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Report of Findings

EVALUATION AND ANALYSIS OF PRECAST CONCRETE ASSOCIATED WITH THE DULLES SILVER LINE PROJECT

Prepared for:

Office of the Inspector General
for Investigations, and Special Projects
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Respectfully submitted,

[redacted]

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DULLES SILVER LINE PROJECT (Phase II)
Evaluation and Analysis of Precast Concrete

1.0 INTRODUCTION

Structural Services, Inc. (SSI) has performed an evaluation and analysis of precast concrete elements constructed by Universal Concrete Products (UCP) for five (5) of the six (6) stations associated with the extension of the Silver Line rail system (Phase 2) from the Wiehle-Reston East Station to Dulles International Airport and beyond to Ashburn. New stations that comprise the work performed by UCP are Reston Town Center, Herndon, Innovation Center, Loudoun (Route 606), and Ashburn (Route 772). Route 606 and Route 772 were temporary station names assigned during construction. On panels were installed at Dulles airport. Documents addressing cracking in precast wall panels at the Dulles Rail Yard were also reviewed.

2.0 EXECUTIVE SUMMARY

Multiple deficiencies have been identified in the precast panels fabricated by UCP for the Silver Line Extension project. The deficiencies include the following:

- The aggregate supplied by the Denver Quarry is potentially reactive. Aggregates from both the Burkholder and Denver quarries comply with project specifications regarding average length expansion after 14 days. Using a separate test not required by the project specifications, aggregates from the Denver Quarry are shown to be potentially deleteriously reactive at one (1) year.

- A significant majority of the concrete core samples examined by DRP, A Twining Company (DRP), Wiss, Janney, Estner (WJE), and CTL Group (CTL) report air contents that varied significantly from the specified air content of 6% ±1.5%. Combined testing by DRP, WJE and CTL indicates the air content of as many as 45 of the 69 (approximately 65%) concrete core samples examined appear to fall below the minimum value specified for air on the project.

- DRP and CTL report a wide variation of w/cm, leading SSI to conclude that UCP did not consistently produce precast panels with the required water/cementitious materials (w/cm) ratio – maximum allowable under the specifications 0.45. Absent remediation, the higher w/cm reported for many of the concrete core samples will negatively impact the durability of the precast concrete panels.

- The concrete cover in the concrete panels does not conform to the 1.5-inch requirement of the project specifications. ACI 318 requirements for plant-precast concrete exposed to an aggressive environment do not appear to be consistent. The 318 Code requires only 0.75 inches cover for plant precast in a corrosive environment while the 318 Commentary, which is not mandatory, appears to recommend 1.5 inches cover for the same conditions. Documentation appears to confirm that all panels with concrete cover less than 0.75 inches and which are not located in the interior of the buildings or exposed to the elements, have been replaced.

  The proximity of reinforcing to the surface of the concrete increases the potential for an intersection of a crack with the reinforcing. In the event a crack intersects or coincides with the reinforcing, the potential for corrosion increases. EVONIK literature for Protectosil® CIT leads us to conclude that the product cannot be expected to protect reinforcing exposed to cracks that exceed 0.015 inches in width or are not dormant. Cracks cannot be dormant if exposed to thermal expansion and contraction, as will be the case for these precast panels. It is likely that the corrosion process will occur at some locations where wide or active cracks intersect the reinforcement in the panel face during the life of the structure.

The initial proposal by Capital Rail Constructors (CRC), and all subsequent communications are based on the cost of the original sealer application of two coats of product. Since testing by EVONIK has shown that a minimum of four coats of Protectosil® CIT are required to protect reinforcing at locations where there are no cracks, it would appear to SSI that the use of the original cost as a basis for calculations is flawed.

The use of the silane sealer on this project is not a perfect solution. Protectosil® CIT cannot be relied upon to protect reinforcing at active cracks or at cracks wider than 0.015 inches in width. The CRC proposal does not appear to anticipate the cost of regular visual inspections to identify and remediate panels that have begun to corrode. It also does not include the cost of remediation in the event corrosion is identified.

- Testing of the installed panels at two stations revealed "notable chloride ingress at wall panels", leading SSI to conclude that a positive means of identifying and mitigating the potential for corrosion of reinforcing in the panels is required. CRC proposed to address this issue by installing a galvanostatic pulse testing station in a single precast panel deemed by them to be most vulnerable to chloride attack.

- Concerns about the efficacy of galvanostatic pulse testing (GPT) of twenty-one (21) panels as a means of identifying the corrosion, potential or actual, of all exposed precast panels were supported by a January 2020 report from CRC that cracks were found in panels that did not contain GPT test stations. Two separate visual crack inspections of all accessible precast panels were conducted. Metropolitan Washington Airports Authority (MWAA) crack inspection results were published April 15, 2020. A second visual crack inspection, commissioned by the Washington Metropolitan Area Transit Authority (WMATA) OIG, was completed by DeSimone Consulting Engineers (DeSimone) and published in August, 2020.

- The DeSimone inspection revealed more cracks in panels at each of the stations than were identified in the surveys completed by UPC/CRC and MWAA. The DeSimone survey also identified cracks more than 0.005" in width that had not been repaired as required by the project specifications.

The measures taken by UCP, CRC, and MWAA to improve the quality of the precast panels fabricated by UCP after February 23, 2017 were generally ineffective. The increased scrutiny provided by one additional full-time QA person at the job site failed to reduce the frequency of NCR's or to impact in any significant way the types of fabrication drawing/production errors that were experienced prior to that date.

SSI is not aware of any QC measures that may have been implemented by UCP to assure that the fabrication drawings were without error. The disconnect between the reinforcing information on the pre-pour [placement] inspection checklists provided to SSI and the results of the ferro scans of each panel suggest that the reinforcing section of the checklist did not receive proper scrutiny.

All Non-Conformance Reports (NCR) relating to issues addressed in this report have been closed or are in the process of being closed. SSI found no Issues Requiring Resolution (IRR) or Deficiency Reports (DR) related to work performed by UCP. All Corrective Action Reports (CAR) related to panels fabricated by UCP have been closed.

DULLES RAIL YARD (PACKAGE B):

The cracks in the precast panels at the Dulles Yard are consistent with the those to be anticipated because of restraint of movement of the concrete in response to normal drying shrinkage and thermal movement. As per the Structural Engineer of Record, the cracks are of no structural consequence. Cracks do, however provide a means of egress for moisture in the panels.

3.0 BACKGROUND AND DESCRIPTION

Construction of Phase 2 of the Dulles Corridor Metrorail Project (Silver Line) is being managed by the Metropolitan Washington Airports Authority (MWAA). Washington Metropolitan Area Transit Authority (WMATA) is the future owner and becomes responsible for the safety, maintenance, and operation of the completed work upon WMATA's acceptance of the project.

Universal Concrete Products (UCP) is a precast concrete supplier to the Silver Line Phase 2 Package "A" Design-Build Contractor, DRP, A Twining Company and MWAA retained CTL. UPC retained Wiss, Janney, Estner (WJE). CRC is a joint venture of Clark Construction Group, LLC and Kiewit Infrastructure South Co. UCP has produced approximately 1,500 precast concrete elements for the project, representing a significant percentage of the precast concrete components of the five (5) at-grade stations of the Silver Line Phase 2 (UCP did not supply precast concrete elements for the Dulles Airport Station). These UCP precast concrete elements primarily consist of structural wall panels with various finish treatments and configurations, but also include assorted stair components (stringers, landings, etc.).

It has been determined by others that UCP failed to consistently manufacture these precast concrete elements in accordance with the project's required industry standard quality control practices and specifications. The deficiencies that have been identified are individually, and collectively, known to be detrimental to the service life (durability) of precast concrete, particularly given the conditions of exposure to which they will be subjected.

Deficiencies that have been identified, and for which extensive testing and analysis have been performed include high water cement ratio (w/cm), low air content (air entrainment) and insufficient concrete cover of reinforcing steel.

Information came to light that suggested UCP may also have used aggregate that did not meet applicable limits for a potential alkali-silica reaction (ASR). The alkali–silica reaction (ASR), given availability of enough moisture, is a swelling reaction that occurs over time in concrete between the highly alkaline cement paste and the reactive non-crystalline silica found in many common aggregates. The concern is that this additional deficiency could have a significant detrimental impact on the durability of the precast concrete, particularly in conjunction with the other deficiencies.

On March 1, 2019, Eastern Testing and Inspection Corporation (ETI) published a Summary of Chloride Ion Tests that noted there was evidence of “notable chloride ingress at the wall panels tested at Reston Center Station and Herndon Station.” On April 30, 2019, ETI published at the request of their client a revised, more complete report that included the same data that were attached to the March 1, 2019 ETI report but did not contain the paragraph noting evidence of “notable chloride ingress”. Both reports stated that according to the International Concrete Repair Institute (ICRI) threshold chloride ion concentrations of 1.0 to 1.5 pounds per cubic yard in concrete in the vicinity of reinforcing steel are enough to initiate active corrosion. This amounts to approximately 0.025% by weight of concrete. Excessive chloride concentrations in the vicinity of reinforcing steel could significantly impact the durability of the precast concrete.

CRC installed Galvanostatic Testing devices in 21 panels they considered to be most vulnerable to corrosive attack. The installation included 4 panels at Reston Station, 5 at Herndon Station, 4 at Innovation Station, 4 at Loudoun Gateway Station, and 4 at Ashburn Station. Galvanostatic pulse testing only provides information about the specific panels and the specific reinforcing grid to which the devices are attached. Information about corrosion, potential or actual, is not provided for any precast panels without test devices. A January 2020 report from CRC that cracks were found in panels that did not contain GPT test stations led to two separate visual crack inspections of all accessible precast panels.

On April 15, 2020, MWAA published a crack survey of precast panels at Reston (N07), Herndon (N08), Innovation (N09), Loudoun Gateway (N11), and Ashburn (N12) Stations. A more thorough crack survey executed by DeSimone Consulting Engineers (DeSimone) at the request of WMATA OIG was completed in August 2020.

DULLES RAIL YARD (PACKAGE B):

Shockey Precast Group (SPG) is a precast concrete supplier to the Silver Line Phase 2 Package “B” Design-Build Contractor, Hensel Phelps (HP). SSI understands concern has been expressed [redacted] regarding cracks in the precast wall panels fabricated by SPG. Specifically, certain exterior insulated precast concrete wall panels designed, fabricated, and furnished by SPG as a part of Package “B” to Phase 2 were observed to have developed vertical cracks. Buildings involved include the Service and Inspection Building, Warehouse Building, Train Wash Facility, and the Transportation Police Building.

4.0 SCOPE OF SERVICES

The services of SSI have been retained to complete an evaluation of precast concrete elements constructed by Universal Concrete Products (UCP) for five (5) of the six (6) stations associated with the extension of the Silver Line rail system (Phase 2) from the Wiehle-Reston East Station to Dulles International Airport and beyond to Ashburn. SSI has also been asked to opine regarding resolution of the cracking of precast concrete panels designed, fabricated, and furnished by SPG for various buildings in the Phase 2 Package "B" portion of the work. A structural evaluation of the UCP precast panels is not within the SSI Scope of Services.

Departure of As-Built Precast Concrete from Specified Parameters:

Specific areas of interest regarding the UCP panels are the impact of departures of various components of as-built precast concrete panels from specified parameters on the operations, maintenance, and cost of the precast concrete over the life of the structure. The departures which will be addressed in this report include air content, water-cementitious (w/cm) ratio, reinforcing coverage, susceptibility to ASR, and chloride content of the concrete.

SSI is asked to evaluate the effectiveness of a silane sealer application as recommended by MWAA and its contractor as an appropriate remediation for the previously listed departures from specified construction parameters. SSI is also charged with reviewing cost estimates associated with future remediation of the as-furnished and treated precast concrete panels.

