OPTIMIZATION OF ADVANCED CEMENTITIOUS MATERIAL OVERLAYS AND UPGRADES, INCLUDING SHOTCRETE

Quarterly Progress Report
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1. Background and Introduction

Ultra-High strength concrete (UHPC) applications have been studied as one of the many strategies in Accelerated Bridge Construction (ABC). Bridge maintenance procedures can be accelerated with the application of UHPC in specific situations. Deck overlays have been placed over deteriorated and damaged bridge decks for many years in order to extend the deck service life. Application of UHPC has the potential to reduce lane closure time during the repair process if sufficient strength is obtained in a few hours. Typically, a concrete strength of 3000 to 4000 psi is required to open a lane to traffic. UHPC also provides a higher strength for the composite bridge deck section and mitigates additional corrosion by inhibiting penetration of additional chloride ions. Commercial UHPC mixes have been developed that have a lower slump that have been shown to hold cross slopes up to 10% by adding admixtures. This research project addresses the design considerations required for successful application of UHPC as an alternative material for deck overlay and other deck repairs and upgrades including the underside of bridge decks and flexural members such as superstructure girders. This research project will conduct a comprehensive literature review on bridge deck overlays and other upgrade applications; perform material level testing; perform large scale level testing for UHPC bridge deck overlays and upgrading flexural members; and numerical modeling to optimize design parameters.

Recent developments in UHPC mixes have been applied with pneumatic spray applications. Such repair methods may be applicable to horizontal, vertical, inclined, and overhead surfaces.

Significant research has been performed on UHPC and their applications as an overlay and upgrading material. However, as outlined later in this report, there are still a number of important questions and concerns that should be addressed and remain to be studied, in addition to the use of new techniques such as pneumatic spray application to eliminate the use of formwork.

2. Problem Statement

Deterioration of bridge deck and flexural members is a major issue for bridge owners. The primary causes of deck deterioration include vehicle traffic, environmental effects (i.e. freeze-thaw, salt spray), and maintenance practices (snowplows, de-icing chemical treatments). Deterioration is featured by delamination, cracking, corrosion of reinforcing steel, abrasion, scaling, and other mechanisms. Deterioration of the top deck surface is common, but in coastal areas subjected to salt spray, the underside of the deck and superstructure girders may also deteriorate.

One of the recent advances in UHPC application is the development of UHPC applied with pneumatic spray methods. Spraying UHPC to the underside of a bridge deck will save the time and effort of building formwork while providing the strength and corrosion mitigation technique discussed above.

While significant research has been conducted on UHPC and their applications as an overlay and repair material, there are still a number of questions and concerns that should be addressed which include:

1. Determining the section capacity of the composite section between UHPC deck overlay, deck normal strength concrete, and bridge girder.
2. Hydro-blasting/Sandblasting and other methods of removing deteriorated concrete and surface preparation may result in varying thickness of overlay to attain design grades. What is the effect of such variation on the overlay performance?
3. How does the roughness of the interfacial surface between UHPC and normal strength concrete impact moment capacity? What is the optimum interfacial surface roughness?
4. Overlays are typically considered for the top surface of the deck, especially in northern climates where de-icing salts are applied. Deterioration may also be found on the bottom of the deck, particularly in coastal areas where salt-spray occurs. Repair techniques should be developed for the deteriorated bottom face of bridge deck and may include UHPC pneumatically sprayed applications.
5. UHPC mix designs typically contain 2% steel fibers, but some applications have been documented with different percentages. What is the effect of iterating steel fiber content?
6. Fatigue or cyclic loading research is lacking. More data is needed for the cyclic loading behavior on UHPC overlays.
7. The higher tensile capacity of the UHPC may allow the material to be placed over expansion joints on single span or as a link slab at intermediate supports. Covering the joints will reduce the level of maintenance needed for the joint. The advantages of reduced joint maintenance would be beneficial to bridge owners.
8. What are the optimum UHPC design mixes to retain a crowning slope up to 7%?
9. Are the recently developed ABC-UTC non-proprietary UHPC mixtures suitable for bridge deck overlay and underside upgrade of bridge desks?

3. Objectives and Research Approach

The objective of this study is to investigate the various parameters involved in optimizing the design of UHPC overlays and upgrades using pneumatic spray application and to develop design guidelines for UHPC overlays and upgrades. The activities listed below will be directed to this objective.

4. Description of Research Project Tasks

Following are descriptions of tasks as described in the research proposal. Figure 1 shows the proposed flowchart for the project tasks for pneumatic UHPC application.

