ABC MODULAR BRIDGE PROJECT- DESIGN AND CONSTRUCTION

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BIOGRAPHY

Michael D. LaViolette is a principal bridge engineer and senior project manager in HNTB's Omaha office. He received BSCE and MSCE degrees from Iowa State University and has over 19 years of experience in complex bridge design and construction. He is currently leading the design and construction of a 400 ft span tied arch bridge for the U.S. Navy in Manama, Bahrain

Ahmad Abu-Hawash is the Chief Structural Engineer with the Iowa Department of Transportation. Ahmad received his BS degree in Civil Engineering from the University of Iowa and his MS degree in Structural Engineering from Iowa State University. He has been working with the Iowa DOT in highway construction, bridge rating, and bridge design since 1983. His current responsibilities include overseeing the design of major bridge projects, design policies review, coordination of bridge research, and the resolution of structural fabrication issues.

SUMMARY

As part of an ongoing, four-year study entitled SHRP 2 R04 Innovative Bridge Designs for Rapid Renewal under the Strategic Highway Research Program, the project team has designed a demonstration bridge that incorporates proven details with the innovative use of a modular steel superstructure and Ultra-high Performance Concrete (UHPC) to shorten the normal bridge replacement period of six months down to only 2 weeks of traffic disruption.

The demonstration bridge features precast concrete semi-integral abutments, precast columns and pier caps connected with high-strength grouted couplers, and a superstructure constructed using prefabricated concrete decked, steel stringer units and field–cast UHPC joints. The enhanced durability provided by the elimination of all open deck joints is seen as a major advance in long-life ABC projects.

ABC MODULAR BRIDGE DEMONSTRATION PROJECT DESIGN AND CONSTRUCTION

Introduction

The continual deterioration of our nation's transportation infrastructure is forcing highway departments, designers and contractors to develop innovative strategies for rapid renewal. Gone are the days of building one bridge at a time using conventional methods. According to research by Sivakumar, every department of transportation in the nation has hundreds if not thousands of bridges that need rebuilding[1].

The US Highway 6 Keg Creek Bridge design is an accelerated bridge construction (ABC) project in the renewal research focus area of the Strategic Highway Research Program Phase 2 (SHRP 2), a congressionally funded program that is tasked with finding innovative ways to save lives, reduce congestion and improve quality of life on America's roads and highways. The program includes 92 projects overall and four areas of research: reliability, renewal, capacity and safety. The program is sponsored by the Federal Highway Administration in cooperation with the American Association of State Highway & Transportation Officials.

This paper presents the design and construction of a demonstration bridge that utilizes proven structural details drawn from bridges across the US and combined into a single project that reduces the construction time from approximately six months down to only two weeks of traffic disruption. The demonstration bridge incorporates proven ABC bridge construction details with the innovative use of Ultra-high Performance Concrete (UHPC) to shorten a normal bridge replacement period.

The demonstration bridge, which features a modular steel/concrete hybrid superstructure and a series of precast concrete substructure components which are connected using high-strength grouted couplers. This bridge is the first in the US to be constructed as a multiple-span continuous bridge by combining field-cast UHPC joints with simple span bridge modules that can be erected with moderate sized cranes. The enhanced durability provided by the elimination of all deck joints is seen as a major advance in long-life ABC projects.

SHRP 2 R04 Project Summary

The current project is part of HNTB's four-year research project under the Strategic Highway Research Program (SHRP 2) and is entitled SHRP 2 R04 Innovative Bridge Designs for Rapid Renewal. This work is sponsored by Federal Highway Administration in cooperation with the American Association of State Highway and Transportation Officials, and is administered by the Transportation Research Board of the National Academies.

As part of this work, the team has met with nearly every state Department of Transportation (DOT) chief bridge engineer to understand and document their most critical ABC project requirements, gathered and evaluated proven ABC bridge details from over 200 projects and sources around the world, and developed a series of innovative ABC construction concepts that can be implemented to construct bridges in either a few days or a few weeks depending on project requirements, available construction space and project cost limitations.

In addition, the team is currently developing standardized ABC bridge details, design examples and AASHTO LRFD design and construction provisions that will govern the use of ABC projects for years to come. The team is also currently developing training materials for the National Highway Institute so that the best ABC practices from around the world will be distributed to bridge owners across the US.

