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Implementing ultra-high-performance concrete for accelerated bridge construction in New York

- This paper describes a collaborative effort led by the New York State Department of Transportation to implement accelerated bridge construction technologies in the state of New York.
- Ultra-high-performance concrete is being used for the joints between precast, prestressed concrete elements.
- Contract provisions allow contractors and fabricators to develop their capabilities on relatively simple projects before significant incentives and penalties become effective.

The New York State Department of Transportation (NYSDOT) has been one of the leading entities in the development of accelerated bridge construction (ABC) technologies in the United States. It has a rich history of collaborating with other government agencies, such as the Federal Highway Administration (FHWA); other state highway agencies; industry organizations such as the Precast Concrete Association of New York and the Associated General Contractors of America; individual companies; and other stakeholders. Collaboration has been one of the main reasons for the successful implementation of ABC methods using prefabricated bridge components joined in the field with ultra-high-performance concrete (UHPC).

Both the need for ABC and the main obstacles to its implementation are well understood at NYSDOT. In the absence of impediments, all bridge construction would be accelerated construction. The potential benefits include reduced user inconvenience, better safety during construction, and reduced environmental impact. Based on NYSDOT's experience, three main obstacles to the wide use of ABC were identified as increased initial con-

Deck bulb tee being lifted into place on the replacement of the bridge superstructure on Route 31 over the Canandaigua outlet in Lyons, N.Y., in 2009. **Courtesy of NYSDOT..**

struction costs, reduced durability due to the poor performance of joints, and lack of understanding of design and construction using ABC. NYSDOT's collaborative efforts have focused on minimizing these obstacles. The progress has been significant in some areas and limited but notable in other areas.

Owners of transportation infrastructure in the United States find themselves in a precarious position. Aging infrastructure requires rehabilitation or replacement. Increasing user demand for existing infrastructure reduces down-time availability for such activities, while resources are static or declining. In general, initial construction costs for ABC continue to be significantly higher than for conventional construction. Meeting these conflicting demands has been difficult for highway agencies. One of the ways in which agencies are coping with this problem is by sacrificing one of the demands. When user inconvenience would be intolerable, the higher cost of accelerated construction is justified. On the other hand, when user inconvenience is acceptable, conventional construction is selected. In fact, both of these solutions are less than desirable.

NYSDOT is fully committed to developing solutions to this problem. Probably the most desirable one is to

Replacement of the bridge superstructure on Route 31 over the Canandaigua outlet in Lyons, N.Y., in 2009. Installation of the deck bulb tees is complete. Ultra-high-performance concrete will be placed in the longitudinal joints. **Courtesy of NYSDOT.**

