ABC MODULAR BRIDGE DEMONSTRATION PROJECT DESIGN AND CONSTRUCTION

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ABSTRACT

Under an comprehensive 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 ABC bridge construction details with the innovative use of 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 an innovative modular 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 and the assembly of precast units without the need for any post-tensioned connections avoids the need for specialized contractors.

The use of UHPC is particularly notable in the demonstration bridge project. UHPC joints will be used for both the longitudinal joints between adjacent modules as well as the moment-resisting transverse superstructure joints at each pier. 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. Construction of the demonstration bridge will be completed in summer 2011.
The paper presents a summary of the overall project along with the design of the UHPC superstructure joints and construction progress of the demonstration bridge.

Keywords: Accelerated bridge construction, UHPC, modular, continuous span

INTRODUCTION

The overwhelming, widespread 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. These days, every department of transportation in the nation has hundreds if not thousands of bridges that need rebuilding[1].

The U.S. 6 Bridge design is an ABC project in the renewal research focus area of 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. SHRP 2 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 6 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 of six months down to only 2 weeks of traffic disruption. The demonstration bridge, which features precast concrete semi-integral abutments, precast columns and pier caps connected with high-strength grouted couplers, and an innovative modular steel/concrete hybrid superstructure. This bridge is the first in the US to construct 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 a four-year research project under the Strategic Highway Research Program (SHRP2) 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.

HNTB is currently leading a comprehensive four-year study for the National Academy of Science under the Strategic Highway Research Program entitled SHRP 2 R04 Innovative Bridge Designs for Rapid Renewal.

As part of this work, the HNTB team has met with nearly every state 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.

The next phases of the project include laboratory testing of the critical field-cast UHPC continuity joints to ensure its long-term reliability and ultimate load capacity. In addition, the HNTB 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 HNTB team will also be 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.

TIERED APPROACH TO ACCELERATED BRIDGE CONSTRUCTION

Approaches to ABC typically focus on the use of bridge-movement technology to move completed bridges into place or use of prefabricated elements to construct in place. In addition to focusing on design and construction technology, the research team has defined three tiers of ABC projects based on the duration of traffic closure. Total project completion time frames, which do not affect traffic, may be longer. A Tier 1 project is one that can be completed over a weekend closure, usually requiring some sort of bridge-movement technology (launching, sliding, etc.). A Tier 2 project is one that can be delivered within sone month. Finally, a Tier 3 project is defined as a large reconstruction contract in which the application of ABC design and construction technology will reduce the overall project schedule and user impacts by months or even years.

Many of the recent ABC demonstration projects around the country have consisted of Tier 1 projects using heavy-lift technology, such as SPMTs or other methods, to replace an entire bridge over a short time. However, far more project sites are suitable for use with more conventional equipment and contractor expertise. Therefore, a bridge was selected that more closely represents an average bridge that could be located in any jurisdiction across the country and can be constructed by a skilled contractor using conventional equipment.

DEMONSTRATION BRIDGE SITE SELECTION

The most significant part of Phase 3 of the project required the construction of a demonstration bridge that utilized the most promising bridge details identified earlier in the research. The Iowa Department of Transportation has significant experience in accelerated bridge construction including projects on both the primary and secondary road system.

A challenge in identifying this type of demonstration project is often presented when the project must be constructed in line with both the owner's program schedule and the research team's schedule to deliver a project. The research team identified a project that met both of these critical objectives.

The U.S. 6 Bridge was chosen as the SHRP 2 ABC demonstration test project for several reasons. The SHRP 2 team was looking for a project that met several criteria. It needed to be a project that was ready for construction in 2011, met a certain size and span configuration that was representative of typical bridge replacements needed across the state and was a project that needed to be built quickly, with as little disruption to traffic as possible.

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 existing 180' x 28' continuous concrete girder bridge (FHWA # 043230) was constructed in 1953 and is currently classified as structurally deficient with sufficiency rating of 33. This bridge currently carries about 4000 vehicles per day. Although not an especially heavily-travelled roadway, the owner preferred not to construct this demonstration bridge in a location that truly necessitated accelerated construction.

Figure 1. Existing US 6 bridge over Keg Creek.

At the time the project site was identified, a replacement bridge was already being designed by the Iowa DOT Office of Bridges and Structures. They identified a conventional, three span prestressed concrete beam bridge with spans of 81 ft- 48 ft- 81 ft. This rather unusual span configuration was necessitated by the need to avoid conflict with the existing pile footings.

The research team designed a modular bridge that can be constructed with only two weeks of traffic disruption as opposed to the normal 6 month construction duration and 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 rendering of the ABC demonstration bridge is presented in Figure 2.