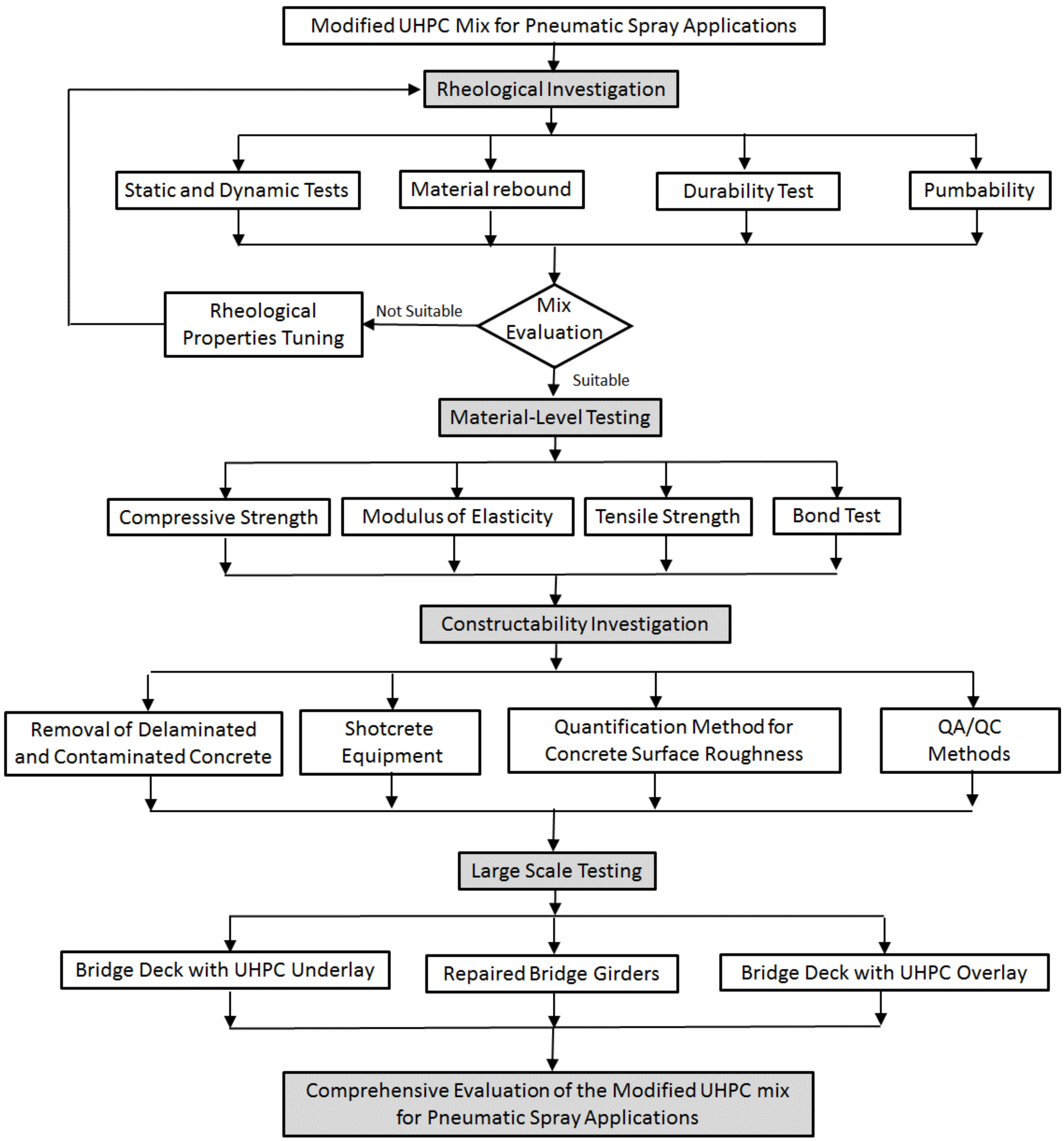


Figure 1. Flow chart of research tasks.

5. Rheology, Material, and Constructability Investigations for UHPC for Pneumatic Application

5.1 Literature Review

In this task, a comprehensive literature review is being conducted. The researchers will continue the review of the development of UHPC deck overlays and upgrades for better understanding of design challenges and issues. The literature review includes the following subject areas:

1. The current design practice of concrete overlays,
2. Material properties of UHPC,
3. Composite action of UHPC and Normal strength concrete, and
4. Pneumatic Spray Application.

The need for cost-effective and durable rehabilitation methods have been documented by many researchers [1-3]. Concrete overlays are classified as bonded or unbonded. Fowler and Trevino [1] points out the primary purpose of an overlay is to extend the life of bridge decks, and that bonded concrete overlays (BCO) have been applied since 1909. Bonded overlays can also improve the frictional surface and increase the durability of the wearing surface. Fowler and Trevino provide a simplified flowchart for developing an overlay in Figure 2.

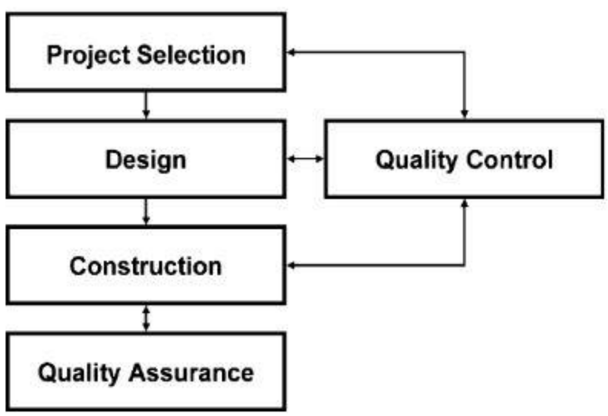


Figure 2. Simplified Flowchart to Develop Overlay (Fowler and Trevino [1])

Bridge overlays typically are placed after concrete removal, in order to limit the increase in dead load which will reduce the live load capacity. Trevino and Fowler also [1] states, "Compatibility between the overlay and original pavement concrete is important, and the coefficient of thermal expansion and modulus of elasticity should be lower than the original concrete if possible." This statement makes sense if overlay and original bridge deck consist of conventional concrete. UHPC is significantly stronger and stiffer than conventional concrete and must be designed with different aspects.

Wibowo and Sritharan [4] presented a study in which an existing bridge was overlaid with UHPC. They noted that bridge deterioration typically begins with cracking in the deck, which then progresses as water and chlorides have an infiltration path, eventually leading to reinforcing steel corrosion. This corrosion can initiate within 4 to 8 years. One of the issues faced by Wibowo and Sritharan was maintaining the cross slope of the UHPC overlay. LafargeHolcim provided a lower slump mix design that held a 2% cross slope in a full-scale bridge application in addition to admixtures which may hold slopes up to 10%. The mix was also placed with a conventional vibratory screed. Wibowo and Sritharan also conducted limited flexural testing on large scale specimens consisting of normal strength concrete with UHPC overlay. Increases in stiffness and ductility were observed, however, the increase in stiffness was attributed to the overall increase in depth. They did not look at a replacement depth of UHPC that would maintain the existing deck thickness. Also, no cyclic testing was performed for this study.

Graybeal, et al., [2] and Haber, et al., [5] studied overlays on existing bridges, with a focus on the tensile strength of the bond between the UHPC and the normal strength concrete. The overlay was placed with a proprietary UHPC mix that had thixotropic properties. Haber [8] indicates that the primary differences between typical UHPC formulations and UHPC mixes that have been formulated for overlay applications are the rheological properties. The overlay formulations are thixotropic in which the UHPC remains solid-like and will flow when agitated or sheared. Typical UHPC formulations will flow freely under gravity.

Caltrans [6] provides design guidance for concrete overlays. This memorandum does not address UHPC, but the general guidelines discuss depth, bonding, live loads, and surface preparation. The memorandum also states that tapering sections should be avoided as they deteriorate quickly.

Several researchers have studied the basic properties of UHPC mixes, including compressive strength, tensile strength, creep, durability among others. Haber et al., [5] presented a table of typical UHPC properties, as shown in Table 1.

Table 1. Typical Properties of Field Cast UHPC Concrete adapted from Haber et al., [8]

Material Characteristic	Average Result
Density	155 lb/ft^3
Compressive Strength (ASTM C39, 28-day strength)	24 ksi
Modulus of Elasticity (ASTM C469, 28-day modulus)	7,000 ksi
Direct Tension cracking strength (uniaxial tension with multiple cracking)	1.2 ksi
Split cylinder cracking strength (ASTM C496)	1.3 ksi
Prism flexural cracking strength (ASTM C1018; 12 in span)	1.3 ksi
Tensile strain capacity before crack localization and fiber debonding	>0.003
Long term creep coefficient (ASTM C512; 11.2 ksi load)	0.78
Long term shrinkage (ASTM C157; initial reading after set)	555 microstrain
Total shrinkage (embedded vibrating wire gage)	790 microstrain
Coefficient of thermal expansion (AASHTO TP60-00)	8.2 x 10^{-6} in/in/^{0}F
Chloride Ion penetrability (ASTM C1202; 28-day test)	360 coulombs
Chloride Ion penetrability (AASHTO T259; 0.5-in depth)	<0.10 lb/yd^3
Scaling resistance (ASTM C672)	No scaling
Abrasion resistance (ASTM C944 2x weight; ground surface)	0.026 oz. lost
Freeze-thaw resistance (ASTM 666A; 600 cycles)	RDM = 99%
Alkali-silica (ASTM C1260; 28-day test)	Innocuous

RDM = Relative dynamic modulus of elasticity; ASTM = American Society of Testing and Materials; AASHTO = American Association of State highway and Transportation Officials.

