	1	0.00	0.00
	758-2C	-2.00	0.00004	0	0.00	0.00

The following assumptions were used in order to estimate the water soluble chloride concentrations as a function of pound per cubic yard of concrete and as a percent of cement mass.

1. The air dry density of normal weight concrete is 3915 pounds per cubic yard (145 pounds per cubic foot).
2. The cement content is assumed as 14% for normal weight concrete.

ACI 318 Chapter 4 Table 4.3.1 provides requirements for maximum concentrations of water soluble chlorides for C2 structures as 0.15. C2 structures are defined as structures exposed to external sources of moisture and chlorides from deicing chemicals. The results listed in Table 3 indicate that the concentrations of water soluble chlorides are lower than this limit and are practically nonexistent at the depth of the top layer of reinforcing steel (i.e. 2 inches from the surface). These results indicate that the reinforcing steel within this structure is not in a corrosive environment and should be in as good a condition as originally placed.

Air Voids and Petrography

Core 758-1P was sent to Highbridge Materials Consulting, Inc. for petrography and air voids. The following is a summary of the test results, for further information; please reference *"Petrographic Examination Report"*, prepared by Highbridge Materials Consulting, Inc. dated March 22, 2015.

The total air voids observed in core 758-1P was 9.0%. This value exceeds modern specifications for concrete that is exposed to freezing and thawing. Current specifications for concrete exposed to freezing and thawing cycles is 3.5% to 6.5% per ACI 318 Chapter 4 Section 4. Concrete with high air content may have lower compressive strengths. The compressive strength data for the cores extracted from this structure did not indicate a reduction in strength due to this higher air content.

The petrographic analysis of the cores indicated that the concrete materials were well mixed, cast and consolidated. There were no obvious signs of workmanship deficiencies. The water is cement ratio for the core is estimated to be in the mid to high 0.40's. Core 758-1P had a trace amount of ASR present in the very top of the core just beneath the overlay interface and within a fractured silty ironstone aggregate particle in the bottom of the core. Other than these two indications, there was no other evidence of ASR present in this core.

We thank you for the opportunity to assist you with this project. If you have any questions, or if you need any further assistance with this project, please contact me at your earliest convenience.

Sincerely,

PENNONI ASSOCIATES INC.

Michael **A**. Padula
Senior Engineer/Division Manager
Inspection & Testing Technology

PENNONI ASSOCIATES INC.
CONSULTING ENGINEERS

March 27, 2015

Design Level Inspection Report
I-95 Wilmington Viaduct

Re: Concrete Coring and Testing Services
Bridge I-758E North and South Bound
I-95 Viaduct, Wilmington, DE

Pennoni Associates Inc. (Pennoni) visited the above referenced bridge on the night of January 11, 2015 to drill and extract concrete core samples. A total of four (4) concrete cores were extracted and transported to our laboratory where they were documented and tested for thickness, compressive strength and water soluble chloride ions. One (1) core was sent to Highbridge Materials, Inc. for petrography and air voids testing. Table 1 below summarizes the physical dimensions, locations and selected testing for each of the concrete cores extracted from Bridge I-758E.

Table 1 - Core Locations, Dimensions and Prescribed Testing

Bridge	Core ID	Core Location				Core Diameter (in)	Core Thickness		Laboratory Testing
		Span	Lane	Distance from Joint (X) (ft)	Distance from Lane Line (Y) (Ft)		Overlay (in)	Structural (in)	
I-758E	758E-1C	2	R	38.0	3.0	3.25	0.00	7.00	Compression Water Soluble Chloride
	758E-2C	3	R	24.0	8.0	3.25	0.00	7.50	Compression
	758E-3C	6	R	19.0	10.0	3.25	0.00	5.50	Compression
	758E-1P	2	R	43.0	5.0	3.25	0.00	7.25	Petrography & Air Voids

We did not observe an overlay wearing surface on the bridge; therefore, no pull testing was performed.

As-Received Core Conditions

The following concrete core photographs were taken as they were received in the laboratory prior to testing.

Core 758E-1C (As-Received)

Core 758E-2C (As-Received)

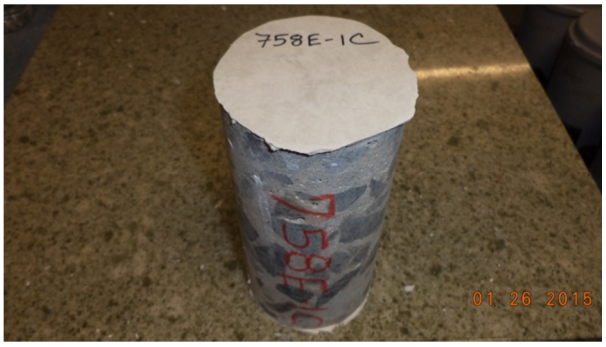
Core 758E-3C (As-Received)

Core 758E-1P (As-Received)

As-Prepared and Tested

The cores were sawn cut to achieve the maximum length to diameter ratios and placed in non-absorptive bags for a minimum of 5 days prior to testing. At the date of testing the ends concrete cores were capped using a high strength hydro-stone capping compound to further level the ends of the cores.

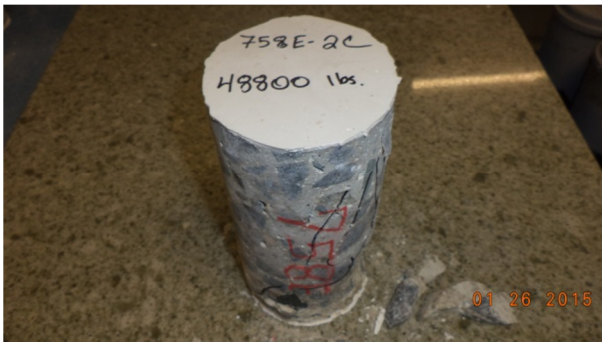
The failures are highlighted in the “tested” photographs for clarity.



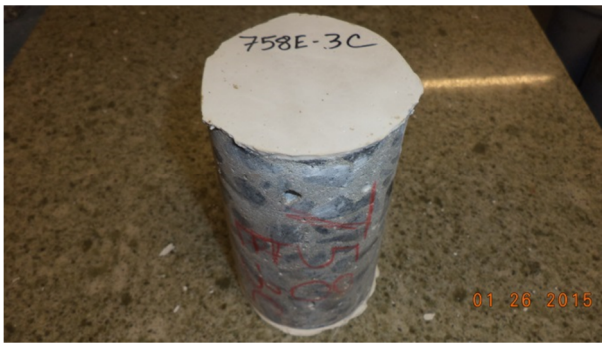
Core 758E-1C (As-Prepared)

Core 758E-1C (Tested)

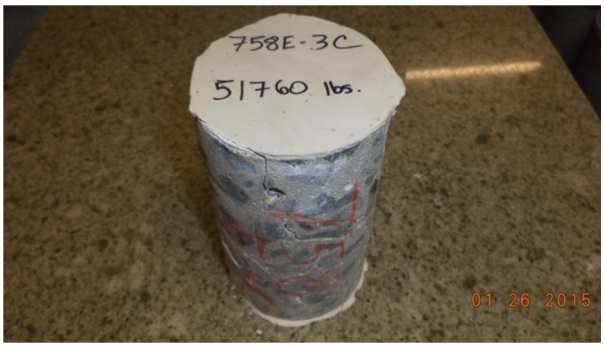
Core 758E-2C (As-Prepared)



Core 758E-2C (Tested)



Core 758E-3C (As-Prepared)



Core 758E-3C (Tested)

Compression Results

Table 2 summarizes the compression testing results of the concrete cores.

Table 2: Compression Testing Summary							
Core ID	Diameter (in)	As-Prepared Length (in)	Cross Sectional Area (in^2)	Ultimate Load (lbs.)	L/D Ratio	Correction Factor	Compressive Strength (psi)
758E-1C	3.25	6.27	8.30	45,200	1.93	0.999	5,440
758E-2C	3.25	6.24	8.30	48,800	1.92	0.998	5,870
758E-3C	3.25	5.34	8.30	51,760	1.64	0.971	6,060
Average Compression Strength (psi)							5,790

The failure mode of the tested cores was generally consistent with a Type 1 fracture pattern. A Type 1 fracture pattern is defined in ASTM C39 as having reasonably well-formed cones on both ends with less than 1 inch of cracking through the capped ends.

Water Soluble Chloride Ion Testing

Core 758E-1C was randomly selected for water soluble chloride ion testing. Testing was performed at three depths from the surface; 0.5 inch, 1 inch and 2 inch. There was no concrete overlay at this core location. Table 3 summarizes the concentrations of water soluble chloride ions for each tested core.

Table 3 - Water Soluble Chloride Ion Test Results						
Bridge	Core ID	Depth (in)	Cl- (%wt)	Cl- (ppm)	Cl- (lbs/yrd^3)	Cl- (% cement)
I-758E	758E-1C	-0.50	0.00404	40	0.16	0.03
	758E-1C	-1.00	0.00087	9	0.03	0.01
	758E-1C	-2.00	0.00004	0	0.00	0.00

The following assumptions were used in order to estimate the water soluble chloride concentrations as a function of pound per cubic yard of concrete and as a percent of cement mass.

1. The air dry density of normal weight concrete is 3915 pounds per cubic yard (145 pounds per cubic foot).
2. The cement content is assumed as 14% for normal weight concrete.

ACI 318 Chapter 4 Table 4.3.1 provides requirements for maximum concentrations of water soluble chlorides for C2 structures as 0.15. C2 structures are defined as structures exposed to external sources of moisture and chlorides from deicing chemicals. The results listed in Table 3 indicate that the concentrations of water soluble chlorides are lower than this limit and are practically nonexistent at the depth of the top layer of reinforcing steel (i.e. 2 inches from the surface). These results indicate that the reinforcing steel within the bridge is not in a corrosive environment and should be in as good a condition as originally placed.

Petrography and Air Voids

Core 758E-1P was sent to Highbridge Materials Consulting, Inc. for petrography and air voids. The following is a summary of the test results, for further information; please reference *"Petrographic Examination Report"*, prepared by Highbridge Materials Consulting, Inc. dated March 16, 2015.

The total air voids observed in core 758E-1P was 5.2%. Current specifications for concrete exposed to freezing and thawing cycles is 3.5% to 6.5% per ACI 318 Chapter 4 Section 4. The results for this core were found to be in compliance with this specification.

The petrographic analysis of the core indicated that the concrete materials were generally well mixed. There was a minor indication of possible shortened mixing time or the addition of water after mixing. However, these indications are very minor and not something of concern. The concrete also appears to have been cast and consolidated in accordance with industry acceptable practices. The water to cement ratio for the core is estimated to be in the mid to high 0.40's. The core had evidence of early stage alkali-silica reactions in the form of axial micro-cracking. However, the reaction is in its very early stages and does not impose an imminent threat to the stability of the concrete.

We thank you for the opportunity to assist you with this project. If you have any questions, or if you need any further assistance with this project, please contact me at your earliest convenience.

Sincerely,

PENNONI ASSOCIATES INC.