Figure 2. Rendering of ABC demonstration bridge

INNOVATIONS IN DEMONSTRATION PROJECT

The overall objective of the SHRP2 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 projects around the US (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 will be visited by DOT and FHWA staff from numerous states. A day-long workshop, including a site visit, is scheduled for September 2011 to provide 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 precast concrete deck / steel beam 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 provison was developed to clearly define suitable materials and construction processes.

- Ultra High Performance Concrete (UHPC): 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 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

ULTRA-HIGH PERFORMANCE CONCRETE

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].

In the US, many bridge owners remain reluctant to utilize post-tensioning in bridge decks for a number of reasons including: cost, the need for specific design and construction expertise and equipment, potential for corrosion and difficulty in future inspection and maintenance of the tendons. 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 x ½" in size. 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].

Developed in France during the 1990s, ultra high-performance concrete (UHPC) has seen relatively limited use in North America. UHPC consists of fine sand, cement, and silica fume in a dense, low water-cement ratio (0.15) mix. Compressive strengths of 18,000 psi to 30,000 psi can be achieved, depending on the mixing and curing process. The material has a low permeability and high durability. To improve ductility, steel or polyvinyl alcohol (PVA) fibers (approximately 2% by volume) are added, replacing the use of mild reinforcing steel. For this project, the patented mix Ductal®developed by Lafarge North America was used with the steel fibers[4].

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.

BRIDGE DESIGN

The bridge consists of three spans, each 70 feet in length. A detailed description of the bridge is provided in following section.

The bridge abutment is a single piece, precast concrete barrel section with a series of hollow pockets that correspond to driven steel piles. Likewise, a pair of precast concrete wingwalls are placed in a u-configuration. After the piles are driven, the precast abutment section and wingwalls are lowered over the piles and the annual spaces around the piles are filled with self consolidating concrete. The precast pieces are temporarily supported until the SCC has gained 3000 psi compressive strength. See Figure 3.

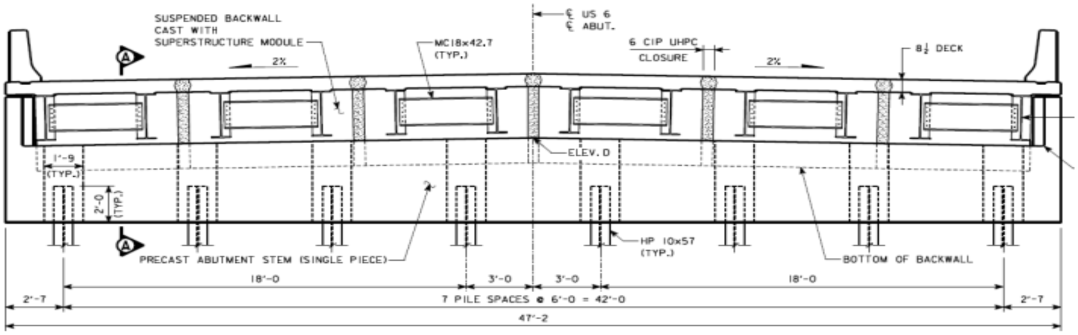

Figure 3. Typical section through precast abutment backwall

In order to eliminate the maintenance and backfill erosion that is associated with an expansion joint at the abutments, the bridge is designed with a semi-integral, suspended backwall that is cast along with the superstructure module deck concrete. The abutment is supported on a neoprene bearing atop the barrel section. See Figure 4.

This type of abutment offers another advantage for ABC construction in that the superstructure can be installed without regard for the ambient temperature at the time.

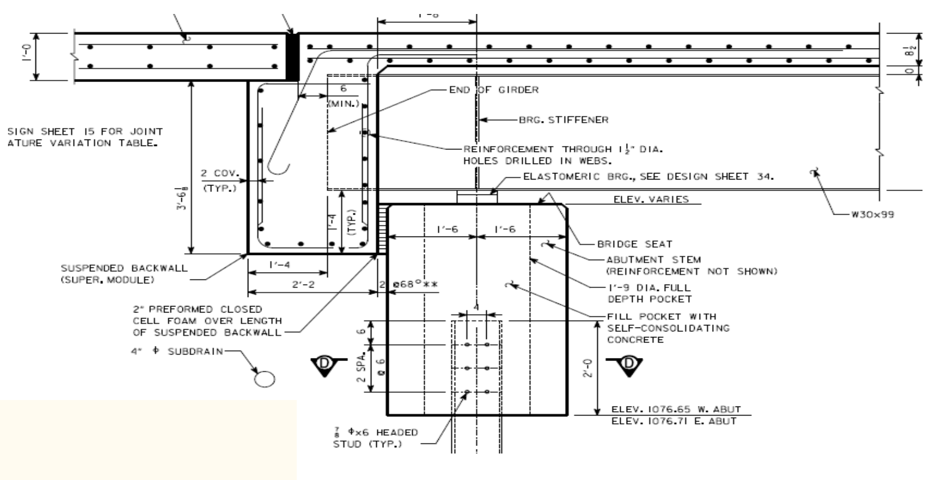

Figure 4. Precast abutment with suspended backwall

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 so that can be installed prior to the closure of the roadway. See Figure 5.

