RAPID REPLACEMENT OF US 6 BRIDGE USING PRECAST SUBSTRUCTURES

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ABSTRACT

The 210 ft. long three-span bridge over Keg Creek in Council Bluffs, Iowa is a three-span prefabricated Composite Modular Bridge with precast substructures and precast bridge approaches. The deck consists of pre-decked steel modular system with precast barriers. The bridge was designed using Accelerated Bridge Construction (ABC) techniques. In the ABC design the contractor was allowed to fabricate the modular superstructure units, precast substructure components consisting of two precast piers, precast abutments and wingwalls, and precast bridge approach slab panels near the bridge site prior to road closure. The bridge has a jointless superstructure connected using Ultra High Performance Concrete (UHPC) closure pours. Precast pier elements were connected in the field using grouted splice sleeve couplers. The paper describes the design and construction of the project. The bridge was assembled in the field in 14 days and opened to traffic on Nov. 1, 2011.

Keywords: Prefabricated bridge elements, Modular bridge, Accelerated bridge construction, Ultra-high-performance concrete, precast substructure elements, precast approach slabs

INTRODUCTION

The 210 ft. long three-span bridge over Keg Creek was originally designed to be constructed with a planned 14 mile detour with estimated construction duration of 6 months. HNTB redesigned this bridge using ABC techniques so that the replacement can be completed in a two-week period using all prefabricated elements. This SHRP2 R04 ABC demonstration bridge project is located in Council Bluffs, Iowa on US 6. The replacement structure is a three-span Composite Modular Bridge with precast substructures and precast bridge approaches. The deck consists of pre-decked steel modular system with precast barriers. In the ABC design the contractor was allowed to fabricate the modular superstructure units, precast substructure components consisting of two precast piers, precast abutments and wingwalls, and precast bridge approach slab panels near the bridge site prior to road closure. All elements were prefabricated by the contractor on-site, adjacent to the bridge. The bridge has a jointless superstructure connected using UHPC closure pours. Precast pier elements were connected in the field using grouted splice sleeve couplers. All of the concrete precast work was done on site (adjacent to the bridge) by the contractor. All precast elements were light enough to be erected with conventional cranes thus reducing erection costs. Special QA/QC procedures were developed for site-casting of substructure elements. The winning bid was $2,660,000 with seven local bidders. The new bridge was opened to traffic on Nov 1, 2011 after a 14 day closure for construction.

The replacement structure is a three-span (67’-3”, 70’-0”, 67’-3”) 210’-2” x 47’-2” Steel/Precast Modular Bridge with precast substructures and precast bridge approaches (shown in figures 1 and 2).

Figure 1. View of completed bridge. US Highway 6 over Keg Creek, Council Bluffs, Iowa.

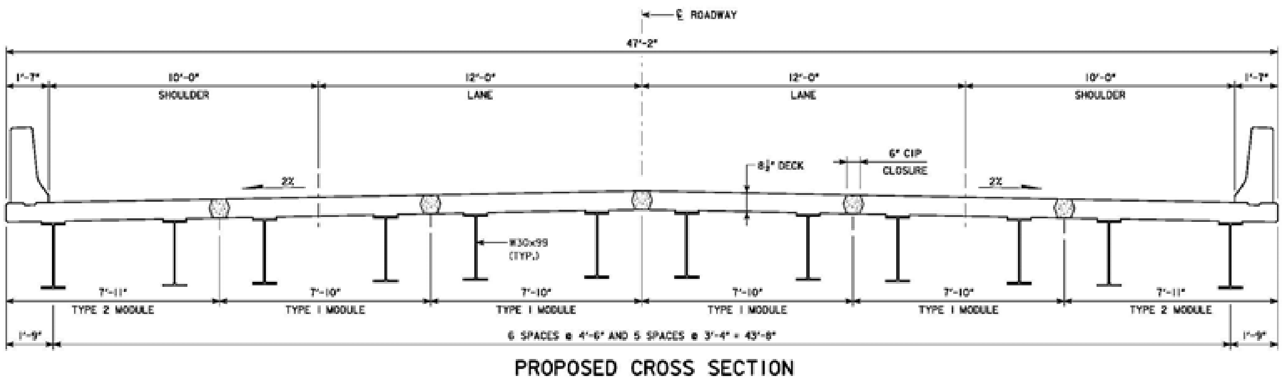

Figure 2. Proposed bridge cross-section. US Highway 6 over Keg Creek, Council Bluffs, Iowa.

