Accelerated Bridge Construction Methods for Bridge 1-438 Replacement

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Abstract: This paper presents the design and implementation of Accelerated Bridge Construction (ABC) techniques for Bridge 1-438 on Blackbird Station Road over Blackbird Creek. The 50'-0" single span beam bridge acts as Delaware's first all precast bridge and incorporates the nation's second Ultra-High Performance Concrete (UHPC) overlay. It illustrates the pros, cons and lessons learned from using ABC techniques for the replacement of Bridge 1-438, with particular attention on UHPC. The paper will also discuss the collaborative efforts between federal and state agencies in producing specifications and plans.

Keywords: Accelerated Bridge Construction (ABC), Ultra-High Performance Concrete (UHPC), Precast Concrete, Federal Highway Administration (FHWA)

1. Introduction

Bridge 1-438 is a bridge replacement project over Blackbird Creek along Blackbird Station Road in a rural part of northern Delaware. The project replaced two 7'-0" x 10'-8" corrugated metal pipe arches with a 50 foot precast concrete structure. The new structure is approximately 40 feet wide and carries two 11 foot travel lanes and two 7 foot shoulders. The existing bridge was identified for replacement because it experienced severe corrosion and loss of fill around the pipe culverts that could have led to an eventual failure. The construction of the new bridge provided what The Delaware Department of Transportation (DelDOT) expects to be a maintenance-free solution for the next 100 years.

At the project's inception, several different structure types were evaluated, including, large reinforced concrete pipes, a precast concrete box culvert, and a precast concrete rigid frame. However, due to hydraulic conditions and poor soils near the surface, these options were eliminated in favor of adjacent box beams set on stub abutments resting on piles.

As a part of the Federal Highway Administration's (FHWA) Every Day Counts Initiative, the bridge was replaced using Accelerated Bridge Construction (ABC) techniques in lieu of conventional bridge replacement methods. The Department is committed to implementing new and innovative bridge replacement techniques that will decrease construction times, increase commuter and work zone safety, and minimize user costs due to the decreased road closure duration. Given the rural location and relatively low ADT, this location was specifically chosen in order to minimize risk and provide valuable experience for future projects. As such, Bridge 1-438 serves as the pilot project for several new ABC techniques in Delaware. This project utilized precast prestressed concrete piles, precast abutments, precast adjacent box beams, and prefabricated steel bridge rails, making it the first bridge in the state of Delaware to be constructed entirely of precast bridge elements. Bridge 1-438 also uses Ultra-High Performance Concrete (UHPC) to transversely connect adjacent beams and as an overlay.

Previous typical construction methods for bridge replacements of similar size to Bridge 1-438 required approximately 90 days to complete. Typical construction of bridges of similar size cost roughly $700,000 to $750,000. The awarded bid price for the replacement of Bridge 1-438 was $1,025,801. Construction work on Blackbird Station Road began with a full road closure on August 8, 2017 and was scheduled to take 33 calendar days, with a large portion of the time being allotted for raising the roadway profile roughly 1'-6". The road was opened to traffic on September 8, 2017, after 31 calendar days, and the bridge construction itself was completed in just 19 days.

2. Precast Elements

While the true focus of this paper is the role UHPC played in the completion of Bridge 1-438, the use of precast elements was also an essential ABC technique.

2.1. Precast Concrete Piles

A single row of (6) 14"x14", 45'-0" long piles were used to support the abutments on each side of the bridge. Because of the precast abutments, tighter tolerances were required on the piles in order to ensure proper fit-up. In order to accommodate the tolerance and achieve proper pile spacing, the contractor erected a robust steel template that could be disassembled and used on future projects. All twelve piles were driven to a depth of approximately 37 feet into a dense sand layer and achieved a capacity of around 400 kips per pile. The pile driving took roughly six hours per side to complete and was finished in two consecutive days. The proper placement of the precast prestressed piles was vital to the overall success of the project and allowed for the rapid erection of the precast abutment sections.