Demonstration Bridge Summary

The project is located in Pottawattamie County, IA, approximately 6 miles east of Council Bluffs. The bridge carries US Highway 6 over Keg Creek and replaces an existing cast-in-place concrete tee-beam bridge. The previous 180' x 28' continuous concrete girder bridge (FHWA # 043230) was constructed in 1953 and was classified as structurally deficient with sufficiency rating of 33. This location currently carries about 4000 vehicles per day. The original bridge is shown in Figure 1.

Figure 1. Previous US 6 bridge over Keg Creek.

The research team designed a modular bridge that can be constructed with only two weeks of traffic disruption as opposed to the normal five to six month construction duration and thus greatly reduced the need to divert traffic over gravel road detours. The ABC bridge is designed so that a skilled contractor can construct the bridge with nothing more than ordinary cranes and equipment. A photo of the completed ABC demonstration bridge is presented in Figure 2.

Figure 2. Completed ABC Demonstration Bridge

Innovations In Demonstration Project

The overall objective of the SHRP 2 R04 Project is to identify and develop innovative bridge designs for rapid renewal (accelerated bridge construction). In meeting this objective, the broad scope focuses on developing standardized approaches for designing, constructing, and reusing (including future widening) complete bridge systems that address rapid renewal needs and efficiently integrate modern construction equipment.

In achieving the goals of this demonstration project, a series of innovative bridge details were used. However, it should be noted that virtually all of the innovative structural components have been proven through research, testing and application in previous projects from Utah, New York, Wisconsin and Iowa.

A unique feature of the proposed bridge is that is incorporates details drawn from these diverse locations and applies them in a single demonstration project that was visited by DOT and Federal Highway Administration (FHWA) staff from numerous states. A day-long workshop was held on October 28, 2011, providing an ideal opportunity to promote the dissemination of information to bridge owners around the country.

Innovations include:

- Prefabricated bridge components in the form of:
    - Modular steel beam/precast concrete deck superstructure units
    - Superstructure units which incorporate precast suspended backwall elements to create a semi-integral abutment
    - Precast concrete pier caps and abutment footings

- Precast concrete bridge approach panels. For each of these prefabricated bridge components, a project special provision was developed to clearly define suitable materials and construction processes.

- UHPC will be used in the joints between the modular superstructure units. Under past projects, a longitudinal superstructure joint consisting of UHPC material has been developed and tested by New York State DOT (NYSDOT) to provide a durable, moment-resisting joint between deck panels. The project will be the first in the US to use UHPC to provide a full, moment-resisting transverse joint at the piers. This detail will allow the superstructure elements to be erected as a simple span and, once the UHPC joints are constructed, perform as continuous joints. As an increased measure of design conservatism, this continuity will not be included in the calculated superstructure capacity. However, the elimination of open deck joints will provide for a more durable, low-maintenance structure in the final condition.

- A Structural Health Monitoring System (HMS): A monitoring plan will be implemented to evaluate and document the innovative aspects of accelerated construction. The monitoring plan may include health monitoring instrumentations to assess the integrity of the structure and deck panel system during and after construction.

- Self Consolidating Concrete (SCC): SCC will be used to improve consolidation and increase the speed of construction for abutment piles. Abutments will consist of prismatic, precast concrete elements which feature a series of open holes which will accommodate driven steel h-piles.

- Use of fully contained flooded backfill: This proven construction method involves placement of a granular wedge behind the abutment backwall that is flooded to achieve early consolidation and significantly reduce the potential for formation of voids beneath the approach pavement.

Modular Steel Superstructure

The bridge superstructure consists of a series of six parallel superstructure modules, each of which includes two W30x99 rolled beams and a precast concrete deck. An MC 18x42.7 diaphragm was provided at each bearing location and at midspan of each module. These diaphragms provided sufficient lateral bracing for the compression flange until the precast concrete deck was placed on each module. See Figure 3.