Quality Control Practices and Remedial Actions:

SSI is asked to conduct a review of the quality control documents from UCP for purposes of evaluating the quality and completeness of the records. This review is to include SSI's determination regarding whether the quality control (QC) program implemented by UCP improved to an acceptable level following identification of alleged falsification of records. Relevant QC documents include but not limited to:

- Quality control plans/procedures,
- Mill certificates for cement, reinforcing steel, aggregate, admixtures, etc.,

- Material delivery tickets,
- Pour cards,
- Batch tickets, and
- Fresh concrete test reports to include cylinder reports, precast lab certifications, Precast/Prestressed Concrete Institute (PCI) inspection/audit reports and certifications, and relevant documents that may be required to make the determination

Non-Conformance Reporting:

SSI is tasked with the evaluation of Non-Conformance Reports (NCR), Issues Requiring Resolution (IRR), Deficiency Reports (DR) and Corrective Action Reports (CAR) and any other report that identifies deficiencies. SSI is to determine if the resolution of these matters would have significant impact to safety, operations, and maintenance costs.

Cracking of Precast Concrete Panels for Phase 2 Package "B:

The development of an acceptable resolution of issues related to observed vertical cracks in the precast panels designed, fabricated, and furnished by SPG for various buildings in Phase 2 Package "B" is beyond SSI's assigned scope. SSI's scope of services in this matter is limited to opining on the appropriateness of the resolution as reflected by documents provided for its review.

5.0 METHODOLOGY AND WORK PERFORMED

During execution of this assignment SSI personnel did the following:

- Reviewed of thousands of project documents,
  - Reviewed documents relative to each of the ASR and non-ASR related issues identified during fabrication of the UCP precast panels,
  - Reviewed contractor recommendations for resolution of each of the ASR and non-ASR related issues,
  - Reviewed QC records provided developed by UCP and provided by CRC,
  - Reviewed email describing changes in the UCP QC program that were implemented following identification of the ASR and non-ASR related issues,
  - Reviewed NCR's, IRR's, DR's, and CAR's regarding potential impact of their resolution on the safety, maintenance or operation of the project,
  - Evaluated contractor's recommendation of a silane sealer application as an appropriate remedial measure for each of the identified ASR and non-ASR related issues,
  - Read Evonik's Manual of Instruction for Sealer Application and product literature developed by Evonik for Protectosil® CIT,
  - Reviewed documentation regarding escrow calculations developed by CRC and responses by MWAA and WMATA, and
  - Reviewed documentation relating to cracks in the S&I building in the rail yard.
- Made two site visits to familiarize ourselves with the Work, meet with key personnel, and observe application of the silane sealer proposed as a remediation option by the Contractor,
  - Offered comments on measures that could be taken by the contractor and those observing the application to improve Quality Control for the application,
- Attended two WMATA Board Meetings that focused on, among other items, the work by UCP,
- Conducted independent research examining documents and questioning technical support personnel for multiple manufacturers of silane sealers,
- Reviewed precast panel crack survey data for accessible precast panels at Reston, Herndon, Innovation, Loudoun Gateway, and Ashburn Stations, prepared by MWAA and DeSimone Consulting Engineers (DeSimone), and
- Developed this report.

6.0 DOCUMENT REVIEW

Documents in several categories were requested and reviewed by SSI. Document categories provided by CRC and MWAA are listed below:

1. Shop drawings related to the UCP precast panels and documentation identifying issues with each panel.
2. Stations where each panel was installed and any issues with individual panels.
3. Supporting documents identifying how the calculation for the escrow related to the panels was determined. Documents provided include correspondence between MWAA/WMATA and Contractor.
4. Correspondence between MWAA-WMATA and the contractor, in addition to reports supporting the determination that application of a silane sealer would resolve the concrete panel issues.
5. Documentation identifying the companies and products considered for the silane sealer application. This documentation included bid pricing and determination on how the successful company was selected.
6. Documentation identifying training, if any, completed by the individuals applying the sealant to the UCP panels.
7. Documentation of the QC process before and after it was discovered that there were issues with the UCP panels.
8. Correspondence with the contractor related to the cracks in the S&I building in the rail yard and recommended remediation.
9. Comprehensive crack surveys of all accessible panels fabricated by UCP by MWAA and DeSimone Consulting Engineers.

At various times during execution of our assignment, additional documents were requested and provided. The documents reviewed during preparation of this report numbered in the thousands of pages. The primary documents used as a basis for SSI's findings are identified in the appropriate sections of this report.

7.0 OBSERVATIONS

SSI representative Eldon Tipping conducted two site visits during execution of this assignment. The site visit on February 7, 2019 was for the purpose of developing a familiarity with the scope of the project and issues relating to successful application of the silane sealer. We toured the portion of the Silver Line under construction by vehicle in the company of OIG personnel to gain an overview of the work. At the construction trailer, we were joined by additional OIG personnel. We were escorted to the Innovation Station and accessed the site by means of the North Pedestrian Bridge. We joined the superintendent with CRC and toured the Innovation Station and the South Pedestrian Bridge. While on site, we observed various finishes of the precast panels, exposure of panels to the environment, and locations that might present challenges to those applying the silane sealer. The sealer was not being applied during this site visit, so that process could not be observed.

Our group then went to the Dulles Rail Yard to observe cracks in walls of the warehouse building at that location. Numerous crack gages had previously been installed for the purpose of monitoring any movement of the cracks. Following our visit to the Dulles Rail Yard, we met with WMATA structural engineers to discuss the history of the project and navigation of the contractor's web site.

The site visit on March 20, 2019 was for the purpose of observing application of the silane sealer to precast walls at Herndon Station. SSI representative Eldon Tipping was accompanied by OIG personnel. We met with and were escorted to the site by a WMATA Project Engineer.

We observed application of the sealer at the North building at the North end of the platform. The sealer was applied on all the walls. This was the first application of sealer to the track-facing wall and the second for the remaining three walls. The first application of sealer on the remaining three walls had been completed two days prior to our visit.

The application was being monitored and recorded independently by quality observers separately retained by CRC and MWAA. There were two teams of sealer applicators. The persons spraying the sealer wore a backpack spray tank with gallon graduations

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marked on the exterior. The panels were too high to be sprayed only from the ground, so a ladder was used to access the upper portions of the wall.

EVONIK requires a minimum of 2 coats of sealer at a coverage rate of 200 sf/gallon/coat – a final coverage rate of 100 sf/gallon. The process used to confirm proper coverage, as explained by a representative of CRC, is to calculate the square feet of surface on the panel and determine the number of gallons that would be required to achieve the proper coverage per coat. The level of sealer in the tank is noted prior to beginning the spraying process and again upon completion of the panel. The assumption using this approach is that the coverage rate is uniform.

After observing the operations, SSI was not persuaded the process was producing uniform coverage. Those portions of the wall easily accessed from the ground appeared to receive more of the sealer than those accessed by ladder. Additionally, areas accessed by ladder were not treated with the nozzle a uniform distance from the panel face, and excess product was noted to be running down the face of the panel. If the correct amount of sealer is applied to the wall, these observations suggest the upper portions of the panels might not be receiving the proper coverage while the lower portions received an excess of product.

SSI asked if the sealer applicators were certified by the manufacturer and if they received any training by EVONIK prior to beginning the work. CRC indicated that the manufacturer EVONIK provided CRC with a letter stating that NLP was a certified sealer applicator. CRC also indicated that an EVONIK representative was present during one of the initial applications. CRC recommended a follow-up meeting with an EVONIK representative to obtain answers to these and any additional questions.

When asked by SSI about the process for reaching small or tight areas not compatible with the spray apparatus being used on most of the panels, CRC stated they would use a roller or sprayer with an extended nozzle.

SSI asked CRC about the results of the baseline chloride ion testing of concrete cores from some of the panels and how CRC chose the panels to be tested. CRC stated that they chose panels with a high w/cm ratio and where exposure to salty road spray was most likely. [Results of chloride ion testing are discussed elsewhere in this report.]

A follow-up meeting was held at CRC offices later that day. CRC's Quality Control Manager chaired the meeting which was attended by OIG, CRC and MWAA quality observers, and SSI. Topics covered in the meeting were product penetration, training of applicators, certification of applicators, procedure for treating "hard-to-reach" spaces, and quality observer checklists.

As a result of the meeting, CRC identified a series of actions they would take based on the site visit and discussions:

- Provide EVONIK with photographs of the application process to address uniformity of coverage and distance of the spray nozzle from the concrete surface,
- Stand down with crew regarding the application process,
- Arrange for random review and observation of application process by EVONIK,
- Add an item to the quality observer checklists regarding uniformity of application, and
- Regarding tight/hard-to-reach areas: CRC to alert NLP and WMATA OIG to observe.

8.0 DISCUSSION AND FINDINGS

8.1 Alkali-Silica Reactivity (ASR)

NCR-1371, dated 5/25/2018, originally brought to light the possibility that aggregate used by UCP in the concrete mixture utilized to produce precast panels failed to meet specified limitations for ASR. The approved concrete mix design for the panels stated that the source of coarse aggregate for the concrete mixture was Martin's Burkholder Quarry, located in Hinkletown, PA. It was discovered that the coarse aggregate used by UCP for the concrete panels was sourced at a separate quarry located in nearby Denver, PA.

The alkali–silica reaction (ASR), as stated previously, is a swelling reaction that occurs over time in concrete between the highly alkaline cement paste and the reactive non-crystalline silica found in many common aggregates when enough moisture is made available. The concern was that the change in aggregate source could have a significant detrimental impact on the durability of the precast concrete, particularly in conjunction with the other deficiencies.

Production of precast panels by UCP was discontinued until the aggregate from the Denver quarry could be tested for ASR potential. CRC retained DRP, A Twining Company and MWAA retained CTL. UPC retained Wiss, Janney, Estner (WJE) to perform ASR "testing of mortar prisms made in part from a coarse aggregate sample identified by Universal Concrete Products as Denver (Martin #8) for use in the Dulles Corridor Metrorail Project."

DPR performed a petrographic analysis of ten (10) concrete core samples taken from precast panels at five (5) different stations and found no evidence of deleteriously expansive alkali-silica reaction. The DRP report did not include the ten (10) core samples initially provided to CTL for evaluation. DRP noted, however, that documents provided by CRC for two different quarries indicated an average expansion of the Burkholder Quarry aggregate to be 0.03% at one year and an average expansion of the Denver Quarry to be 0.05% at one year (page 1). The appendix to ASTM C1293-08b (reapproved 2015) *Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction* "indicates that material may be classified as potentially deleteriously reactive if the average expansion is equal to or greater than 0.04% at one year."

The CTL Report included the ten (10) concrete cores evaluated by DRP in addition to the ten (10) concrete core samples initially provided to CTL. The CTL estimates of w/cm ratio and air percentage were close to the values reported by DRP for the ten (10) cores evaluated by both firms. Both laboratories found small amounts of potentially reactive forms of silica in the aggregates. Neither of the laboratories found evidence in the core samples of deleteriously expansive alkali-silica reaction.

Testing of the Denver Quarry aggregate, performed by Wiss, Janney, Elstner Associates (WJE) revealed that the average length expansion was less than specified for the project – 0.06% as compared to the specified maximum of 0.08% after fourteen (14) days exposure when tested according to ASTM C1260, *Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)*. It was determined by MWAA that the aggregates were acceptable for use and that a non-conformance in the product did not exist.

In summary, the average expansion of the coarse aggregates was evaluated using two separate ASTM testing methods – C1293 and C1260. The test over a one (1) year period yielded results that could classify the Denver Quarry aggregate as potentially deleteriously reactive. The test at fourteen (14) days yielded average length expansion results that were 0.06% - less than the 0.08% allowed by the project specifications.