UHPC overlays are gaining in popularity as a rehabilitation material due to the material properties. These properties include high compressive strength and tensile capacity compared to normal strength concrete, along with lower permeability and low shrinkage. UHPC also has a high early strength that allows for reduced lane closure and construction time. Haber, et al., [7] presented strengths of about 9,000 psi at 2-day.

Current research has shown that UHPC bonds well to normal strength concrete, both in direct tension testing [2, 7] and shear testing [4]. Shrinkage stresses do not appear to be a significant design concern either [3]. UHPC has also been shown to mitigate corrosion activity [8]. Graybeal [2] presented a direct tension test methodology, as illustrated in Figure 3.

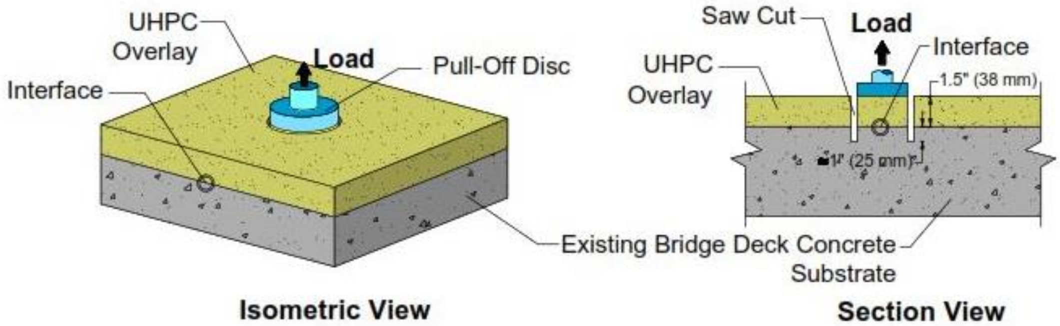


Figure 3. Illustration. Direct tension pull-off bond test based on ASTM C1583 [2].

Bruwiler [9] indicated UHPC exhibits both a tension hardening and a tension softening behavior. This is shown in Figure 4. Elastic behavior extends from point O to point A, followed by hardening from point A to point B. Softening behavior is exhibited as the stress reduces with an increase in the macro crack width. This softening behavior results from pulling the steel fibers out of the cement matrix.

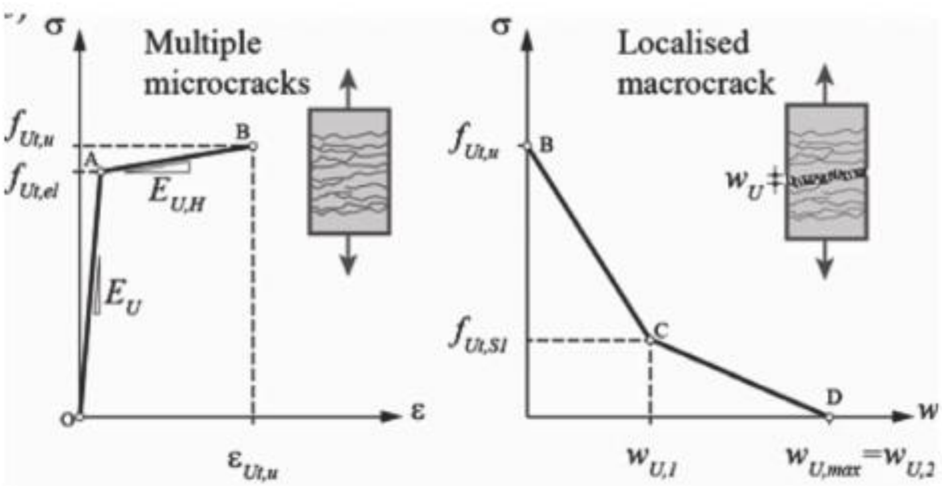


Figure 4. UHPC Tensile Behavior [9].

Al-Basha, et al., [10] performed a series of tension, slant shear and another testing to look at variations in roughness at the bond interface. Some of their results are presented in Table 2. They concluded acceptable bond strengths which can be obtained between UHPC and NSC, but this strength is dependent on the surface roughness.

Table 2. Average direct tensile strengths for different textures [10].

Texture (average texture depth)	Rough (2.8 mm)	Horizontal Grooves (0.9 mm)	Chipped (1 mm)
Average Tensile Strength (MPa)	0.96	0.44	1.06

Only two studies have been identified to date that included cyclic loading [7, 9]. It appears there is a need for more cyclic load data with regard to UHPC overlay and upgrades.

For pneumatic spray application, Kyong-Ku Yun et al. [11] shows that air entraining admixture (AEA) and silica fume are beneficial for both shootability and pumpability and in turn, pumping efficiency, built-up thickness and rebound mitigation. Polymer and viscosity modifying agent (VMA) were found to have negative effects on pumpability because they significantly increased the torque viscosity of wet mix shotcrete (WMS) mixtures. There was no clear relationship between flow resistance and final pump piston pressure. The rebound rate had an almost inverse relationship with the built-up thickness.

For UHPC flowability, Zemei Wu et al. [12] shows that the flowability of UHPC with 1%, 2% and 3% straight fibers, the flowability decreased by 14.9%, 25.6% and 38.1% as compared to the one without fiber. Steel fiber content had little effect on first crack strength and first crack deflection of flexural load-deflection curve of UHPC, but considerable effect on the peak load. When 2% straight, hooked end and corrugated fibers were added, the peak load increased by 46.3%, 81.1% and 61.4% and the peak deflection increased by 76.7%, 153.3% and 123.3%.

Rui Wang et al. [13] The addition of steel fiber decreased the flowability and entrapped air content of fresh UHPC mixtures. To prepare flowable UHPC, a very high dosage for superplasticizer reducing the water to binder ratio will have an adverse effect on strength gain. Adding of 1% steel fiber causes little increases in flexural strength, however, adding 2-3% steel fiber provided a remarkable increase in flexural strength

Kyong-Ku Yun et al. [14] states that upon addition of AEA, both the torque viscosity and flow resistance tended to decrease in a balanced manner. A superplasticizer had a more pronounced effect on the flow resistance rather than torque viscosity.

One of the researchers leading this project has spoken with “shotcrete applicators” and attended typical shotcrete applications. In these discussions, the applicators suggest adding fly ash to the mix design to enhance the flow of the material through the hoses. The application may be possible with a smaller diameter hose, as the UHPC has little aggregate, reducing the amount of waste typically associated with spray applications. These discussions are still preliminary, as is the initial research into how the material should be applied. Ductal provided an Identity Card of Material, which summarized several material properties of spray-applied UHPC, but it does not include details on the mix design or constituents.