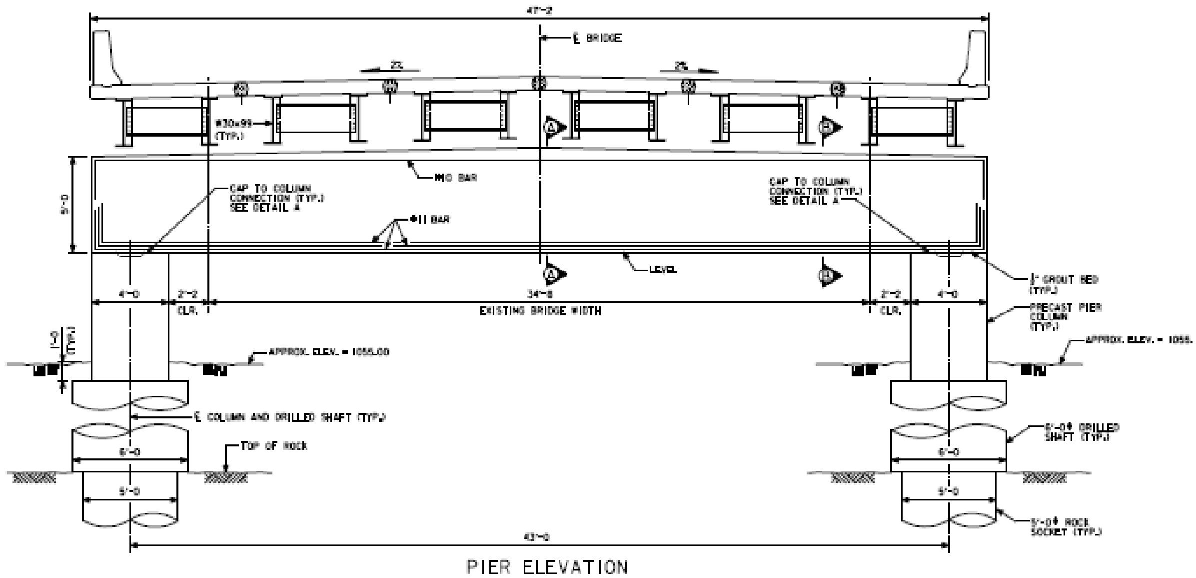

Figure 5. Typical section through pier

Precast concrete columns are 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 recessed pockets that are cast into the ends 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. See Figure 6.

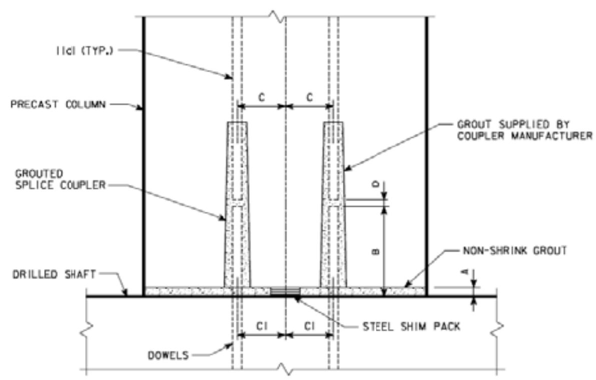

Figure 6. Grouted splice coupler details

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 prestresing 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 7.