2.2. Precast Concrete Abutments

Typical practice on previous DelDOT projects has been to cast bridge abutments in place. This requires a large amount of time to place and tie rebar, build formwork, pour the concrete, and allow the concrete to cure. Bridge 1-438's substructure consists of two 46'-0" long precast concrete variable height stub abutments. Two separate sections were cast for each abutment. Both abutments were able to be set in just over an hour. A closure pour consisting of Type I 4,500 psi concrete with a 2% high early strength admixture was used to connect the piles to the abutments. By using this concrete mix for the closure pour, the contractor was able to place the beams one day after performing the closure pour.

2.3. Precast Adjacent Box Beams

The superstructure of Bridge 1-438 consists of ten 52’-0” long x 2’-0” deep x 4’-0” wide prestressed precast adjacent box beams. Placement of the beams, core drilling, doweling, and grouting the connections between the beams and the abutments were all completed in a single day. With the precast adjacent box beams in place, the UHPC connections and backwall could be poured.

3. UHPC Connections and Backwall

Previous DelDOT practice for a bridge of this type was to use grouted keyways, welded shear connector plates, and post tensioned tie rods to connect the individual beams together in a single composite unit once they were in place. However, this method of construction has caused reflective longitudinal cracking in the deck of many of Delaware’s adjacent box beam bridges, and

has led the Department to shift standard practice toward the use of UHPC in a revised shear key shape developed by the Federal Highway Administration (FHWA). DelDOT specifications for the UHPC joint mix require a minimum compressive strength of 22 ksi. The formwork of the newly adopted shear key design was fabricated out of steel by the precaster for the purpose of being reused on future DelDOT projects. The steps of the precaster to develop a reusable formwork are an important step in mainstreaming the use of UHPC. Bridge 1-438 is the second box beam bridge in Delaware to transversely connect adjacent box beams with UHPC. Since the completion of this project, a third adjacent box beam bridge was replaced using UHPC connections.

This project also uses UHPC for the backwalls, which were poured simultaneously with the shear key joints. The decision to pour the small backwall with UHPC was made in an attempt to protect the ends of the beams from impact during plowing operations. In addition, pouring the UHPC simultaneously with the shear keys allowed the contractor to eliminate the need for an additional pour and costly cure time.

The contractor’s decision to spend a full day preparing the formwork for the joints and backwalls proved to be a valuable decision in terms of the overall construction duration. Because of the self-consolidating nature of UHPC, if care is not taken during the forming, leaks and blowouts can become a costly and time consuming issue. On several previous UHPC projects, contractors have attempted to seal formwork for UHPC joints with an array of materials like expansive foam, furring strips, backer rods, and wood. At times, the use of these forming methods has caused the loss of UHPC, resulting in increased cost and delays. However, on the replacement of Bridge 1-438, the contractor alleviated this issue by sealing the joints with mastic. While the mastic took longer to place, the contractor’s diligence prevented the loss of any UHPC through the joints and eliminated time-consuming delays to repair leaks in the formwork.

All of the work associated with the UHPC joint pour took three days: one day to prepare the surface and install formwork, and two days of pouring. Typically the UHPC pour for the joints is completed in a single day for a bridge of this size. However, instead of using buckets to create a pressure head and force the UHPC through the joints, the contractor opted to use troughs. This significantly slowed down the pace of work for the UHPC pour. Compounding the issue, during the first day of pouring, issues arose with the yield of the UHPC mix, and the provided quantity was approximately 1 cubic yard short, resulting in three unfinished joints. As per the direction of the UHPC subcontractor, Lafarge, and DelDOT, the contractor formed a bulkhead within the unfinished joints to create a vertical cold joint. Before the second pour, the contractor removed the bulkhead and applied a bonding agent to the vertical cold joint. Through these actions, the contractor was able to minimize the delay to a single day and avoid potentially costly repairs.