Michael A. Padula
Senior Engineer/Division Manager
Inspection & Testing Technology

PENNONI ASSOCIATES INC.
CONSULTING ENGINEERS

March 27, 2015

Design Level Inspection Report
I-95 Wilmington Viaduct

Re: Concrete Coring and Testing Services
Bridge I-758F North and South Bound
I-95 Viaduct, Wilmington, DE

Pennoni Associates (Pennoni) visited the above referenced bridge on the night of January 11, 2015 to drill and extract concrete core samples from the structure. A total of four (4) concrete cores were extracted and transported to our laboratory where they were documented and tested for thickness, compressive strength and water soluble chloride ions. One (1) core was sent to Highbridge Materials, Inc. for petrography and air voids testing. Table 1 summarizes the physical dimensions, locations and selected testing for each of the concrete cores extracted from Bridge I-758F.

Table 1 - Core Locations, Dimensions and Prescribed Testing

Bridge	Core ID	Core Location				Core Diameter (in)	Core Thickness		Laboratory Testing
		Span	Lane	Distance from Joint (X) (ft)	Distance from Lane Line (Y) (Ft)		Overlay (in)	Structural (in)	
I-758F	758F-1C	2	R	31.0	8.0	3.25	0.00	6.75	Compression Water Soluble Chloride
	758F-2C	2	R	85.0	3.0	3.25	0.00	7.25	Compression
	758F-3C	4	R	31.0	8.0	3.25	0.00	6.25	Compression
	758F-1P	3	R	45.0	7.0	3.25	0.00	4.63	Petrography & Air Voids

We did not observe any overlay on this bridge; therefore no pull testing was performed.

As-Received Core Conditions

The following concrete core photographs were taken as they were received in the laboratory prior to testing.

Core 758F-1C (As-Received)

Core 758F-2C (As-Received)

Core 758F-3C (As-Received)

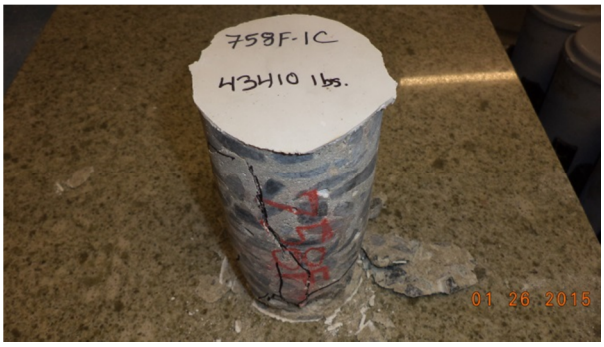
Core 758F-1P (As-Received)

As-Prepared and Tested

The cores were sawn cut to achieve the maximum length to diameter ratios and placed in non-absorptive bags for a minimum of 5 days prior to testing. At the date of testing the ends concrete cores were capped using a high strength hydro-stone capping compound to further level the ends of the cores.

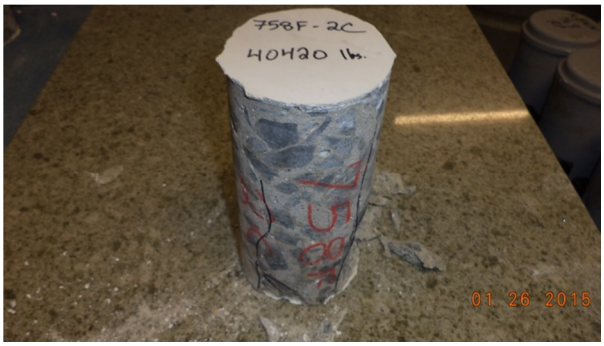
The failures are highlighted in the “tested” photographs for clarity.

Core 758F-1C (As-Prepared)



Core 758F-1C (Tested)

Core 758F-2C (As-Prepared)



Core 758F-2C (Tested)

Core 758F-3C (As-Prepared)

Core 758F-3C (Tested)

Compression Results

Table 2 summarizes the compression testing results of the concrete cores.

Table 2: Compression Testing Summary							
Core ID	Diameter (in)	As-Prepared Length (in)	Cross Sectional Area (in^2)	Ultimate Load (lbs.)	L/D Ratio	Correction Factor	Compressive Strength (psi)
758F-1C	3.25	6.34	8.30	43,410	1.95	1.000	5,230
758F-2C	3.25	6.33	8.30	40,420	1.95	1.000	4,870
758F-3C	3.25	6.20	8.30	43,510	1.91	0.997	5,230
Average Compression Strength (psi)							5,110

The failure mode of the tested cores was generally consistent with a Type 1 fracture pattern. A Type 1 fracture pattern is defined in ASTM C39 as having reasonably well-formed cones on both ends with less than 1 inch of cracking through the capped ends.

Water Soluble Chloride Ion Testing

Core 758F-1C was randomly selected for water soluble chloride ion testing. This location did not have a concrete overlay wearing surface. Testing was performed at three (3) depths from the surface; 0.5 inch, 1 inch and 2 inches. Table 3 summarizes the concentrations of water soluble chloride ions for each tested core.

Table 3 - Water Soluble Chloride Ion Test Results						
Bridge	Core ID	Depth (in)	Cl- (%wt)	Cl- (ppm)	Cl- (lbs/yrd^3)	Cl- (% cement)
I-758F	758F-1C	-0.50	0.00467	47	0.18	0.03
	758F-1C	-1.00	0.00084	8	0.03	0.01
	758F-1C	-2.00	0.00012	1	0.00	0.00

The following assumptions were used in order to estimate the water soluble chloride concentrations as a function of pound per cubic yard of concrete and as a percent of cement mass.

1. The air dry density of normal weight concrete is 3915 pounds per cubic yard (145 pounds per cubic foot).
2. The cement content is assumed as 14% for normal weight concrete.

ACI 318 Chapter 4 Table 4.3.1 provides requirements for maximum concentrations of water soluble chlorides for C2 structures as 0.15. C2 structures are defined as structures exposed to external sources of moisture and chlorides from deicing chemicals. The results listed in Table 3 indicate that the concentrations of water soluble chlorides are lower than this limit and are practically nonexistent at the depth of the top layer of reinforcing steel (i.e. 2 inches from the surface). These results indicate that the reinforcing steel within this bridge is not in a corrosive environment and should be in as good a condition as originally placed.

Petrography and Air Voids

Core 758F-1P was sent to Highbridge Materials Consulting, Inc. for petrography and air voids. The following is a summary of the test results, for further information; please reference *"Petrographic Examination Report"*, prepared by Highbridge Materials Consulting, Inc. dated March 16, 2015.

The total air voids observed in core 758F-1P was 6.5%. Current specifications for concrete exposed to freezing and thawing cycles is 3.5% to 6.5% per ACI 318 Chapter 4 Section 4. The results for this core were found to be at the upper limit of this specification.

The petrographic analysis of the core indicated that the concrete materials were generally well mixed. There was a minor indication of possible shortened mixing time or the addition of water after mixing. However, these indications are very minor and not something of concern. The concrete also appears to have been cast and consolidated in accordance with industry standard practices. The water to cement ratio for the core is estimated to be in the mid to high 0.40's. The core had trace evidence of early stage alkali-silica reactions in the form of axial micro-cracking. However, the reaction is in its very early stages and does not impose an imminent threat to the stability of the concrete.

We thank you for the opportunity to assist you with this project. If you have any questions, or if you need any further assistance with this project, please contact me at your earliest convenience.

Sincerely,

PENNONI ASSOCIATES INC.

Michael A. Padula
Senior Engineer/Division Manager
Inspection & Testing Technology

PENNONI ASSOCIATES INC.
CONSULTING ENGINEERS

March 27, 2015

Design Level Inspection Report
I-95 Wilmington Viaduct

Re: Concrete Coring and Testing Services
Bridge I-758G North and South Bound
I-95 Viaduct, Wilmington, DE

Pennoni Associates Inc. (Pennoni) visited the above referenced bridge on the night of January 11, 2015 to drill and extract concrete core samples. We revisited this bridge on the night of January 14, 2015 to perform pull testing. A total of four (4) concrete cores were extracted and transported to our laboratory where they were documented and tested for thickness, compressive strength and water soluble chloride ions. One (1) core was sent to Highbridge Materials, Inc. for petrography and air voids testing. Table 1 summarizes the physical dimensions, locations and selected testing for each of the concrete cores extracted from Bridge I-758G.

Table 1 - Core Locations, Dimensions and Prescribed Testing

Bridge	Core ID	Core Location				Core Diameter (in)	Core Thickness		Laboratory Testing
		Span	Lane	Distance from Joint (X) (ft)	Distance from Lane Line (Y) (Ft)		Overlay (in)	Structural (in)	
I-758G	758G-1C	1	R	40.0	2.0	3.25	1.50	5.00	Compression
	758G-2C	7	R	54.0	8.0	3.25	0.00	6.50	Compression
	758G-3C	8	R	31.0	3.0	3.25	0.00	6.75	Compression Water Soluble Chloride
	758G-1P	5	R	53.0	6.0	3.25	0.00	7.00	Petrography & Air Voids

Pull testing was performed on this bridge at one location. This location was adjacent to the compression core sample identified as 1C. We did not observe an overlay at any of the other core locations.

As-Received Core Conditions

The following concrete core photographs were taken as they were received in the laboratory prior to testing.

Core 758G-1C (As-Received)

Core 758G-2C (As-Received)

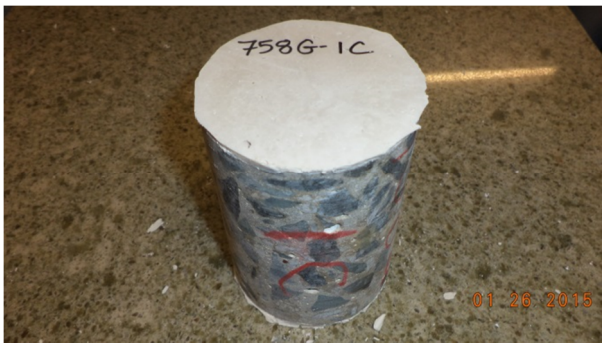
Core 758G-3C (As-Received)

Core 758G-1P (As-Received)

As-Prepared and Tested

The cores were sawn cut to achieve the maximum length to diameter ratios and placed in non-absorptive bags for a minimum of 5 days prior to testing. At the date of testing the ends concrete cores were capped using a high strength hydro-stone capping compound to further level the ends of the cores.

The failures are highlighted in the “tested” photographs for clarity.

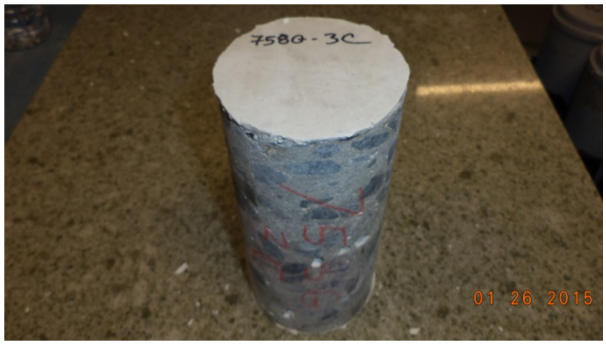


Core 758G-1C (As-Prepared)

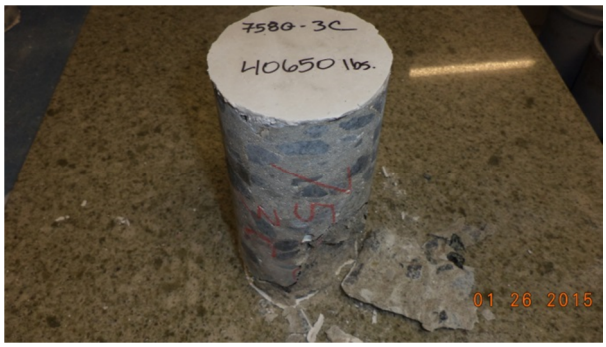
Core 758G-1C (Tested)

Core 758G-2C (As-Prepared)

Core 758G-2C (Tested)



Core 758G-3C (As-Prepared)



Core 758G-3C (Tested)

Compression Results

Table 2 summarizes the compression testing results of the concrete cores.