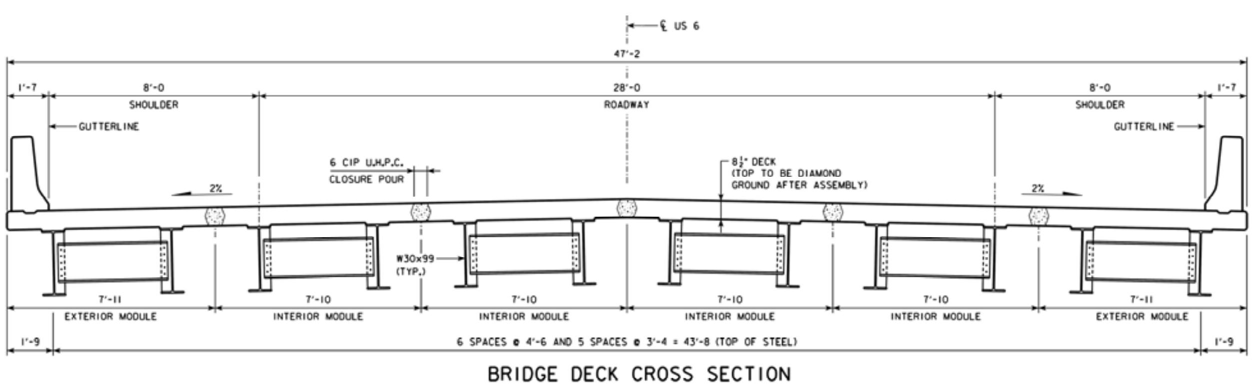

Figure 3. Bridge deck cross section

These modules were designed with sufficient capacity to function as simple spans for both dead and live load. However, in order to ensure the longest possible life for the bridge and to gain some additional structural load capacity, the modules were made continuous for live load through an UHPC closure pour over each pier.

The structural connection between adjacent spans is the most critical element in the demonstration bridge. The transverse joint at each pier was designed to provide a full moment-resistant connection to ensure continuity and will provide greater structural efficiency and durability than a series of similar simple spans. Exterior modules also include a precast concrete barrier rail that is installed prior to erecting the modules onto the permanent piers. In this way, the time for installing the barriers does not require expending time during the ABC period. See Figure 4.

Figure 4. Exterior superstructure module during shipment to bridge site

This joint consists of a bolted connection at the bottom of each rolled section which is integral with the bearings at the piers. This element is designed to carry the compression forces developed in a continuous span. The tension forces at the top of the deck are resisted by a field-cast UHPC joint that is placed after the modules are in their final position atop the piers and abutments. The design of the field-cast UHPC joints has been the subject of numerous research projects, lab tests and on-going studies at the FHWA Turner-Fairbank laboratory.

The bridge includes one fixed pier (Pier 1) which provides longitudinal fixity through a shear key as shown in Figure 5. The expansion pier utilizes similar laminated neoprene bearing pads, but does not provide a shear key at this location.

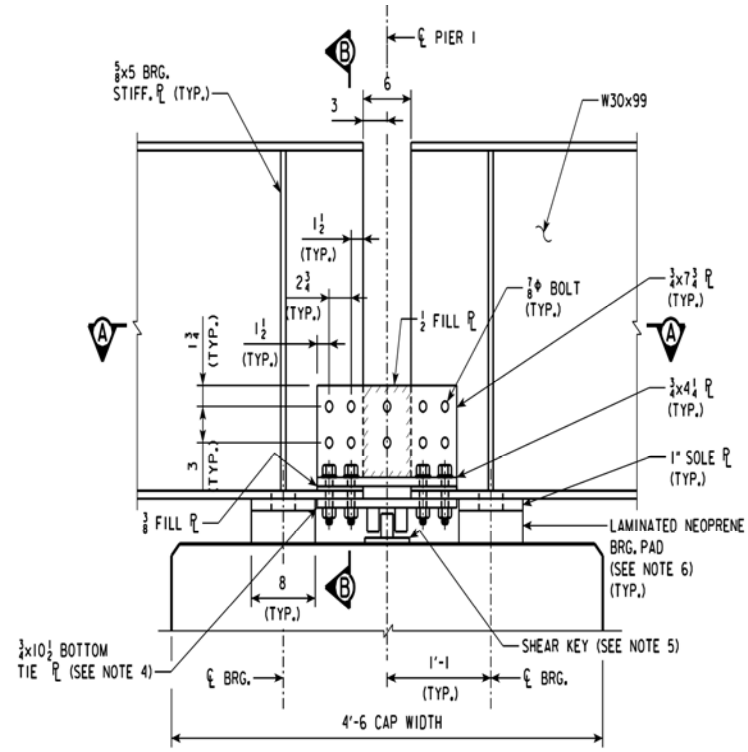

Figure 5. Structural steel connection between adjacent spans (precast deck not shown)

Steel Fabrication and Assembly

In order to prepare for the 14-day ABC period during which the existing bridge would be demolished and replaced, the contractor performed a number of off-line operations that could be completed without impacting the traffic on Highway 6. Each of these operations will be briefly discussed in the following sections.