4. UHPC Overlay

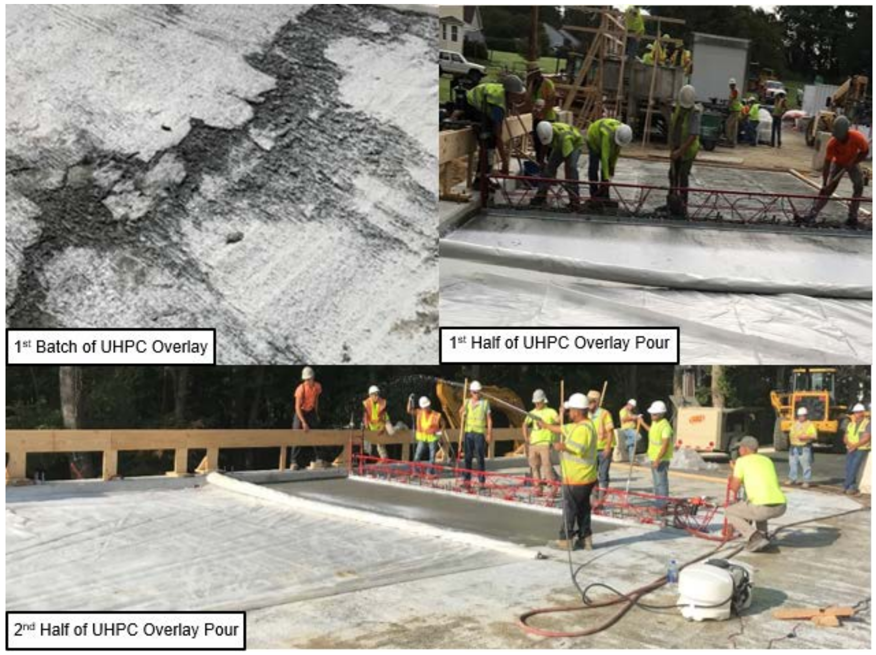
Instead of a typical cast-in-place concrete deck, which takes time to cure, an overlay that could be applied to the bridge quickly was chosen. While an overlay is not necessary for a bridge with UHPC joints from a structural standpoint, the Department chose to utilize an overlay to help accommodate construction tolerances and provide a uniform appearance. On previous projects, DelDOT has had issues with the application and durability of certain overlays. To address the issue of durability while still minimizing construction time, DelDOT opted for a UHPC overlay. While this application is still very new, the hope is that the UHPC overlay will provide the durability of a typical cast-in-place concrete deck without the extensive curing time. Because of the nature of the mix, UHPC has self-arresting crack properties, which make it impermeable. This trait will aid in protecting the structure from de-icing agents and water intrusion, and the subsequent issues that arise from them.

The UHPC overlay, which is a slightly modified mix design from the UHPC material used in the joints and backwalls, has only been used on one other project within the United States, a deck rehabilitation project in Iowa. The Department worked with members of the FHWA, Iowa Department of Transportation, Iowa State University, and Lafarge to develop the nation's first specification for ultra-high performance concrete overlay. This project was awarded a $257,950 Accelerated Innovation Deployment (AID) Demonstration Grant from the FHWA to implement the UHPC overlay and monitor its condition over the service life of the structure.

DelDOT's UHPC overlay specification requires that the material reach a compressive strength of 14 ksi. Because the UHPC overlay is produced using a different and stiffer mix design than the typical UHPC joint mix, there were many unknowns going into the product application. On July 20, 2017 the contractor set up a demonstration pour offsite weeks prior to the start of construction, where they applied approximately a 20' wide x 10' long x 1½" thick segment of UHPC overlay using a vibratory screed. The demonstration pour was applied to a superelevation similar to what was on site. The demonstration allowed the contractor, along with members of DelDOT's design and construction team, to gain an understanding of the mix properties, handling practices, and placement techniques for the UHPC overlay. Because this mix design is different than normal concrete and even the UHPC mix design used in the joints and backwall, the test pour provided information that was vital to the proper placement of the UHPC overlay in the field.