Table 2: Compression Testing Summary							
Core ID	Diameter (in)	As-Prepared Length (in)	Cross Sectional Area (in^2)	Ultimate Load (lbs.)	L/D Ratio	Correction Factor	Compressive Strength (psi)
758G-1C	3.25	4.28	8.30	58,970	1.32	0.938	6,670
758G-2C	3.25	6.01	8.30	55,200	1.85	0.990	6,590
758G-3C	3.25	6.48	8.30	40,650	1.99	1.000	4,900
Average Compression Strength (psi)							6,050

The failure mode of the tested cores was generally consistent with a Type 1 fracture pattern. A Type 1 fracture pattern is defined in ASTM C39 as having reasonably well-formed cones on both ends with less than 1 inch of cracking through the capped ends.

Water Soluble Chloride Ion Testing

Core 758G-3C was randomly selected for water soluble chloride ion testing. This location did not have a concrete overlay wearing surface. Testing was performed at three (3) depths from the surface; 0.5 inch, 1 inch and 2 inches. Table 3 below summarizes the concentrations of water soluble chloride ions for each tested core.

Table 3 - Water Soluble Chloride Ion Test Results						
Bridge	Core ID	Depth (in)	Cl- (%wt)	Cl- (ppm)	Cl- (lbs/yrd^3)	Cl- (% cement)
I-758G	758G-3C	-0.50	0.00528	53	0.21	0.04
	758G-3C	-1.00	0.00241	24	0.09	0.02
	758G-3C	-2.00	0.00018	2	0.01	0.00

The following assumptions were used in order to estimate the water soluble chloride concentrations as a function of pound per cubic yard of concrete and as a percent of cement mass.

1. The air dry density of normal weight concrete is 3915 pounds per cubic yard (145 pounds per cubic foot).
2. The cement content is assumed as 14% for normal weight concrete.

ACI 318 Chapter 4 Table 4.3.1 provides requirements for maximum concentrations of water soluble chlorides for C2 structures as 0.15. C2 structures are defined as structures exposed to external sources of moisture and chlorides from deicing chemicals. The results listed in Table 3 indicate that the concentrations of water soluble chlorides are lower than this limit and are practically nonexistent at the depth of the top layer of reinforcing steel (i.e. 2 inches from the surface). These results indicate that the

reinforcing steel within this bridge is not in a corrosive environment and should be in as good a condition as originally placed.

Pull Testing of Overlay Wearing Surface

Pull testing of the concrete overlay wearing surface was performed at core location 758G-1C. The overlay thickness at this location was 1.5 inches. The pull testing was performed in general compliance with ASTM C1583. A 3 inch diameter cored hole was drilled through the overlay wearing surface and into the underlying concrete slab by approximately 0.5 inches. A 3 inch diameter steel disk was then epoxied to the surface of the overlay and pulled at a constant rate until failure. The application of tensile load was monitored using an inline dynamometer. Failure occurred at a tensile load of 1000 pounds (141 psi) and the failure plane was noted to be at the bond line between the overlay wearing surface and the structural slab.

ACI 345 – Concrete Highway Bridge Deck Construction does not list values for the bond strength between the substructure and the concrete wearing surface. However, developing a good bond between the two surfaces is a fundamental requirement for most concrete overlay wearing surfaces. Without an adequate bond, the overlay wearing surface is susceptible to delamination which can range from localized minor spalling or the removal of extensive sections. In both cases, the removal of the wearing surface allows the infiltration of various chemicals and weather conditions to attack the underlying structure.

Petrography and Air Voids

Core 758G-1P was sent to Highbridge Materials Consulting, Inc. for petrography and air voids. The following is a summary of the test results, for further information; please reference *"Petrographic Examination Report"*, prepared by Highbridge Materials Consulting, Inc. dated March 16, 2015.

The total air voids observed in core 758G-1P was 5.9%. Current specifications for concrete exposed to freezing and thawing cycles is 3.5% to 6.5% per ACI 318 Chapter 4 Section 4. The results for this core were found to be within this specification.

The petrographic analysis of the core indicated that the concrete materials were generally well mixed. There was a minor indication of possible shortened mixing time or the addition of water after mixing. However, these indications are very minor and not something of concern. The concrete also appears to have been cast and consolidated in accordance with industry standard practices. The water to cement ratio for the core is estimated to be in the mid to high 0.40's. The core had trace evidence of early stage alkali-silica reactions in the form of axial micro-cracking. However, the reaction is in its very early stages and does not impose an imminent threat to the stability of the concrete.

We thank you for the opportunity to assist you with this project. If you have any questions, or if you need any further assistance with this project, please contact me at your earliest convenience.

Sincerely,

PENNONI ASSOCIATES INC.

Michael A. Padula
Senior Engineer/Division Manager
Inspection & Testing Technology

PENNONI ASSOCIATES INC.
CONSULTING ENGINEERS

March 27, 2015

Design Level Inspection Report
I-95 Wilmington Viaduct

Re: Concrete Coring and Testing Services
Bridge I-758H North and South Bound
I-95 Viaduct, Wilmington, DE

Pennoni Associates Inc. (Pennoni) visited the above referenced bridge on the night of January 11, 2015 to drill and extract concrete core samples. Pennoni revisited this structure on the night of January 14, 2015 to perform pull testing. A total of four (4) concrete cores were extracted and transported to our laboratory where they were documented and tested for thickness, compressive strength and water soluble chloride ions. One (1) core was sent to Highbridge Materials, Inc. for petrography and air voids testing. Table 1 summarizes the physical dimensions, locations and selected testing for each of the concrete cores extracted from Bridge I-758H.

Table 1 - Core Locations, Dimensions and Prescribed Testing

Bridge	Core ID	Core Location				Core Diameter (in)	Core Thickness		Laboratory Testing
		Span	Lane	Distance from Joint (X) (ft)	Distance from Lane Line (Y) (Ft)		Overlay (in)	Structural (in)	
I-758H	758H-1C	1	R	39.0	4.0	3.25	0.00	7.50	Compression
	758H-2C	5	R	7.0	8.0	3.25	0.00	6.75	Compression Water Soluble Chloride
	758H-3C	6	R	24.5	4.0	3.25	0.00	5.00	Compression
	758H-1P	5	R	72.0	8.0	3.25	0.00	3.50	Petrography & Air Voids

We did not observe an overlay wearing surface on this bridge; therefore, no pull testing was performed.

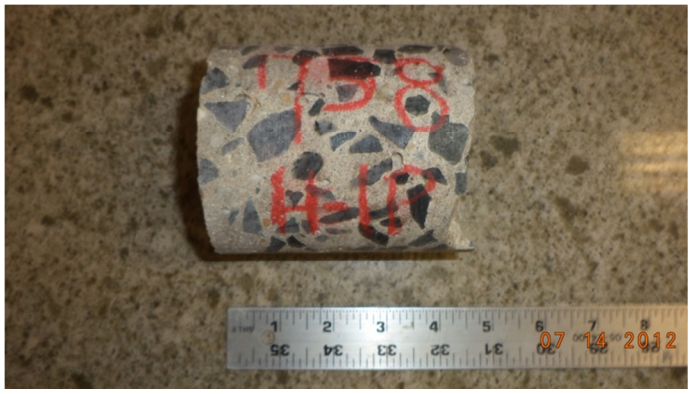
As-Received Core Conditions

The following concrete core photographs were taken as they were received in the laboratory prior to testing.

Core 758H-1C (As-Received)

Core 758H-2C (As-Received)

Core 758H-3C (As-Received)

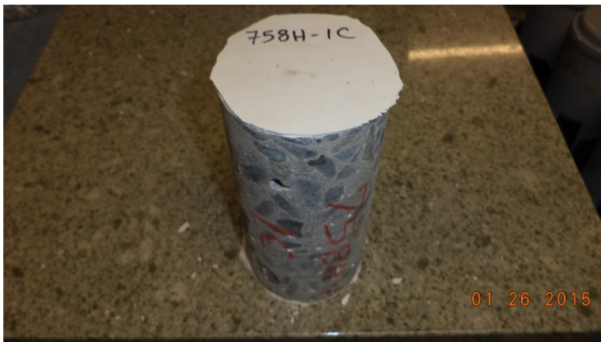


Core 758H-1P (As-Received)

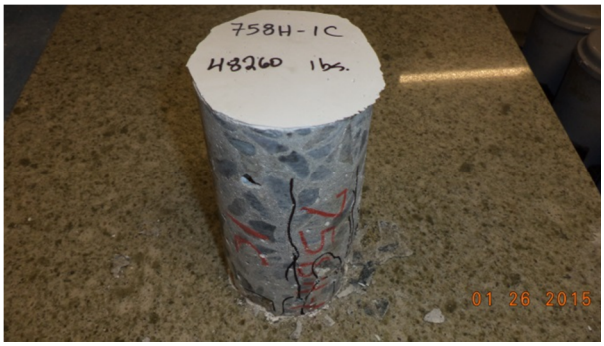
As-Prepared and Tested

The cores were sawn cut to achieve the maximum length to diameter ratios and placed in non-absorptive bags for a minimum of 5 days prior to testing. At the date of testing the ends concrete cores were capped using a high strength hydro-stone capping compound to further level the ends of the cores.

The failures are highlighted in the “tested” photographs for clarity.