SSI FINDING: The aggregate supplied by the Denver Quarry is potentially reactive. Aggregates from both the Burkholder and Denver quarries comply with project specifications regarding average length expansion after fourteen (14) days. Using a separate test not required by the project specifications, aggregates from the Denver Quarry are shown to be potentially deleteriously reactive at one (1) year.

8.2 Air Entrainment

Project specifications and the submitted concrete mix design call for entrained air in the precast panels. The specified air content was to be 6% ±1.5%. The purpose of entraining air within the concrete is to provide durable concrete in a freeze-thaw environment. Low air content, as stated in page 2 the Pivot Report dated September 25, 2017, "could lead to damage from freezing and thawing cycles over the life of the structures if these elements are exposed to significant amounts of moisture and become critically saturated. Dry concrete is not susceptible to freeze-thaw damage, regardless of air content."

As discussed previously in this report, the accuracy of QC reports provided by UCP has been questioned, so SSI's assessment of this issue is based on physical testing of concrete core samples taken from precast panels at various times during execution of the Work. Petrographic analyses of concrete core samples taken at several stations have been completed by three separate laboratories – DRP, WJE, and CTL.

DRP published a petrographic analysis for four (4) concrete core samples taken at the Reston Station. The report, dated May 9, 2017, reported all cores to be air entrained with air content for the core samples varying from 4.0% to 7.1% as evaluated per ASTM C457 and as shown below (page 5 of the DRP report). One (1) of the four (4) samples falls outside of the specified range for air content.

Table 3. Summary of air void data.

Parameter	3049	3079	3124	4072	Mix
Aggregate Content	64.1%	65.7%	67.3%	65.0%	67.3%
Paste Content	28.8%	28.8%	26.8%	31.1%	26.7%
Air Content	7.1%	5.5%	5.9%	4.0%	6.0%
Paste/Air Ratio (p/A)	4.1	5.3	4.5	7.9	4.5
Void Frequency (mm^{-1})	0.386	0.390	0.400	0.278	
Specific Surface (mm^{-1})	21.70	28.59	27.05	28.15	
Avg. Chord Length (mm)	0.184	0.140	0.148	0.142	
Spacing Factor (mm)	0.19	0.17	0.16	0.20	

DRP published a petrographic analysis for seven (7) concrete core samples taken at the Innovation Station. The report, dated May 10, 2017, reported air content for the core samples varying from 2.3% to 3.7% as evaluated per ASTM C457 and as shown below (page 7 of the DRP report). DRP noted that the air content was below values typically observed in air-entrained concrete, but that CRC reported air content measurements tested in the plastic state indicated a range of values from 4.5-7.0% for this set of cores. Air content of all seven (7) of the samples falls outside the specified range for air.

Table 3. Summary of air content and proportioning data

Parameter	218	215	224	212	Stair	233	213	Mix
Aggregate Content	70.2%	68.6%	72.0%	66.9%	70.9%	68.2%	73.9%	67.3%
Paste Content	27.3%	29%	25.2%	29.4%	25.9%	28.8%	23.8%	26.7%
Air Content	2.5%	2.4%	2.8%	3.7%	3.2%	3.0%	2.3%	6.0%
Paste/Air Ratio (p/A)	10.9	12.0	8.9	8.0	8.2	9.7	10.3	4.5%
Void Frequency (mm^{-1})	0.123	0.152	0.170	0.204	0.194	0.220	0.125	
Specific Surface (mm^{-1})	19.78	25.10	24.05	22.10	24.64	29.60	21.52	
Avg. Chord Length (mm)	0.202	0.159	0.166	0.181	0.162	0.135	0.186	
Spacing Factor (mm)	0.33	0.27	0.25	0.26	0.24	0.21	0.30	

WJE published a petrographic analysis for thirteen (13) concrete core samples taken at four (4) different stations. The report, dated May 17, 2017, reported air content for the core samples varying from 3.5% to 8.0%. The air content of all thirteen (13) samples was evaluated per visual and microscopic observations. Additionally, three (3) core samples were also evaluated per ASTM C457 as shown below (page 4 of the WJE report).

Table 5. Total Air Content Estimates

Core/Panel ID	Casting Date	Total Air Content Estimate (percent)
1406	January 27, 2017	4.5 to 5.5
1423	February 22, 2017	5.5 to 6.5
2637	December 1, 2016	3.5 to 4.5
3059	November 4, 2016	5.5 to 6.5
3071	October 26, 2016	5 to 6
4116	February 14, 2017	7 to 8
4121	January 18, 2017	5 to 6
4131	February 6, 2017	6 to 7
4206	March 20, 2017	5 to 6
4317	March 22, 2017	4.5 to 5.5
4320	February 10, 2017	5 to 6
4601	February 20, 2017	3.5 to 4.5
4602	February 23, 2017	4.5 to 5.5

Table 6. Air Void Analysis Results

Core IDs / Parameters	Core 2637	Core 4116	Core 4601
Air content (percent)	5.1	7.3	4.7
Paste content (p) (percent)	32.4	30.1	29.7
Sand content %	27.3	23.7	25.8
Coarse aggregate content %	35.2	38.9	39.9
Void frequency (n)	8.5	9.5	8.0
Paste-air ratio (p/A)	6.3	4.1	6.3
Average chord length (inch)	0.006	0.008	0.006
Specific surface (in^2/in^3)	664	517	681
Spacing factor (inch)	0.008	0.008	0.008
Total traverse length (inch)	80.4	76.3	75.5
Total points counted	1207	1145	1133
Total area tested (in^2)	15.0	6.3	15.0
Magnification used in testing	90X	90X	90X
Estimated Air Content (percent)	3.5 to 4.5	7 to 8	3.5 to 4.5

DRP published a petrographic analysis for ten (10) concrete core samples taken at the Herndon Station. The report, dated August 13, 2017, reported air content for the core samples varying from 0.6% to 8.3% as evaluated per ASTM C457 and as shown below (page 3 of the DRP report). Air content of nine (9) of the ten (10) samples falls outside the specified range for air.

Table 3. Summary of air content data

Sample ID	Aggregate Content	Paste Content (p)	Air Content (A)	Paste/Air Ratio (p/A)
2643A	68.6%	29.2%	2.2%	13.1
2644D	62.4%	32.3%	5.3%	6.1
2546A	70.4%	27.2%	2.3%	11.6
2500B	68.6%	28.3%	3.2%	9.0
2513C	68.6%	29.4%	2.0%	14.7
2543B	69.1%	26.7%	4.2%	6.4
2544C	69.5%	27.2%	3.3%	8.2
2551C	71.8%	27.6%	0.6%	45.4
2555B	64.8%	26.9%	8.3%	3.2
2557C	66.4%	29.2%	4.4%	6.6

DRP published a petrographic analysis for five (5) concrete core samples taken at the Innovation Station. The report, dated August 14, 2017, reported air content for the core samples varying from 0.9% to 3.6% as evaluated per ASTM C457 and as shown below (page 3 of the DRP report). Air content of each of the five (5) samples falls below the specified range for air.

Table 3. Summary of air content data

Sample ID	Aggregate Content	Paste Content (p)	Air Content (A)	Paste/Air Ratio (p/A)
106C	71.1%	27.1%	1.8%	15.4
107B	67.1%	29.3%	3.6%	8.3
1244C	68.4%	28.7%	2.9%	9.7
1250C	70.2%	28.9%	0.9%	33.0
1251A	70.3%	28.1%	1.7%	16.9

DRP published a petrographic analysis for ten (10) concrete core samples taken at five (5) different stations. The report, dated July 6, 2018, reported estimated air content for the core samples varying from less than 3% to as high as 7%, as evaluated per visual and microscopical observations – not ASTM C457 and as shown below (page I of the DRP report). Air content of six (6) of the ten (10) samples falls outside the specified range for air.

Table ES1. Summary of Petrographic Observations*

Core	Station	Insulated	Depth to Steel	Air Content	Carbonation	ASR
204	Innovation	Yes	~ 35 mm	< 3%	~ 1 mm	None
410	Innovation	Yes	~ 25 mm	3-4%	None	None
2503	Herndon	Yes	Not intercepted	3-4%	~ 1 mm	None
2508	Herndon	No	Not intercepted	4-5%	~ 1 mm	None
3070	Reston	Yes	0-6 mm	5-7%	~ 2 mm	None
3080	Reston	No	Not intercepted	5-7%	2-3 mm	None
4301	Loudoun	Yes	Not intercepted	< 3%	1-3 mm	None
4306	Loudoun	Yes	Not intercepted	5-7%	~ 3 mm	None
5005	Ashburn	Yes	~ 25 mm	~ 4%	~ 1 mm	None
5114	Ashburn	Yes	~ 20 mm	~ 4%	~ 1 mm	None

**Notes: Depth to steel is measured from the face adjacent to the insulation; see Figure 1 for illustration of different faces of the cores. Air contents were estimated based on visual and microscopical observations. Depths of carbonation were measured from the interior visible face; no carbonation was observed at the face adjacent to the insulation. ASR refers to any evidence of alkali silica reaction.*

DRP published another petrographic analysis for ten (10) concrete core samples taken at five (5) different stations. The report, dated August 3, 2018, reported estimated air content for the core samples varying from less than 3% to 5-7%, as evaluated per visual and microscopical observations – not ASTM C457 and as shown below (page i of the DRP report). Air content of six (6) of the ten (10) samples falls outside the specified range for air.

Table ES1. Summary of Petrographic Observations*

Core	Station	Insulated	Depth to Steel	Air Content	Carbonation	ASR
I-408	Innovation	Yes	Not intercepted	3-5%	None	None
I-1315	Innovation	Yes	~ 20 and ~ 25 mm	2-4%	3-5 mm	None
H-2554	Herndon	Yes	Not intercepted	4-6%	2-3 mm	None
H-2648	Herndon	Yes	~ 40 mm	< 3%	3-4 mm	None
R-3127	Reston	Yes	Not measured**	3-4%	1-2 mm	None
R-3050	Reston	Yes	~ 20 mm	3-4%	0-1 mm	None
L-4223	Loudoun	Yes	Not intercepted	4-6%	3-5 mm	None
L-4242	Loudoun	Yes	Not intercepted	2-4%	2-3 mm	None
A-5200	Ashburn	Yes	~ 50 mm	5-6%	~ 2 mm	None
A-5404	Ashburn	Yes	~ 50 mm	2-4%	~ 2 mm	None

**Notes: Depth to steel is measured from the face adjacent to the insulation; see Figure 1 for illustration of different faces of the cores. Air contents were estimated based on visual and microscopical observations. Depths of carbonation were measured from the interior visible face; no carbonation was observed at the face adjacent to the insulation. ASR refers to any evidence of alkali silica reaction.*
*** Core R-3127 terminated at a fracture surface such that the depth of steel could not be measured.*

CTL published a petrographic analysis for twenty (20) concrete core samples taken at fived (5) different stations. Ten (10) of the core samples constitute a side-by-side evaluations with DRP. The report, dated August 16, 2018, reported estimated air content for the core samples varying from less than 1% to as high as 9%, as evaluated per visual and microscopical observations – not ASTM C457 and as shown below (pages 5-7 of the CTL report). An additional eight (8) of the ten (10) samples independently reported by CTL fall outside the specified range for air.