Before the UHPC overlay could be applied, the UHPC in the beam joints needed to achieve a minimum compressive strength of 14 ksi and the surface needed to be appropriately prepared. To save the time spent manually roughening the application surface, the contractor had the beam fabricator tine the top surface of the beams to create a surface that would facilitate mechanical bonding. After the UHPC joints were properly cured, the contractor used a grinding machine to appropriately roughen them and remove any excess UHPC. The contractor also had to set up longitudinal and transverse formwork for the overlay and assemble the guide for the vibratory screed to follow. In setting up the guide for the screed, it was realized that unforeseen differential camber in the beams created an issue with the minimum UHPC overlay thickness of 1½". To address this issue, the Department allowed the contractor to decrease the minimum overlay thickness from 1½" to 1" in small localized areas outside of the travel lanes. The 1" overlay thickness was a minimum depth established by Switzerland for several projects implementing UHPC as an overlay. Given the successful overlay application by Switzerland, and the use of UHPC longitudinal joints below the overlay, the Department felt comfortable with the decision to decrease the minimum UHPC overlay thickness. The final UHPC overlay thickness ranged from 1" to 3¼". Instead of the self-consolidating characteristics of the UHPC joint mix, the UHPC overlay is a thixotropic mix. Because of the thixotropic characteristics of the material, the UHPC overlay can be spread relatively easily shortly after being mixed/agitated. However, once the material is under a static condition, the UHPC overlay becomes much stiffer. This property allowed the material to accommodate the 4.4% superelevation of the roadway.

The contractor opted to apply the UHPC overlay in two separate segments over the course of two days. Each UHPC segment constituted one half of the bridge. By doing the overlay in two pours, the contractor was able to use a smaller more maneuverable screed, which helped achieve a quality finish and maintain the proper profile. The first UHPC overlay pour took place on August 24, 2017. The initial batch of the first pour unexpectedly produced a consistency much stiffer and



1st Batch of UHPC Overlay

1st Half of UHPC Overlay Pour

2nd Half of UHPC Overlay Pour

less workable than what was experienced in the demonstration. This led to a very rough finish for the first 8 to 10 feet of the overlay; however, once the mix of the successive batches was refined to be more workable, the overlay finish was greatly improved. In hindsight, the first batch of the UHPC should not have been placed until a proper mix was achieved. As the overlay was being laid down and finished by the vibratory screed, curing compound and polyethylene was applied almost immediately. The first half of the bridge overlay was completed in roughly two hours. The second UHPC overlay pour was applied on August 28, 2017, and was similarly completed in two hours. During the second pour, the contractor was able to avoid any of the previous issues with the workability of the mix and achieved the desired finish. In addition, during the second pour, the contractor also patched the poorly finished portion of the first pour with additional UHPC overlay material. The depth of the UHPC overlay patch varied from ¼” to ½”. Because the patched section was so shallow, many people had doubts about how it would bond to the UHPC below it and hold up during the surface grinding. On September 5, 2018, the contractor used a 4’-0” grinder to finish the overlay to its final riding surface. The grinding required two passes of the entire bridge and took one day to complete. The contractor used a hand grinder to finish the edges of the bridge and grind down any imperfections the blanket grind did not reach. It is important to note that the UHPC overlay patch held up through the grinding and adequately bonded to the rest of the riding surface. The grinding process also exposed the steel fibers of the UHPC, but it is the