Structural steel fabrication for the bridge was performed by DeLongs of Jefferson City, MO. During the shop drawing phase of the project, the contractor elected to construct the steel rolled beams without camber to simply the fabrication. Although the deadload deflection due to the deck concrete would cause a visible "sag" in the bottom flange, given the rural location of the project site, this was not seen as objectionable. The contractor simply adjusted the haunch depth of the precast concrete deck to account for the lack of beam camber.

The contractor assembled the structural steel on timber falsework in the assembly yard immediately adjacent to the bridge. This falsework was constructed with the exact geometry of the permanent piers including the same capbeam cross-slope and elevation differences between piers and abutments. See Figure 6.

Figure 6. Timber falsework bents for module assembly

Structural steel assembly was performed using bolted splice plates to connect adjacent modules at the pier locations. Although the spans were designed with sufficient moment capacity to function as simple spans, the transverse deck joints are also designed with sufficient capacity to provide continuity between adjacent spans with the impermeable UHPC bonded to the precast concrete to eliminate the intrusion of water into these joints. The bolted splices provide the compression flange connection each location while the UHPC joints in the deck provide the tension connection.

The original fillet-welded connection of the splice plates at each pier were modified during construction to eliminate the need for fillet welds on both sides of the L-shaped connection plates. The double-sided filled weld was replaced with a partial-penetration weld which provides an equal capacity without the need to weld one side, flip the piece over, weld the back side and all the while work to prevent distortion.

The modules used for the end spans of the bridge include an semi-integral suspended backwall which is cast along with the precast deck concrete as shown in Figure 7. This backwall overhangs the lower portion of the abutment, eliminating the potential for leakage onto the bearing devices and also provides a supporting corbel for the bridge approach pavement.

Following installation of the superstructure modules, six - #5 reinforcing bars were fed through the overlapping hairpin bars in each deck joint. This operation required at least moderate effort and the contractor was very careful to protect the epoxy coating while the bars were slid into position. The transverse joints were rather congested and the effort to insert the bars required the use of a manlift to access the bridge fascia to start the insertion. Future projects should closely evaluate this design for improvements.

Figure 7. End span module with suspended backwall

Ultra-High Performance Concrete

According to Perry, the use of Post-Tensioning (P/T) across the joints of precast deck panels has been used as a method to ensure the deck effectively remains structurally monolithic while performing under the constant pounding of truck wheel loads and seasonal conditions, more specifically; to ensure the joint does not deteriorate or leak[3]. The use of Ultra-High Performance Concrete (UHPC) has been tested in both laboratory and field environments as a possible replacement for post-tensioning in precast concrete bridge decks.

The material's high mechanical properties are a result of proportioning the constituent ingredients to produce a modified compact grading with a nominal maximum coarse aggregate size of 400 µm, and steel fibers measuring 0.008 inch diameter x 0.5 inch long. The ratio of maximum coarse aggregate size to fiber is important to facilitate random orientation of fibers and a ductile behavior. These performance characteristics result in improved micro-structural properties of the mineral matrix, especially toughness and control of the bond between the matrix and fiber[3]. The material's ultra-high strength properties and low permeability also provide excellent protection of the rebar against corrosion and improved bond with the rebar, thereby providing short bond development lengths.

Mixing was performed by a pair of 0.5 cubic meter capacity, electric mixers positioned at the east end of the bridge. The component materials for each batch were provided in bulk packages – an 1800 pound "super sack" of powder mix and three boxes of steel fibers. In addition to the dry ingredients, water and the required admixtures were carefully weighed using a digital scale.

UHPC was transported to the bridge using several mobile "Georgia buggies" as shown in Figure 8. The contractor fabricated plywood hoppers to minimize spillage and waste. UHPC was placed in the joints and allowed it to flow around the reinforcing steel and completely fill the joint. The contractor used strips of ¾ inch plywood on each side of the joint to allow a slight overfilling. Once the concrete was cured, the excess concrete was easily ground off by the diamond milling machine.

Figure 8. Placement of UHPC concrete for superstructure joints.

Bridge Substructure

The bridge abutment is a single piece, precast concrete barrel section with a series of hollow pockets formed by sections of corrugated metal pipe (CMP) that correspond to driven steel piles. Likewise, a pair of precast concrete wingwalls are attached in a u-configuration. After the piles are driven, the precast abutment section and wingwalls are then lowered over the piles and the annular spaces around the piles are filled with self consolidating concrete. The precast pieces were temporarily supported on 12" thick unreinforced concrete pads until the SCC had gained 3000 psi compressive strength.

