Utilization of Ultra-High Performance Concrete (UHPC) in New York

Mathew Royce, P.E., Office of Structures
New York State Department of Transportation

1. Abstract

This paper presents New York State Department of Transportation's (NYSDOT) experience with Accelerated Bridge Construction (ABC) using Prefabricated Bridge Elements and Systems (PBES) with field-cast UHPC joints. New York State frequently is in need of bridge deck and superstructure replacement using short term closures to maintain acceptable levels of mobility within the highway network. It has a long history of using PBES for accelerating bridge construction. While the objective of accelerating the construction was routinely achieved, long term durability of these structures was a big concern. The reason for this was the inferior performance of joints between pre-fabricated components.

Starting from 2008 NYSDOT has been deeply involved in the development, testing, trial application and utilization of field-cast UHPC joints between prefabricated elements for ABC. As of now this technology has been utilized in a large number of bridges within the state. Performance of these bridges, many of them carrying interstate highways with exposure to high levels of chlorides has been very good. This paper will narrate the case studies of the construction of different bridge types using this construction technology.

Keywords: UHPC, field-cast, joints, durability, accelerated, bridges, construction, user-cost diamond-grinding, deck, prefabricated, Superstructure.

2. Introduction

New York State has played a leading role in the development and implementation of field-cast UHPC joints between prefabricated components for ABC. NYSDOT collaborated with the construction and prefabrication industry, material suppliers, trade associations and the Federal Highway Administration in developing and testing UHPC joints. Various noteworthy endeavors have resulted in the development and testing of the connection between precast deck elements as well as the deck to beam connection using UHPC. The precast specimens were designed, fabricated and joined together using UHPC and shipped to the FHWA Turner-Fairbank testing laboratory under the leadership of NYSDOT. As of now NYSDOT has successfully completed the construction of 30 bridges utilizing UHPC connections of prefabricated elements.

3. Case Study 1, Route 31 over Canandaigua Outlet

The superstructure replacement of Rte. 31 over Canandaigua is the first field application of UHPC joints in bridge construction in New York as well as in the country. Deck Bulb-Tee are efficient sections for design as well as for shortening construction time, since cast in place concrete decks can be eliminated. Due to inferior performance of joints using non-shrink cementitious grouts, use of DBT superstructures were limited to local roads with low levels of truck traffic. UHPC joints completely change that and make the system potentially even more durable than a cast in place system. The superior quality of the prefabricated High Strength High

Performance Concrete (HSHPC) component is combined with the UHPC joint system which is even more durable than the component itself.

NYSDOT developed a non-proprietary performance based specification requiring qualification testing for acceptance and used in this project. Modified versions of this specification are in current use by NYSDOT and some other states.

Figure 1–Case Study 1–Rte. 31 over Canandaigua outlet DBT in place before UHPC placement

Span: 85 feet single span bridge with limited available beam depth
Type of work: Superstructure replacement
Type of PBES used: Pre-stressed Concrete Deck Bulb-Tees (DBT)
UHPC connection details used: Longitudinal UHPC joints

3.1 Lessons Learned

Since this was the first field application of UHPC, close attention was given to all operations by the DOT staff, the contractor and the material supplier. Pre-wetting of the precast components' mating surfaces was done properly. The material supplier educated the contractor about the importance of leak-proof forms before placing UHPC. UHPC joints were sufficiently overfilled to ensure that the entire finished joint was filled with high quality material. The top quarter inch or so of the UHPC joint fill has a tendency to have a low quality flaky material which needs to be removed.

This superstructure was designed to have an asphalt overlay with water proofing membrane over the DBT. Camber control during fabrication and storage and field adjustments of camber variations between the units were included in the contact which was helpful in obtaining the required final deck surface without significantly varying the overlay thickness. The success of this experience led to design and construction of a number of bridge superstructures with prefabricated deck beam elements with UHPC joints.