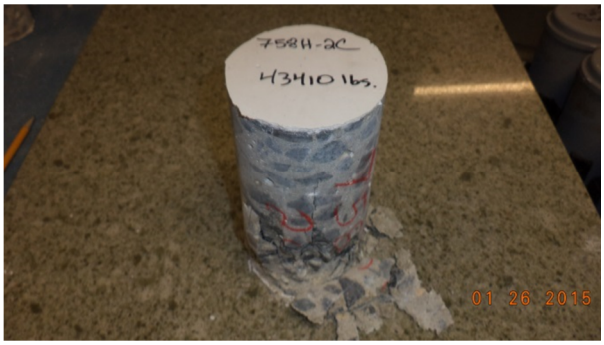


Core 758H-1C (As-Prepared)

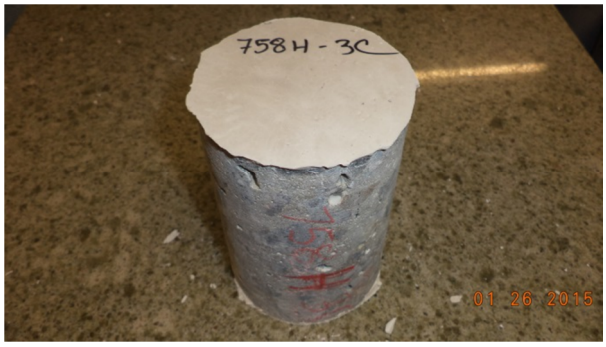


Core 758H-1C (Tested)

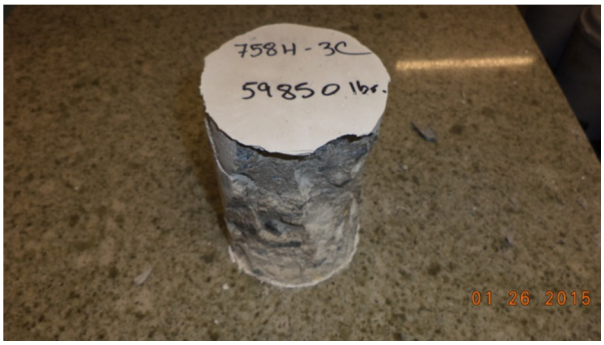
Core 758H-2C (As-Prepared)



Core 758H-2C (Tested)



Core 758H-3C (As-Prepared)



Core 758H-3C (Tested)

Compression Results

Table 2 summarizes the test results for compression testing of the concrete cores.

Table 2: Compression Testing Summary							
Core ID	Diameter (in)	As-Prepared Length (in)	Cross Sectional Area (in^2)	Ultimate Load (lbs.)	L/D Ratio	Correction Factor	Compressive Strength (psi)
758H-1C	3.25	6.37	8.30	48,260	1.96	1.000	5,820
758H-2C	3.25	6.39	8.30	43,410	1.97	1.000	5,230
758H-3C	3.25	4.58	8.30	59,850	1.41	0.949	6,850
Average Compression Strength (psi)							5,970

The failure mode of the tested cores was generally consistent with a Type 1 fracture pattern. A Type 1 fracture pattern is defined in ASTM C39 as having reasonably well-formed cones on both ends with less than 1 inch of cracking through the capped ends.

Water Soluble Chloride Ion Testing

Core 758H-2C was randomly selected for water soluble chloride ion testing. This location did not have a concrete overlay wearing surface. Testing was performed at three depths from the surface; 0.5 inch, 1 inch and 2 inch. Table 3 summarizes the concentrations of water soluble chloride ions for each tested core.

Table 3 - Water Soluble Chloride Ion Test Results						
Bridge	Core ID	Depth (in)	Cl- (%wt)	Cl- (ppm)	Cl- (lbs/yrd^3)	Cl- (% cement)
I-758H	758H-2C	-0.50	0.00655	66	0.26	0.05
	758H-2C	-1.00	0.00144	14	0.06	0.01
	758H-2C	-2.00	0.00014	1	0.01	0.00

The following assumptions were used in order to estimate the water soluble chloride concentrations as a function of pound per cubic yard of concrete and as a percent of cement mass.

1. The air dry density of normal weight concrete is 3915 pounds per cubic yard (145 pounds per cubic foot).
2. The cement content is assumed as 14% for normal weight concrete.

ACI 318 Chapter 4 Table 4.3.1 provides requirements for maximum concentrations of water soluble chlorides for C2 structures as 0.15. C2 structures are defined as structures exposed to external sources of moisture and chlorides from deicing chemicals. The results listed in Table 3 indicate that the concentrations of water soluble chlorides are lower than this limit and are practically nonexistent at the depth of the top layer of reinforcing steel (i.e. 2 inches from the surface). These results indicate that the reinforcing steel within this bridge is not in a corrosive environment and should be in as good a condition as originally placed.

Petrography and Air Voids

Core 758G-1P was sent to Highbridge Materials Consulting, Inc. for petrography and air voids. The following is a summary of the test results, for further information; please reference *"Petrographic Examination Report"*, prepared by Highbridge Materials Consulting, Inc. dated March 16, 2015.

The total air voids observed in core 758H-1P was 9.5%. Current specifications for concrete exposed to freezing and thawing cycles is 3.5% to 6.5% per ACI 318 Chapter 4 Section 4. The results for this core were significantly above this specified limit. Air void contents in this range usually result in lower compressive strengths. However, the compressive strength results for this structure indicated relatively high compressive strength.

The petrographic analysis of the core indicated that the concrete materials were generally well mixed. There was a minor indication of possible shortened mixing time or the addition of water after mixing. However, these indications are very minor and not something of concern. The concrete also appears to have been cast and consolidated in accordance with industry standard practices. The water to cement ratio for the core is estimated to be in the mid to high 0.40's. The core had exceedingly trace evidence of early stage alkali-silica reactions in the form of axial micro-cracking. However, the reaction is in its very early stages and does not impose an imminent threat to the stability of the concrete.

We thank you for the opportunity to assist you with this project. If you have any questions, or if you need any further assistance with this project, please contact me at your earliest convenience.

Sincerely,

PENNONI ASSOCIATES INC.

Michael A. Padula
Senior Engineer/Division Manager
Inspection & Testing Technology

PENNONI ASSOCIATES INC.
CONSULTING ENGINEERS

March 27, 2015

Design Level Inspection Report
I-95 Wilmington Viaduct

Re: Concrete Coring and Testing Services
Bridge I-744 North and South Bound
I-95 Viaduct, Wilmington, DE

Pennoni Associates (Pennoni) visited the above referenced structure on the nights of November 18, 24 and 25 of 2014 to drill and extract concrete core samples. Pennoni revisited this structure on the nights of January 15 and 22, 2015 to perform overlay pull testing. A total of ten (10) concrete cores were extracted and transported to our laboratory where they were documented and tested for thickness, compressive strength and water soluble chloride ions. Two (2) cores, 1 from each direction of the structure, were sent to Highbridge Materials, Inc. for petrography and air voids testing. Table 1 below summarizes the physical dimensions, locations and selected testing for each of the concrete cores extracted from Bridge I-744.

Table 1 - Core Locations, Dimensions and Prescribed Testing

Bridge	Core ID	Core Location				Core Diameter (in)	Core Thickness		Laboratory Testing
		Span	Lane	Distance from Joint (X) (ft)	Distance from Lane Line (Y) (Ft)		Overlay (in)	Structural (in)	
I-744 (NB)	744NB-1C	2	R	34.0	12.0	3.25	2.25	6.25	Compression
	744NB-2C	5	C	31.0	12.0	3.25	1.50	6.00	Compression
	744NB-3C	5	C	77.0	8.0	3.25	2.00	5.50	Compression Water Soluble Chloride
	744NB-3Cx	5	C	77.0	5.0	3.50	2.50	1.50	No Test - Too short
	744NB-1P	5	R	16.0	4.0	3.25	1.50	5.50	Petrography & Air Voids
	744NB-1Px	5	R	19.0	4.0	3.50	1.75	3.00	No Test - Too short
I-744 (SB)	744SB-1C	7	R	23.0	8.0	3.25	2.63	5.88	Compression
	744SB-2C	4	R	28.0	4.0	3.25	2.50	5.50	Compression Water Soluble Chloride
	744SB-3C	1	C	72.0	11.0	3.25	2.50	5.50	Compression
	744SB-1P	5	C	16.0	4.0	3.25	2.50	4.00	Petrography & Air Voids

Pull testing was performed at six (6) locations. Three (3) tests were performed adjacent to the compression core locations on both the northbound and southbound sides of the structure.

As-Received Core Conditions

The following concrete core photographs were taken as they were received in the laboratory prior to testing.

Core 744NB-1C (As-Received)

Core 744NB-2C (As-Received)

Core 744NB-3C (As-Received)

Core 744NB-3CX (As-Received)

Core 744NB-1P (As-Received)

Core 744SB-1C (As-Received)

Core 744SB-2C (As-Received)

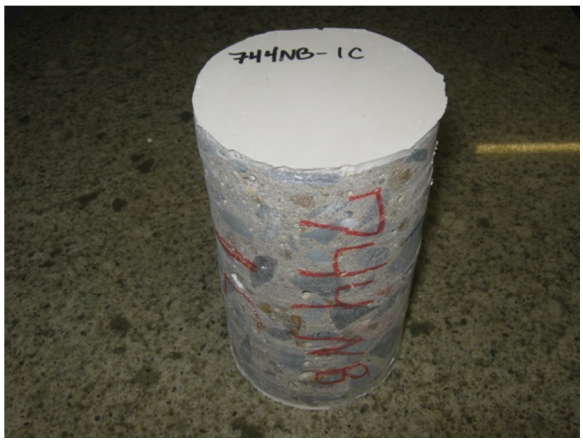
Core 744SB-3C (As-Received)

Core 744SB-1P (As-Received)

As-Prepared and Tested

The cores were sawn cut to achieve the maximum length to diameter ratios and placed in non-absorptive bags for a minimum of 5 days prior to testing. At the date of testing the ends concrete cores were capped using a high strength hydro-stone capping compound to further level the ends of the cores.

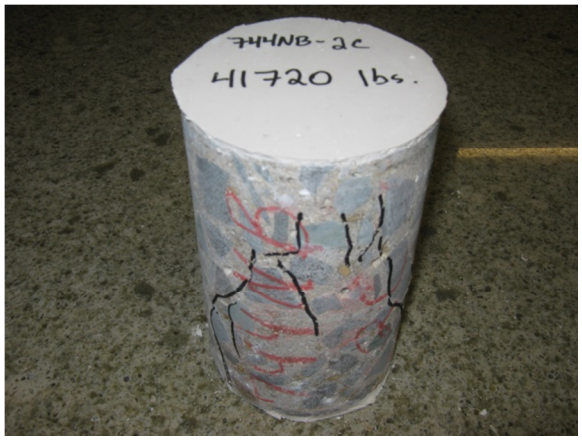
The failures are highlighted in the “tested” photographs for clarity.