In order to eliminate the maintenance and backfill erosion that is associated with an expansion joint at the abutments, the bridge was designed with a semi-integral, suspended backwall that is cast along with the superstructure module deck concrete. This type of abutment offers another advantage for ABC projects in that the superstructure can be installed without regard for the ambient temperature at the time of construction. The superstructure modules are supported on neoprene bearings atop the barrel section.

The piers consist of 6-foot diameter drilled shafts on 43-foot centers with precast concrete pier columns and capbeams. The drilled shafts are located outside the footprint of the existing bridge and were installed prior to the closure of the roadway.

Precast concrete columns were connected to the top of the drilled shafts by means of a grouted coupler system. A set of dowel bars protrude from the top of the drilled shaft and are mated to a series of cylindrical couplers that are cast into the bottom end of the precast column. After the columns are erected, shimmed to the correct elevation and rigidly braced, the coupler pockets are pressure-injected with a non-shrink cementitious grout.

The precast capbeam is also composed of normal reinforced concrete. A number of precast, pretensioned and post-tensioned capbeams were investigated for use in the demonstration bridge. However, the weight savings available by using a prestressed system was not seen to offer sufficient benefit to offset the additional cost and complexity of installation. In addition, without the need for prestressing forces, the design eliminated the need to consider camber. Likewise, the precast capbeam is connected to the precast columns using a similar grouted coupler system. See Figure 9.

Figure 9. Connection of precast cap to precast column

Lab Testing And Monitoring Program

Iowa State University performed full scale lab testing for the transverse superstructure joint that provides continuity between adjacent spans. In order to simulate the loads applied by an AASHTO design vehicle, the bridge model is supported in a knife-edge at the contraflexure points on opposite sides of the pier and concentrated loads are applied to the girder bearings to simulate the reactions that will be created during truck passage. In order to facilitate the loading frame and tiedown locations in the lab, the specimen is being testing in an inverted position to facilitate the loading frame and equipment. In addition, the placement of the UHPC concrete for the joint is greatly simplified. See Figure 10.

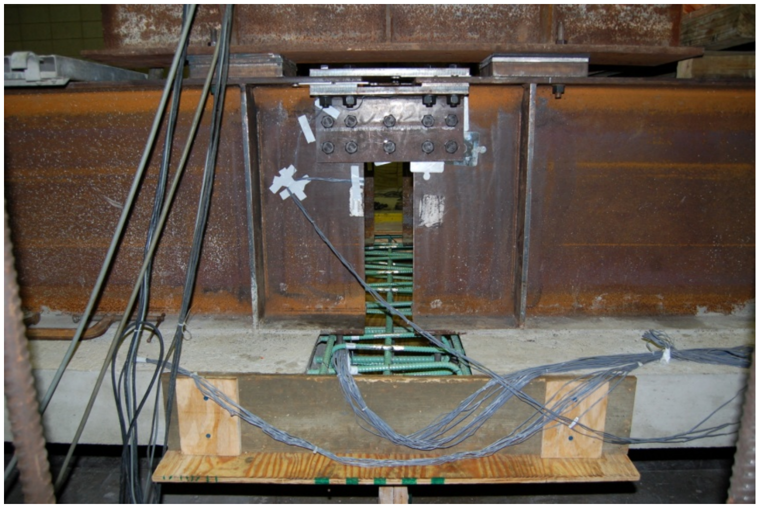

Figure 10. Full scale lab test specimen prior to placing UHPC concrete

The lab test program included 1 million cycles of truck loading followed by an ultimate load test to validate both the durability and the reserve capacity of the critical transverse joint. The full scale specimen is equipped with 45 strain sensors and 24 displacement transducers to monitor system-wide and individual element behavior during the lab testing. Cyclic load testing was completed in July 2011. Following the data analysis from the cyclic loading, an ultimate load test was conducted in August 2011 prior to construction of the demonstration bridge.

In addition to lab testing, the Iowa DOT will utilize funds through the FHWA Highways for Life program to install additional instrumentation on the actual demonstration bridge to monitor the bridge modules during casting, erection and in-service. Following completion of the bridge, a live-load test will be conducted to validate design assumptions and further document the performance of the bridge.

Although the results of the lab testing are not presented herein due to space limitations, a final report on the laboratory testing is anticipated in March 2012. Results of the lab tests, field monitoring and live load tests will be published at a future conference and in technical journals.