Completed NYSDOT projects using prefabricated components and UHPC joints							
Bridge identification number	**Town**	**County**	**Highway carried**	**Feature crossed**	**Span arrangement**	**Type of work**	**Year completed**
1017580	Oneonta	Otsego	Route 23	Otego Creek	Single	Precast concrete deck (replacement bridge)	2009
1021750	Lyons	Wayne	Route 31	Canandaigua Outlet	Single	Deck bulb tee	2009
1043200	Greenwood	Stuben	Route 248	Bennet Creek	Single	Deck bulb tee	2011
1025190	Lexington	Greene	Route 42	Westkill River	Single	Precast concrete deck (replacement bridge)	2011
1025200	Lexington	Greene	Route 42	Westkill River	Single	Precast concrete deck (replacement bridge)	2011
1050430	Sloatsburg	Rockland	Seven Lakes Drive (981G)	Ramapo River	Single	Precast concrete deck (replacement bridge)	2011
1021850	Brutus	Cayuga	Route 31	Putnam Brook	Single	Deck replacement	2012
1051091	Syracuse	Onondaga	I-690 westbound	Crouse Avenue	Single	Deck replacement	2012
1051092	Syracuse	Onondaga	I-690 eastbound	Crouse Avenue	Single	Deck replacement	2012
1051159	Syracuse	Onondaga	I-690 westbound	Peat Street	Single	Deck replacement	2012
1051159	Syracuse	Onondaga	I-690 eastbound	Peat Street	Single	Deck replacement	2012
1093672	Syracuse	Onondaga	I-481 northbound	Kirkville Road	Single	Deck replacement	2012
1031529	Syracuse	Onondaga	I-81 southbound	East Calthrop Avenue	Three single	Deck replacement	2013
1031529	Syracuse	Onondaga	I-81 northbound	East Calthrop Avenue	Three single	Deck replacement	2013
1031559	Syracuse	Onondaga	I-81 southbound	East Castle Street	Three single	Deck replacement	2013
1031559	Syracuse	Onondaga	I-81 northbound	East Castle Street	Three single	Deck replacement	2013
1009290	Greene	Chenango	Route 12	Spring Brook	Single	Deck replacement	2013
1007780	Delhi	Delaware	Route 10	Webster Brook	Single	Deck replacement	2013
1024090	Newark Valley	Tioga	Route 38	Wilson Creek	Single	Deck replacement	2013
1054720	Owego	Tioga	Route 962G (Halstead Ave.)	Route 17	Two continuous	Deck replacement	2013
1004262	Colonie	Albany	Route 2 eastbound	Route 9	Single	Deck beam superstructure	2013
1004262	Colonie	Albany	Route 2 westbound	Route 9	Single	Deck beam superstructure	2013
1050821	Syracuse	Onondaga	I-690 westbound	Onondaga Creek	Three Single	Deck replacement	2013
1050910	Syracuse	Onondaga	I-690	North Salina Street	Single	Deck replacement	2013
1032622	Southeast	Putnam	I-84	Dingle Ridge Road	Single	NEXT beam superstructure	2013
1031441	Preble	Cortland	I-81	Prebble Road	Single	Deck beam superstructure	2013
5500019	Pelham	Westchester	Route 907W (Hutch)	Route 1	Single	Deck replacement	2013

Note: NEXT = northeast extreme tee beam.

Installation of precast concrete deck system on Route 23 over Otego Creek in Oneonta, N.Y., completed in 2009. The pockets open to the top surface were used to install studs for the shear connection. Courtesy of NYSDOT.

develop methods of accelerated construction with little or no cost premium. A reduction in cost would make it even more attractive.

Most of the bridge-related construction in New York State falls into three categories:

- full replacement of existing bridges
- partial replacement of existing bridges
- rehabilitation of existing bridges

To provide benefits in all of these areas, NYSDOT has devoted the most attention to developing accelerated construction methods in deck and superstructure replacements. Cost reduction or containment was one of the main objectives.

One of the main reasons for the higher cost of accelerated construction over conventional construction is the need for costly materials and hardware, such as UHPC; high-performance concrete; grouted sleeves for splicing reinforcing bars; mechanical connectors; and waterproofing membranes. Although NYSDOT has little control over the cost of these items, it can limit their use.

NYSDOT developed deck panels using low-permeability, high-performance concrete and joints with UHPC. NYSDOT decided not to expend additional resources to place an expensive membrane and overlay over these decks, instead simply diamond grinding to finish the deck surface.

Showing the layout of precast concrete panels in the contract document is the common practice today. Because the capabilities of the contractor and the fabricator of the panels are not known during the contract plan development, the general tendency is to be conservative. Due to the emulative nature of precast concrete deck systems using UHPC joints, the panel layout and joint locations are not needed for deck design. The contractor is allowed to develop the most suitable panel layout for fabrication, shipping and handling, and final installation while minimizing the use of UHPC. The proposed layout is submitted as part of the shop drawings to be reviewed and approved by NYSDOT. As an incentive to limit costs, NYSDOT bases payment to the contractor on the finished deck area, including the UHPC in joints.