Figure 2–Case Study 2-Route 23 over Otego Creek in Oneonta Precast Deck Placement in Progress

Span: 127 Feet
Type of work: precast concrete deck with concrete overlay
Type of PBES used: Full depth precast deck with transverse and longitudinal UHPC joints
UHPC connection details used: Deck panel to Deck Panel
Composite connection: Grouted haunches with studs through panel openings

4. Case Study 2, Route 23 over Otego Creek

The second trial application was the construction of a 127 ft. single span steel girder bridge precast concrete deck with UHPC joints near Oneonta NY. The composite connections of the deck panel to the top flange of the steel girder utilized a non shrink cementious grout and stud sheer connectors installed through openings in the deck panels, which eventually was filled with grout. This system needed a concrete overlay for the protection of the grouted openings as well as to obtain a smooth riding surface.

4.1 Lessons Learned

UHPC placement operation was completed in two days without any major problems. This placement could have been completed in a day if the contractor had provided sufficient labor and had larger UHPC mixers. This knowledge helped DOT staff to guide contractors in later deck replacement projects with super compressed schedules. Another important observation was the need for careful storage of the UHPC pre-mix all through the storage period. Any moisture penetration into the premix powder will result in the formation of silica balls the UHPC mix. The material supplier made improvements in the packaging and storage of the material as well as the mixing process to reduce or eliminate this problem in future applications.

During the placement of UHPC in the joints a few areas of leakage were noticed and corrected during construction. NYSDOT contract documents currently alert the contractors about the need for water-tight forms for UHPC.

The above mentioned demonstration projects were completed in 2009. Both of these projects utilized prefabricated components and obtained considerable reduction of construction time compared to a conventional cast in place method. Both of these projects met or exceeded the Department's goals in the speed of construction as well as the performance of the final product. At the conclusion of the above mentioned trial projects, needs for further improvements in this technology were identified as critical areas of improvement to achieve acceleration of construction in the order of days rather than weeks or months.

5. Overlays

Use of overlays over the precast components consumed significant portion of available construction time and their avoidance was identified as a needed improvement. Overlays were particularly problematic when concrete overlays were used due to the needed cure time. The use of asphalt overlays with water proofing membrane was less time consuming, but still undesirable. As a solution NYSDOT developed precast deck systems that have ½ inch sacrificial thickness for diamond grinding after the completion of the deck to obtain a smooth riding surface.

6. Compressive Strength

Acceleration of compressive strength gain of the UHPC joints was identified as another highly desirable improvement. A compressive strength of 14 KSI was determined to be adequate for the performance of UHPC joints under live traffic. In order to complete a deck removal and replacement during one weekend closure the available cure time for UHPC was determined to be 12 to 14 hours. Based on feedback from the industry as well as the test results from the FHWA Turner-Fairbank Laboratory, an accelerated UHPC mix cured at a 100°F for 12 hours was determined to provide the necessary strength. Later on, maturity curves (time-temperature vs. compressive strength) were developed for field application of maturity method of curing.

In maturity method the area under time vs. internal curing temperature curve (maturity curve) is associated with compressive strength. This approach will provide on-time strength data for the cured material, allow heat input adjustments during curing enabling proactive management of the strength.

7. Composite Connection

In order to avoid the overlays, two types of composite connections were developed. The first one utilized UHPC haunches with open stud pockets in addition to the UHPC joints. The second one utilized hidden haunches with two types of fill material, cementitious grout or UHPC. Cemetitious grout fill material needed 6 inch studs penetrating above the bottom layer of the deck reinforcement. This arrangement needed tight tolerances in fabrication and erection of panels but resulted in lower material cost. In addition, this approach enabled the Department to limit the quantity of UHPC per project, since a limitation existed prior to 2014 due to the Buy America provisions. UHPC filled haunches were designed with 3 inch studs. The conceptual idea behind this approach is that shorter development is achievable in the UHPC due to its high sustained tensile strength. UHPC filled haunches with 3 inch studs was the most efficient way of construction though the material cost is bit higher. Both of these haunch types were tested in the FHWA Turner-Fairbank Laboratory.

