Design and Evaluation of Accelerated Bridge Construction

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ABSTRACT

New bridge systems are needed that will allow components to be fabricated off-site and moved into place for quick assembly while maintaining traffic flow. Depending on the specific site conditions, the use of prefabricated bridge systems can minimize traffic disruption, improve work zone safety, minimize disruption to the environment, improve constructibility, increase quality, and lower life-cycle costs. This technology is applicable and needed for both existing and new bridge construction. The Federal Highway Administration (FHWA) has recently developed a program to promote accelerated construction through the use of precast bridge elements.

This paper will present the design and construction process for the first application of truly accelerated bridge projects in the state of Iowa. The FHWA Innovative Bridge Research and Construction program has awarded funding for two bridges that utilize precast, high-performance concrete elements to be constructed in Boone County and Madison County, Iowa.

Researchers from the Bridge Engineering Center at Iowa State University will install instrumentation and monitor the structural behavior of these two bridges following construction. A discussion of the structural instrumentation and monitoring of these innovative bridges will be presented.

Key words: accelerated bridge construction—bridge construction—bridge replacement—innovative bridge design—instrumentation—structural monitoring
INTRODUCTION

This paper presents an overview of the preliminary design for two innovative bridge replacement projects, located in Boone County and Madison County, Iowa. The projects are being partially funded by the Federal Highway Administration (FHWA) Innovative Bridge Research and Construction (IBRC) program.

These two bridge projects are representative of those undertaken by county engineers across Iowa and throughout the nation. Projects such as these are located on lightly traveled local roads. Due to the light volume of traffic, it is not essential to construct the bridge in an overly accelerated fashion. However, the rapid construction technologies demonstrated on these projects can hopefully be expanded and adapted for use in higher traffic urban areas on the primary road system in Iowa.

IBRC PROGRAM

The FHWA established the IBRC program as part of the Transportation Equity Act (TEA-21) federal highway funding bill in 1998. The program is intended to demonstrate the application of innovative material technology in the construction of bridges and other highway structures, and has two components. The larger component provides funds for repair, rehabilitation, replacement, or new construction of bridges and other highway structures using innovative materials. The smaller component is intended to support research and technology transfer activities related to the program’s goals.

Projects submitted for funding to the IBRC program are encouraged to utilize the capabilities and qualities of the innovative materials being deployed, including the following:

- Bridge components designed for rapid installation or expansion
- Combinations of more than one innovative material in a bridge component
- Innovative bridge designs that result in beneficial features such as shallow superstructures, longer spans, or fewer substructure units
- Innovative applications that enhance bridge integrity and decrease vulnerability to damage from both natural and manmade hazards
- Bridges that incorporate smart materials or embedded instrumentation for future continuous monitoring of operational performance
- Projects that stress innovative technology to monitor, measure, and report on engineering and operational performance of bridges, particularly those with high performance materials

Application for FY 2004

The Iowa DOT, working closely with the FHWA Iowa Division Office, submitted applications for two IBRC projects for accelerated construction in fiscal year 2004.

Madison County

The innovative aspects of the Madison County project are intended to minimize construction time by using high-performance concrete, such that the overall profile (grade and elevation) of the bridge does not change by designing girders with shallower cross-sections and by using precast concrete abutment units. As a result of the reduced profile, the bridge owner will not need to purchase additional right-of-way and will minimize any required earthwork. It was envisioned that the overall construction time could be reduced by 50%, which addresses the IBRC goal of using bridge components designed for rapid construction. The total federal funding requested was $400,000. This total included approximately $235,000 for innovative materials and $155,000 for instrumentation and performance evaluation.
The total FHWA funding awarded was $200,000.

Boone County

The innovative aspects of the Boone County project are the use of precast reinforced concrete abutments, piers, and slab units, which will significantly reduce construction time. The two piers required for the replacement structure will make it possible to install two different types of systems for side-by-side comparison. It is estimated that the use of precast bridge elements will reduce construction time by approximately 60%. The total federal funding requested was $435,000. This total included approximately $270,000 for innovative materials, $15,000 for preliminary engineering, and $150,000 for an innovative material performance evaluation for a post-construction period of approximately two years.

The total FHWA funding awarded was $400,000.