This ABC demonstration project implements a series of innovations described in the following bullets. It incorporates details drawn from diverse locations and applies them in a single demonstration project that was visited by DOT and FHWA personnel from numerous states. The project received Highways for Life (Hfl) funding due to the many innovative features incorporated in the design. Project innovations include:

- Overall, a complete bridge system was designed and constructed using superstructure and substructure systems comprised of prefabricated elements. The bridge approach slab also consists of precast elements. A complete precast system was used for the piers (Figure 3). Abutments and wingwalls consisted of prismatic, precast concrete elements which feature a series of open holes which will accommodate driven steel H-piles (Figure 4).

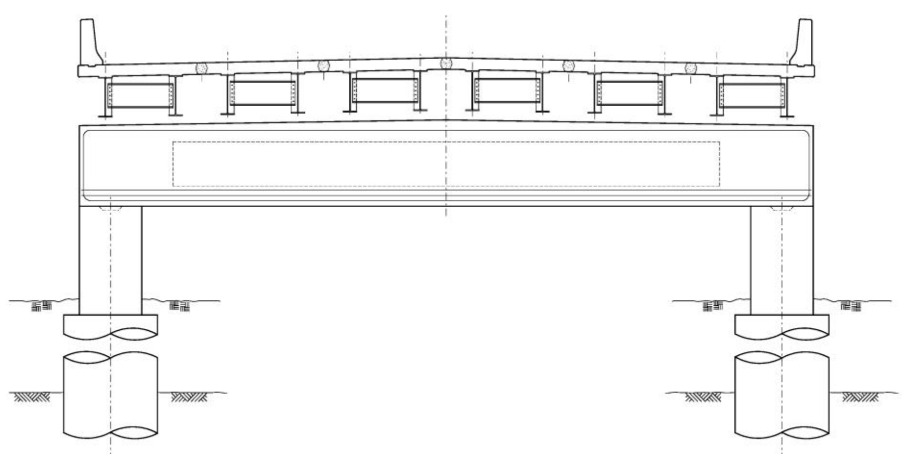

Figure 3: Precast pier elevation

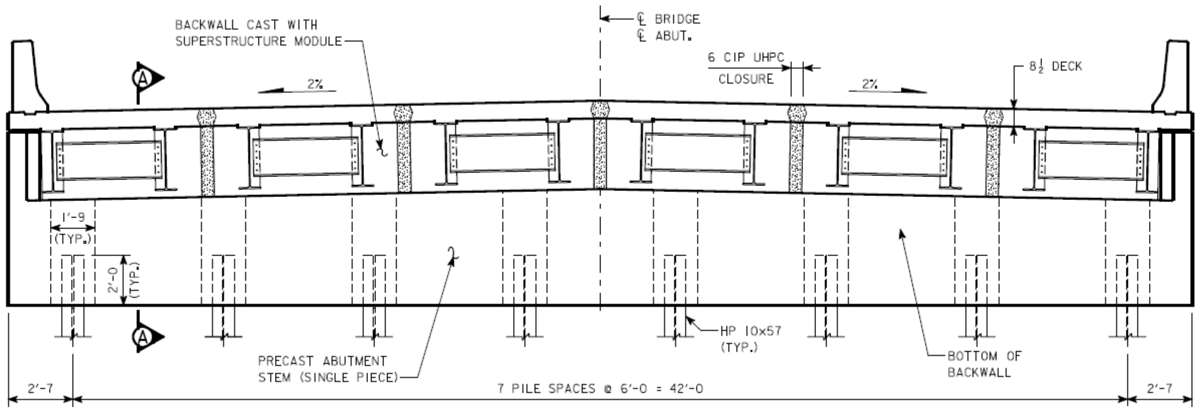

Figure 4: Precast abutment on steel H-piles

- Superstructure units which incorporate precast suspended backwall elements to create a semi-integral abutment (Figure 5).
- UHPC was used in the joints between the modular superstructure units (Figure. 2). UHPC was also used for longitudinal joints and transverse joints over the piers. This project was the first in the US to use UHPC to provide a full, moment-resisting transverse joint at the piers. The elimination of open deck joints will provide for a more durable, low-maintenance structure in the final condition.