Figure 3–Case Study 3-Route 42 over Westkill Panel Joint Placement in Progress

Span: 120 Feet
Type of work: precast deck over new multi-girder steel superstructure
Type of PBES used: Full depth precast concrete deck system without overlay
UHPC connection details used: Deck panel to Deck Panel
Composite connection: UHPC haunches with studs through panel openings

8. Case Study 3, Route 42 over Westkill:

Two bridges on Rte. 42 crossings over the Westkill were constructed in Lexington, NY during the winter of 2011 under an emergency contract. The original bridges were washed out during Hurricane Irene in August of 2011. These bridges utilized precast concrete decks with UHPC joints over steel girders. The composite connections of the deck panel to the top flange of the steel girder were made with stud sheer connectors installed through openings in the deck panel with UHPC filled haunches and stud pockets. Since UHPC was used in the stud pockets, a diamond ground deck surface with no overlay was used for these bridges. Curing of UHPC under artificial heating was used since the ambient temperature during the curing time was mostly below freezing.

8.1 Lessons Learned

Based on the experience with the construction of these two bridges, the Department is now confident that construction during wintertime is feasible with the use of precast elements with UHPC. Avoiding overlays is particularly beneficial in winter construction. Even though curing of UHPC joints needs artificial heating, the heating set up is significantly less complex and the duration is shorter compared to what would be needed for a cast-in-place operation. In addition, based on the Department's past experience, artificial heating of cast-in-place decks offen results in deck cracking. That problem was avoided with these bridges.

9. Case Study 4 - 17 Deck Replacement Projects During 2012 and 2013

This case study involves a large number of bridges done under various contracts in different parts of the state. This demonstrated the feasibility of achieving construction acceleration matching the needs of the locations and situations on a system wide basis. This group of bridges included a number of single span bridges, a two span steel curve girder bridge and four three span bridges. Ten of these bridges are located in urban areas carrying interstate traffic while seven are on state highways in rural settings.

Consideration of the user cost associated with a lengthy conventional construction demonstrated that spending the additional cost associated with accelerated construction is a better value. The degree of construction acceleration was decided based on the needs of the specific location. About half of these bridges required deck replacement within a window of 72 hours; Friday night closure to early Monday morning opening to traffic. Many of them used five to ten days of closure time. Cost of deck replacement increased along with the degree of acceleration. The Department allowed the longest window feasible to keep the cost to the lowest possible. Photographs of a three-span bridge are given as a typical example:

Figure 4-Case Study 4 – I-81 over East Castle St. Precast Deck Placement in Progress

Span: 120 Feet
Type of work: precast deck over existing multi-girder steel super-structure.
Type of PBES used: Full depth precast concrete deck system without overlay
UHPC connection details used: Deck panel to Deck Panel
Composite connection: Hidden haunches with non-shrink grout and studs penetrating above the bottoms of precast panels.

9.1 *Lessons Learned*

Based on the performance of these decks the Department started the practice of avoiding overlays when UHPC is used for joint fill as well as sealing the UHPC/concrete panel interface with high molecular weight methacrylate to eliminate potential leakage. Since the UHPC joints are significantly stronger and more durable than the precast panels themselves, leaving the locations of the joints to the contractor was not a concern for the Department. This allowed the contractor and the fabricator to develop the most suitable panel layout for fabrication, storage, transportation and installation. In addition, the Department came away with the concept of allowing precast decks with UHPC as an alternate to the cast-in-place option for future contracts. This approach is particularly beneficial when available construction duration is such that a cast-in-place option cannot be ruled out. This approach has been used in a few contracts and the cast-in-place option was selected in a few instances over the precast option. The department is now confident that this market based approach is obtaining the best value.