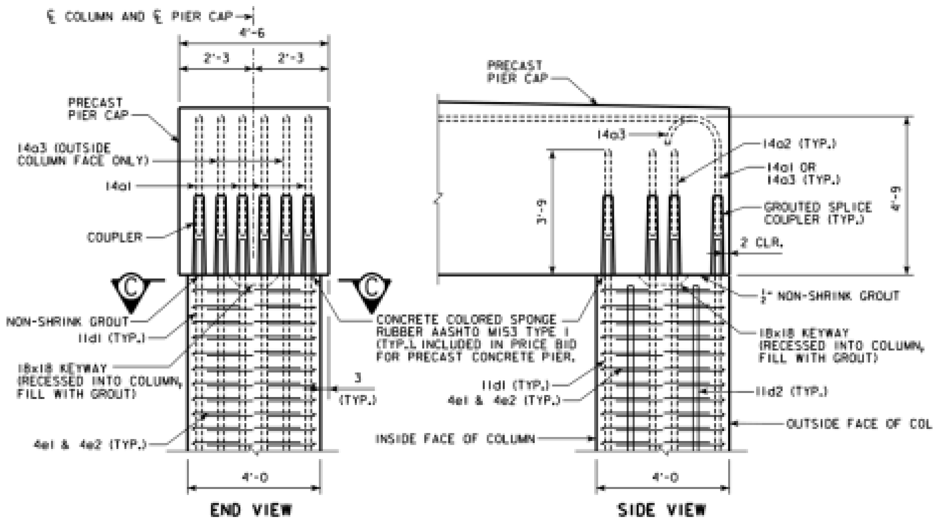

Figure 7. Connection of precast cap to precast column

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. The 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 8.

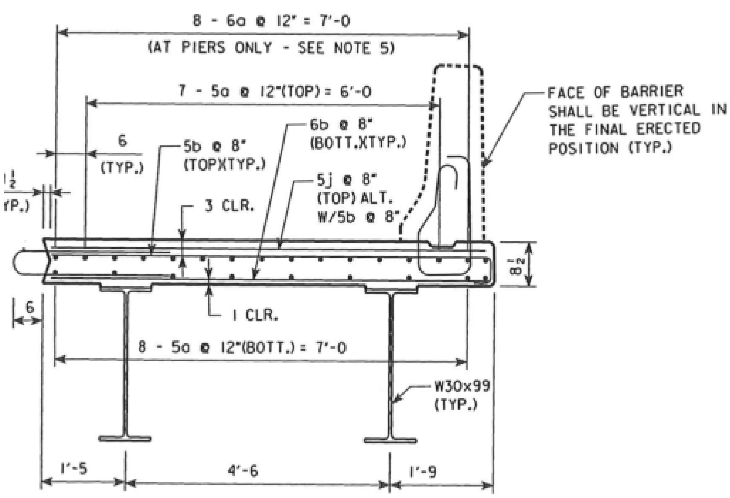

Figure 8. Section through exterior superstructure module

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. See Figure 9.

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.

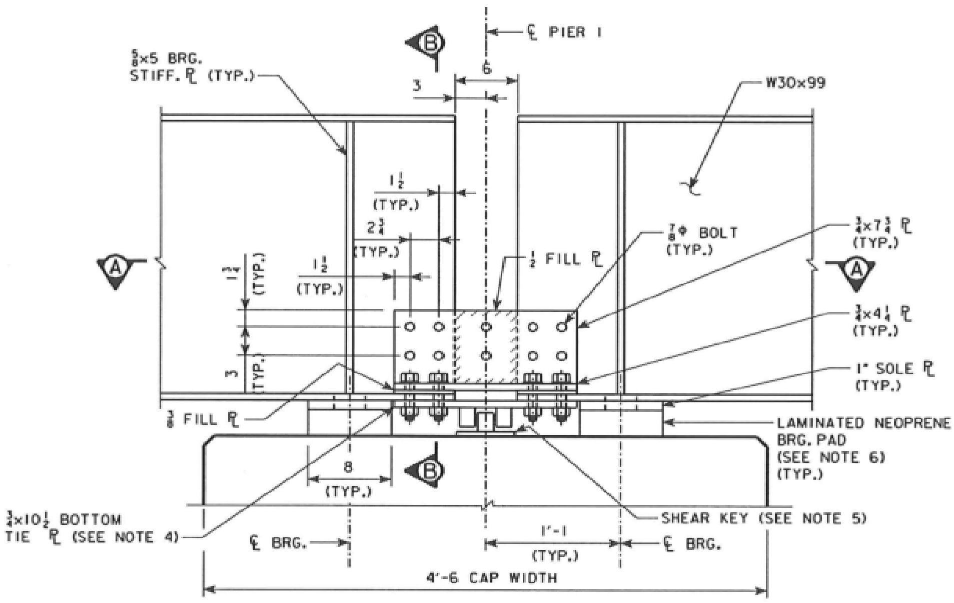

Figure 9. Structural steel connection between adjacent spans

LAB TESTING

Iowa State University is currently performing 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.