Filling and Screeding the UHPC Patch

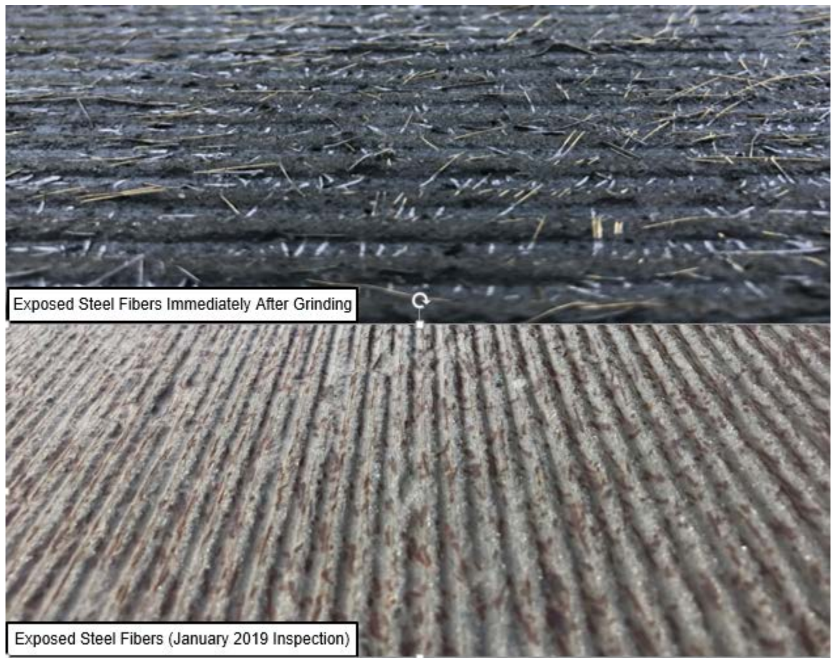
Hand Finishing the UHPC Patch

UHPC Patch After Curing

UHPC Patch After Being Ground

Department's belief that the finish of the UHPC overlay will improve over time as the exposed fibers are worn away from the weather and traveling vehicles. While the finish of the UHPC overlay is not as smooth to the touch as what could be achieved with traditional concrete finishing techniques, the grinding successfully eliminated a majority of the imperfections of the overlay and created a comfortable and durable riding surface. It is worth noting that while the overlay is rough to the touch, the overlay rides exceptionally smooth.

5. UHPC Overlay Inspection



Since the completion of the replacement of Bridge 1-438 September 2017, the UHPC overlay has been inspected three times as a part of the AID Demonstration Grant. The three inspections occurred in November 2017, July 2018, and January 2019. Bridge 1-438 has now been through two winter seasons of freeze/thaw conditions, plows, and de-icing agents. Visual inspections of the entire overlay surface were performed in an effort to identify any defects that may exist. In addition to the visual inspection, the entire surface was chain-dragged and sounded using hammers to check for any signs of delamination between the UHPC overlay and the top surface of the beams. Particular attention has been paid to the travel lanes of the roadway, the longitudinal joint in the center of the bridge where the two separate overlay pours meet, and the patched section in the westbound lane of the overlay. The other main point of focus has been the number of exposed steel fibers remaining from the initial riding surface grind.

Visual inspections of the bridge deck have revealed no cracking. Any cracks that developed immediately after the surface was finished were removed when the riding surface was ground. The surface of the deck has a few areas of existing defects that were visually inspected. The existing defects included a small low-spot created by the first batch of UHPC being too stiff, an area filled with bonding agent (at the recommendation of LaFarge), and several small nicks. The overlay also has small pockets or voids sporadically throughout its surface. These pockets are believed to be caused by air bubbles that were initially trapped under the UHPC overlay that rose to the surface as the material cured. The pockets show no signs of continued cracking or deterioration. After sounding these areas, the existing defects remained sound and pose no impact to the overall condition, ride-ability, and durability of the overlay. The visual inspection of the joint at the centerline of the bridge and the patched area have revealed no signs of deterioration. In fact, the location of the joint and patch are nearly impossible to identify, and the bridge appears as if it was completed in one homogeneous pour.