5.2 Rheological investigation

Rheological investigations for this project started on various UHPC mixes to assist in evaluating the pneumatic application of UHPC. Critical parameters for ‘shotcrete” are the “pumpability” and “shootability” of the mix.

The pumpability requirements have been described in terms of slump for normal strength concrete. For self-compacting high-performance concrete such as UHPC, a static and dynamic flow test is prescribed by ASTM C1437. The minimum value desired for pumping a high-performance concrete such as UHPC is considered to be 9 in resulted from the dynamic flowability [11].

Shootability of the mix is a quantitative measure of how well the material stays in place after application and includes the concept of material rebound. The existence of a yield stress value seems to provide a good explanation as to why “shotcrete” is shootable [15]. The higher the yield stress, the greater the thickness that can be built up without sloughing. This results in better “shootability”.

Proposed Mix Designs Based on Effects of Mix Composition on Concrete Rheology: W/C Ratio:

The water-cement ratio (W/C) is the most important parameter with respect to the properties of fresh and hardened concrete. An increase in the W/C ratio reduces the plastic viscosity and flow resistance (increasing pumpability). For low W/C ratios, high range water reducer (HRWR) should be used to produce workable or pumpable concrete. A Higher W/C ratio generally lowers compressive strengths which is not desirable in most cases.

HWRW (Superplasticizer):

The effect of superplasticizer is to produce a large reduction of flow resistance and a small reduction of plastic viscosity. They are mainly used for low W/C concretes such as UHPC. Its effect is much greater as compared to other admixtures.

Air Entraining Agents:

Air Entraining agents such as wood resin, salts of fatty acids, and lignosulphonates cause a rapid decrease in flow resistance and plastic viscosity. It has been observed by other researchers that flow resistance can be significantly reduced for air content of up to 10% for normal strength concrete. However, the plastic viscosity only reduces significantly up to 5% air content [15].

Researchers have found that an increase in air content of the “shotcrete” mix will improve pumpability. During the shooting process much of the excess air is expelled, in turn leading to an increase in “shootability”.

So it will be fair to say that in order to reduce the flow resistance and plastic viscosity, an air content from 5-10% should be tested in trial mixes. The strength reduction can be compensated by having lower W/C ratio. Even though UHPC durability can be impacted by air entraining agents, the shotcrete process could help expelling the air content at impact which is advantageous.

Steel Fibers:

Steel fiber content increases both flow resistance and plastic viscosity. If longer fibers are added, only the flow resistance increases. Therefore, increasing the fiber content will reduce the workability of the mix.

The investigations will be performed on the Ductal UHPC premix (JS1000), Fast Set UHPC from Ductal (JS-1212), and ABC-UTC non-proprietary UHPC mix. All three mixtures will be using either steel fiber or synthetic/flexible fibers. The following tests will be performed to assist in this evaluation:

1. Static and dynamic flow tests will be conducted in accordance with ASTM C1437. Flowability of the pneumatically applied mixes are very critical and is a key indicator

of pumpability of the UHPC. This test will be performed on various mixes in order to evaluate the best mix for pumping.

2. Initial and final setting time will be recorded in accordance with the AASHTO T197 test method for penetration resistance. This will be performed on each mix to evaluate how quickly each mix will set.

The mix designs listed in Table 3 will be prepared for rheological investigation.

Table 3. Mix designs for rheological testing

Mix Designation	Basic Mix	W/C Ratio by Weight	Super-plasticizer % by Weight	Fibers % by Weight	Date	Air Content before shotcrete	Air Content after shotcrete	Temp ^{0}F	Test at Time	Flow - Static	Flow - Dynamic	No. of Cylinders
Mix # 1	Ductal Premix Fast Set	MR*	MR	6.2		not adjusted			0 min; 15 min; 30 min			1@ 3 ; 1@ 7; 3 @ 28
Mix # 2	Ductal Premix Fast Set	MR	MR	5.0		not adjusted			0 min; 15 min; 30 min			1@ 3 ; 1@ 7; 3 @ 28
Mix # 3	Ductal Premix Fast Set	MR	MR	7.5		not adjusted			0 min; 15 min; 30 min			1@ 3 ; 1@ 7; 3 @ 28
Mix # 4	Ductal Premix Fast Set	+0.5	MR	6.2		not adjusted			0 min; 15 min; 30 min			1@ 3 ; 1@ 7; 3 @ 28
Mix # 5	Ductal Premix Fast Set	+1.0	MR	6.2		not adjusted			0 min; 15 min; 30 min			1@ 3 ; 1@ 7; 3 @ 28
Mix # 6	Ductal Premix Fast Set	MR	+0.2	6.2		not adjusted			0 min; 15 min; 30 min			1@ 3 ; 1@ 7; 3 @ 28
Mix # 7	Ductal Premix Fast Set	MR	+0.4	6.2		not adjusted			0 min; 15 min; 30 min			1@ 3 ; 1@ 7; 3 @ 28
Mix # 8	Ductal Premix Fast Set	MR	MR	6.2		5%			0 min; 15 min; 30 min			1@ 3 ; 1@ 7; 3 @ 28
Mix # 9	Ductal Premix Fast Set	MR	MR	6.2		10%			0 min; 15 min; 30 min			1@ 3 ; 1@ 7; 3 @ 28
Mix # 10	Ductal Premix Fast Set	MR	MR	6.2-7.5		5-10%			0 min; 15 min; 30 min			1@ 3 ; 1@ 7; 3 @ 28

5.3 Material investigation

In addition to the rheological testing; the following material testing will be performed on the mixes:

1- Compressive strength,
2- Tensile strength,
3- Modulus of elasticity
4- Bond test between UHPC and normal concrete

The results of the rheological tests and material tests will be considered in order to finalize the mixes which will be used for pneumatic application. UHPC cores which will be obtained from a test panel constructed from pneumatic spray application will be obtained. The UHPC cores will also be tested for compressive strength, tensile strength and modulus of elasticity.

Bond strength between the concrete substrate and the modified UHPC mix using pneumatic spray applications will be evaluated through either bi-surface shear or direct tension pull-off bond tests with different concrete surface roughness and UHPC layer thickness. Sandblasting will be one of most important surface preparation methods since the application of upgrading the underside of the existing bridge deck and superstructure elements will require either sandblasting or water-jetting.

5.4 Constructability Investigation:

Pneumatic spray application of UHPC in this project is meant to repair, upgrade or protect bridge elements. Such sub-standard bridge elements usually contain contaminated concrete as well as damaged concrete. When using UHPC, it is not necessary to remove the entire mass of contaminated concrete. Further, there is a need for identifying methods of removing contaminated concrete as well as the effects of various removal methods on properties of finished concrete.