Another possible source of cost increases is the potential for penalties associated with construction delays. NYSDOT's approach to this problem was to include multiple bridge projects in a single contract with construction spanning two construction seasons. The earlier projects were less complicated and had less severe penalties for late completion. This allowed the contractors to try out their operations and gain experience before progressing to more complex projects with higher penalties. This approach also helped the NYSDOT design staff make some adjustments in the design and detailing of projects that were completed in the second construction season.

Another area of cost escalation is the degree of acceleration. NYSDOT's approach was to select the degree of acceleration appropriate for each bridge. A few had weekend closures, which tend to be the most expensive, while others had less expensive 5-day or 10-day closures. This approach allowed NYSDOT to save on costs where extreme acceleration was not necessary.

There are also some potential savings for accelerated construction, mainly from the use of prefabricated bridge elements and systems. The main areas of savings are a reduction in labor cost, automation in the fabrication process, reduced maintenance, protection of traffic, and reduced cost for environmental protection measures.

In general the NYSDOT experience shows that by selecting the right technology, increasing the experience and confidence of bridge contractors, and selecting appropriate contract provisions, the cost differential between ABC and conventional cast-in-place concrete construction can be reduced significantly.

Reduced durability mainly due to the poor long-term performance of joints between precast concrete components has been a significant problem, particularly for decks or superstructure components where deicing chemicals are used. NYSDOT has a history of using precast concrete deck systems. One of the earliest attempts was with a precast concrete deck with grouted joints. Cracking, leaking, and the resulting deterioration led to

Preparation of the girders with new studs and formwork for haunches for a three-span deck replacement on southbound Interstate 81 over East Castle Street, Syracuse, N.Y., was completed in July 2013. Courtesy of NYSDOT.

Installation of precast concrete deck panels for northbound Interstate 81 over East Calthrop Avenue, Syracuse, N.Y., completed in July 2013.
Courtesy of NYSDOT.

the use of membranes and concrete or asphalt overlays. These systems slightly improved performance but still lagged behind cast-in-place concrete decks. Overlayed decks cost more than cast-in-place decks. The next major attempt was to use precast concrete deck systems with posttensioning. This reduced the leaking of the joints, but overlays and posttensioning further increased the cost differential.

NYSDOT investigated other ways of solving this problem. The use of UHPC for field cast joints emerged as a potential solution. UHPC has high compressive and tensile strengths, crack resistance, low drying shrinkage, super low permeability, and high freeze-thaw resistance, making it suitable for deck panel joints. UHPC is also capable of developing reinforcing bars at a fraction of the needed length in conventional concrete. NYSDOT determined in early 2008 that UHPC joints held great promise and decided to proceed with testing this application in the lab as well as in the field.[1]

By that time, the Ontario Ministry of Transportation had completed a trial application of UHPC as deck panel joining material.[2] The FHWA was testing UHPC and exploring potential applications. NYSDOT discussed the possible use of UHPC with FHWA and came up with a plan to conduct testing of precast concrete panels joined with UHPC. NYSDOT designed the joints. Test specimens were prepared with cooperation from the precast concrete industry and a UHPC supplier and were shipped to Turner Fairbank for testing. Details of these tests and the results are reported elsewhere.[3]

In addition to the laboratory testing, two field applications were also developed. The first, the reconstruction of the bridge carrying Route 31 over the Canandaigua Outlet (BIN 1021750) in Lyons, N.Y., was completed in June 2009. This structure is 85 ft (26 m) long from centerline of bearings to centerline of bearings and 42.75 ft (13.03 m) wide (out to out), with a 15 degree skew, and carries two lanes of traffic and two shoulders. The bridge used eight precast concrete deck bulb tee beams for the superstructure. The beams were modified from standard shapes by increasing the top flange width and thickness sufficiently to eliminate the need for a separate concrete

The precast concrete deck panels on westbound Interstate 690 over Crouse Avenue in Syracuse, N.Y., completed in 2012, have been installed and the deck surface geometry has been checked. Courtesy of NYSDOT.

deck slab. The adjacent beams were joined with longitudinal closure joints at the edge of the top flange using UHPC.