Core 744NB-1C (As-Prepared)

Core 744NB-1C (Tested)

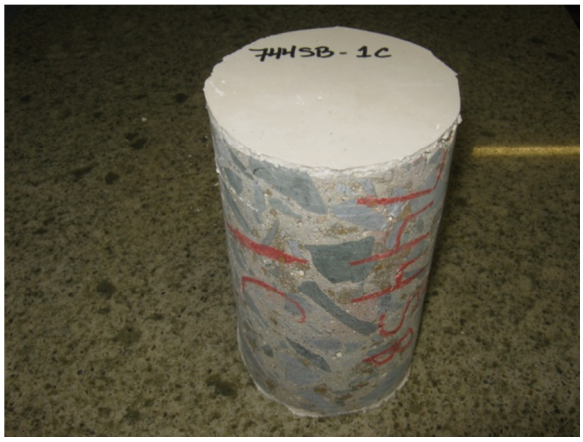
Core 744NB-2C (As-Prepared)



Core 744NB-2C (Tested)

Core 744NB-3C (As-Prepared)

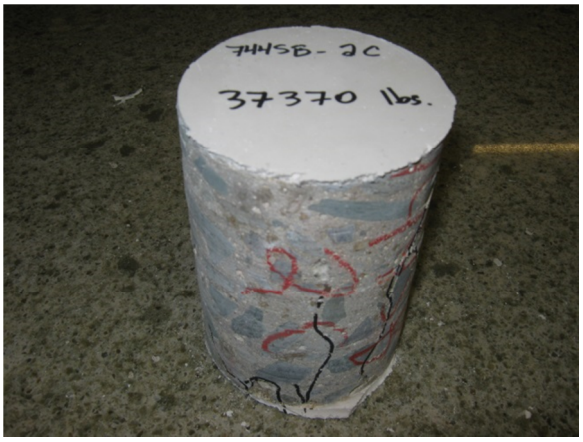
Core 744NB-3C (Tested)



Core 744SB-1C (As-Prepared)

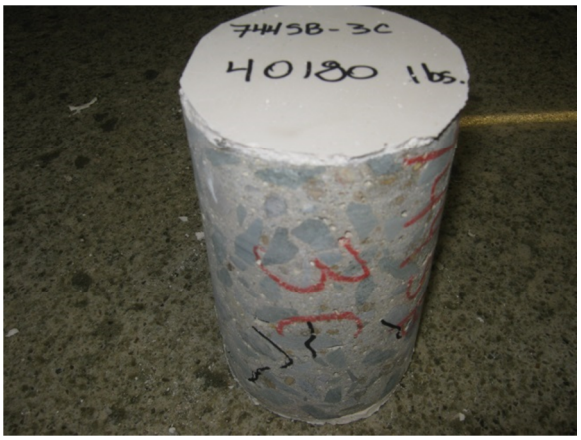
Core 744SB-1C (Tested)

Core 744SB-2C (As-Prepared)



Core 744SB-2C (Tested)

Core 744SB-3C (As-Prepared)



Core 744SB-3C (Tested)

Compression Results

Table 2 summarizes the compression testing results of the concrete cores.

Table 2: Compression Testing Summary							
Core ID	Diameter (in)	As-Prepared Length (in)	Cross Sectional Area (in^2)	Ultimate Load (lbs.)	L/D Ratio	Correction Factor	Compressive Strength (psi)
744NB-1C	3.25	5.55	8.30	47,770	1.71	0.977	5,620
744NB-2C	3.25	5.37	8.30	41,720	1.65	0.972	4,890
744NB-3C	3.25	4.50	8.30	44,660	1.38	0.946	5,090
744SB-1C	3.25	5.53	8.30	39,900	1.70	0.976	4,690
744SB-2C	3.25	4.62	8.30	37,370	1.42	0.951	4,280
744SB-3C	3.25	5.43	8.30	40,180	1.67	0.974	4,720
Average Compression Strength (psi)							4,880

The failure mode of the tested cores was generally consistent with a Type 1 fracture pattern. A Type 1 fracture pattern is defined in ASTM C39 as having reasonably well-formed cones on both ends with less than 1 inch of cracking through the capped ends.

Water Soluble Chloride Ion Testing

Cores 744NB-3C and 744SB-2C were randomly selected for water soluble chloride ion testing. Testing was performed at three depths from the surface of the structural concrete; 0.5 inch, 1 inch and 2 inch. The thickness of the concrete overlay at core 744NB-3C was 2.00 inches. The thickness of the concrete overlay at core 744SB-2C was 2.50 inches. Table 3 below summarizes the concentrations of water soluble chloride ions for each tested core.

Table 3 - Water Soluble Chloride Ion Test Results

Bridge	Core ID	Depth (in)	Cl- (%wt)	Cl- (ppm)	Cl- (lbs/yrd^3)	Cl- (% cement)
I-744	744NB-3C	-0.50	0.00304	30	0.12	0.02
	744NB-3C	-1.00	0.00223	22	0.09	0.02
	744NB-3C	-2.00	0.00206	21	0.08	0.01
	744SB-2C	-0.50	0.01658	166	0.65	0.12
	744SB-2C	-1.00	0.00615	61	0.24	0.04
	744SB-2C	-2.00	0.00164	16	0.06	0.01

The following assumptions were used in order to estimate the water soluble chloride concentrations as a function of pound per cubic yard of concrete and as a percent of cement mass.

1. The air dry density of normal weight concrete is 3915 pounds per cubic yard (145 pounds per cubic foot).
2. The cement content is assumed as 14% for normal weight concrete.

ACI 318 Chapter 4 Table 4.3.1 provides requirements for maximum concentrations of water soluble chlorides for C2 structures as 0.15. C2 structures are defined as structures that are exposed to external sources of moisture and chlorides from deicing chemicals. The results listed in Table 3 indicate that the concentrations of water soluble chlorides are lower than this limit and are practically nonexistent at the depth of the top layer of reinforcing steel (i.e. 2 inches from the surface). These results indicate that the reinforcing steel within this structure is not in a corrosive environment and should be in as good a condition as originally placed. These data also indicates that the concrete overlay wearing surface is providing adequate protection to the concrete structural slab at location 744NB-3C. The surface concentration of water soluble chlorides at core 744SB-2C is fairly high. Pennoni recommends DelDOT revisit this area in the future to monitor if further infiltration has occurred.

Pull Testing of Overlay Wearing Surface

Pull testing of the concrete overlay wearing surface was performed at core locations 744NB-1C to 744NB-3C and 744SB-1C to 744SB-3C. The overlay thickness at these locations varied from 1.50 inches to 2.63 inches. The pull testing was performed in general compliance with ASTM C1583. A 3 inch diameter cored hole was drilled through the overlay wearing surface and into the underlying concrete slab by approximately 0.5 inches. A 3 inch diameter steel disk was then epoxied to the surface of the overlay and pulled at a constant rate until failure. The application of tensile load was monitored using an inline dynamometer. Table 4 below summarizes the results from the overlay pull testing.

Table 4 - Pull Test Results of Concrete Overlay Wearing Surface

Bridge	Core ID	Load Area (in^2)	Tensile Load (lbs)	Bond Strength (psi)	Failure Type
I-744	744NB-1C	7.07	200	28	Bond Fail
	744NB-2C	7.07	1000	141	Bond Fail
	744NB-3C	7.07	750	106	Bond Fail
	744SB-1C	7.07	750	106	Bond Fail
	744SB-2C	7.07	500	71	Bond Fail
	744SB-3C	7.07	200	28	Bond Fail

The bond strengths listed in Table 4 had high variability ranging from 28 psi to 141 psi. ACI 345 – Concrete Highway Bridge Deck Construction does not list values for the bond strength between the substructure and the concrete wearing surface. However, developing a good bond between the two surfaces is a fundamental requirement for most concrete overlay wearing surfaces. Without an adequate bond, the overlay wearing surface is susceptible to delamination which can range from localized minor spalling or the removal of extensive sections. In both cases, the removal of the wearing surface allows the infiltration of various chemicals and weather conditions to attack the underlying structure. The concrete repair institute (ICRI) generally notes bond strengths should not be below 100 psi.

Petrography and Air Voids

Cores 744NB-1P and 744SB-1P were sent to Highbridge Materials Consulting, Inc. for petrography and air voids. The following is a summary of the test results, for further information; please reference *"Petrographic Examination Report"*, prepared by Highbridge Materials Consulting, Inc. dated 02/14/2015.

The total air voids observed in both cores, 744NB-1P and 744SB-1P were closer to the upper limit, 6.7% and 6.4% respectively, with respect to modern specifications for concrete that is exposed to freezing and thawing. Current specifications for concrete exposed to freezing and thawing cycles is 3.5% to 6.5% per ACI 318 Chapter 4 Section 4.

The petrographic analysis of the cores indicated that the concrete materials were well mixed, cast and consolidated. There were no obvious signs of workmanship deficiencies. The water is cement ratio for the cores is estimated to be in the mid to high 0.40's. Core 744SB-1P had evidence of early stage alkali-silica reactions in the form of axial micro-cracking through its entire length. The reactions have not compromised the integrity of the concrete and no imminent threat is suggested by the existing conditions.

We thank you for the opportunity to assist you with this project. If you have any questions, or if you need any further assistance with this project, please contact me at your earliest convenience.

Sincerely,

PENNONI ASSOCIATES INC.

Michael A. Padula
Senior Engineer/Division Manager
Inspection & Testing Technology

PENNONI ASSOCIATES INC.
CONSULTING ENGINEERS

March 27, 2015

Design Level Inspection Report
I-95 Wilmington Viaduct

Re: Concrete Coring and Testing Services
Bridge I-745 North and South Bound
I-95 Viaduct, Wilmington, DE

Pennoni Associates (Pennoni) visited the above referenced bridge on the nights of November 24 and 25 of 2014 to drill and extract concrete core samples. Pennoni revisited this structure on the nights of January 15 and 22, 2015 to perform overlay pull testing. A total of eight (8) concrete cores were extracted and transported to our laboratory where they were documented and tested for thickness, compressive strength and water soluble chloride ions. Two (2) cores, 1 from each direction of the bridge, were sent to Highbridge Materials, Inc. for petrography and air voids testing. Table 1 below summarizes the physical dimensions, locations and selected testing for each of the concrete cores extracted from Bridge I-745.

Table 1 - Core Locations, Dimensions and Prescribed Testing

Bridge	Core ID	Core Location				Core Diameter (in)	Core Thickness		Laboratory Testing
		Span	Lane	Distance from Joint (X) (ft)	Distance from Lane Line (Y) (Ft)		Overlay (in)	Structural (in)	
I-745 (NB)	745NB-1C	2	C	40.0	11.0	3.25	2.25	5.75	Compression
	745NB-2C	3	C	56.0	7.0	3.25	2.75	5.25	Compression Water Soluble Chloride
	745NB-3C	6	R	43.0	4.0	3.25	2.25	4.75	Compression
	745NB-1P	6	C	7.0	2.0	3.25	3.25	4.75	Petrography & Air Voids
I-745 (SB)	745SB-1C	6	R	23.0	5.0	3.25	3.25	4.75	Compression Water Soluble Chloride
	745SB-2C	4	C	75.0	10.0	3.25	0.00	6.00	Compression
	745SB-3C	1	C	42.0	10.0	3.25	3.00	5.00	Compression
	745SB-1P	4	R	16.0	11.0	3.25	2.75	5.25	Petrography & Air Voids

Pull testing was performed at four (4) locations. Three (3) tests were performed adjacent to the compression core locations on the northbound side of the bridge and one (1) test was performed adjacent to core 2C on the southbound side. There was no concrete overlay at concrete core 745SB-2C.

As-Received Core Conditions

The following concrete core photographs were taken as they were received in the laboratory prior to testing.

Core 745NB-1C (As-Received)

Core 745NB-2C (As-Received)

Core 745NB-3C (As-Received)

Core 745NB-1P (As-Received)

Core 745SB-1C (As-Received)

Core 745SB-2C (As-Received)

Core 745SB-3C (As-Received)

Core 745SB-1P (As-Received)

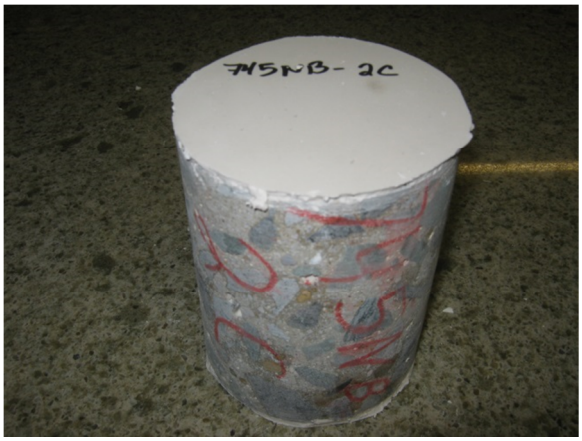
As-Prepared and Tested

The cores were sawn cut to achieve the maximum length to diameter ratios and placed in non-absorptive bags for a minimum of 5 days prior to testing. At the date of testing the ends concrete cores were capped using a high strength hydro-stone capping compound to further level the ends of the cores.