Figure 5: Overhanging backwall at abutment

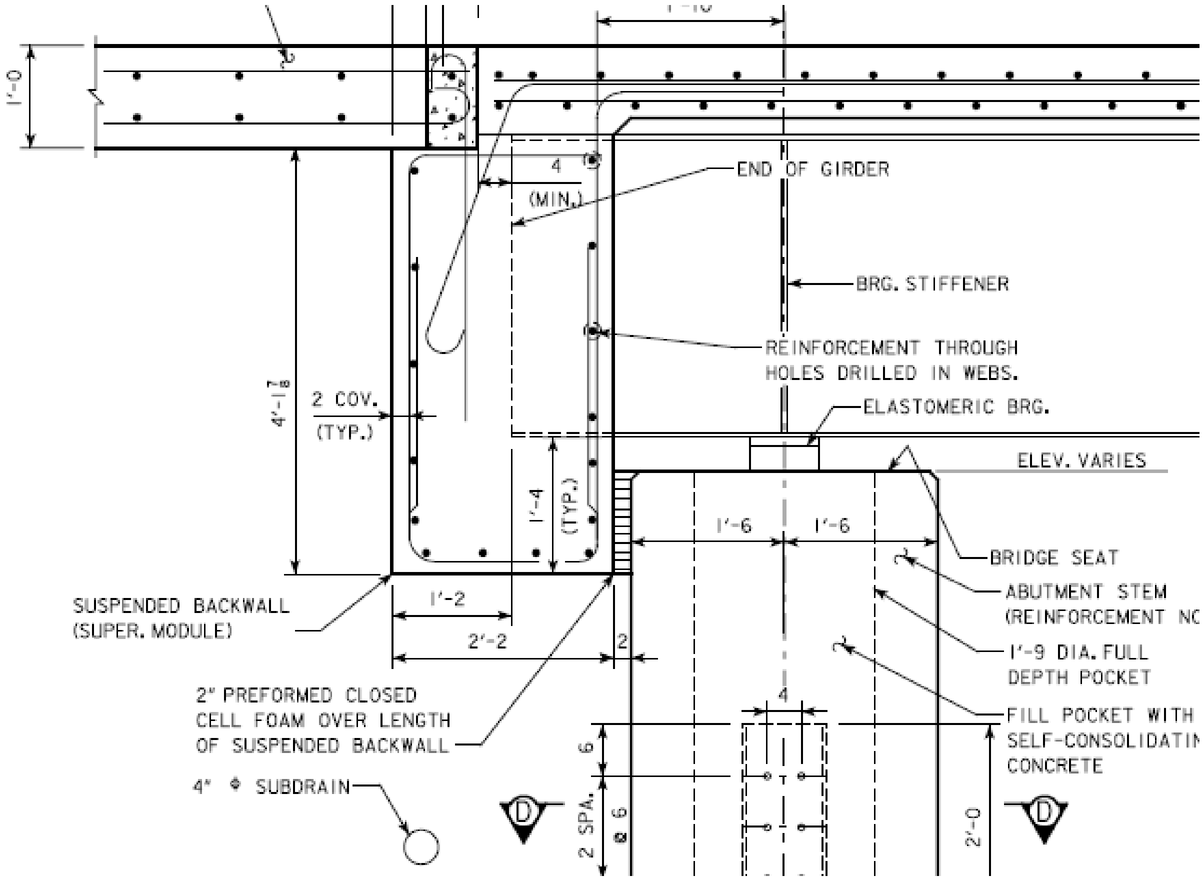

Figure 6. Detail of semi – integral abutment with approach slab and flooded backfill