TABLE 2 SUMMARY OF PETROGRAPHIC OBSERVATIONS

Characteristics	Core 1	Core 2	Core 3	Core 4	Core 5	Core 6	Core 7
	Innovation #204	Innovation #410	Innovation #408	Innovation #1315	Herndon #2503	Herndon #2508	Herndon #2554
Cracking	None observed	None observed	None observed	None observed	None observed	None observed	None observed
Coarse Aggregate[1]	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks
Fine Aggregate[2]	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand
Estimated Air Content	Approximately 1%	2 to 4%	2 to 4%	1 to 3%	3 to 5%	2 to 4%	1 to 3%
Paste Physical Properties	Moderately hard to hard paste with low water absorbency	Hard paste with low water absorbency	Hard paste with low water absorbency	Moderately hard to hard paste with low water absorbency	Hard paste with low water absorbency	Hard paste with low water absorbency	Moderately hard to hard paste with low water absorbency
Estimated w/c[3]	Moderately low to moderate (0.40 to 0.50)	Low (less than 0.40)	Low (less than 0.40)	Moderately low (0.35 to 0.45)	Moderately low (0.35 to 0.45)	Moderately low (0.35 to 0.45)	Moderately low (approximately 0.35 to 0.45)
Depth of Carbonation	Less than 0.04 in.	Less than 0.04 in.	Less than 0.04 in.	0.12 to 0.2 in.	Less than 0.04 in. to locally 0.08 in.	0.04 to 0.08 in.	0.08 to 0.12 in.
Evidence of Deleterious ASR	None observed	None observed	None observed	None observed	None observed	None observed	None observed

Characteristics	Core 8	Core 9	Core 10	Core 11	Core 12	Core 13	Core 14
	Herndon #2648	Reston #3070	Reston #3080	Reston #3127	Reston #3050	Loudoun #4301	Loudoun #4306
Cracking	None observed	None observed	None observed	None observed	None observed	None observed	None observed
Coarse Aggregate[1]	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks
Fine Aggregate[2]	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand
Estimated Air Content	Approximately 1%	5 to 7%	7 to 9%	2 to 4%	3 to 5%	1 to 3%	7 to 9%
Paste Physical Properties	Moderately hard to hard paste with low water absorbency	Moderately hard to moderately soft with high water absorbency	Moderately hard with high water absorbency	Moderately hard to hard with moderately low water absorbency	Moderately hard with moderately high water absorbency	Moderately hard with moderately high water absorbency	Moderately hard with moderate to moderately high water absorbency
Estimated w/c[3]	Moderately low to moderate (0.40 to 0.50)	Moderate to moderately high (0.50 to 0.60)	Moderate to moderately high (0.50 to 0.60)	Moderately low to moderate (0.40 to 0.50)	Moderate (0.45 to 0.55)	Moderate (0.45 to 0.55)	Moderately low to moderate (0.40 to 0.50)
Depth of Carbonation	0.1 to 0.14 in.	0.08 to 0.12 in.	0.04 in. to locally 0.16 in.	0.06 to 0.12 in.	0.04 to 0.12 in.	0.12 in. to locally 0.28 in.	0.12 in. to locally 0.28 in.
Evidence of Deleterious ASR	None observed	None observed	None observed	None observed	None observed	None observed	None observed

1. Thin-section examination reveals the presence of small amounts of microcrystalline quartz and strained quartz in the limestone coarse aggregate.
2. The fine aggregate contains small amounts of quartzite and chert. Thin-section examination reveals that some quartzite particles are highly strained.
3. Estimated water-cement ratio based on the observed physical and microscopical paste properties.

Legend

Core Samples evaluated by DRP 8/3/2018

TABLE 2 (CONTINUED) SUMMARY OF PETROGRAPHIC OBSERVATIONS

Characteristics	Core 15	Core 16	Core 17	Core 18	Core 19	Core 20
	Loudoun #4223	Loudoun #4242	Ashburn #5005	Ashburn #5114	Ashburn #5200	Ashburn #5404
Cracking	None observed	None observed	None observed	None observed	A few fine cracks or hairline cracks extend to depth of 0.3 in. from outer surface; likely shrinkage-related	A few fine cracks or hairline cracks extend to depth of 0.5 in. from outer surface region, likely shrinkage-related
Coarse Aggregate[1]	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks
Fine Aggregate[2]	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand
Estimated Air Content	3 to 5%	1 to 3%	1 to 3%	2 to 4%	2 to 4%	2 to 4%
Paste Physical Properties	Moderately hard with moderately high water absorbency	Moderately hard to hard with low water absorbency	Hard with low water absorbency	Hard with low water absorbency	Moderately hard to hard with low water absorbency	Moderately hard to hard with low water absorbency
Estimated w/c[3]	Moderate to moderately high (0.50 to 0.60)	Moderately low (0.35 to 0.45)	Moderately low (0.35 to 0.45)	Moderately low (0.35 to 0.45)	Moderately low (0.35 to 0.45)	Moderately low (0.35 to 0.45)
Depth of Carbonation	0.08 to 0.16 in.	0.06 to 0.1 in.	Approximately 0.04 in.	0.12 to locally 0.24 in.	0.08 to 0.12 in.	0.06 to 0.1 in.
Evidence of Deleterious ASR	None observed	None observed	None observed	None observed	None observed	None observed

1. Thin-section examination reveals the presence of small amounts of microcrystalline quartz and strained quartz in the limestone coarse aggregate.
2. The fine aggregate contains small amounts of quartzite and chert. Thin-section examination reveals that some quartzite particles are highly strained.
3. Estimated water-cement ratio based on the observed physical and microscopical paste properties.

Legend
Core Samples evaluated by DRP 8/3/2018

SSI FINDING: A significant majority of the concrete core samples examined by DRP, WJE, and CTL report air contents that varied significantly from the specified air content of 6% ±1.5%. Most important is that combined testing by DRP, WJE and CLT indicates the air content of as many as 45 of the 69 (approximately 65%) concrete core samples examined appear to fall below the minimum value specified for air on the project.

8.3 Water/Cement (w/cm) Ratio

Project specifications call for a maximum w/cm ratio of 0.45; the submitted concrete mix design provided a w/cm ratio of 0.40 for precast concrete panels. The decision to submit a mix design with a w/cm ratio of 0.40 and f'_c of 5,000 psi is consistent with ACI 318-14 Code requirements for this project exposure. One purpose of requiring concrete with a low w/cm ratio is to provide durable concrete with low permeability. Low permeability is of critical importance for concrete exposed to a freeze-thaw environment.

According to ACI 201.2R-16 *Guide to Durable Concrete,* "the initial porosity of a cement paste is determined by the w/cm. As cement hydrates, hydration products fill some of the void space formerly occupied by water. With time, this process results in a continued decrease in the porosity of the cement paste…For a w/cm of 0.45, the degree of hydration must reach approximately 70 percent to bring the porosity down to 30 percent. For a w/cm of 0.60, the degree of hydration must reach approximately 100 percent to reach the same porosity...for cement paste with a w/cm of 0.38, all the capillary pore space was just filled by maximum density gel when all the cement was hydrated. Sealed, fully hydrated cement pastes made at w/cm above 0.38 have remaining capillary pore space equal to the excess above 0.38…Even for w/cm of 0.40 to 0.45, extended moist curing or other favorable curing conditions are necessary to achieve the desired low permeability."

The accuracy of QC reports provided by UCP regarding moisture content of the precast concrete has been questioned (Re: NCR 0878), so SSI's evaluation of this issue is based on physical testing of concrete core samples taken from precast panels at various times during execution of the Work. Petrographic analysis of concrete core samples taken at several stations have been completed by three (3) separate laboratories – DRP, WJE, and CTL.

DRP published a petrographic analysis for four (4) concrete core samples taken at the Reston Station. The report, dated May 9, 2017, offers the following about the w/cm ratio of these four (4) concrete core samples (page 9 of the DRP report):

> The characteristics of the paste are consistent from core to core and point toward w/c that ranges from 0.40-0.50. These estimations are preliminary and subject to revision with additional work using samples prepared with the same materials under controlled conditions that represent a range of w/c from 0.35-0.55.

DRP published a petrographic analysis for seven (7) concrete core samples taken at the Innovation Station. The report, dated May 10, 2017, offers the following about the w/cm ratio of these four (4) concrete core samples (page 12 of the DRP report):

> The characteristics of the paste are consistent from core to core and point toward w/c that ranges from 0.35-0.45. These estimations are preliminary and subject to revision with additional work using samples prepared with the same materials under controlled conditions that represent a range of w/c from 0.35-0.55.

WJE published a petrographic analysis for thirteen (13) concrete core samples taken at four (4) different stations. The report, dated May 17, 2017, stated that the "concrete represented in each core has w/cm that range from 0.39 to 0.46 overall" (page 5 of the WJE report).

DRP published a petrographic analysis for ten (10) concrete core samples taken at the Herndon Station. The report, dated August 13, 2017, was developed specifically to determine the hardened air content of the concrete core samples and did not address w/cm ratio for the concrete core samples.

DRP published a petrographic analysis for five (5) concrete core samples taken at the Innovation Station. The report, dated August 14, 2017, was developed specifically to determine the hardened air content of the concrete core samples and did not address w/cm ratio for the concrete core samples.

DRP published a petrographic analysis for ten (10) concrete core samples taken at five (5) different stations. The report, dated July 6, 2018, offers the following about the w/cm ratio of these ten (10) concrete core samples (page 6 of the DRP report):

> **3.3** ***Components: Paste*** The paste consists of hydrated portland cement; no fly ash, slag cement or other supplemental cementitious materials were observed. The paste is gray, has a smooth texture and is hard (Mohs ~ 3.5). The hydration is normal. Calcium hydroxide is fine-grained and distributed evenly. Observations of the paste microstructure indicate the estimated water-cement ratio (w/c) ranges from 0.35-0.45. **Figure 3** shows photographs and photomicrographs of the paste from Core 410 as an example.

CTL published a petrographic analysis for twenty (20) concrete core samples taken at fived (5) different stations. Ten (10) of the core samples constitute a side-by-side evaluations with DRP. The report, dated August 16, 2018, estimates the w/cm ratio of the twenty (20) concrete core samples to vary from low (less than 0.40) to between

Moderate and Moderately High (0.50 to 0.60). CTL offers the following regarding their method for arriving at the reported estimates (page 4 of the CTL report):

> Estimated water-cement ratio (w/c), when reported, is based on observed concrete and paste properties including, but not limited to: 1) relative amounts of residual (unhydrated and partially hydrated) portland cement particles; 2) amount and size of calcium hydroxide crystals; 3) paste hardness, color, and luster; 4) paste-aggregate bond; and 5) relative absorbency of paste as indicated by the readiness of a freshly fractured surface to absorb applied water droplets. These techniques have been widely used by industry professionals to estimate w/c.

CTL results for individual concrete core samples are shown below (pages 5-7 of the CTL report):

TABLE 2 SUMMARY OF PETROGRAPHIC OBSERVATIONS

Characteristics	Core 1	Core 2	Core 3	Core 4	Core 5	Core 6	Core 7
	Innovation #204	Innovation #410	Innovation #408	Innovation #1315	Herndon #2503	Herndon #2508	Herndon #2554
Cracking	None observed	None observed	None observed	None observed	None observed	None observed	None observed
Coarse Aggregate[1]	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks
Fine Aggregate[2]	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand
Estimated Air Content	Approximately 1%	2 to 4%	2 to 4%	1 to 3%	3 to 5%	2 to 4%	1 to 3%
Paste Physical Properties	Moderately hard to hard paste with low water absorbency	Hard paste with low water absorbency	Hard paste with low water absorbency	Moderately hard to hard paste with low water absorbency	Hard paste with low water absorbency	Hard paste with low water absorbency	Moderately hard to hard paste with low water absorbency
Estimated w/c[3]	Moderately low to moderate (0.40 to 0.50)	Low (less than 0.40)	Low (less than 0.40)	Moderately low (0.35 to 0.45)	Moderately low (0.35 to 0.45)	Moderately low (0.35 to 0.45)	Moderately low (approximately 0.35 to 0.45)
Depth of Carbonation	Less than 0.04 in.	Less than 0.04 in.	Less than 0.04 in.	0.12 to 0.2 in.	Less than 0.04 in. to locally 0.08 in.	0.04 to 0.08 in.	0.08 to 0.12 in.
Evidence of Deleterious ASR	None observed	None observed	None observed	None observed	None observed	None observed	None observed

1. Thin-section examination reveals the presence of small amounts of microcrystalline quartz and strained quartz in the limestone coarse aggregate.
2. The fine aggregate contains small amounts of quartzite and chert. Thin-section examination reveals that some quartzite particles are highly strained.
3. Estimated water-cement ratio based on the observed physical and microscopical paste properties.