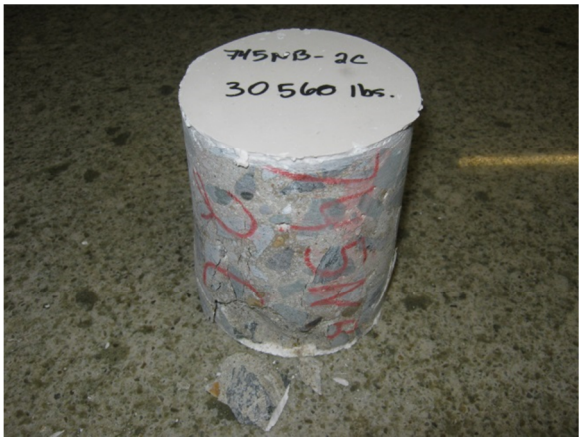
The failures are highlighted in the “tested” photographs for clarity.

Core 745NB-1C (As-Prepared)

Core 745NB-1C (Tested)



Core 745NB-2C (As-Prepared)



Core 745NB-2C (Tested)

Core 745NB-3C (As-Prepared)

Core 745NB-3C (Tested)

Core 745SB-1C (As-Prepared)

Core 745SB-1C (Tested)

Core 745SB-2C (As-Prepared)

Core 745SB-2C (Tested)

Core 745SB-3C (As-Prepared)

Core 745SB-3C (Tested)

Compression Results

Table 2 summarizes the compression testing results of the concrete cores.

Table 2: Compression Testing Summary							
Core ID	Diameter (in)	As-Prepared Length (in)	Cross Sectional Area (in^2)	Ultimate Load (lbs.)	L/D Ratio	Correction Factor	Compressive Strength (psi)
745NB-1C	3.25	5.22	8.30	39,870	1.61	0.969	4,650
745NB-2C	3.25	4.13	8.30	30,560	1.27	0.933	3,440
745NB-3C	3.25	4.50	8.30	43,290	1.38	0.946	4,940
745SB-1C	3.25	4.46	8.30	37,860	1.37	0.945	4,310
745SB-2C	3.25	5.24	8.30	60,990	1.61	0.969	7,120
745SB-3C	3.25	4.44	8.30	38,970	1.37	0.944	4,430
Average Compression Strength (psi)							4,820

The failure mode of the tested cores was generally consistent with a Type 1 fracture pattern. A Type 1 fracture pattern is defined in ASTM C39 as having reasonably well-formed cones on both ends with less than 1 inch of cracking through the capped ends.

The core 745NB-2C had a compressive strength that was significantly lower than the other cores for Bridge I-745. Due to the low compressive strength test results in this area, Pennoni recommends impact echo testing results be reviewed.

Water Soluble Chloride Ion Testing

Cores 745NB-2C and 745SB-1C were randomly selected for water soluble chloride ion testing. Testing was performed at three depths from the surface of the structural concrete; 0.5 inch, 1 inch and 2 inch. The thickness of the concrete overlay at core 745NB-2C was 2.75 inches. The thickness of the concrete

overlay at core 745SB-1C was 3.25 inches. Table 3 below summarizes the concentrations of water soluble chloride ions for each tested core.

Table 3 - Water Soluble Chloride Ion Test Results						
Bridge	Core ID	Depth (in)	Cl- (%wt)	Cl- (ppm)	Cl- (lbs/yrd^3)	Cl- (% cement)
I-745	745NB-2C	-0.50	0.01227	123	0.48	0.09
	745NB-2C	-1.00	0.00958	96	0.38	0.07
	745NB-2C	-2.00	0.00051	5	0.02	0.00
	745SB-1C	-0.50	0.01277	128	0.50	0.09
	745SB-1C	-1.00	0.00603	60	0.24	0.04
	745SB-1C	-2.00	0.00038	4	0.01	0.00

The following assumptions were used in order to estimate the water soluble chloride concentrations as a function of pound per cubic yard of concrete and as a percent of cement mass.

1. The air dry density of normal weight concrete is 3915 pounds per cubic yard (145 pounds per cubic foot).
2. The cement content is assumed as 14% for normal weight concrete.

ACI 318 Chapter 4 Table 4.3.1 provides requirements for maximum concentrations of water soluble chlorides for C2 structures as 0.15. C2 structures are defined as structures exposed to external sources of moisture and chlorides from deicing chemicals. The results listed in Table 3 indicate that the concentrations of water soluble chlorides are lower than this limit and are practically nonexistent at the depth of the top layer of reinforcing steel (i.e. 2 inches from the surface). The concentrations of water soluble chlorides at a depth of 1.00 inch from the surface for both cores was moderate (0.04 – 0.07 as a percent of cement mass). While still considered to be low, Pennoni recommends DelDOT revisit this area in the future to confirm concentrations remain low at this depth and chloride infiltration remains minimal at a depth of 2 inches.

Pull Testing of Overlay Wearing Surface

Pull testing of the concrete overlay wearing surface was performed at core locations 745NB-1C to 745NB-3C and 745SB-2C. The overlay thickness at these locations varied from 0 inches to 2.25 inches. The pull testing was performed in general compliance with ASTM C1583. A 3 inch diameter cored hole was drilled through the overlay wearing surface and into the underlying concrete slab by approximately 0.5 inches. A 3 inch diameter steel disk was then epoxied to the surface of the overlay and pulled at a constant rate until failure. The application of tensile load was monitored using an inline dynamometer. Table 4 summarizes the results from the overlay pull testing.

Table 4 - Pull Test Results of Concrete Overlay Wearing Surface					
Bridge	Core ID	Load Area (in^2)	Tensile Load (lbs)	Bond Strength (psi)	Failure Type
I-745	745NB-1C	7.07	750	106	Bond Fail
	745NB-2C	7.07	500	71	Bond Fail
	745NB-3C	7.07	200	28	Bond Fail
	745SB-2C	7.07	1500	212	Bond Fail

The bond strengths listed in Table 4 had high variability ranging from 28 psi to 212 psi. ACI 345 – Concrete Highway Bridge Deck Construction does not list values for the bond strength between the substructure and

the concrete wearing surface. However, developing a good bond between the two surfaces is a fundamental requirement for most concrete overlay wearing surfaces. Without an adequate bond, the overlay wearing surface is susceptible to delamination which can range from localized minor spalling or the removal of extensive sections. In both cases, the removal of the wearing surface allows the infiltration of various chemicals and weather conditions to attack the underlying structure. The concrete repair institute (ICRI) generally notes bond strengths should not be below 100 psi.

Air Voids and Petrography

Cores 745NB-1P and 745SB-1P were sent to Highbridge Materials Consulting, Inc. for petrography and air voids. The following is a summary of the test results, for further information; please reference *"Petrographic Examination Report"*, prepared by Highbridge Materials Consulting, Inc. dated February 14, 2015.

The total air voids observed in both cores, 745NB-1P and 745SB-1P were closer to the lower limit, 3.5% and 4.0% respectively, with respect to modern specifications for concrete that is exposed to freezing and thawing. Current specifications for concrete exposed to freezing and thawing cycles is 3.5% to 6.5% per ACI 318 Chapter 4 Section 4. Concrete core 745SB-1P was also found to be deficient in the amount of fine air content. These low air void contents leave this concrete susceptible to freeze thaw distress.

The petrographic analysis of the cores indicated that the concrete materials were well mixed, cast and consolidated. There were no obvious signs of workmanship deficiencies other than the possibility of poor handling which could be the cause for the deficient fine air content in core 745SB-1P. The water is cement ratio for the cores is estimated to be in the mid to high 0.40's. The course aggregates appear to be different between 745NB-1P and 745SB-1P while the fine aggregates appear consistent. Core 745NB-1P had evidence of early stage alkali-silica reactions in the form of axial micro-cracking in the upper half of the core. The reactions have not compromised the integrity of the concrete and no imminent threat is suggested by the existing conditions.

We thank you for the opportunity to assist you with this project. If you have any questions, or if you need any further assistance with this project, please contact me at your earliest convenience.

Sincerely,

PENNONI ASSOCIATES INC.

Michael A. Padula
Senior Engineer/Division Manager
Inspection & Testing Technology

PENNONI ASSOCIATES INC.
CONSULTING ENGINEERS

March 27, 2015

Design Level Inspection Report
I-95 Wilmington Viaduct

Re: Concrete Coring and Testing Services
Bridge I-746 North and South Bound
I-95 Viaduct, Wilmington, DE

Pennoni Associates (Pennoni) visited the above referenced bridge on the nights of November 24 and 25 of 2014 to drill and extract concrete core samples. Pennoni revisited this structure on the nights of January 15 and 22, 2015 to perform overlay pull testing. A total of eight (8) concrete cores were extracted and transported to our laboratory where they were documented and tested for thickness, compressive strength and water soluble chloride ions. Two (2) cores, 1 from each direction of the structure, were sent to Highbridge Materials, Inc. for petrography and air voids testing. Table 1 below summarizes the physical dimensions, locations and selected testing for each of the concrete cores extracted from Bridge I-746.

Table 1 - Core Locations, Dimensions and Prescribed Testing

Bridge	Core ID	Core Location				Core Diameter (in)	Core Thickness		Laboratory Testing
		Span	Lane	Distance from Joint (X) (ft)	Distance from Lane Line (Y) (Ft)		Overlay (in)	Structural (in)	
I-746 (NB)	746NB-1C	1	R	44.0	12.0	3.25	2.00	6.00	Compression
	746NB-2C	2	R	23.0	8.0	3.25	1.25	4.75	Compression Water Soluble Chloride
	746NB-3C	3	L	26.0	6.0	3.25	1.38	5.13	Compression
	746NB-1P	2	C	8.0	5.0	3.25	2.00	5.50	Petrography & Air Voids
I-746 (SB)	746SB-1C	3	R	22.0	9.0	3.25	3.00	4.00	Compression
	746SB-2C	2	R	7.0	6.0	3.25	2.50	6.50	Compression
	746SB-3C	1	C	54.0	11.0	3.25	2.75	4.25	Compression Water Soluble Chloride
	746SB-1P	2	C	61.0	7.0	3.25	1.75	5.25	Petrography & Air Voids

Pull testing was performed at four (4) locations. Three (3) tests were performed adjacent to the compression core locations on the northbound side of the bridge and one (1) test was performed adjacent to core 3C on the southbound side.

As-Received Core Conditions

The following concrete core photographs were taken as they were received in the laboratory prior to testing.