- Self-Consolidating Concrete (SCC) was used to improve consolidation and increase the speed of construction for abutment piles (fill pockets) and abutment to wingwall connections. Abutments consist of prismatic, precast concrete elements which feature a series of open holes which accommodated driven steel H-piles (Figure 4).
- Use of fully contained flooded backfill at abutments: This proven construction method ideally suited for ABC, is used to achieve early consolidation and significantly reduce the potential for formation of voids beneath the approach pavement. In detail, a floodable backfill system consists of a geotextile fabric liner which separates the bridge embankment from the porous backfill material, a perforated sub-drain that runs the length of the abutment and wraps around each wingwall and backfilling with porous backfill in layers approximately 1 foot thick. As each layer of porous backfill is placed, it was flooded with water and subjected to vibratory compaction. This method was quite successful in eliminating approach settlement (Figure 6).
- ABC entails prefabricating as much of the bridge components as feasible considering site and transportation constraints. This project took the approach that for ABC to be successful, ABC designs should allow maximum opportunities for the contractors to do their own precasting at a staging area adjacent to the project site or in the yard using their

own crews. The design of the components was performed such that a local contractor could self-perform all of the precasting work for non-prestressed components without outsourcing much of the work to precasters. The winning bidder chose to do that by leasing a temporary casting yard next to the bridge site (Figure 7).

PREFABRICATION

The contractor acquired a short-term lease on approximately 4 acres of farmland immediately adjacent to the southeast corner of the bridge site (Figure 7). This land was used as an on-site fabrication and casting yard and was prepared using a number of 12” thick timber crane mats, supported on a sand bedding to provide a uniform bearing surface and a level area to build forms and cast the bridge components. The close proximity of the casting yard was a tremendous benefit to the contractor’s operations and is a distinct advantage for bridges in a rural area where space is available.

The contractor assembled all of the superstructure structural steel on timber false work in the assembly yard. This false work was constructed to simulate the exact geometry of the permanent piers including the same cap beam cross-slope and elevation differences between piers and abutments.