Past Iowa IBRC Projects

It should be noted that the Iowa DOT and a number of Iowa counties, have been involved with IBRC projects since the inception of the program. Past projects have used the following advanced technologies:

- Fiber reinforced polymer (FRP) deck panels and reinforcing
- High-performance concrete deck using proprietary admixtures
- Rehabilitation of steel girder bridge using external FRP prestressing tendons
- Construction of bridge deck using corrosion-resistant MMFX reinforcing steel
- Bridge replacement utilizing glue-laminated timber composite with FRP materials
- High-performance steel girders (hybrid)
- Strengthening of steel girder bridge using FRP plates bonded to bottom flange
- Ultra high strength (up to 30 ksi) prestressed concrete beams
- Temporary detour bridge using FRP superstructure units

BOONE COUNTY BRIDGE

The proposed bridge site is located on 120th Street over Squaw Creek in north-central Boone County, Iowa, approximately two miles east of US Highway 17. The calculated drainage area for this particular site encompasses 88 square miles and provides a design discharge of 3,450 cubic feet per second. Soil conditions at the site consist of very sandy lean clay near the abutments and west pier and a firm to very firm glacial clay foundation material near the east pier. Standard blow counts range from 19 to 27 in the intended very firm glacial clay foundation layer.

The existing bridge is one of only eleven Marsh Rainbow Arch bridges remaining in Iowa. The bridge is a 76-foot–long, single arch span with an 18-foot–wide roadway measured from gutter-to-gutter. The narrow roadway, as well as the deteriorated condition of the existing concrete arch ribs, has necessitated the replacement of this historic structure (see Figure 1).

The Marsh Rainbow Arch Bridge was once fairly common in Iowa and other states in the central part of the United States (Hippen 1997). This patented bridge design, developed by James B. Marsh of Des Moines, was constructed from 1911 to the late 1930s. The bridges were designed for use as relatively small highway bridges with individual spans from 40 to 100 feet. The arch spans provide an early example of composite construction, consisting of structural steel lattice girders encased in cast-in-place concrete (see Figure 2). In addition to the aesthetic appeal of the Rainbow Arch, the structural steel components provided sufficient strength prior to placing concrete to permit construction of the bridge without the need for falsework in the streambed.
Figure 1. Existing bridge, Boone County

Figure 2. Marsh arch details
Proposed Replacement Bridge

The proposed replacement bridge is a 151-ft 4-in. by 33-ft 2-in., three-span, deck-on-girder structure, which will be constructed with a 30-degree right ahead skew. The span length geometry of the replacement bridge is based on a typical Iowa county bridge standard that would have been constructed had this structure not been chosen as a demonstration of innovative accelerated bridge construction. The three spans are 47-ft 5-in., 56-ft 6-in., and 47-ft 5-in., respectively. The abutments will be designed as integral abutments, and both piers will be designed as fixed piers.

The proposed replacement abutments will utilize a steel H-pile foundation. In order to accelerate construction, a precast concrete pile cap will be designed. The connection of the cap to the piles will be made using a grouted connection to the pile group (see Figure 3). Voids in the precast abutment pile cap will be sized to accommodate the piles and pile driving tolerances.

The use of steel pipe piles or concrete-encased steel H-piles is being considered, and it is possible that both types will be used in separate piers, pending final review of the geotechnical information available from the site and the development of a suitable structural connection to the cap beam. The pier itself will consist of a precast pile cap with cast-in-place concrete diaphragms surrounding the girder ends (see Figure 4).

Figure 3. Precast concrete abutment, Boone County
The bridge superstructure will consist of pretensioned, prestressed concrete beams (Iowa DOT LXA series) with full-depth, precast, posttensioned concrete deck panels. The deck panels will be set on the beams using a screw leveling system, allowing panel adjustment to accommodate the profile grade. Grouted keys will be used between each panel to accommodate irregularities in the panel edges and avoid localized stress concentrations when posttensioning. Following the posttensioning, shear keys in the deck panels and haunches will be grouted to connect the deck to the PPC beams.

The use of a precast concrete deck is complicated by the 30-degree skew. In order to avoid the need for custom tapered panels and to make the abutment act as an integral connection to the superstructure, the deck at the ends of the bridge will be cast in place integrally with the abutment diaphragm also following the posttensioning of the deck panels (see Figure 5).