Core 746NB-1C (As-Received)

Core 746NB-2C (As-Received)

NO PHOTO

Core 746NB-3C (As-Received)

Core 746NB-1P (As-Received)

Core 746SB-1C (As-Received)

Core 746SB-2C (As-Received)

Core 746SB-3C (As-Received)

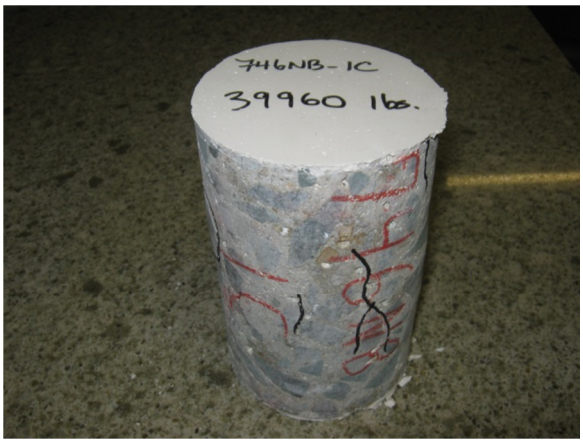
Core 746SB-1P (As-Received)

As-Prepared and Tested

The cores were sawn cut to achieve the maximum length to diameter ratios and placed in non-absorptive bags for a minimum of 5 days prior to testing. At the date of testing the ends concrete cores were capped using a high strength hydro-stone capping compound to further level the ends of the cores.

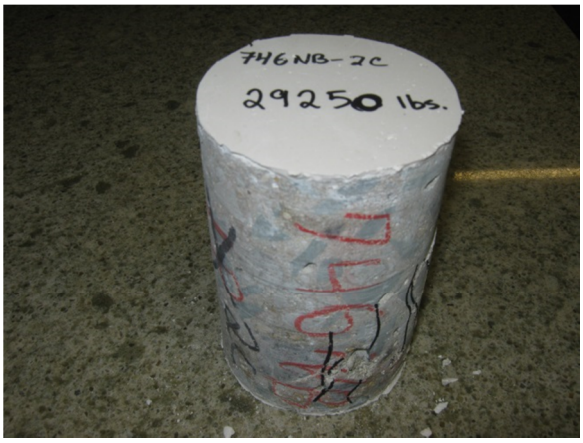
The failures are highlighted in the "tested" photographs for clarity.

Core 746NB-1C (As-Prepared)

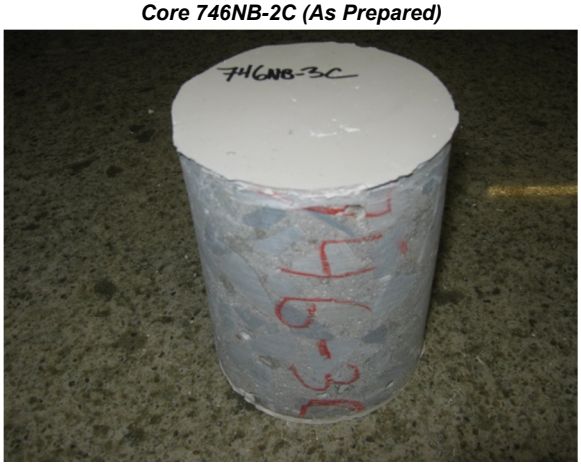


Core 746NB-1C (Tested)

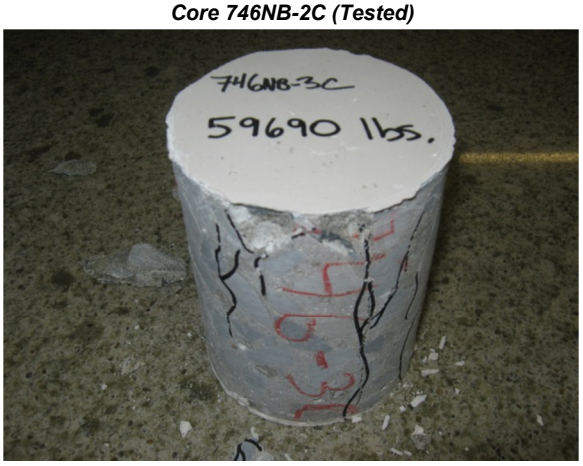
Core 746NB-2C (As Prepared)



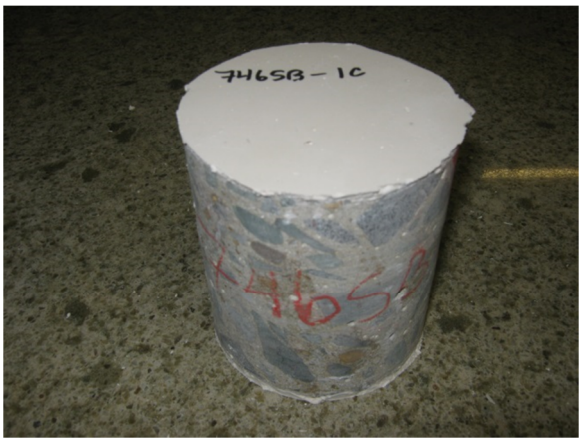
Core 746NB-2C (Tested)



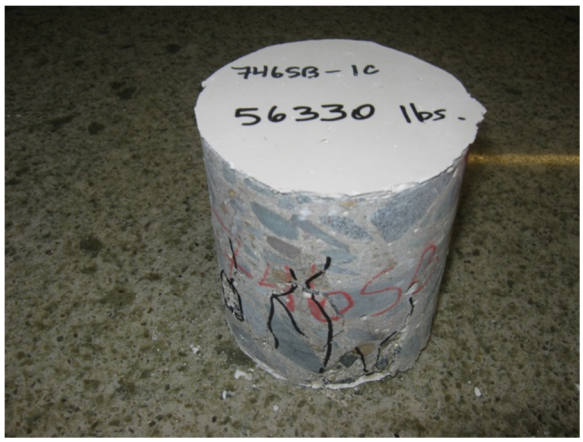
Core 746NB-3C (As Prepared)



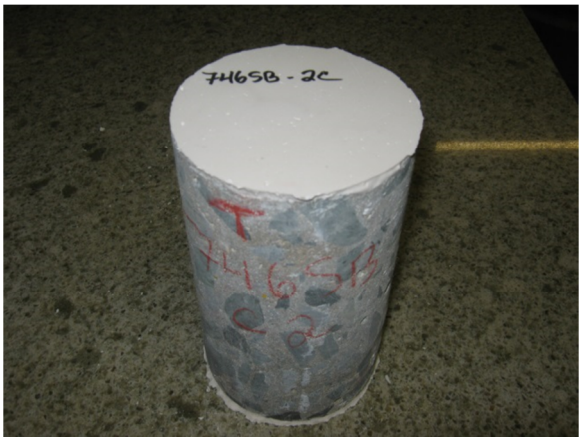
Core 746NB-3C (Tested)



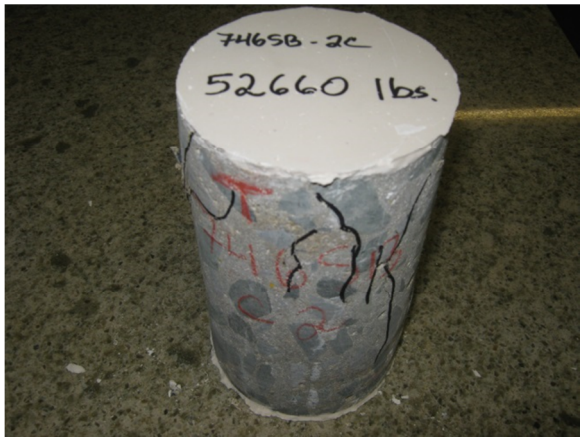
Core 746SB-1C (As-Prepared)



Core 746SB-1C (Tested)

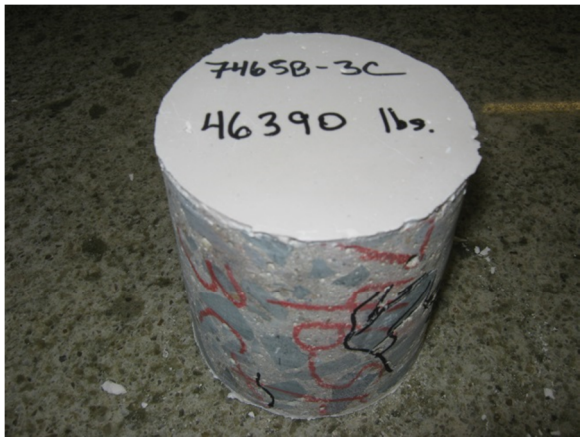


Core 746SB-2C (As-Prepared)



Core 746SB-2C (Tested)

Core 746SB-3C (As-Prepared)



Core 746SB-3C (Tested)

Compression Results

Table 2 summarizes the compression testing results of the concrete cores.

Table 2: Compression Testing Summary							
Core ID	Diameter (in)	As-Prepared Length (in)	Cross Sectional Area (in^2)	Ultimate Load (lbs.)	L/D Ratio	Correction Factor	Compressive Strength (psi)
746NB-1C	3.25	5.11	8.30	39,960	1.57	0.966	4,650
746NB-2C	3.25	4.97	8.30	29,250	1.53	0.962	3,390
746NB-3C	3.25	4.13	8.30	59,690	1.27	0.933	6,710
746SB-1C	3.25	3.77	8.30	56,330	1.16	0.908	6,170
746SB-2C	3.25	5.45	8.30	52,660	1.68	0.974	6,180
746SB-3C	3.25	3.45	8.30	46,390	1.06	0.885	4,950
Average Compression Strength (psi)							5,340

The failure mode of the tested cores was generally consistent with Type 1 fracture patterns. A Type 1 fracture pattern is defined in ASTM C39 as having reasonably well-formed cones on both ends with less than 1 inch of cracking through the capped ends.

The core 746NB-2C had a compressive strength that was significantly lower than the other cores for Bridge I-746. Due to the low compressive strength test results in this area, Pennoni recommends impact echo testing results be reviewed.

Water Soluble Chloride Ion Testing

Cores 746NB-2C and 746SB-3C were randomly selected for water soluble chloride ion testing. Testing was performed at three depths from the surface of the structural concrete; 0.5 inch, 1 inch and 2 inch. The thickness of the concrete overlay at core 746NB-2C was 1.25 inches. The thickness of the concrete overlay at core 746SB-3C was 2.75 inches. Table 3 below summarizes the concentrations of water soluble chloride ions for each tested core.

Table 3 - Water Soluble Chloride Ion Test Results

Bridge	Core ID	Depth (in)	Cl- (%wt)	Cl- (ppm)	Cl- (lbs/yrd^3)	Cl- (% cement)
I-746	746NB-2C	-0.50	0.00398	40	0.16	0.03
	746NB-2C	-1.00	0.00184	18	0.07	0.01
	746NB-2C	-2.00	0.00021	2	0.01	0.00
	746SB-3C	-0.50	0.01459	146	0.57	0.10
	746SB-3C	-1.00	0.01051	105	0.41	0.08
	746SB-3C	-2.00	0.00707	71	0.28	0.05

The following assumptions were used in order to estimate the water soluble chloride concentrations as a function of pound per cubic yard of concrete and as a percent of cement mass.

1. The air dry density of normal weight concrete is 3915 pounds per cubic yard (145 pounds per cubic foot).
2. The cement content is assumed as 14% for normal weight concrete.