Figure 8. Aerial view of bridge site

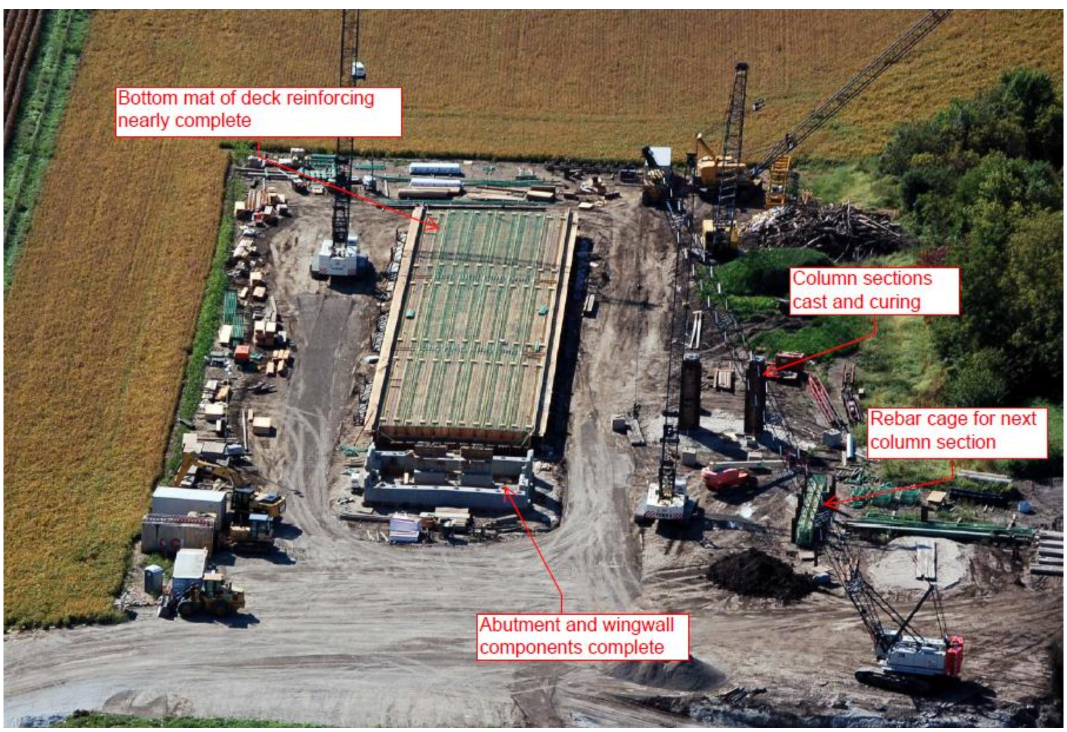

Figure 9. Close up of Assembly Yard

DRILLED SHAFT CONSTRUCTION

The drilled shafts were constructed just outside the footprint of the existing bridge and allowed traffic to continue throughout (Figure 9). Reinforcing cages for the drilled shafts were fully tied in the assembly area and moved down to the pier locations for insertion and concrete placement. In order to accommodate the grouted coupler connections to the precast column sections, a set of #14 reinforcing bar dowels were embedded in the top of the drilled shaft concrete prior to initial set (Figure 10). It was absolutely critical that these dowels be accurately set in order to match the columns, so the contractor constructed laser-cut templates for both halves of the connection. These dowels were placed to the correct orientation and elevation and secured in place until the shaft concrete was cured.

Figure 9. Drilled shaft construction

Figure 10. Installation of dowel bars for drilled shaft

SUBSTRUCTURE COMPONENTS

Pier columns were precast vertically on a forming bed consisting of 12” thick timber crane mats (Figure 11). The forms were guyed and braced prior to concrete placement and remained so until the columns were moved to their permanent location. Lifting and guying of pier columns was performed using strands embedded in the top center of each column and threaded inserts in the top of each face. In order to accurately place the grouted reinforcing couplers prior to pouring concrete, the contractor built laser-cut templates to match similar templates in the drilled shafts and capbeams.

Abutment and wingwall components were also cast on a forming bed consisting of 12” thick timber crane mats. Pier capbeams were formed and placed on temporary casting beds located beneath and immediately adjacent to the existing bridge on a temporary creek crossing (Figure 12). Due to the heavy weight of these caps, approximately 168,000 pounds each, this location was selected to reduce the distance that the capbeams would be moved after curing.

Figure 11. Pier columns formed in casting yard

Figure 12. Pier cap beam casting adjacent to bridge

ABUTMENT CONSTRUCTION

Abutment construction during the ABC period consisted of a series of relatively simple and conventional operations. The process began with the excavation and creation of the earthwork bench for piles. Steel H-piles were then driven to the appropriate bearing capacity at locations matching pocket voids. Once driven, the piles were cut off to their final elevation (2 feet above the top of bench elevation) and welded studs were attached to the top of the piles. Once the installation of piles was completed, the abutment barrels and the four wing wall units were brought from the casting yard to the bridge site. Figure 13 illustrates how the precast abutment barrel and wingwall sections were then lifted and placed over the protruding H- piles. Self-consolidating concrete was placed in annular spaces around steel H-piles and between the joints connecting the abutment wing walls to the abutment footing.

One significant problem occurred during the pile driving at the west abutment. Following installation of the abutment pieces, but prior to placement of the SCC concrete in the pile pockets, it was observed that the abutment was approximately 26” east of the correct location. It was determined that a survey error had led to the mistaken pile installation. After study and consultation with designer and owner, the contractor decided to cut off and abandon the original set of piles and drive a new set in the correct location. This error, and the resulting rework, cost the contractor an estimated 2 days on the critical path schedule.

Figure 13. Installation of abutment and wingwalls

Placement of SCC concrete presented no particular problems for the contractor. In order to support the abutment sections at the correct elevation while the SCC gained strength, the contractor placed a series of 3 ft. x 4 ft. unreinforced concrete pads beneath the abutment barrel and wingwall sections.

The bridge abutment is a single piece, precast concrete barrel section with a series of hollow pockets formed by sections of corrugated metal pipe that correspond to driven steel piles. Likewise, a pair of precast concrete wingwalls is 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.