Additionally, there is a need for identifying the equipment needed for pneumatic spray applications using UHPC. It is believed that current spray equipment used for normal strength concrete could be used if flexible synthetic fibers are used.

Based on the discussion provided above, specific objectives related to this category will be as follows:

1- Identifying methods for the removal of contaminated concrete and the effect the removal methods will have on bridge elements, strengthened, upgraded or protected using UHPC in a pneumatic spray application.
2- Identifying the equipment suitable for pneumatic spray application using appropriate UHPC mixtures. The nozzle and hose size should be identified due to the use of fibers. Compressor and pump capacity should be evaluated with respect to the UHPC plastic properties.
3- Establishing methods that could be used in the field to quantify the concrete surface roughness and surface moisture condition to achieve quality finished products. Different applications require different concrete surface roughness. For example, repair application requires rough surfaces with exposed aggregate using sandblasting or water-jetting, however, bridge deck overlay application for new construction requires rough surfaces using puddling.
4- Identifying quality control and quality assurance methods that can be used to assess the quality of finished products.

6. Specimen for UHPC Shotcrete

6.1 Small Scale Specimens

Testing of composite flexural beams will be performed. The testing will iterate various parameters such as thickness of the UHPC overlay and roughness of the concrete interface between the NSC and UHPC. Flexural strength and Modulus of Rupture of normal strength concrete (NSC) Beams with ½-inch and 1-inch of UHPC overlays will be determined experimentally. UHPC application to the beam specimens will be applied conventionally on some specimens and applied with spray application techniques on other specimens. The flexure beams will be instrumented to obtain load-deflection data.

Fabrication of the composite flexure beams continued this period. In the prior period, Normal Strength Concrete (NSC) was placed in 18 beam molds. Conventionally placed UHPC was placed as overlays on 6 of the beams during this period. UHPC cylinders, 4 in. x 8 in., were cast for elastic modulus and compressive strength testing. The casting process is shown in Figure 5 and Figure 6. Two of the beams are full depth normal strength concrete as reference, to determine flexure strength of the normal strength concrete. Two No. 3 reinforcing bars 3 were placed in each beam mold, with approximately 1-inch cover from the bottom. Testing will be conducted on sets of beams with varying roughness profiles on the interface between the NSC and UHPC. UHPC will either be placed with spray application techniques on the remaining 10 flexure beams.

Figure 5. Beam and Cylinder Molds.

Figure 6. Casting Specimens

The roughness profiles were created on an initial set of reference beams. These beams serve as the molds for roughness profiles. Repeatable roughness profiles were created to allow for meaningful correlations of data. Forms were made by applying an elastomeric roofing compound to the initial reference beams, and removing the compound carefully after setting. A series of profile forms, also called skins, were made with this process. The interface roughness will represent:

1. Trowel finish, identified as Profile 1.
2. A trowel finish that was lightly stippled, identified as Profile 2.
3. Puddled surface to represent a typical unformed cold-joint, identified as Profile 3.
4. A puddled surface that was also chipped, identified as Profile 4.

Static load testing will be conducted on beam sections with various UHPC thickness, interfacial surface roughness coefficients, and mix designs as shown in Table 4. Load-deflection data will be obtained. A set of beams will be tested with the UHPC on the upper face, and another set will be testing with the UHPC overlay on the bottom face.

Normal Strength concrete design mix typical for bridge decks was selected. The design 28-day compressive strength is 4,500 psi. Compressive strength and Modulus of Elasticity tests on NSC and UHPC cylinders will be conducted. Results of the compressive strength tests performed on NSC cylinders is shown in Figure 7. Figure 8 shows the cylinder after 7-day compressive strength.

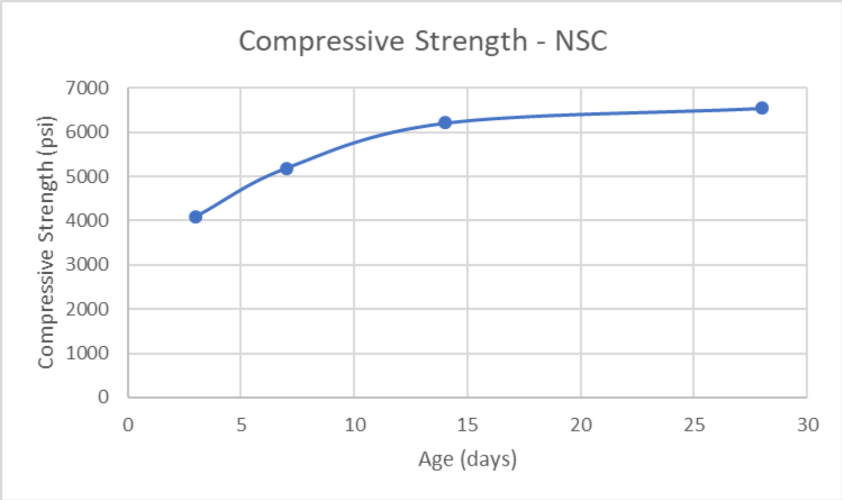
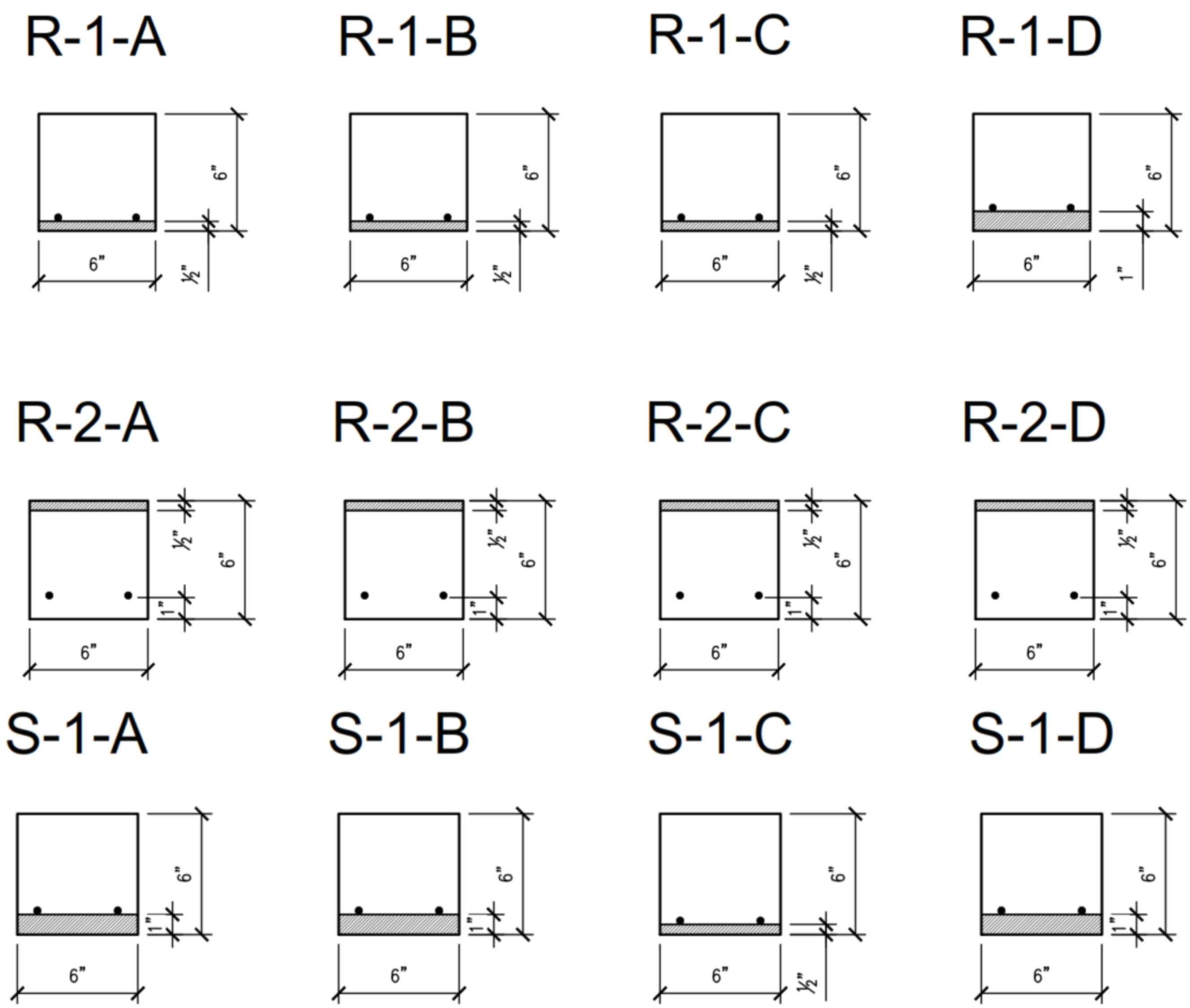