Legend

Core Samples evaluated by DRP 8/3/2018

TABLE 2 (CONTINUED) SUMMARY OF PETROGRAPHIC OBSERVATIONS

Characteristics	Core 8	Core 9	Core 10	Core 11	Core 12	Core 13	Core 14
	Herndon #2648	Reston #3070	Reston #3080	Reston #3127	Reston #3050	Loudoun #4301	Loudoun #4306
Cracking	None observed	None observed	None observed	None observed	None observed	None observed	None observed
Coarse Aggregate[1]	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks
Fine Aggregate[2]	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand
Estimated Air Content	Approximately 1%	5 to 7%	7 to 9%	2 to 4%	3 to 5%	1 to 3%	7 to 9%
Paste Physical Properties	Moderately hard to hard paste with low water absorbency	Moderately hard to moderately soft with high water absorbency	Moderately hard with high water absorbency	Moderately hard to hard with moderately low water absorbency	Moderately hard with moderately high water absorbency	Moderately hard with moderately high water absorbency	Moderately hard with moderate to moderately high water absorbency
Estimated w/c[3]	Moderately low to moderate (0.40 to 0.50)	Moderate to moderately high (0.50 to 0.60)	Moderate to moderately high (0.50 to 0.60)	Moderately low to moderate (0.40 to 0.50)	Moderate (0.45 to 0.55)	Moderate (0.45 to 0.55)	Moderately low to moderate (0.40 to 0.50)
Depth of Carbonation	0.1 to 0.14 in.	0.08 to 0.12 in.	0.04 in. to locally 0.16 in.	0.06 to 0.12 in.	0.04 to 0.12 in.	0.12 in. to locally 0.28 in.	0.12 in. to locally 0.28 in.
Evidence of Deleterious ASR	None observed	None observed	None observed	None observed	None observed	None observed	None observed

Characteristics	Core 15	Core 16	Core 17	Core 18	Core 19	Core 20
	Loudoun #4223	Loudoun #4242	Ashburn #5005	Ashburn #5114	Ashburn #5200	Ashburn #5404
Cracking	None observed	None observed	None observed	None observed	A few fine cracks or hairline cracks extend to depth of 0.3 in. from outer surface; likely shrinkage-related	A few fine cracks or hairline cracks extend to depth of 0.5 in. from outer surface region, likely shrinkage-related
Coarse Aggregate[1]	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks	Dark gray-black crushed carbonate rocks
Fine Aggregate[2]	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand	Siliceous sand
Estimated Air Content	3 to 5%	1 to 3%	1 to 3%	2 to 4%	2 to 4%	2 to 4%
Paste Physical Properties	Moderately hard with moderately high water absorbency	Moderately hard to hard with low water absorbency	Hard with low water absorbency	Hard with low water absorbency	Moderately hard to hard with low water absorbency	Moderately hard to hard with low water absorbency
Estimated w/c[3]	Moderate to moderately high (0.50 to 0.60)	Moderately low (0.35 to 0.45)	Moderately low (0.35 to 0.45)	Moderately low (0.35 to 0.45)	Moderately low (0.35 to 0.45)	Moderately low (0.35 to 0.45)
Depth of Carbonation	0.08 to 0.16 in.	0.06 to 0.1 in.	Approximately 0.04 in.	0.12 to locally 0.24 in.	0.08 to 0.12 in.	0.06 to 0.1 in.
Evidence of Deleterious ASR	None observed	None observed	None observed	None observed	None observed	None observed

1. Thin-section examination reveals the presence of small amounts of microcrystalline quartz and strained quartz in the limestone coarse aggregate.
2. The fine aggregate contains small amounts of quartzite and chert. Thin-section examination reveals that some quartzite particles are highly strained.
3. Estimated water-cement ratio based on the observed physical and microscopical paste properties.

Legend

Core Samples evaluated by DRP 8/3/2018

SSI FINDING: Issues that led to the issuance of NCR 0878 were corrected, but the wide variation of w/cm reported by DRP and CTL leads SSI to conclude that UCP did not consistently produce precast panels with the required w/cm ratio – maximum allowable under the specifications 0.45. Absent remediation, the higher w/cm reported for many of the concrete core samples will negatively impact the durability of the precast concrete panels.

8.4 Reinforcing Cover

While evaluating the w/cm ratio issue for precast units manufactured by UCP, it was discovered that several of the panels had insufficient cover over the reinforcing. NCR 0946 dated 6/5/2017 provides the first indication that reinforcing cover is less than the 1.5 inches shown on the structural drawings. It was eventually determined through use of an analysis by TCG, dated August 11, 2017, using STADIUM Modeling Software that a minimum cover of 0.75 inches would provide a 100-year-service life after proper application and maintenance of a silane sealer. NCR 0946 was voided and NCR's were issued for individual panels. The first of these was NCR 1059 dated 09/20/2017.

CRC, in a letter dated 12/22/2017, identified sixty (60) precast panels as being rejected and replaced because of reinforcing being less than 0.75 inches from the surface. This is confirmed by the closure correspondence for NCR 0946, which lists sixty-five (65) panels as failing to meet the minimum cover requirements of 0.75 inches. CRC requested that five (5) of the sixty-five (65) panels (2556, 2558, 3033, 3034, and 3035) "be left 'as-is' as the location of the panel is considered to be in the interior of the building and not exposed to the elements."

The reduction in reinforcing cover from 1-1/2 inches to 3/4 inches is one of the more troubling of the deficiencies identified in the precast panels. The proposed resolution for this deficiency as proposed by CRC is the proper application and maintenance of a silane sealer. This solution works well so long as there are no active cracks in the concrete that will allow a path for moisture to reach the reinforcing. It is unfortunate that a total absence of active cracks in the hundreds of panels fabricated by UCP is unlikely. Where those cracks intersect or coincide with reinforcing, exposure of some part of the reinforcing to chlorides and eventual corrosion is a likely result.

SSI also finds a portion of the warranty language provided by Evonik in their Technical Service Report dated October 14, 2019 to be troubling. The document – reproduced in part below - apparently used the original design documents which require a concrete cover of 1.5 inches, to develop the warranty language. As discussed previously in this section, a cover of 0.75 inches is prevalent throughout the project. Our research confirms that a value of 250 parts per million of chloride is an acceptable and appropriate value for the warranty. It is SSI's opinion, however, that the warranty should limit that level of chloride to the actual depth of reinforcing, which in the case of this project is 0.75 inches.

> **TREATED AREA(S): 155,000 sq. ft. / architectural precast at the following five (5) Silver Line Metro Stations in Fairfax and Loudoun Counties of Virginia: Reston Town Center, Herndon, Innovation Center, Loudoun Gateway, and Ashburn. (Summary spreadsheet attached.)**
>
> will maintain for a period of twenty (20) years from the date of application the treated concrete surfaces in such state that these surfaces will not absorb more than 250 parts per million of chloride at the 1¼ to 1¾ inches from the exposed exterior surface, nor absorb more than 1% water by mass of concrete over the established baselines. Evonik also agrees that steel reinforcement will not exhibit a corrosion current of more than 5.0 $\mu A/cm^2$ (58 um per year of cross-sectional steel loss) as determined by galvanostatic pulse technique equipment. If it is determined that there are areas with corrosion rates above the specified limit during the limited warranty period, Evonik will provide sufficient **Protectosil® CIT** to lower the corrosion current below 5.0 $\mu A/cm^2$ as well as cover the labor costs to apply it.

The most troubling aspect of the warranty is that it does not cover the condition that SSI believes is most likely to present maintenance issues for the panels – that of water penetration facilitated by cracks. The warranty does not cover improper application and several other conditions, as noted in the excerpt below:

> This warranty does not cover any loss of water repellent effect due to improper surface preparation, improper application, the improper use of PRODUCT, structural defects or movement, water penetration caused by cracks or joint areas requiring caulking, sealants or repointing, failure of the building, any damage to the building or contents thereof, any leakage due to mechanical damage or abuse, or any leaks or damages arising out of any improper architectural or engineering specifications relied upon or submitted to Evonik.

It is our understanding that EVONIK did not have full-time representation on the job site during application of the Protectosil® CIT. Our experience has been that disagreements about "improper application" are best addressed by requiring full-time observation by the manufacturer. Because the precast wall faces are vertical, the faces are not susceptible to ponding. This will reduce the potential for penetration of water into the panels. It can also be stated that the frequency of wetting – particularly for the panels exposed to repetitive road spray – will increase the potential for penetration of water into the panels.

Regarding cracks, the EVONIK product literature for Protectosil® CIT points to some ability of the product to protect cracked concrete. An excerpt from the manufacturer's technical data sheet for Protectosil® CIT, which can be found at the link shown below, points to significant corrosion protection for cracked concrete versus a control specimen.

https://www.protectosil.com/sites/lists/re/documentssl/protectosil-cit-tds-us.pdf

PERFORMANCE DATA
Cracked Concrete Beam Test (adapted from ASTM G109): **Protectosil CIT** reduces the corrosion rate by 90% versus the control specimen after 1 year.

The technical data sheet, in a section on concrete repairs, states that "Shallow cracks that are dormant, shallow in depth and lacking structural significance can be treated with a multiple-coat application of Protectosil® CIT. Other cracks should be routed, treated with Protectosil® CIT and then sealed with an appropriate sealant." This portion of the technical data sheet is reproduced below for reference purposes:

CONCRETE REPAIRS
All delaminated, loose or spalled concrete must be removed and repaired. Shrinkage cracks that are dormant, shallow in depth and lacking structural significance can be treated with a multiple-coat application of **Protectosil CIT**. Other cracks should be routed, treated with **Protectosil CIT** and then sealed with a suitable sealant. **Protectosil CIT** does not affect the adhesion of most sealants to concrete or that of concrete to rebar. **Protectosil CIT** may be applied directly to the cleaned rebar prior to placing repair material.

In other Protectosil® CIT literature, EVONIK points to additional testing of cracked concrete. In that document, EVONIK identifies the width of cracks in the concrete being tested as 0.015 inches. Excerpts of that document, which can be found at the link below, are provided for reference purposes:

https://www.protectosil.com/sites/lists/RE/DocumentsSL/Protectosil-CIT-US.pdf

Lab Study: FHWA Corrosion Performance Tests on Cracked Concrete

The effectiveness of Protectosil® CIT and other corrosion inhibitors was documented using the rigorous FHWA RD-98-153 protocol. To measure the inhibitor's ability to reduce corrosion resistance, the protocol spanned two years and consisted of weekly salt water ponding on reinforced concrete specimens with transverse cracking.

Protectosil® CIT was applied to the surface of cracked concrete specimens and after 48 wet dry cycles, the results demonstrated that Protectosil® CIT ranked exceptionally high in the test over competitors and was 99% effective in preventing corrosion.