PIER ASSEMBLY

After the existing bridge was demolished, pier construction operations were able to begin. Temporary casing at the top of the drilled shafts was cut and the top of shaft concrete was prepared. Following this preparation, the four column sections were moved from the casting yard to the bridge site and the grout bed was placed on top of each drilled shaft. The precast columns were then installed on top of the drilled shafts and guy wires were installed. During column connection, grouted reinforcing steel couplers were installed at the base of each column as shown in Figure 14. A one-half to three-quarter inch thick bed consisting of non-shrink grout was constructed on the top of the drilled shaft in preparation for setting the precast column. The grout bed was designed to completely fill any irregularities between the mating components and any excess grout was intended to be squeezed out when the column was placed.

Figure 14. Rebar couplers

Figure 15. Injecting grout into couplers

Precast columns were placed by aligning the female end of the grout couplers (Figure 14) with the projecting dowel bars coming from the drilled shaft. The grouted couplers at the bottom of the column were injected with grout in accordance with the manufacturer's specifications (Figure 15). Grout is injected using a hand-pump through the port near the bottom of each coupler. Injection is continued until a steady stream of grout is observed oozing from the upper port of the same coupler. The ports are capped with a plastic plug and the grout is allowed to cure approximately 18 hours until the required strength is obtained.

The precast cap beam is also composed of normal reinforced concrete. A number of precast, pretensioned and post-tensioned cap beams 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. Once cured, the two cap beam sections were positioned for lifting onto the columns. A grout bed was placed on top of the precast columns and the cap beams were lifted into place. The precast cap beam was connected to the precast columns using a similar grouted coupler system (Figure 16). The reinforcing steel couplers at the top of columns were then grouted and allowed to cure.

Figure 16. Connection of precast cap to precast column

SUPERSTRUCTURE ASSEMBLY

Movement of the superstructure modules from the casting yard to the bridge site presented a number of challenges due to the large size and weight of the panels. In addition, the eccentric load caused by the integral barrier rail on the exterior modules along with the 90 degree left turn and steep slope on the road to the bridge site further complicated the operation. The contractor was very careful to block and strap the modules to the truck bed to avoid any tipping. They also shifted the position of the panel on the truck to maintain the center of gravity of the load between the wheel lines.

Lifting of the modules was performed by two cranes (Figure 17). In the end spans, a large 200 ton truck crane was positioned behind the abutment and a 110 ton crane was positioned on the channel crossing near the pier. The backwall was cast integral with the deck of the end span units and overhung the semi-integral abutment stem (Figure 5). For installing the center span modules, a pair of 110 ton cranes were positioned side-by side near each pier and the cranes were walked forward to place the module in its final location.

Figure 17. Erection of superstructure modules

ASSEMBLY OF APPROACH SLABS

Following installation of the final superstructure module, the next step was to construct the precast approach pavement at each end of the bridge. This precast approach pavement consisted of four doubly-reinforced concrete panels, each of which was 20 ft. long and 10’-7½“wide. Prior to installing the approach slab panels, a floodable backfill system was installed behind each abutment. A precast reinforced concrete sleeper slab was installed and leveled using a bed of fine sand (Figure 18). The sleeper slab was cast with an integral 2 inch crown, matching the bridge deck and the approach roadway. The precast approach panels were installed and leveled to fill the space between the abutment wingwalls.

Figure 18. Installation of precast approach slabs

CONCLUSIONS

Although the contractor lost approximately 2 days due to the necessary rework, he was able to complete the bridge assembly within the allotted time of 14 days. Contractor working hours during the ABC period were typically 6:30 am until 8 pm. The schedule was challenging for the onsite workers, due to the shorter daylight hours during the fall season. Most cranes were of moderate size, typically 110 ton capacity. To erect the larger modules a 200 ton hydraulic crane was utilized.

ABC has the potential to become a very powerful tool in the transportation industry. We must find smarter and faster ways of rebuilding our deficient bridges using standardized approaches that allows economies of scale in manufacturing and construction, and increased safety. ABC is beginning to gain momentum nationally as owners begin to consider the added value of safety, quality and the impacts of long-term road closures for construction, in determining the total cost of a project. New technologies that were implemented successfully on this project will accelerate the adoption of the innovations in the U.S. Project deliverables including the SHRP2 Project R04 Final Report (Reference 2) and SHRP2 ABC Toolkit (Reference 1) includes design standards and design examples for complete prefabricated bridge systems that are intended to assist designers and owners new to ABC.

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