The chain-dragging and hammer sounding of the entirety of the UHPC overlay revealed no signs of deterioration. The joint, patch, and rest of the deck show no signs of delamination from the tops of the adjacent box beams.

As predicted, the number of exposed fibers on the UHPC overlay have continued to diminish as time elapses. With the steel fibers being exposed to the elements, many of them have corroded and broken away at the surface of the overlay. While the surface of the overlay remains rough to the touch, the ride-ability of the bridge remains excellent. The corrosion of the fibers appears to arrest at the surface of the overlay, and to-date, has not had an adverse effect on the performance of the UHPC overlay. The rusting of the steel fibers has resulted in a staining of the bridge overlay. The Department does not view the overlay staining as an adverse effect, but it is certainly a factor that should be considered on future projects located in high-visibility locations.

Overall Riding Surface at Project Completion

Overall Riding Surface (July 2018 Inspection)

6. Conclusions

The replacement of Bridge 1-438 in 31 days was deemed a tremendous success and provided the Department and the contractor with valuable insight and experience. Although this bridge replacement proved to be somewhat more expensive than conventional construction methods used in Delaware, the road was opened in a third of the time. On future projects involving higher volume roadways, these road user cost savings could help to significantly offset the higher costs of ABC techniques. The Department also anticipates the higher prices associated with accelerated bridge construction to diminish as better details are developed, ABC practices become more mainstream, and contractors gain more experience. While further advancements in accelerated bridge construction techniques can be made in Delaware, the knowledge gained from this project will allow future DelDOT projects to be completed by much quicker and safer means. Given the many unknowns associated with implementing new ABC techniques, the Department closely monitored the progress of this project. Some of the major lessons learned from the replacement of Bridge 1-438 can be found below:

- Utilizing other agencies and DOTs is vital to the success of an ABC project. During the design phase, the design team reached out to several DOTs, FHWA, and LaFarge while developing details and specifications. It was clear that this allowed for a quicker and smoother construction process.

- Care should be used when sealing the beams and building the formwork for the UHPC joint pours. The contractor opted to use a mastic instead of the commonly used spray-foam. On previous projects, issues have arisen when the spray-foam did not properly seal the joint and led to costly leaks. The mastic created an extremely effective seal, and no UHPC was lost due to leaking.
- The manufacturer recommended approach for pouring the UHPC joints is to top-form the joint prior to pouring and use buckets to create a pressure head that forces the UHPC into all of the voids of the joints. The contractor opted to top-form as he poured and to use a longer trough. This procedure slowed down the placement of the UHPC significantly and resulted in only one mixer being able to be utilized.
- The Department, contractors, and even the manufacturer are still learning the best practices when applying UHPC. The Department erred on the side of caution when it came to loading the UHPC joints and completing the second half of the UHPC overlay. This project showed that a time-savings could be experienced by compressing the time between these tasks without compromising the integrity of the UHPC. Testing more UHPC samples would help facilitate tighter timeframes for these tasks.
- The UHPC overlay provides an impervious and durable riding surface on the bridge. The high cost of this material may prevent it from being adopted to serve solely as an overlay on new bridge replacements; however, the Department sees this being a viable option for rehabilitation projects. The high strength of the UHPC overlay could extend the life of a failing deck by 20 to 30 years. Also, in the future, if the structural capacity provided by the UHPC overlay was accounted for, it could potentially allow for shallower beam members to be used.
- Since the completion of Bridge 1-438, the Department has successfully applied a UHPC overlay to a bridge carrying a roadway that acts as a major artery for the entire state of Delaware. The overlay, which originally was not part of the plans, was applied as a result of deck thickness issues created by unexpected camber of the superstructure. The UHPC overlay will provide additional strength to the thinner concrete bridge deck. In addition to this application, DelDOT also has plans to use a UHPC overlay on three bridge deck rehabilitation projects on another major Delaware roadway.

7. References

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8. Acknowledgements

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