Post-Tensioning Retrofit

The most significant conclusion of the laboratory tests was that the bond between UHPC concrete and the precast deck concrete was not adequate to prevent the debonding of these two materials under service loads.

The design of the modules allows them to perform as a simple span without the need for connection between spans and ultimate load capacity of the modules actually exceeded design calculations by nearly 10%. However, in order to prevent intrusion of moisture into the deck, it was greatly preferable that these joint remain totally closed during service loads.

In order to avoid a potential for long-term deterioration of the deck caused by moisture intrusion, the team developed a simple, post-tensioned retrofit that could be installed after the modules were in installed and the

UHPC concrete cast. This retrofit included simple brackets mounted to the top of the beam webs, a 1 inch diameter, 150 ksi threaded rod, and anchorage hardware. See Figure 11.

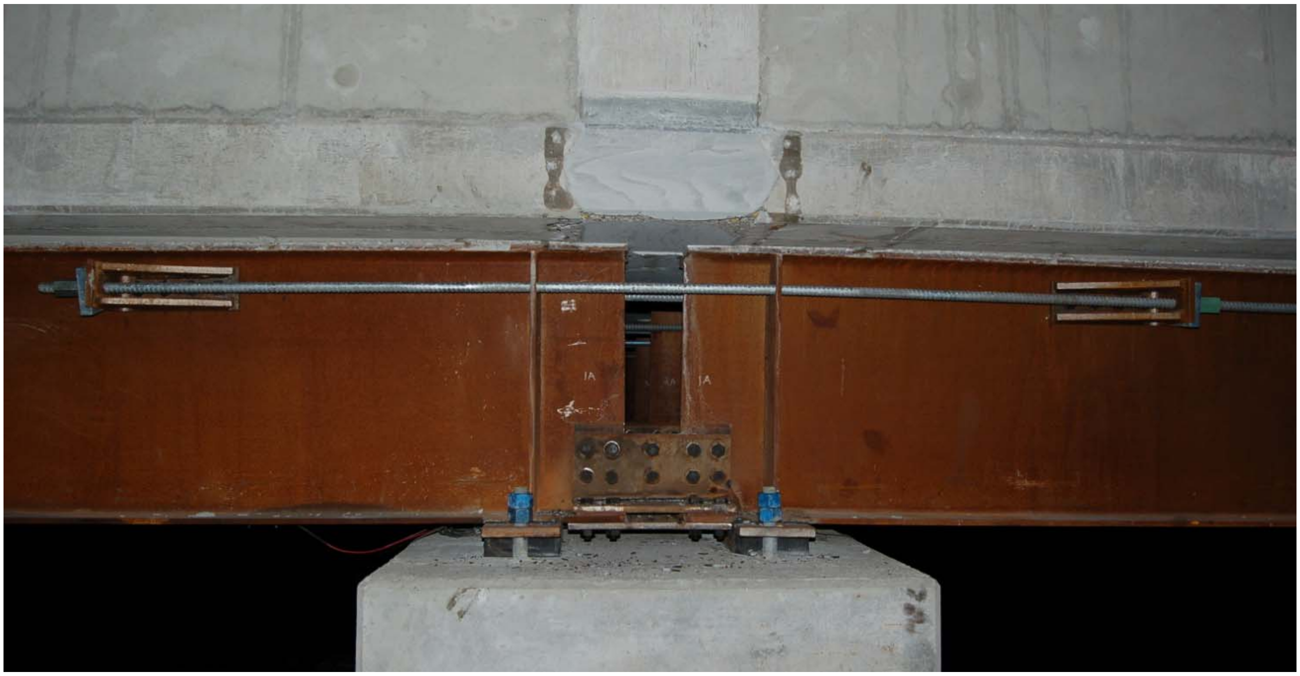

Figure 11. Post-tensioned retrofit for modules

Initially, the PT force at each rod was specified at 60 kips per rod. This force level was selected because, according to the manufacturer, it would be possible for a contractor to apply this level of force simply by applying the required torque on the anchor nuts with a torque wrench and multiplier. Following subsequent load testing at ISU, the level of post-tensioning was increased to 70 kips per rod in order to ensure that the deck joints remained fully in compression during service loads.

In addition to the post-tensioning retrofit, the team decided to provide an epoxy bond between the UHPC and precast deck concrete. Although this could not be testing in the laboratory due to time constraints, In the actual Keg Creek bridge this bond was provided through the use of Rezi-weld adhesive applied to faces of the transverse deck joints immediately prior to placement of UHPC.