10. UHPC Link Slab

The NYSDOT Office of Structures has developed an innovative link slab design utilizing Ultra High Performance Concrete (UHPC) to eliminate transverse deck joints wherever feasible. The link slab design assumes that the UHPC section is subject to bending. The link slab also acts as a semi-rigid link between spans transferring compressive, tensile, and shear stresses due to various loads.

The ability of UHPC to develop ultimate tensile strains up to 0.007, by developing micro cracking within, is what allows the link slab to accommodate girder end rotations. A maximum design strain of 0.0035 at the extreme tensile fiber was chosen in order to control the crack width. The crack spacing associated with a strain of 0.0035 is approximately 3/16", resulting in extremely fine cracks that are invisible to the naked eye. Limiting the tensile strain will increase the service life of the link slab by preventing the penetration of moisture and chlorides.

The design of the link slab is influenced by variables such as span arrangement, bearing type and arrangement, girder end rotation due to live load, and bridge skew. A number of rehabilitation projects are being progressed within the Department utilizing UHPC link slabs to eliminate joints.

10.1 Lessons Learned

UHPC link slabs provide an excellent way to eliminate joints in existing bridges. Based on NYSDOT's experience to date, link slabs are performing well with no visible cracks within the UHPC slab. These bridges overall are performing as designed also.
Proper design with proper consideration of overall bridge behavior is of critical importance ensure good performance of the link slab. A faulty design may cause failure of the link slab and more importantly may cause structural damage to other components of the bridge.

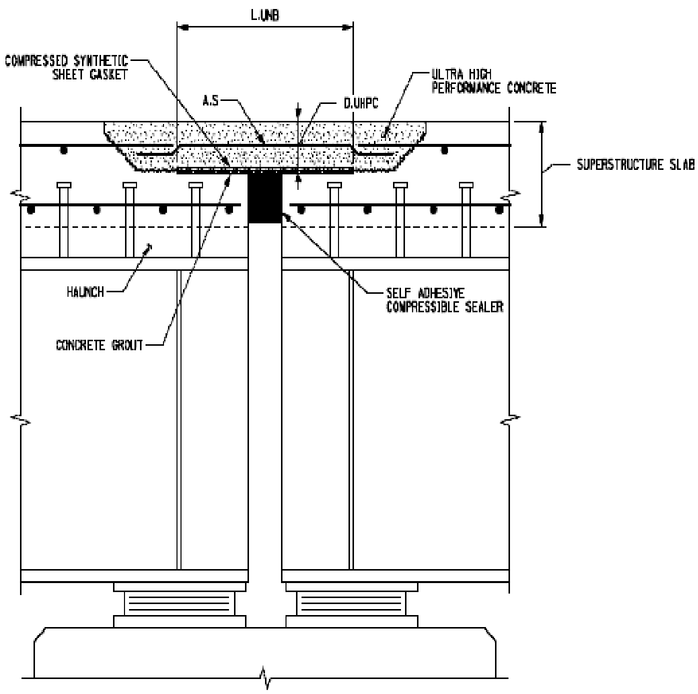

Figure 5-Link Slab Cross Section

Figure 6-Finished Link Slab

11. Conclusions

The non-proprietary performance-based specification requiring qualification testing for the acceptance of Ultra High Performance Concrete (UHPC) has performed well for NYSDOT

From a total cost perspective the combination of user and construction costs, and the use of precast components with UHPC joints is a good value when construction acceleration is needed.

An exposed aggregate finish on the mating surface of the precast component is beneficial to improve bonding of UHPC.

Overfilling of joints in the range of ¼ inch is needed to deal with consolidation settlement of UHPC.

Pre-wetting of precast surfaces to saturated surface dry before joint fill is critically important.

Due to the highly flowable nature of UHPC, leak proof formwork is essential.

The maturity method for strength tests is desirable when accelerated curing is used.

All bridge structures that have utilized PBES with UHPC joints have been reportedly performing well.

NYSDOT practice is to use corrosion resistant rebars such as epoxy coated or stainless steel to avoid macro corrosion development.

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