Properties	Protectosil® CIT	Amino alcohol/carboxyl based	Silicate based
Typical Active Content	100%	30% to 35%	10% to 15%
Low Viscosity, Low Surface Tension (<water)	Yes	No	No
Application Temperature	20°F to 100°F	35°F to 100°F	40°F to 100°F
Chemically Bonds to Substrate	Yes	No	No
Corrosion Reduction via ASTM G109	>90%	0 to 65%	0%
Corrosion Reduced at > 90% RH & 100°F	Yes	No Data	No Data
Corrosion Reduction with 15 mil micro-cracks (FHWA –RD-98-153)	>90%	No Data	No Data
Max. Chloride Ion Content per Cement Weight	4% to 6%	1% to 2%	No Data
Reduces Additional Chloride Penetration	Yes	No	No
Penetrates/Reduces Corrosion in Concrete Previously Treated w/Repellents or Inhibitors	Yes	No	No
Weather Resistant/Water Insoluble	Yes	No	No
Corrosion Based Warranty	Yes	No	No

SSI FINDING: The concrete cover in the concrete panels does not conform to the 1.5-inch requirement of the project specifications. The 0.75 inch cover requirement agreed to for the project does conform to current ACI 318 requirements for plant-precast concrete exposed to an aggressive environment but not with the recommendations found in the ACI 318 commentary. Documentation reviewed by SSI appears to confirm that all panels with concrete cover less than 0.75 inches and which are not located in the interior of the buildings or exposed to the elements have been replaced.

The proximity of reinforcing to the surface of the concrete increases the potential for an intersection of a crack with the reinforcing. In the event a crack intersects the reinforcing, the potential for corrosion increases. SSI's review of the EVONIK literature for Protectosil® CIT leads us to conclude that the product cannot be expected to protect reinforcing exposed to cracks that exceed 0.015 inches in width or are not dormant. Since cracks cannot be dormant if exposed to thermal expansion and contraction, as will be the case for these precast panels, SSI thinks it likely that the corrosion process will occur at some locations during the life of the structure where active or cracks wider than 0.015 inches intersect the reinforcement.

8.5 Chlorides

Damage to concrete and reinforcing caused by chlorides in various forms is well documented in the literature. Alternately wet and dry conditions and concentrated forms of Calcium Chloride can cause disintegration of concrete. In porous or cracked concrete, various forms of chloride attack steel, causing corrosion and eventual spalling of the concrete.

Initial chloride ion testing of the several precast concrete panels was performed by Eastern Testing and Inspection Corporation (ETI). Results of their testing are summarized below:

Cores taken from 22 in-place panels

- ETI Report Date 10/16/2018 – 3 panels (panel number not identified – possibly 1423, 1435, and one other)
- ETI Report Date 2/13/2019 – Innovation Station: 2 panels (1220, 1242)
- ETI Report Date 2/27/2019 – Loudoun Gateway [Route 606] and Ashburn [Route 772] Stations: 7 panels (4523, 4125, 4222, 4305, 5047, 5409, 5112)
- ETI Report Date 3/1/2019 – Ashburn [Route 772] Station: 1 panel (5311)
- ETI Report Date 2/13/2019 – Reston and Herndon: 9 panels (3061, 3055, 3139, 3081, 2615, 2630, 2508, 2540, 2636)

Summary of Chloride Ion Tests per AASHTO T260 by ETI dated April 30, 2019

- Chloride ion concentration (CIC) exceeding 0.025% found in two (2) of twenty-two (22) panels. Results reported for panels matching coring reports above.
- CIC exceeded 0.025% at 1/2 inch and at 1 inch in one panel at Herndon (2636)
- CIC exceeded 0.025% at 1/2 inch in one panel at Reston Town Center (3139)

As reported by ETI and "according to the International Concrete Repair Institute (ICRI) the chloride ion concentration, in the vicinity of the reinforcing steel, sufficient to initiate active corrosion has a threshold value of 1.0 to 1.5 pcy of concrete, or 0.025% when compared by weight of concrete." Using these criteria, the chloride ion concentration in two (2) of the twenty-two (22) panels tested is enough to initiate active corrosion.

Summary of Water Absorption Tests per ASTM D6489 by ETI dated July 26, 2019

- Untreated Specimens
  - 18 core samples reported with less than 1% water absorbed by mass of concrete
  - Mock-Up Wall panels 2556A, 2556B, 2556C
  - Wall panels 1220, 1242, 2508, 2540, 2615, 2630, 2636, 3055, 3061, 3081, 3139, 4125, 4222, 4305, and 4523

Results for 1423, 1435, 5047, 5112, 5311, and 5409 are not presented in this summary. Results for these panels are shown in the Summary Report dated September 23, 2019.

- Treated specimens
  - Applied two (2) coats of sealer (ref. SP0596531)
  - 18 core samples reported with less than 1% water absorbed by mass of concrete
  - Mock-Up Wall panels 2556A, 2556B, 2556C
  - Wall panels 1220, 1242, 2508, 2540, 2615, 2630, 2636, 3055, 3061, 3081, 3139, 4125, 4222, 4305, 4523

Results for 1423, 1435, 5047, 5112, 5311, and 5409 not presented in this summary. Results for these panels are shown in the Summary Report dated September 23, 2019.

Summary of Chloride Ion Content and Water Absorption Tests by ETI dated September 23, 2019

- Reston Town Center, Herndon, Innovation Center, Loudoun Gateway [Route 606], and Ashburn [Route 772])
    - Results for 21 panels (1435, 1423, 1220, 1242, 4523, 4125, 4222, 4305, 5047, 5409, 5112, 5311, 3061, 3055, 3139, 3081, 2615, 2630, 2508, 2540, and 2636)

Results for 1423, 1435, 5047, 5112, 5311, and 5409 are presented in this testing summary. Results for these panels comply with requirements established for both chloride ion and water absorption testing. Chloride ion levels for panels 2636 and 3139 match those in previous reports dated July 26, 2019.

Technical Service Report by EVONIK dated October 14, 2019

- Approximately 1519 total panels coated with Protectosil® CIT
- Fifty-two concrete cores were tested using an ink test
- Six (6) brick panels reported by EVONIK to have passed with two (2) coats [Table 1 of EVONIK report]
- Seven (7) of the fifteen (15) non-brick reported by EVONIK to have passed with two (2) coats [Table 1 of EVONIK report]
- EVONIK reported that eight (8) of the fifteen (15) non-brick panels failed the initial penetration test (2508, 2630, 2636, 2615, 3139, 3061, 3081, and 4125) and received two (2) additional coats [Table 1 & Table 2 of EVONIK report]
- Application technique was modified and two (2) additional coats at 200 sf/gallon for each coat applied to all non-brick panels
- Panel 4125 received a total of 6 coats of Protectosil® CIT [Table 2 of EVONIK report]
- Eight (8) panels that failed initially were retested by EVONIK after application of additional coats [Table 2 of EVONIK report] and passed

The EVONIK document included as an attachment to their October 14, 2019 report a sheet titled “Protectosil® CIT Corrosion Inhibitor FAQ#2: How Deep Can the Reinforcing Steel be for CIT to be Effective?” SSI’s interpretation of the material in this attachment is that the product will protect reinforcing at a depth of up to four times the depth of penetration shown by the Ink Test, which measures the Protectosil® CIT absorbed in the capillary suction phase of the application – not the diffusion phase. EVONIK used this Ink Test – the detection limit of CIT of which is very high – in their report to evaluate the effectiveness of the Protectosil® CIT.

The depth of reinforcing for this project has been established as being at least 0.75 inches (refer to the Reinforcing Cover section of this report for additional information). For the Protectosil® CIT to provide corrosion protection for reinforcing at this depth, the required depth of penetration of the product would be 0.1875 inches (0.75 inches/4).

A review of Table 1 results in the EVONIK report suggests that EVONIK used the average depth of penetration (DOP) to evaluate the effectiveness of the two (2) field-applied coats of Protectosil® CIT. Disregarding three samples that were tested without wax, there is a close correlation between the panels selected for retesting and those with an average penetration of less than one-fourth (1/4) of the 0.75-inch typical reinforcing depth. The outliers are panels 2615 and 2636—1, both of which would appear to have DOP to reach the 0.75-inch depth and panel 4523 which had an average DOP equal to that of panel 2615. Table 1 results are reproduced below for reference purposes:

Table 1: Field Samples Treated with 2 Coats of Protectosil CIT

Panel No.	DOP (LOW)	DOP (HIGH)	AVERAGE	4XCOATMIN	4XCOATAVG	4XCOATMAX	COAT
1220	0.1250	0.3750	0.2500	0.5000	1.0000	1.5000	2
1242	0.1250	0.3750	0.2500	0.5000	1.0000	1.5000	2
1423	0.5000	0.5000	0.5000	2.0000	2.0000	2.0000	2
1435	0.2500	0.3750	0.3125	1.0000	1.2500	1.5000	2
2508-1	0.0625	0.2500	0.1563	0.2500	0.6250	1.0000	2
2540	0.5000	0.5000	0.5000	2.0000	2.0000	2.0000	2
2615	0.1250	0.2500	0.1875	0.5000	0.7500	1.0000	2
2630	0.1250	0.1250	0.1250	0.5000	0.5000	0.5000	2
2636-1	0.1250	0.3750	0.2500	0.5000	1.0000	1.5000	2
3055	0.5000	0.5000	0.5000	2.0000	2.0000	2.0000	2
3061-1	0.0625	0.1250	0.0938	0.2500	0.3750	0.5000	2
3081-1	0.0625	0.1250	0.0938	0.2500	0.3750	0.5000	2
3139-1	0.0625	0.2500	0.1563	0.2500	0.6250	1.0000	2
4125	0.0625	0.2500	0.1563	0.2500	0.6250	1.0000	2
4222	0.5000	0.5000	0.5000	2.0000	2.0000	2.0000	2
4305	0.2500	0.3750	0.3125	1.0000	1.2500	1.5000	2
4523	0.1250	0.2500	0.1875	0.5000	0.7500	1.0000	2
5112	0.2500	0.3125	0.2813	1.0000	1.1250	1.2500	2
5311	0.2500	0.2500	0.2500	1.0000	1.0000	1.0000	2
5047	0.6250	0.6250	0.6250	2.5000	2.5000	2.5000	2
5409	0.1875	0.2500	0.2188	0.7500	0.8750	1.0000	2
2636-2	0.2500	0.5000	0.3750	1.0000	1.5000	2.0000	2
3139-2	0.1250	0.2500	0.1875	0.5000	0.7500	1.0000	2
3061-2	0.0625	0.1250	0.0938	0.2500	0.3750	0.5000	2
2508-2	0.1250	0.1250	0.1250	0.5000	0.5000	0.5000	2
3081-2	0.0625	0.1250	0.0938	0.2500	0.3750	0.5000	2

Panels identified for retesting with 4 coats (Re: Table 2)
Brick Face
No Wax
Values less than depth of reinforcing (0.75 inches)

Using an average DOP of 0.1875 inches as acceptance criteria, Table 2 results in the EVONIK report shows that reinforcing at a depth of 0.75 inches would be protected by the additional two (2) coats of Protectosil® CIT applied using the revised technique. Table 2 results are reproduced below for reference purposes:

Table 2: Two (2) Field-Applied Coats; Additional Coats Using Revised Technique

Panel No.	DOP (LOW)	DOP (HIGH)	AVERAGE	4XCOATMIN	4XCOATAVG	4XCOATMAX	COATS
2508-3	0.1250	0.3750	0.2500	0.5000	1.0000	1.5000	4
2630-2	0.1250	0.2500	0.1875	0.5000	0.7500	1.0000	4
2636-3	0.2500	0.3125	0.2813	1.0000	1.1250	1.2500	4
2615-2	0.2500	0.3125	0.2813	1.0000	1.1250	1.2500	4
3081-3	0.5000	1.0000	0.7500	2.0000	3.0000	4.0000	4
3061-3	0.1250	0.3750	0.2500	0.5000	1.0000	1.5000	4
3139-3	0.1875	0.5000	0.3438	0.7500	1.3750	2.0000	4
4125-2	0.5000	0.7500	0.6250	2.0000	2.5000	3.0000	6

Panels identified for retesting with multiple coats (Re: Table 1)

Values less than depth of reinforcing (0.75 inches)

Table 4 in the EVONIK report is interesting for what it does not appear to show – an increased average DOP with the application of additional coats. These results were produced from Mock-Ups provided by CRC. One would assume these would be an accurate reflection of results that might be anticipated in the field.