Figure 7. Compressive Strength Test Results, NSC

Figure 8. Compressive Cylinder at 7 days

Figure 9 shows cross sections of the 18 beams. Table 5 summarizes the 'as-built" conditions of the beams and presents the proposed testing program. Figures 10 to Figure 12 shows specimens after removing both roughness skin and molds. When the samples were stripped, sample R-1-C had honeycombs in the concrete. Also, the plywood spacers in the form for sample R-1-B were warped, so that the overlay thickness at the ends of the beam will be about ½ inch, but will be about 1 inch at the center.

UHPC was placed on Beams R-2A, R-2-B, S-1-D, S-2-B, S020C, and S-2-D on October 11, 2019.



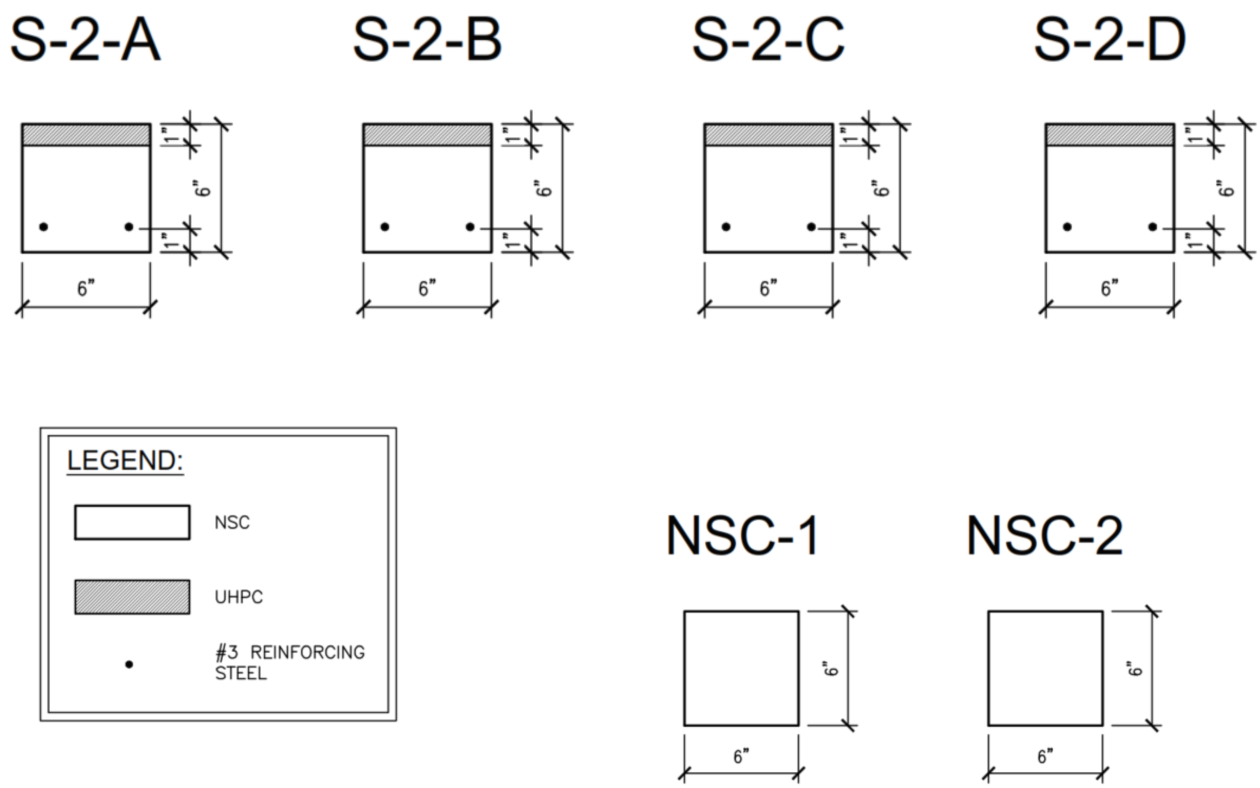


Figure 9. Flexural specimens for material testing.

Table 4. Schedule of Flexure Beam Testing

Beam Designation	Overlay thickness	Roughness profile	Re-bar location	Proposed overlay application and location
R-1-A	1/2	3	adjacent	Spray application on bottom
R-1-B	1/2	3	adjacent	Spray application on bottom
R-1-C	1/2	2	adjacent	Spray application on bottom
R-1-D	1	3	adjacent	Spray application on bottom
R-2-A	1/2	4	opposite	Conventional application on top
R-2-B	1/2	4	opposite	Conventional application on top
R-2-C	1/2	4	opposite	Spray application on top
R-2-D	1/2	4	opposite	Spray application on top
S-1-A	1	1	adjacent	Spray application on bottom
S-1-B	1	1	adjacent	Spray application on bottom
S-1-C	1/2	1	adjacent	Spray application on bottom
S-1-D	1	1	adjacent	Conventional application on bottom
S-2-A	1	2	opposite	Spray application on top
S-2-B	1	2	opposite	Conventional application on top
S-2-C	1	2	opposite	Conventional application on top
S-2-D	1	3	opposite	Conventional application on top

Notes:
Initial placement (NSC) date: 8-7-19
Beam R-1-C had honeycombing in the NSC concrete.
Beam R-1-B had a warped spacer, the thickness of the overlay will vary from ½” at the ends to about 1” in the center.