The use of a precast concrete barrier rail is being considered for this bridge. A precast barrier would consist of individual T-shaped segments similar in appearance to a corral rail-style of barrier common on secondary roads in the Midwest. The precast segments would be posttensioned to the precast concrete deck panels using high-strength rods.
MADISON COUNTY BRIDGE

The proposed bridge site is located on 290th Street over an unnamed branch of North Fork Clanton Creek in southern Madison County, Iowa, approximately one mile east of U.S. Highway 169.

The calculated drainage area for this particular site encompasses 212 acres and provides a design discharge of 340 cubic feet per second. Soil conditions at the site consist of approximately 30 to 35 feet of clays with blow counts ranging from 7 to 21 overlaying shale and limestone.

The existing bridge consists of a single 21-foot–long span comprised of timber stringers with transverse plank decking with a gravel wearing surface. The roadway width measures 17-ft 8-in., measured to the face of the timber guardrail. The bridge is supported on timber piling and backwalls (see Figure 6).

Proposed Replacement Bridge

The proposed replacement structure consists of a single span, 46 ft 8 in. long, and will provide a 24-foot–wide roadway section. This increased roadway width and span length will involve a small quantity of excavation as the existing profile grade will be matched. No additional right-of-way will need to be acquired for the replacement of this structure. However, a temporary easement will be needed to rebuild a field entrance near the bridge site.

The substructure for the proposed bridge will consist of a precast concrete abutment section supported on driven steel H-pile end bearings in limestone. Connection of the precast component to the piles will be by means of either a welded connection to an embedded plate in the bottom of the abutment barrel or by means of a grouted connection following installation of the abutment section (see Figure 7).
The proposed replacement superstructure consists of a set of precast, pretensioned concrete box girder sections. The details for these specific box girders have been obtained from the Illinois DOT and may be modified slightly in the final design to satisfy owner preferences. The box girder sections are 27 in. deep and 48 in. wide (see Figure 8). Adjacent box girders are connected by means of a 1-in. diameter steel rod with shear transfer provided by a grouted shear key (see Figure 9). Earth behind the abutment will be retained by means of a concrete diaphragm cast within the precast box girder sections. A gravel overlay may be placed on the bridge deck to obtain the proper deck cross-section and to protect the precast panels from grading operations. Steel guardrails will also be installed.

Connection of the box girders to the precast abutment will be made through the use of steel dowel bars at the fixed abutment, similar to the details used by the Illinois DOT. Due to the short expansion length of this bridge, a fixed connection at both abutments is also being considered. In addition, the use of a posttensioned connection may be utilized in an attempt to promote continuous, rigid frame behavior similar to a typical integral abutment bridge.
Figure 8. Illinois DOT standard concrete deck beams

Figure 9. Transverse tie assembly for precast concrete box girders
INSTRUMENTATION AND MONITORING

Instrumentation will be installed and monitored by researchers from the Bridge Engineering Center at Iowa State University to document and aid in the understanding of these two bridges. The final instrumentation plan cannot be determined until the final specific details of the bridges have been determined. However, a number of key components of the two bridges will be monitored to understand both the overall bridge and individual component behaviors throughout an extended period of time, which will cover more than a full annual thermal cycle.

Differential deflection and load transfer between precast concrete superstructure elements is a primary concern of the research team. The deck panels used on the Boone County bridge and the precast concrete box girders used on the Madison County bridge will be instrumented to measure both flexural strain in these components as well as any slip between adjacent deck units.

The connection between the superstructure and substructure components, as well as between the precast substructure elements and the steel piles, will be monitored to assess the degree of structural continuity between these elements. Monitoring will be performed using both strain gauges and deflection or rotation transducers.

A series of controlled load tests, using a tandem axle dump truck of known weight, will be performed to develop a baseline understanding of bridge behavior. Following an extended period of bridge usage by the public, another round of load testing may be performed to assess any change in performance.

SCHEDULE

The Iowa DOT Office of Bridges and Structures is currently performing the final design on the two bridges. The current schedule indicates a January 2006 letting date, with construction to be performed during the 2006 construction season. Structural monitoring instrumentation will be installed and load testing will be performed following completion of construction.
REFERENCE