Mock-Ups 1, 3, and 4 results are consistent with an expectation that the application of additional coats of Protectosil® CIT will provide a corresponding increase in the average DOP of the product and protection to the reinforcing.

Mock-Up 2 provides some puzzling results. The average DOP for this mock-up decreases with the application of additional coats – 0.9167 inches for 3 coats, 0.7917 inches for 4 coats, and 0.5417 inches for 5 coats. Table 4 results are reproduced below for reference purposes:

Table 4: Cores from Three Different Mock-Up Panels

Mock-Up	Location	DOP (LOW)	DOP (HIGH)	AVERAGE	4XCOATMIN	4XCOATAVG	4XCOATMAX	MOCKUPCOATAVG	COATS
1	A-T	0.0000	0.0625	0.0313	0.0000	0.1250	0.2500		1
1	B-T	0.0625	0.1250	0.0938	0.2500	0.3750	0.5000	0.2083	1
1	C-T	0.0000	0.0625	0.0313	0.0000	0.1250	0.2500		1
2	LT	0.0625	0.1250	0.0938	0.2500	0.3750	0.5000		3
2	LC	0.1250	0.3125	0.2188	0.5000	0.8750	1.2500	0.9167	3
2	LB	0.2500	0.5000	0.3750	1.0000	1.5000	2.0000		3
2	CT	0.1250	0.1875	0.1563	0.5000	0.6250	0.7500		4
2	CC	0.1250	0.2500	0.1875	0.5000	0.7500	1.0000	0.7917	4
2	CB	0.1875	0.3125	0.2500	0.7500	1.0000	1.2500		4
2	RT	0.1250	0.1875	0.1563	0.5000	0.6250	0.7500		5
2	RC	0.1250	0.1875	0.1563	0.5000	0.6250	0.7500	0.5417	5
2	RB	0.0625	0.1250	0.0938	0.2500	0.3750	0.5000		5
3	A	0.1250	0.2500	0.1875	0.5000	0.7500	1.0000		2L
3	B	0.0625	0.1875	0.1250	0.2500	0.5000	0.7500	0.6250	2L
3	C	0.0625	0.2500	0.1563	0.2500	0.6250	1.0000		2L
4	A	0.0625	0.1875	0.1250	0.2500	0.5000	0.7500		2
4	B	0.0625	0.1875	0.1250	0.2500	0.5000	0.7500	0.5000	2
4	C	0.0625	0.1875	0.1250	0.2500	0.5000	0.7500		2

Values less than depth of reinforcing (0.75 inches)

Concerns about the potential for corrosion of reinforcing in the precast panels over the service life of the project led CRC to install galvanostatic pulse testing stations in 21 panels as a means of quickly and non-destructively determining if corrosion were active at those locations. The panels were selected by CRC as being those they felt were most vulnerable to corrosive attack. Specific panels in which the test stations were installed were as follow:

Reston	3055, 3061, 3081, and 3139
Herndon	2615, 2630, 2636, 2540, and 2508
Innovation	1220, 1242, 1423, and 1435
Loudoun Gateway	4125, 4305, 4222, and 4523
Ashburn	5409, 5311, 5047, and 5112

Concerns about the efficacy of galvanostatic pulse testing of 21 panels as a means of identifying the corrosion, potential or actual, of all exposed precast panels led to multiple separate visual crack inspections of all accessible precast panels, first by UCP/CRC and later by MWAA and a more comprehensive effort by CRC. Each of these surveys produced different results, so WMATA commissioned its own crack survey, which was performed by DeSimone.

On April 15, 2020, MWAA published a crack survey of precast panels at Reston (N07), Herndon (N08), Innovation (N09), Loudoun Gateway (N11), and Ashburn (N12) Stations. On June 2, 2020, results of a more thorough crack survey executed by DeSimone Consulting Engineers (DeSimone) at the request of WMATA were transmitted to SSI for our review. In response to NCR-1594, UCP and CRC jointly inspected panels at the 5 stations and reported the results on June 9, 2020.

Results of the DeSimone crack survey is shown below:

Station Name	Number Of Panels	Total Cracked	% with Cracks	Cracks ≥ 0.005 in	% ≥ 0.005 in	Total Number of Cracks
Ashburn Station						57
Completed	326	35	10.74	34	10.43	
Partial	18	0				
Loudoun Gateway Station						49
Completed	224	30	13.4	27	12	
Partial	17	0				
Innovation Station						54
Completed	257	31	12.06	24	9.33	
Partial	14	1	7.14	1	7.14	
Herndon Station						121
Complete	366	53	14.48	36	9.84	
Partial	39	0				
Reston Town Center						61
Complete	327	34	10.4	24	7.3	
Partial	15	0				
Total Panels Inspected	**1603**					
Total Panels Cracked		**184**				
Percentage of Panels Cracked			**11.48**			
Total Number of cracks ≥ 0.0005 inches				**146**		
Percentage of cracks ≥ 0.0005 inches					**9.11**	
Total Number of Cracks						342

The results reported by DeSimone are detailed and comprehensive. The report identified 184 panels with cracks. However, when evaluating the panels and developing its baseline for future visual surveys, WMATA should review and evaluate the UCP, MWAA, and CRC's crack surveys as well.

On February 24, 2020, CRC submitted a proposed procedure for repair of cracks in the precast panels where required by project specifications. The submittal included product data and daily reports for a mockup of the repair dated 1/28/2020 and 1/30/2020 in which the repair procedure and products were described. The submittal was approved with no exceptions taken by Dewberry on 3/6/2020.

SSI FINDING: The baseline chloride ion level in a portion of the concrete panels at the depth of reinforcing is enough to initiate active corrosion. In the event a crack intersects or coincides with the reinforcing in one of these panels in conjunction with the availability of moisture, potential for corrosion increases. SSI concludes it is likely the corrosion process will occur at some locations during the life of the structure where active cracks intersect or coincide with the reinforcement in the panel face.

The potential for corrosion also exists at precast panels with baseline chloride levels that are below the level necessary to initiate active corrosion. The combination of an active crack or a crack wider than 0.015 inches and exposure to road spray would likely add to the existing baseline chloride level and thus raise the chloride ion level at the depth of the reinforcing enough to initiate active corrosion.

Galvanostatic pulse testing of 21 panels as a means of identifying the corrosion, potential or actual, of all exposed precast panels does not provide sufficient information regarding possible corrosion in the panels. Periodic visual inspections of accessible panels provide the most reliable information concerning the state of corrosion, if any, in the precast panels.

8.6 Precast Remediation Escrow

As discussed in the RECOMMENDATIONS section of this report, if the panels are accepted, SSI's recommendation is that WMATA accept the CRC proposal to properly apply and maintain a silane sealer to each of the exposed precast panels. This solution is neither permanent nor perfect. Properly applied and maintained, the sealer will prevent moisture from saturating the precast panel in a freeze-thaw/corrosive environment and allow the concrete to achieve its design life at locations where the concrete is not cracked. At active cracks or those wider than 0.015", the sealer is not effective.

SSI's concludes Protectosil® CIT cannot be expected to protect reinforcing exposed to cracks that exceed 0.015 inches in width or are not dormant. Since these precast panels and any existing cracks in the panels will be exposed to ambient conditions, movement of the cracks in response to thermal swings is to be anticipated and the potential for corrosion increases. It would be prudent to conduct a visual inspection of the panels at regular intervals during the life of the structure to identify the presence of corrosion so repairs can be implemented prior to the occurrence of serious damage to the concrete or the reinforcing.

A periodic reapplication of the sealer will be required to maintain the effectiveness of the Protectosil® CIT. The span between reapplication dates and the cost of reapplications in the future are unknown, but a reapplication at least every twenty (20) years is required to maintain the warranty.

SSI has reviewed the initial CRC Precast Remediation Proposal dated December 22, 2017 and the subsequent exchanges between CRC, MWAA, and occasionally WMATA, regarding the sinking fund. [redacted]

SSI FINDING: The initial CRC proposal and all subsequent communications are based on the cost of the original sealer application of two coats of product. Since testing by EVONIK has shown that a minimum of four coats of Protectosil® CIT are required to protect reinforcing at locations where there are no cracks, it would appear to SSI that the use of the original cost as a basis for calculations is flawed.

As previously discussed, the use of the silane sealer on this project is not a perfect solution. Protectosil® CIT, according to EVONIK, cannot be counted on to protect reinforcing at active cracks or at cracks wider than 0.015 inches in width. For reference purposes, a credit card is typically about 0.025 inches thick. The CRC proposal does not appear to anticipate the cost of regular visual inspections to identify and remediate panels that have begun to corrode. It also does not include the cost of remediation in the event corrosion is identified.

9.0 UNIVERSAL CONCRETE PRODUCTS (UCP) QUALITY CONTROL (QC) PROCEDURES

The following description of UCP QC Oversight, dated February 23, 2017, was provided to SSI for our use in evaluating the evolution of the UCP QC program after identification of the issues that led to development of this report:

Dulles Corridor Metrorail Project Joint Venture Capital Rail Constructors (CRC) has responsibility for the implementation of the Quality Management Plan on the project.

- *Construction Quality Control Manager oversees personnel who perform tests, inspections, and other needed procedures.*
- *Construction Quality Assurance Manager is responsible for subcontractor quality plans, performing audits of CRC processes, and performing audits of subcontractor facilities and QC functions.*

MWAA QA is tasked with ensuring that project work conforms to established procedures, contract quality requirements and industry standards.

- *Project Quality Assurance Manager works with the Airports Authority staff and CRC to ensure appropriate coordination, communication, and documentation to deliver the project in compliance with contract requirements.*

Universal Concrete's laboratory was audited by CRC's QA twice in 2015; 8/20/15 and 10/16/15. Both audits' findings related to not following published procedures/check lists and failure to maintain certifications and calibrations for people and equipment.

A joint CRC/MWAA QA audit, 3/29/16, looked at the laboratory and plant operations. Findings highlighted continued problems of not following procedures and MWAA issued <u>five</u> Corrective Action Requests (CAR).

- *Universal hired a new plant QC manager.*
- *Changed methods of securing embeds.*
- *Conducted additional training.*
- *CRC added a QC manager at the plant.*

MWAA's QA relies on CRC's QC program for <u>day to day oversight of Universal Concrete's</u> production of precast. The incident of low strength (5490 psi vice 6000 psi) beams being delivered and installed at Reston Station is a result of Universal not adhering to procedures, switching to an unaccredited laboratory in late summer of 2016, and on-site CRC QC personnel being unaware.

- *8/1/16 to 10/1/16- technicians broke 1 cylinder vice standard 3 per beam to verify strength.*
- *Beams where installed before CRC Ops & CRC Quality checked 28-day test results.*
- *Coring of beams is ongoing to determine path forward.*

It is reasonable to note that the complexity of the member geometry and associated detailing of embeds and other elements of the precast elements at the Silver Line (Phase II) extension surpasses any which SSI has previously encountered. The complexity of the fabrication process alone would be enough to result in the issuance of a certain number of NCR's. By SSI's estimation, however NCR's were issued for approximately 15% of all the precast elements produced by UCP. Potential sources of these errors would appear to be either flawed fabrication drawings or flawed execution. SSI's review of the NCR Log failed to identify which of these potential sources was more prevalent. SSI is not aware of any QC measures that may have been implemented by UCP to assure that the fabrication drawings were without error.

The QC records associated with fabrication of precast panels produced by UCP were provided to SSI for review. It would appear, from the records submitted, that the QC records for the precast pieces are either incomplete or inconsistent. As an example, SSI finds two types of fabrication checklists among the documents submitted – one for pre-placement inspection (Specification 03 45 00, Paragraph 1.03A.8) and another for the finished piece (Specification 03 45 00, Paragraph 1.03A.8). One of each type form should be a part of the QC record for each piece, but there are numerous instances in which one of the forms - generally the pre-pour inspection form is not included in the material submitted for review.