ACI 318 Chapter 4 Table 4.3.1 provides requirements for maximum concentrations of water soluble chlorides for C2 structures as 0.15. C2 structures are defined as structures exposed to external sources of moisture and chlorides from deicing chemicals. The results listed in Table 3 indicate that the concentrations of water soluble chlorides are lower than this limit and are practically nonexistent at the depth of the top layer of reinforcing steel (i.e. 2 inches from the surface) for core 746NB-2C. The concentration of water soluble chlorides at a depth of 2.00 inches from the surface at core 746SB-3C was moderate (0.05 as a percent of cement mass). While still considered to be low, Pennoni recommends DelDOT revisit this area in the future to confirm concentrations remain low.

Pull Testing of Overlay Wearing Surface

Pull testing of the concrete overlay wearing surface was performed at core locations 746NB-1C to 746NB-3C and 746SB-3C. The overlay thickness at these locations varied from 1.25 inches to 2.75 inches. The pull testing was performed in general compliance with ASTM C1583. A 3 inch diameter cored hole was drilled through the overlay wearing surface and into the underlying concrete slab by approximately 0.5 inches. A 3 inch diameter steel disk was then epoxied to the surface of the overlay and pulled at a constant rate until failure. The application of tensile load was monitored using an inline dynamometer. Table 4 summarizes the results from the overlay pull testing.

Table 4 - Pull Test Results of Concrete Overlay Wearing Surface					
Bridge	Core ID	Load Area (in^2)	Tensile Load (lbs)	Bond Strength (psi)	Failure Type
I-746	746NB-1C	7.07	500	71	Bond Fail
	746NB-2C	7.07	750	106	Bond Fail
	746NB-3C	7.07	500	71	Bond Fail
	746SB-3C	7.07	500	71	Bond Fail

The bond strengths listed in Table 4 were fairly consistent ranging from 71 psi to 106 psi. ACI 345 – Concrete Highway Bridge Deck Construction does not list values for the bond strength between the substructure and the concrete wearing surface. However, developing a good bond between the two surfaces is a fundamental requirement for most concrete overlay wearing surfaces. Without an adequate bond, the overlay wearing surface is susceptible to delamination which can range from localized minor spalling or the removal of extensive sections. In both cases, the removal of the wearing surface allows the infiltration of various chemicals and weather conditions to attack the underlying structure. The concrete repair institute (ICRI) generally notes bond strengths should not be below 100 psi.

Petrography and Air Voids

Cores 746NB-1P and 746SB-1P were sent to Highbridge Materials Consulting, Inc. for petrography and air voids. The following is a summary of the test results, for further information; please reference *"Petrographic Examination Report"*, prepared by Highbridge Materials Consulting, Inc. dated February 14, 2015.

The total air voids observed in both cores, 746NB-1P and 746SB-1P were 4.7% and 1.1% respectively. Core 746SB-1P had no evidence of intentional air entrainment. Core 746NB-1P is within the ACI specifications for concrete that is exposed to freezing and thawing. Current specifications for concrete exposed to freezing and thawing cycles is 3.5% to 6.5% per ACI 318 Chapter 4 Section 4. Concrete that is exposed to freezing and thawing cycles that is not intentionally air entrained is susceptible to durability problems associated with freezing and thawing cycles due to a lack of room for infiltrated water particles to expand when they freeze. When the infiltrated water particles freeze, they expand and these expansive forces cause the concrete to eventually scale or delaminate over time.

The petrographic analysis of the cores indicated that the concrete materials for Core 746NB-1P was well mixed, cast and consolidated. Core 746SB-1P had evidence of vertical bleed channels which is common for concrete that is not intentionally air entrained. Both cores had two wearing course levels with each level measuring between 0.5inches and 0.8 inches. The water to cement ratio for both cores is estimated to be in the mid to high 0.40's. Early stage alkali-silica reactions were identified in Core 746NB-1P in the form of vertical micro-cracking. However, the reactions have not compromised the integrity of the concrete and no imminent threat is suggested by the existing conditions.

We thank you for the opportunity to assist you with this project. If you have any questions, or if you need any further assistance with this project, please contact me at your earliest convenience.

Sincerely,

PENNONI ASSOCIATES INC.

Michael A. Padula, P.E.
Senior Engineer/Division Manager
Inspection & Testing Technology

PENNONI ASSOCIATES INC.
CONSULTING ENGINEERS

April 13, 2015

Design Level Inspection Report
I-95 Wilmington Viaduct

Re: Concrete Coring and Testing Services
Bridge I-758F and I-758G Abutments
I-95 Viaduct, Wilmington, DE

Pennoni Associates (Pennoni) visited the above referenced structures on March 2, 2015 to drill and extract concrete core samples from the abutment stems of Bridges I-758F and I-758G (Abutments F and G). A total of six (6) concrete cores were extracted and transported to our laboratory where they were documented and tested for thickness, compressive strength, water soluble chloride ions. One core from each abutment was also tested for alkali silica reactivity (ASR) using ultraviolet light. A total of two (2) cores were extracted from Abutment F and four (4) cores were extracted from Abutment G. Table 1 summarizes the core locations, measurements and laboratory testing.

Table 1 - Core Locations, Dimensions and Prescribed Testing

Bridge	Core ID	Core Location		Core Diameter (in)	Core Thickness		Laboratory Testing
		Distance from Left Edge (X) (Ft)	Distance above Grade (Y) (Ft)		Repair Material (in)	Structural (in)	
I-758F	F1	1.8	5.2	3.25	4.09	7.30	Compression, Water Soluble Chloride Ion and ASR
	F2	2.7	4.9	3.25	5.06	7.00	Compression and Water Soluble Chloride Ion
I-758G	G1	5.0	3.5	3.25	0.00	7.10	Compression and Water Soluble Chloride Ion
	G2	9.0	3.0	3.25	0.00	7.54	Compression and Water Soluble Chloride Ion
	G3	16.0	3.0	3.25	0.00	7.58	Compression, Water Soluble Chloride Ion and ASR
	G4	24.5	3.0	3.25	0.00	6.60	Compression and Water Soluble Chloride Ion

The cores extracted from Abutment F were drilled through an existing cementitous repair material. Wire mesh was visible in core F2 at an approximate depth of 3.6” from the exterior face of the repair material. A vertical crack starting at the exposed surface was observed to propagate the thickness of the repair material for core F2 and the crack went around the existing wire mesh, terminating into the concrete substrate.

As-Received Core Conditions

The following concrete core photographs were taken as they were received in the laboratory prior to testing.

Core F1 (As-Received)

Core F2 (As-Received)

Core G1 (As-Received)

Core G2 (As-Received)

Core G3 (As-Received)

Core G4 (As-Received)

As-Prepared and Tested

The cores were sawn cut to achieve the maximum length to diameter ratios and placed in non-absorptive bags for a minimum of 5 days prior to testing. Cores G2 and G4 had noticeable cracking within the core and therefore trimming was performed beyond these cracks so they were not included in the tested sample. Cores F1 and F2 were cored through areas of the abutment that had a cementitous repair material applied to the existing concrete substrate. It was noted that in both F1 and F2 cores, the repair material had a vertical crack that extended from the exposed surface to approximately 1/2" to 1" into the surface of the existing structural concrete. Core F1 fractured during coring at approximately 0" to 1/2" from the bond line between the repair material and the existing concrete substrate (See Photograph Core F1 (As-Received), above). Core F2 also fractured during the coring at approximately 3/4" to 1" from the bond line between the repair material and the existing concrete substrate (See Photograph Core F2 (As-Received), above). At the date of testing, the concrete core ends were capped using a high strength hydro-stone capping compound to further level the ends of the core ends.

Core F1 (Tested)

Core F2 (Tested)

Core G1 (Tested)

Core G2 (Tested)

Core G3 (Tested)

Core G4 (Tested)

Compression Results

Table 2 below summarizes the test results for compression testing of the concrete cores.

Table 2: Compression Testing Summary							
Core ID	Diameter (in)	As-Prepared Length (in)	Cross Sectional Area (in^2)	Ultimate Load (lbs.)	L/D Ratio	Correction Factor	Compressive Strength (psi)
F1	3.23	5.35	8.19	38,230	1.66	0.972	4,540
F2	3.25	5.99	8.30	29,900	1.84	0.990	3,560
Abutment F - Average Compression Strength (psi)							4,050
G1	3.24	5.98	8.24	35,590	1.85	0.990	4,260
G2	3.25	3.15	8.30	37,910	0.97	0.870	3,970
G3	3.26	6.35	8.35	40,825	1.95	1.000	4,890
G4	3.25	4.95	8.30	37,495	1.52	0.962	4,330
Abutment G - Average Compression Strength (psi)							4,363

The failure mode of the tested cores was generally consistent with a Type 1 fracture pattern. A Type 1 fracture pattern is defined in ASTM C39 as having reasonably well-formed cones on both ends with less than 1 inch of cracking through the capped ends.

Water Soluble Chloride Ion Testing

Each of the cores from Abutments F and G were tested for water soluble chloride ions after compression testing. Testing was performed at two depths from the surface of the structural concrete; 1" and 2". Table 3 summarizes the concentrations of water soluble chloride ions for each tested core.

Table 3: Water Soluble Chloride Ion Testing Summary

Core ID	Test Depth from Surface (in)	Cl- (% by weight of concrete)	Cl- (lbs/yd^3 of concrete)	Cl- (% by weight of cement)
F1	-1	0.002	0.07	0.01
	-2	0.002	0.06	0.01
F2	-1	0.007	0.28	0.05
	-2	0.002	0.08	0.01
G1	-1	0.001	0.03	0.01
	-2	0.000	0.01	<0.01
G2	-1	0.000	<0.01	<0.01
	-2	0.000	<0.01	<0.01
G3	-1	0.000	0.01	<0.01
	-2	0.000	<0.01	<0.01
G4	-1	0.003	0.11	0.02
	-2	0.002	0.06	0.01

The following assumptions were used in order to estimate the water soluble chloride concentrations as a function of pound per cubic yard of concrete and as a percent of cement mass.

1. The air dry density of normal weight concrete is 3915 pounds per cubic yard (145 pounds per cubic foot).
2. The cement content is assumed as 14% for normal weight concrete.

ACI 318 Chapter 4 Table 4.3.1 provides requirements for maximum concentrations of water soluble chlorides for C2 structures as 0.15. C2 structures are defined as structures that are exposed to external sources of moisture and chlorides from deicing chemicals. The results listed in Table 3 indicate that the concentrations of water soluble chlorides are lower than this limit and are practically nonexistent at the depth of the top layer of reinforcing steel (i.e. 2" from the surface). These results indicate that the reinforcing steel within this structure is not in a corrosive environment and should be in as good a condition as originally placed.

Alkali Silica Reactivity (ASR)

Core F1 and G3 were selected for ASR testing using an ultraviolet light (AASHTO T299). Both cores had only minor and isolated indications of ASR present in the core. There were no significant ASR rings detected around the aggregates.

We thank you for the opportunity to assist you with this project. If you have any questions, or if you need any further assistance with this project, please contact me at your earliest convenience.

Sincerely,

PENNONI ASSOCIATES INC.

Michael A. Padula
Senior Engineer/Division Manager
Inspection & Testing Technology