Figure 10. Flexural beam removed from form, roughness profile skin partially removed.

Figure 11. Flexural beam removed from form, roughness profile skin removed.

Figure 12. Flexural Beam R-1-C honeycombs

Transducers will be instrumented to the beams to measure force-deflection curve. Grids will be drawn on the side of beams for photo documentation before and after testing. Table 5 shows the possible comparison between the test results of the specimens.

Table 5. Anticipated Evaluations of Composite Beam Data

Samples			Comparisons	Common Attributes of Samples
S-1-C	S-1-A	S-1-B	½” vs 1”	Spray applied to bottom; profile 1
S-1-A	S-1-B	S-1-D	Spray vs Normal	Applied to bottom; profile 1; 1” thick
S-2-A	S-2-B	S-2-C	Spray vs Normal	Applied to top; profile 2; 1” thick
S-1-C	R-1-C*	R-1-A R-1-B	Profiles 1, 2, 3	Spay applied to bottom, ½” thick
S-2-B	S-2-C	S-2-D	Profiles2,3	Normal applied to top; 1” thick
R-1-A	R-1-B	R-1-D	½’’ vs 1”	Spray applied to bottom; profile 3
R-2-A	R-2-B	R-2-C R-2-D	Spray vs Normal	Applied to top, ½’ thick profile 4

6.2 Slab Specimen

Full-scale specimens have been cast to validate the models and incorporate parameters discussed above. Large-scale specimens representing bridge deck section with dimensions of 3 ft. wide by 8 ft. long have been cast. The specimens are 9-inch thick and reinforced with two layers (top and bottom) of No. 4 bars on 6-inch centers. The specimen descriptions as follow:

1- Benchmark specimen made of normal strength concrete without any UHPC overlay or bottom application, as shown in Figure 13;
2- Repair specimen with blockout built in the bottom section. The block out is 2-in thick, 4 ft. long and 3 ft. in width. The blockout will be filled with UHPC through pneumatic spray application in addition to the outer bottom surfaces, as shown in Figure 14. This specimen represents the repair of the bottom of the deck using pneumatic spray for overhead application.

3- Repair specimen for deck overlay, as shown in Figure 15. The UHPC overlay will be applied by pneumatic spray on a flat surface.

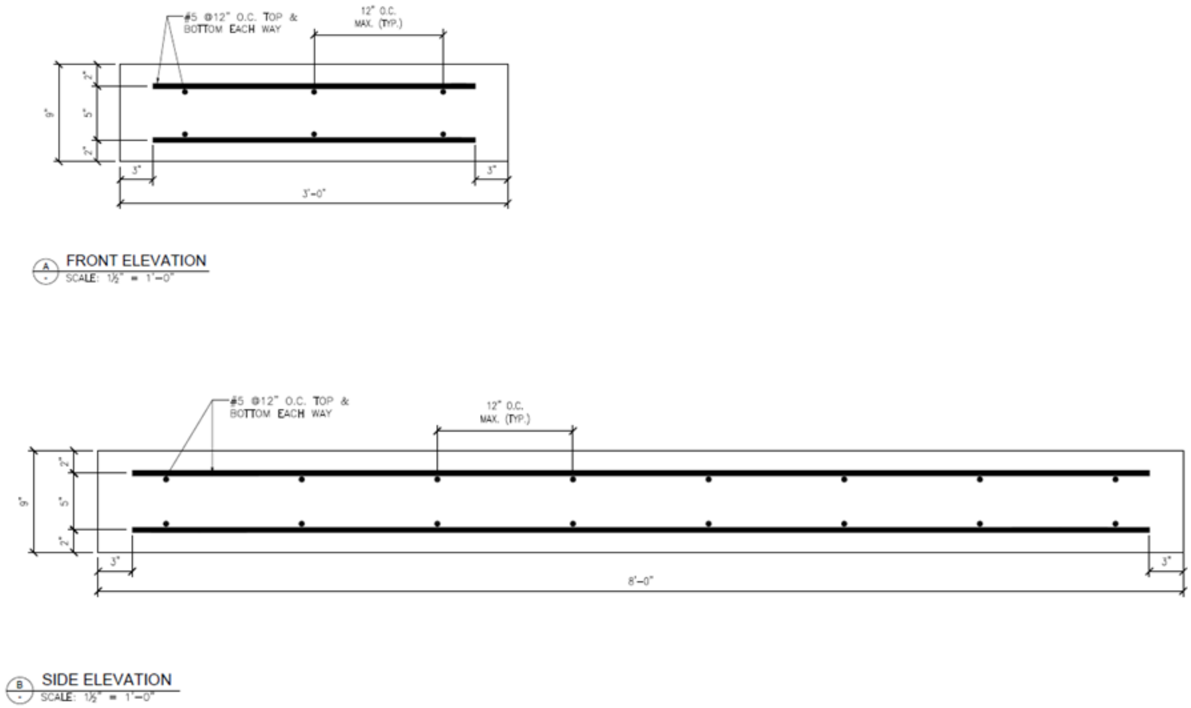


Figure 13. Details of the first specimen (Benchmark)