The second project was a precast concrete deck for a replacement bridge with a steel girder superstructure. This project mainly focused on developing the deck system rather than accelerating the construction. This replacement bridge on Route 23 over Otego Creek (BIN 101 7580) in Oneida, N.Y., had a 130 ft (40 m) span and 42.5 ft (13.0 m) width with integral abutments and no skew. The deck system used transverse and longitudinal UHPC joints. Composite connection of the deck to the girder top flanges was established with stud shear connectors placed through pockets exposed to the top surface. Haunches and pockets were grouted with nonshrink cementitious grout. A high-performance concrete overlay was used to protect the grout pockets from moisture infiltration and provide a smooth riding surface. Construction was completed in summer 2009 without any major problems. Experience from this project gave valuable information about the feasibility of this system for accelerated construction.

The use of concrete overlays was not desirable for accelerated construction mainly due to the lengthy curing time required. Open pockets for placing the stud shear connectors necessitated an overlay. Overlays also serve to control the surface geometry and provide a smooth driving surface.

Another area that needed improvement was the rate of strength gain of the UHPC to permit opening a newly replaced deck for traffic after a weekend closure. Conventional curing takes three days at temperatures above 70°F (20°C) to reach the required compressive strength of 14,000 to 15,000 psi (97 to 103 MPa). The need for precast concrete barriers to accelerate construction was also noted during the construction of this bridge.

After the first application of precast concrete deck construction, ways to eliminate the need for overlays were considered. Diamond grinding of the top surface of the deck seemed a promising method to obtain a smooth riding surface. To ensure the durability of the deck, open pockets for stud shear connectors had to be avoided. To use hidden pockets, stud shear connectors for steel or composite shear connectors for prestressed concrete beams would have to be in place before the installation of panels. To connect the panel to the girders, transverse reinforcements are exposed in the hidden pocket. The exposed reinforcement could interfere with the studs because AASHTO[4] requires studs to penetrate at least 2 in. (50 mm) into the concrete deck.

A potential solution was to fill the pockets with UHPC. UHPC has significantly higher tensile strength than conventional concrete, and its post-crack behavior is similar to that of reinforced concrete due to strain hardening. It also has much shorter development lengths for reinforcement. Ideas for trying out studs approximately 3 in. (75 mm) long in the haunches were developed to avoid interference with the exposed deck reinforcement. NYSDOT discussed this idea with FHWA and obtained their willingness to test this approach. Test specimens were fabricated by Northeast Prestressed Products, LLC, Schuylkill, Pa., based on NYSDOT's design and shipped to the Turner Fairbank Highway Research Center. The results of these tests are documented in the report.[5]

The same detail is suitable for use with nonshrink grout for the haunches and the hidden pockets provided that the stud shear connectors are long enough to project above the transverse reinforcing bars in the pockets.

In addition, the FHWA tested UHPC with accelerated strength gain. One approach was to cure it at higher temperatures. They found that compressive strengths of 12,000 to 15,000 psi could be achieved by curing UHPC at about 110°F (43°C) for 12 to 14 hours. This rate of strength gain was sufficient for application of UHPC joints for weekend construction.[5]

After careful evaluation of the information gathered during the construction of the two projects using UHPC and the results of the laboratory testing of the UHPC joints and composite connection between the precast concrete panels and girders with hidden pockets filled with UHPC, NYSDOT decided to implement this technology on a larger scale.

Depending on the inconvenience to the users of each structure, different degrees of acceleration were chosen. Deck replacements for most of the bridges carrying interstate highways used weekend closure of all lanes in one direction, with detours routed through local streets. For bridges carrying Interstate 81, where two nearby bridges had their decks replaced, a 5-day closure for two bridges in one direction was used. For deck replacements for bridges carrying other highways, short-term closures ranging from 4 days to 10 days were chosen.

Intersection of transverse and longitudinal joints partially filled with ultra-high-performance concrete. Courtesy of NYSDOT.