Regarding the pre-pour inspection forms that were submitted, SSI notes that the reinforcing steel segment of the form consistently states the reinforcing steel was of the proper size, spacing, and had proper coverage. Some of the forms note that problems with coverage were "fixed", but do not provide specific information about the "fix". Given the ferro scan results that were ultimately produced for each of the precast panels, one must conclude that the information provided in that part of the forms is questionable or that the reinforcing consistently shifted during concrete placement operations. Examination of occasional accompanying photographs taken prior to concrete placement appears to suggest the occasional problem with clearance or coverage of reinforcing, but it is possible the photographs were taken prior to final corrections and in advance of concrete placement.

Document packages submitted by UCP for each of the stations varied in content. The records typically include most of the following for each precast panel:

- Concrete mix design and compressive strength test results.
- Property Test Report Form (ASTM C39).
- Pre-Pour Inspection Checklist. Items on the form include inspection of various aspects of formwork, embeds, electrical, blockouts, reinforcing steel, lifting devices, and finishing.
- Precast piece-mark shop drawings showing panel geometry, reinforcing, embeds, and finish. Plan and section views of each of the pieces, with highlights of items checked along with notes of any corrections required. A portion of these shop drawings contained an additional note in Red Print alerting the fabricator that a minimum coverage of 1.5" is required on all mesh and rebar.
- Photographs were occasionally attached to illustrate the notes made during inspection of the members.

Following identification of the previously-noted quality issues associated with precast panels produced by UCP, modifications in the production process were implemented by UCP, CRC, and MWAA and identified in an email from the QA/QC Program Manager for MWAA for the Dulles Corridor Metrorail Project on February 23, 2017. Responses by MWAA to WMATA provided in this email are reproduced in part below and provide the basis for SSI's findings [some content paraphrased by SSI to improve readability and to clarify SSI's interpretation of the content]:

In response to a query regarding steps CRC and MWAA took to determine that the precast products being delivered met specification requirements, MWAA provided the following:

- CRC hired an extra person to QA team to be on site full time at UCP.
- Audit and Surveillance activities were intensified.
- MWAA QA Specialists assured through on-site observations that the contractor [UCP] complied with specification requirements.

If one assumes the purpose of increased scrutiny during production of the precast panels was to reduce the number of NCR's, then one could arguably conclude that the effort failed. The earliest date for an NCR regarding precast panels fabricated by UCP is January 29, 2016 (NCR-0300); the latest date for a UCP NCR is March 15, 2019 (NCR-1535 & NCR-1536). The February 23, 2017 date falls about 1/3 of the way through the time period and 1/4 of the way through the total number of NCR's relating to work by UCP. As noted previously in this report, it was later in 2017 that the issue with reduced cover over the reinforcing came to light – not as a result of increased scrutiny during fabrication, but rather as a consequence of the w/cm evaluation initiated by NCR-0878 (April 12, 2017).

SSI FINDING: The measures taken by UCP, CRC, and MWAA to improve the quality of the precast panels fabricated by UCP after the February 23, 2017 email referenced in this report were generally ineffective. The increased scrutiny provided by one additional full-time QA person at the job site failed to reduce the frequency of NCR's or impact in any significant way the types of fabrication drawing/production errors that were experienced prior to that date.

SSI is not aware of any QC measures implemented by UCP to assure that the fabrication drawings were without error. The NCR's reviewed by SSI point only to the defect in various panels and not to causation. Misplaced embeds, for example, might be misplaced because the drawings were not properly coordinated or because of failure on the part of UCP to accurately fabricate the pieces. The disconnect between the reinforcing information on the pre-pour inspection checklists provided to SSI and the results of the ferro scans of each panel suggest that that part of the checklist did not receive proper scrutiny.

10.0 REVIEW OF NON-CONFORMANCE REPORTS, (NCR) ISSUES REQUIRING RESOLUTION (IRR), DEFICIENCY REPORTS (DR) AND CORRECTIVE ACTION REPORTS (CAR)

SSI's review of various reports regarding issues addressed in this report revealed the following:

Non-Conformance Reports

A total of 276 NCR's has been issued with respect to UCP's work on the precast panels. As of the writing of this report, 261 have been officially closed. Disposition of the closed NCR's is as follows:

Use As Is	39
Repair	169
Rework	4
Scrap	26
Void	23
Total	**261**

Of the remaining 15 NCR's, disposition as of the writing of this report is as follows:

Closed Awaiting final Posting	4
Submitted	8
EOR For Evaluated, REV1	1
EOR For Evaluated, REV2	1
Rebar As-Builts	1
Total	**15**

Of the 276 NCR's that pertain to work by UCP, 48 deal with the issues addressed in this report and are attached as Appendix A. The distribution is as follows:

Low Air Content	0
High Water-Cement (w/cm) Ratio	1
Reinforcing Proximity to Surface	46
Alkali-Silica Reactivity (ASR)	1
Chlorides	0

Issues Requiring Resolution

There are no IRR's related to work by UCP as of the date of this report.

Deficiency Reports

There are no DR's related to work by UCP as of the date of this report.

Corrective Action Reports

A total of 13 CAR's – All Closed, were issued relative to work by UCP.

SSI FINDING: All NCR's regarding issues addressed in this report have been closed or are in the process of being closed. SSI found no IRR's or DR's related to work performed by UCP. All CAR's regarding issues addressed in this report have been closed.

11.0 PRECAST WALL PANELS AT DULLES YARD

Cracking in precast panels for various rail yard building structures was raised as an Issue Requiring Resolution (IRR) HP-051-18 dated August 10, 2018. Hensel Phelps was directed to evaluate the cracks, to include monitoring of any progression and determine the root cause of the cracks. The results of the analysis were to be submitted to the Airports Authority for review and acceptance prior to implementation of any mitigation or repair.

Taken from the Package B Precast Concrete Wall Panel Investigation dated November 7, 2018:

> *The precast wall panels at the Dulles Yard were "designed, fabricated and furnished to the Project as a part of Package B by Shockey Precast Group. Project staff observed and recorded numerous cracks at the exterior surface of the subject wall panels in the late spring of 2018, and in August 2018 tasked Dulles Rail Consultants (DRC) with identifying the cause of the cracks in the wall panels and identifying appropriate remedial measures." (Page 1)*
>
> *"DRC noted that very similar cracks had been observed at the Warehouse Building (WHB), Service and Inspection Building (SIB), Transportation Police Building (TBP), and Train Wash Facility (TWF) with the most extensive cracking observed at the SIB. In general, most of the cracks that had been observed [were] vertical, or nearly vertical, cracks visible at the exterior surface of the panel, extending up from the base of the panels." (Page 2)*
>
> *"DRC engaged the CTL Group to perform Ground Penetrating Radar scanning of wall panels exhibiting vertical, or nearly vertical, cracks originating at the bottom of the panel, and for panels exhibit[ing] a pattern of horizontal and vertical cracks…CTL has indicated that the observed cracking does not appear to be based on missing or misplaced reinforcing, or, deviations of panel thickness." (Page 3)*

"…it appears that most of the cracks in the insulated precast concrete wall panels are a result of the panel connections to the foundation restraining the thermal and concrete shrinkage movement of the panels….potential options for remediation of the cracks were…discussed…including routing the cracks and installation of a sealant; however, this option would have a negative impact on the appearance of the panels and would require periodic replacement. Another option discussed was the application of a clear breathable, penetrating sealer to all of the panel surfaces. This material would prevent moisture from penetrating the narrow cracks. This material would also need to be periodically reapplied." (Page 4)

"…consideration should be given to requiring the Shockey Group to reevaluate the precast concrete panel connection system and remediate the connections and mitigate the restraint. This should be beneficial in reducing the potential for additional cracks and for reducing the lengthening of existing cracks." (Page 4)

Taken from the Hensel Phelps Correspondence Number HP_P2B_1400 dated January 31, 2019:

"In letter MWAA-P2B-04776, the Airports Authority requested that Shockey 're-evaluate the precast concrete panel connection system, remediate the connections and mitigate the restraint.' Shockey Precast has completed the exercise requested and the result of that report, reviewed with the Engineer of Record, is that 'due to the heavy load demands on the wall groups and severe access constraints, the repairs would be limited in scope with questionable efficacy.'

Based on this assessment, it is the design-builders recommendation that the clear exterior application of Sikagard 670w protective coating as advised by the precast subcontractor's engineer in previous correspondence."

Product literature for Sikagard 670W indicates that it is not to be used over moving cracks. Since the cracks that have formed in the precast panels at the Dulles Yard will be subject to thermal movements, this product is not appropriate for the proposed application.

The most recent correspondence – an email from Joselito Dela Vega, PE, with the Dulles Corridor Metrorail Project – indicates that the product now under consideration is Sikagard 550W, but the IRR has not yet been closed because they are waiting for the results of a life cycle analysis by HP to confirm the frequency of re-application.

Adhesion tests by Sika on sample areas confirm the product will adhere successfully with, or without, the use of a primer. The product data sheet for Sikagard 550W indicates it is suitable for bridging cracks, so functionally it would be an appropriate product for the application.

Aside from the necessary frequency of re-application, which should be provided by the HP analysis, the primary question which must be answered is the extents of the application. The product data sheet states that the product comes in 469 standard colors and that color matching is available. It would appear, since the cracks are located at the base of the panels, that the coating might not be required for the entire panel surface.

SSI FINDING: The cracks in the precast panels at the Dulles Yard are consistent with restraint of movement of the concrete in response to thermal and normal drying shrinkage. Cracks of this type are of no structural consequence but do provide a means of egress for moisture in the panels. The prevention of moisture entering the panels will mitigate the possibility of corrosion of the panel reinforcing at some point in the future.

12.0 RECOMMENDATIONS

If the panels are accepted, SSI's recommendation is that WMATA accept the CRC proposal to properly apply and maintain a silane sealer to each of the exposed precast panels. Properly applied and maintained, the sealer will prevent moisture from saturating the precast panel between active cracks in a freeze-thaw environment, mitigate the potential for corrosion, and allow the concrete to achieve its design life.

This recommendation is supported by the analysis performed by Tourney Consulting Group (TCG) in their report dated 8/24/2017. TCG used STADIUM Modeling Software to evaluate the likely impact of low air content and worst-case w/cm on the 100-year-service life of the project.

The availability of moisture is necessary for the expansion associated with ASR to occur. If the panels are accepted, SSI's recommendation to accept the CRC proposal to properly apply and maintain a silane sealer to each of the exposed precast panels will prevent the necessary moisture from reaching the aggregate and allow the precast panel to achieve its design life.

Assuming cracks wider than 0.005" in the DeSimone and CRC reports have been repaired, SSI recommends periodic visual inspections of each of the stations to identify rust-staining of the concrete, which is a precursor to physical damage because of corrosive expansion of the reinforcing. Visual observations of accessible panels in each station should be made using the current DeSimone reports as a basis. The first inspection should take place a year following completion of crack repairs, with following intervals determined by observations made during the first post-crack repair inspection. Assuming little or no evidence of corrosion during the first post-crack repair inspection, subsequent intervals of 3-to-5 years between inspections will allow identification and remediation of any problem areas during the life of the structure.

If the panels are accepted, consider modifying funds in escrow account to accommodate the future cost of additional coats of sealer at each application, the cost of regular visual inspections, and the cost of remediation in the event corrosion is identified. Our review of literature regarding silane sealers is that it is more common to require a reapplication every 5-to-7 years and not the 10 years anticipated in the escrow calculations for this project.

DULLES RAIL YARD (PACKAGE B):

SSI's recommendation is that the design-builder HP proposal to apply Sikagard 550W on the exterior face of the precast panels be accepted. The area to which the protective acrylic coating will be applied, the frequency of reapplication, and cost of reapplication all need to be established prior to final acceptance.