Bridge Construction Progress

The Keg Creek bridge was awarded to Godberson-Smith Construction of Ida Grove, Iowa in March 2011. Bridge construction began in July 2011with the formation of an precasting and assembly area adjacent to the permanent bridge location.

The project specifications clearly defined which work tasks could be completed prior to closing the road and which tasks must be completed during the 14 day ABC period. The contractor was strictly held to these requirements in order to demonstrate that this bridge can truly be constructed during a strict time limit. A liquidated damages clause in the construction contract specified that liquidated damages of $22,000 per day would be assessed. The contractor developed a CPM schedule that allowed all of the stated items to be completed during the 14 day period – see Figure 12.

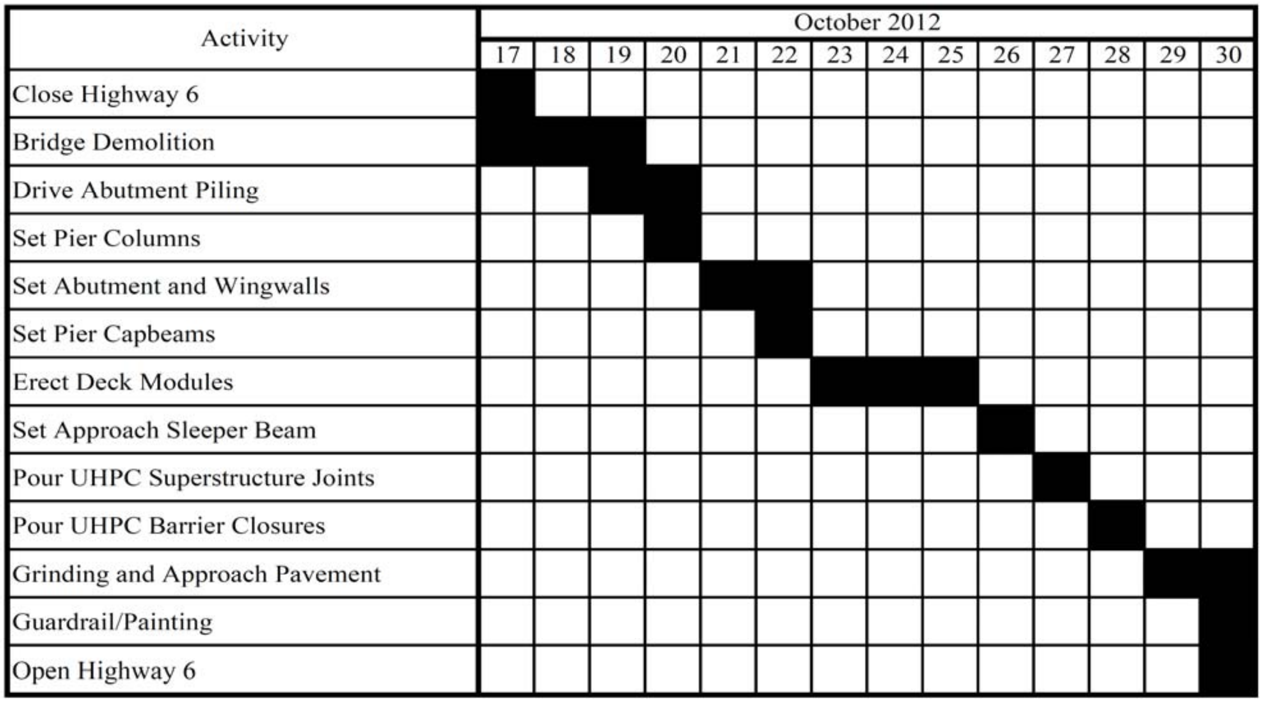

Figure 12. Contractor CPM schedule for 14-day roadway closure period

Construction of drilled shafts was the one major item of bridge structure that was able to be completed before the roadway is closed. These shafts were started in July 2011 and were completed in early August with the normal cross-hole sonic logging tests.

The contractor maintained the 14-day schedule very well throughout the ABC period – with one small exception. During the installation of the precast abutment components, the contractor discovered that a survey error had caused the west abutment piles to be installed approximately 24 inches further east than shown in the plans. Rather than spend time extracting the incorrect piles, the contractor simply ordered new piles and had them delivered to the site later the same day. The piling were redriven in the correct location and the abutments modules were reset. Although the contractor lost approximately 2 days due to the necessary rework, all other work tasks were completed within the allotted time.