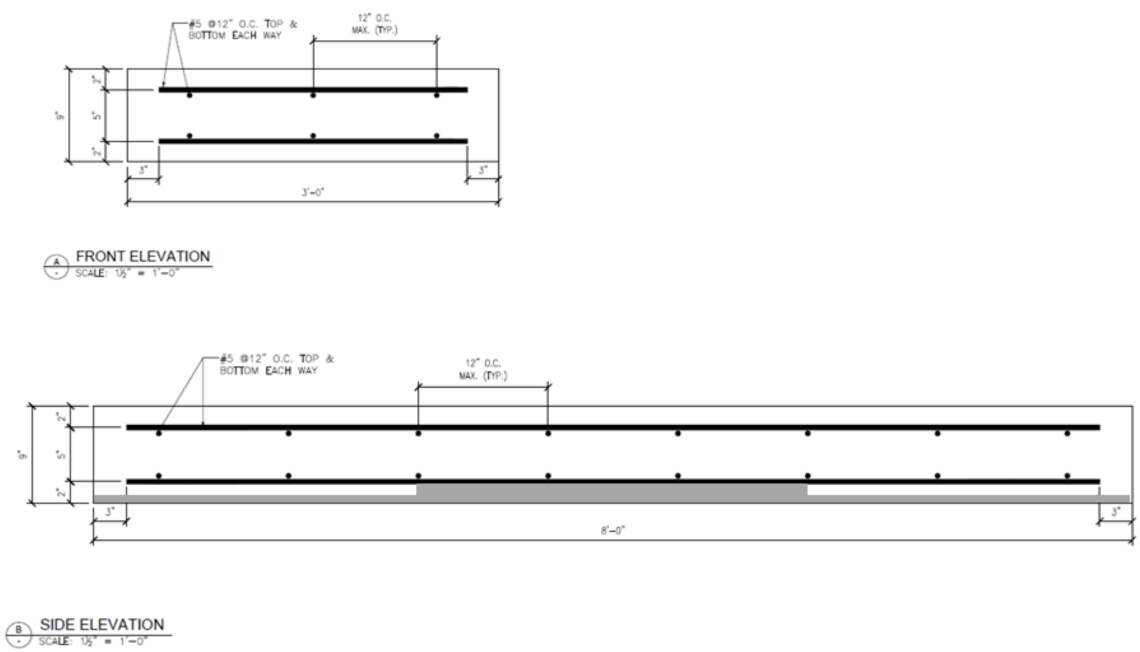


Figure 14. Details of the second specimen (bottom repair)

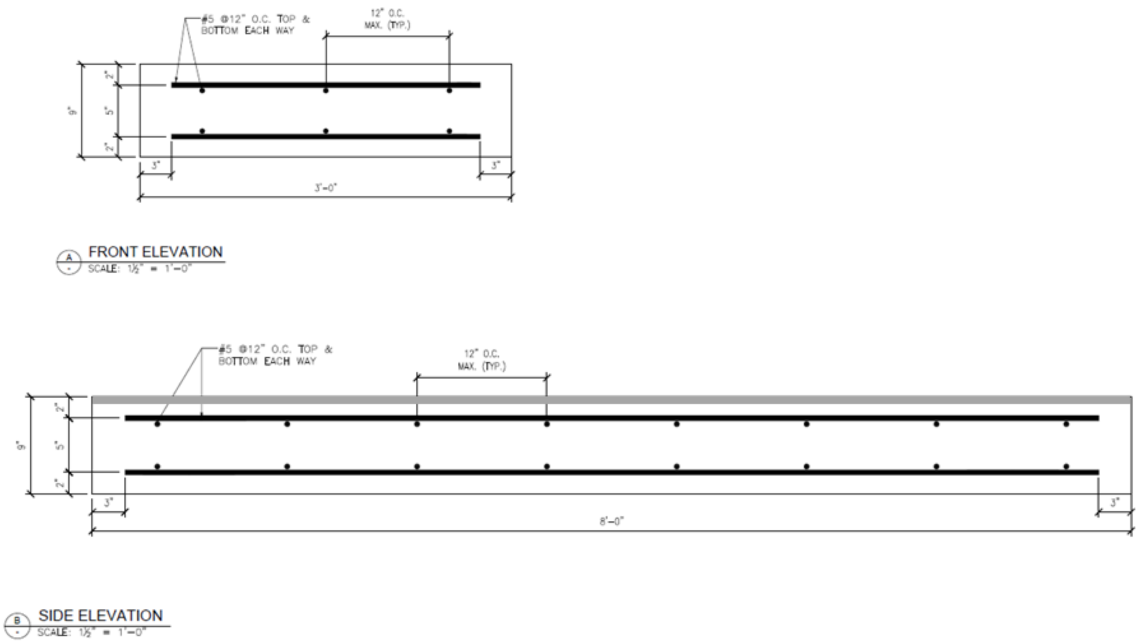


Figure 15. Details of the second specimen (Bridge Overlay)

Large scale specimens are shown in Figure 16. Both the second and third specimens were sandblasted to roughen the concrete surface to enhance the bond between sprayed UHPC and concrete substrate as shown in Figures 17 and 18.

Two additional specimens (Figure 19) will also include a surface overlay, 1- inch thick, and tested statically. These specimens will be 3 1/2 -in. thick slabs with single layer of steel reinforcement. They are 2 ft wide and 6 ft long. Rebar hooks will be provided for lifting in each of these specimens. They will be cast at a later stage. Bond strength testing following Graybeal's procedure will be performed on these samples.

Figure 16. Large scale slab samples

Figure 17. Sand-blasted slab specimen (Top-surface)

Figure 18. Sand-blasted slab specimen (Bottom-surface)

Figure 19. UHPC panel for bond testing and overlay testing of UHPC shotcrete.

7. Expected Results and Specific Deliverables

It is anticipated that UHPC will be investigated for use as overlay material, applied with traditional methods and with spray applications. The high strength of the UHPC provides a stronger bridge sections and culvert with higher corrosion resistance. Factors such as the required interfacial surface roughness, variable thickness and selection of a mix design will be addressed with guidelines for selection of these variables. The procedure will be presented in the form of a selection matrix or flow chart to guide the design and construction practice.

8. Schedule

Duration of this project is 18 months. Timeline for various tasks is shown in Figure 20 up to the date of the third quarter report.

Item	% Completed
Percentage of Completion of this project to Date	45%

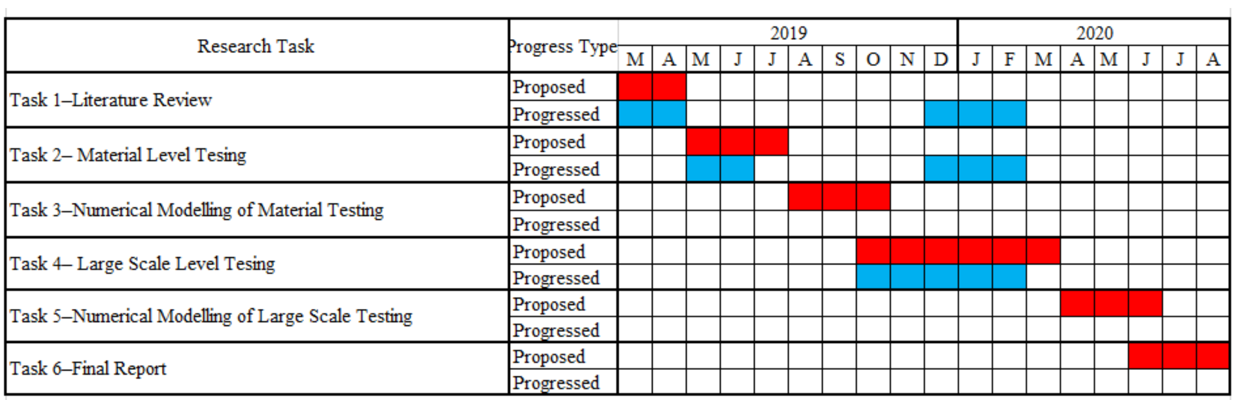


Figure 20. Project Progress.

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