Accelerated curing of UHPC using external heating to raise the deck temperature above 100°F (38°C) was used for weekend closures. ASTM C1074-11[6] was used to measure the strength when accelerated curing was employed. Maturity curves, time versus strength gain curves for temperatures 80, 90, 100, 110, and 120°F (27, 32, 38, 43, and 49°C) were developed for the UHPC supplier by an AASHTO-approved independent testing laboratory for the proposed UHPC mixture. Based on these curves, internal curing temperatures between 100 and 110°F would provide compressive strengths of 12,000 to 14,000 psi (83 to 97 MPa) in 14 to 15 hours. Thermocouples were installed in the UHPC joints prior to placement to measure the internal temperature at key locations during curing. The strength was determined from the maturity curves. The deck replacements, which had longer closure times, did not use accelerated curing because the UHPC gained sufficient strength within two to three days. Artificial heating was also used for two emergency bridge replacements on Route 42 over the Westkill River. These replacements were done on a compressed schedule during winter. The use of precast concrete decks with UHPC joints worked well in winter conditions.

Superstructure construction using deck bulb tees, northeast extreme tees, or deck beam superstructure elements used varying degrees of acceleration based on project requirements. None of these projects used accelerated curing with external heating because with the early strength gain it was not necessary. UHPC can reach compressive strengths of 12,000 to 14,000 psi within 24 hours at temperatures of about 80°F (27°C). External heating should be used only when essential. In addition to the added cost, thermal expansion of steel girders puts pressure on the joints, causing minor leakage in heavy rain. This problem was dealt with by sealing the joint interface with methyl methacrylate. For later projects, external heat was applied to the girders a few hours before placing UHPC in the joints to expand the girders before joint placement. In addition, the interface surfaces of the precast concrete components had an exposed aggregate finish to enhance the bond between the panel and the UHPC. The interfaces of the precast concrete panels were conditioned to saturated surface dry before placement of the UHPC. Inspection after significant rainfall found no leakage through the interface of joints prepared using these procedures.

Almost all accelerated deck replacements completed during 2012 and 2013 used a full-depth precast concrete deck system. This approach lowers cost by avoiding membranes and asphalt overlays, is feasible for accelerated construction, saves time, reduces dead load (which could be critical for some existing structures), and eliminates the need for future replacement of overlays.

Diamond grinding of the entire deck provided a smooth riding surface. The precast concrete panels had an additional $^1/_2$ in. (13 mm) sacrificial thickness to allow for grinding. The overall surface quality after grinding has been superior to that of cast-in-place concrete decks. During mixing and placement, some air was entrapped in the UHPC. It floated to the surface soon after placement, resulting in settling of the top surface. This problem was dealt with by overfilling the joints by about $^1/_4$ in. (6 mm). Use of a top form for the joint was also necessary to keep the UHPC, which is highly flowable, from running out at the lower ends.

The NYSDOT specification[7] requires the contractor to have a technical representative of the UHPC supplier present to make sure that mixing, quality control testing, and placement of the material is done properly. Because this is a high-performance material, proper control in all of these areas is important to achieve the required performance.

Various additional projects involving full replacement, superstructure replacement, and deck replacement are at different stages of completion, and a few projects are in the design stage. Other state highway agencies have started using UHPC joints for accelerated bridge construction. Based on NYSDOT experience, the use of prefabricated components with UHPC joints offers a valuable solution for replacing or rehabilitating aging infrastructure.

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Abstract

Deployment of ultra-high-performance concrete (UHPC) for accelerated bridge construction in the state of New York has proceeded step by step. The New York State Department of Transportation has collaborated with the Federal Highway Administration and private companies to develop, test, and implement this technology. Contracts allow erectors to develop their skills on simpler projects before working on more complex ones. UHPC joints permit accelerated repair and replacement of bridges without sacrificing durability.

Keywords

Accelerated bridge construction, joint, rehabilitation, repair, replacement, UHPC.

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