Contractor working hours during the ABC period were typically 6:30 am until 8 pm unless critical operations were required to be completed in order to maintain the schedule.   The contractor was very careful to ensure that all operations requiring especially precise work, such as the lifting and placement of large bridge components were completed during daylight hours.

These working hours, especially on a 7 days per week schedule, were challenging for the onsite workers, Due to the shorter daylight hours during the fall season, the productive working hours were somewhat less than would be available during June or July. With longer working days, or even using a split shift for workers to staff the project nearly round-the-clock, it would be possible to complete the required work to replace a similar bridge in potentially fewer days, but the critical path would still be controlled by curing time for grout and UHPC joints.

The contractor did not use any unusually large or specialized equipment for the demonstration project site. At times, there were as many as seven cranes working on the site. Most cranes were of moderate size, typically 110 ton capacity. During the erection of the large abutment and superstructure module components, a large 200 ton hydraulic crane was utilized.

Two other pieces of equipment proved invaluable during the ABC period - hydraulic boom lifts and portable lighting units. The contractor commonly used as many as 6 boom lifts at any one time and often had up to 10 lighting generators available to permit safe working conditions during all hours of the day or night.

Post-Construction Review Meeting

The Iowa DOT hosted a post-construction review meeting in Ames following completion of the project and included attendees from the perspective of the owner, designer, contractor and research team. The purpose of the meeting was to review the design and construction process for the demonstration bridge and document not only the successful elements of the project, but also those aspects of the project that could be improved for future projects. The SHRP 2 R-04 research team is developing standard bridge details for this type of modular bridge and many of these suggestions will be incorporated into these standards.

Summary And Lessons Learned

Overall, the Keg Creek bridge project was a tremendous success. The bridge was completely replaced in 16 days using only conventional equipment and labor and without significant problems. All parties (owner, designer and contractor) worked closely together to resolve challenges as they arose during the ABC period. Following the post-construction review meeting, a number of "lessons learned" are summarized below:

- Structural steel offers great benefits in an ABC environment due to its lighter weight which reduces the size of cranes and equipment necessary to assemble large components.
- The use of an adjacent casting yard works very well and should be considered for future projects when space is available. Onsite prefabrication of bridge components can be performed by contractors and result in a high quality product. Onsite inspection staff should be prepared for work that is not exactly like their normal projects.
- Bolted connections for the compression flange continuity work very well. However, the details used for the bolted connection should be carefully evaluated for constructability and potential to eliminate the need for field welding where possible.
- Project special provisions should be carefully written to provide for both onsite, as well as more traditional precast concrete operations. The special provisions should describe casting, quality assurance and inspection.
- Bond between UHPC and conventional precast concrete is critical. Surface preparation prior to placement of UHPC should be performed per the manufacturer's recommendations. Future direct tension testing of bond specimens at ISU will be beneficial in understanding this condition.
- The post-tensioning retrofit was designed and installed on very short notice, but provides a simple means of adding additional reliability to the UHPC joints, along with supplemental ultimate load capacity.

- Joint reinforcement using hairpin bars should be carefully evaluated for future projects. It may be possible to simplify this joint construction by using headed reinforcing bars or mechanical couplers that would allow these joints to be more easily constructed. Bars should be staggered and projecting bars potentially shortened if possible.
- Surveying is a critical element of fast-track bridge replacement projects. In order to avoid critical and time-consuming errors, two sets of independent survey should be used to verify accurate pile driving during the ABC period.
- Precast approach pavement may not be the most efficient means of connecting an ABC bridge to the adjacent roadway. It may be faster to place a section of cast-in-place approach concrete using accelerators since a small closure pour will almost inevitably be needed in any case.
- Consider providing additional isometric views to plans to allow contractor and inspection personnel to better understand how the bridge components fit together.
- Although it was not needed on this project, the Contractor should have a backup plan in the event that a bridge component is damaged during ABC period. At the very least, a repair plan should be agreed upon in advance.
- Carefully consider overlapping hairpin bars in superstructure module joints and barrier rail bars. A slight adjustment of the barrier hairpins in the field was required prior to fitup of modules.

Conclusions

The recently completed SHRP 2 R-04 demonstration bridge near Council Bluffs, Iowa is the culmination of a four-year study of accelerated bridge construction technology. The bridge incorporates tested and proven details from bridge projects across the United States.

An ongoing phase of the research is the development of standard ABC details that can be incorporated by bridge owners for future project. In addition, the research team is currently developing AASHTO design and construction specifications that can be specifically applied to ABC projects.

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