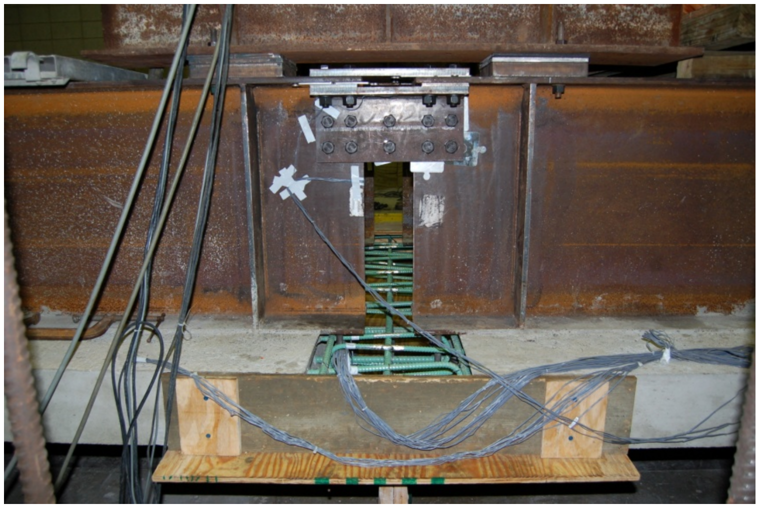

Figure 10. Full scale lab test specimen prior to placing UHPC concrete

The lab test program includes 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 conducted in July 2011 and will require approximately 2 weeks to complete. Following the data analysis from the cyclic loading, an ultimate load test will be 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.

Due to publishing requirements, it was not possible to include the results of the lab testing were not available for inclusion in this paper. Results of the lab tests, field monitoring and live load tests will be published at a future PCI National Bridge Conference.

BRIDGE CONSTRUCTION PROGRESS

The Keg Creek bridge was awarded to Godberson-Smith Construction of Ida Grove, IA in March 2011. Bridge construction began in July 2011 and is scheduled to be completed by early November.

Construction of drilled shafts is the one major item of bridge structure that can be completed before the roadway is closed. These shafts were started in July 2011 and should be completed in early August.

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 will be strictly held to these requirements in order to demonstrate that this bridge can truly be constructed during a strict time limit. A significant liquidated damages clause in the construction contract was established to encourage compliance. The contractor developed a CPM schedule that will allow all of the stated items to be completed during the 14 day period – see Figure 11.

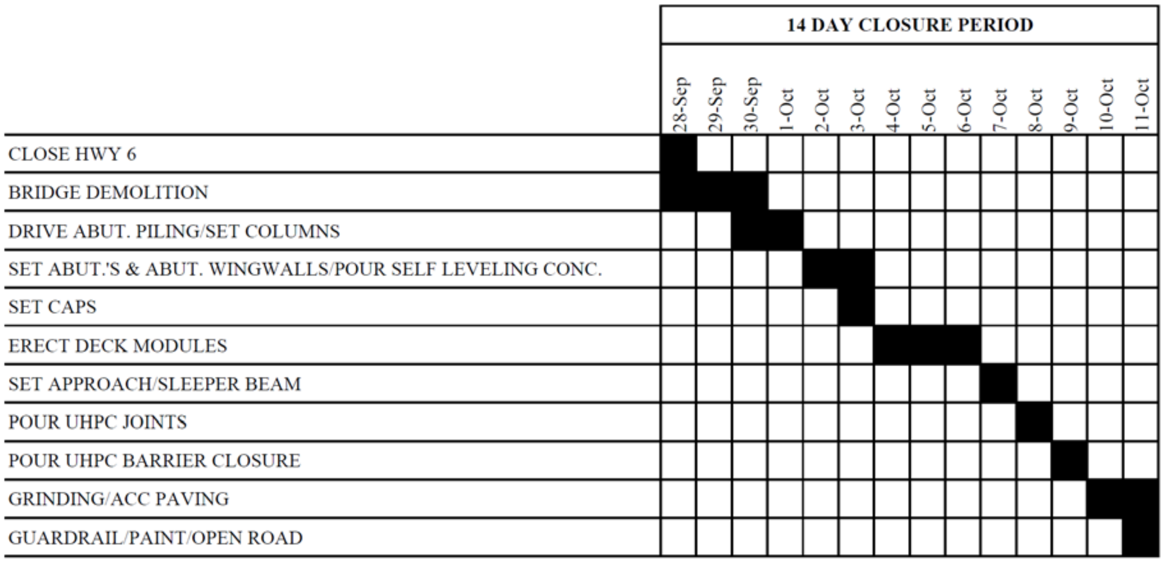

Figure 11. Contractor CPM schedule for 14-day roadway closure period

CONCLUSIONS

The SHRP demonstration bridge, currently under construction 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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