Context Sensitive Designs: Testing of Multi-Performance Level Box Beam Standards

tech transfer summary

June 2017

RESEARCH PROJECT TITLE
Context Sensitive Designs: Testing of Multi-Performance Level Box Beam Standards

SPONSORS
Iowa Highway Research Board
(IHRB Project TR-681)
Iowa Department of Transportation
(InTrans Project 14-513)
Federal Highway Administration

PRINCIPAL INVESTIGATOR
Brent Phares, Director
Bridge Engineering Center
Iowa State University
bphares@iastate.edu / 515-294-5879
(orcid.org/0000-0001-5894-4774)

MORE INFORMATION
www.bec.iastate.edu

Bridge Engineering Center
Iowa State University
2711 S. Loop Drive, Suite 4700
Ames, IA 50010-8664
515-294-8103
www.bec.iastate.edu

The Bridge Engineering Center (BEC) is part of the Institute for Transportation (InTrans) at Iowa State University. The mission of the BEC is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

IOWA STATE UNIVERSITY
Institute for Transportation

This project developed and laboratory tested an innovative concrete box beam joint that included a roughened interface surface along the beam faces on each side of the joint, was constructed using reinforcement steel, and was filled using shrinkage-compensating concrete.

Objectives

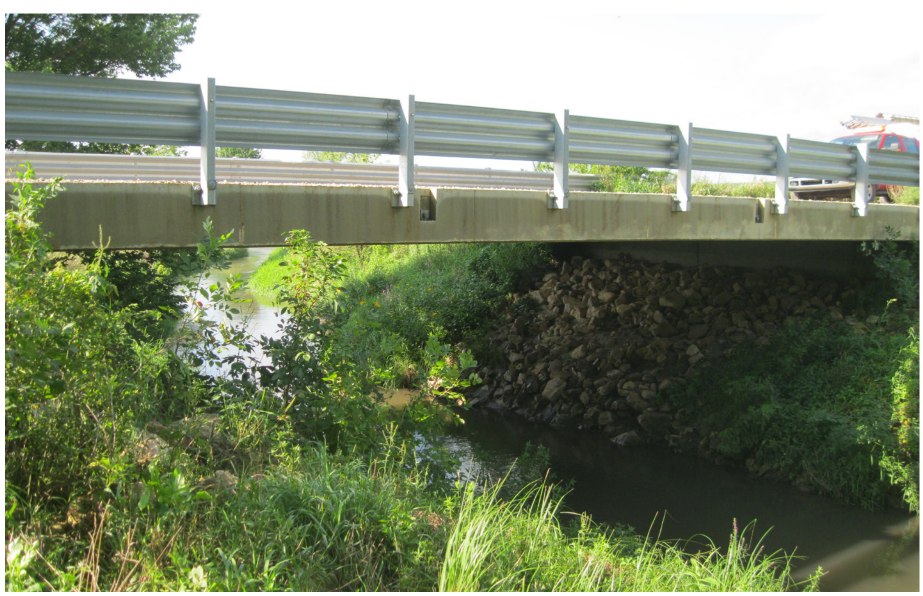
The goal of this project was to develop a new box beam bridge joint design for use between adjacent concrete box beams, with a particular interest in its applicability for use by counties.

Background and Problem Statement

Concrete box beam bridges constitute more than 15% of the bridges built or replaced each year. This type of bridge is generally constructed by placing box beams next to one another, grouting adjoining shear keys, applying a transverse post-tensioning force, and then placing either a thin (~3-in.) wearing surface or a thick (~6-in.) structural deck. In some cases, the top of the box beams are left bare to serve as the riding surface.

Historically, adjacent precast elements have suffered from differential displacements, which cause cracking in adjoining joint material (or, in some cases, in cast-in-place topping material). Sources of differential deflection can come from a variety of conditions, including live loads and temperature effects.

Generally, the reflective cracks in-and-of themselves do not pose a safety hazard. However, these cracks provide a direct path for water (plus chlorides) to enter the structural system causing corrosion of the mild and prestressing steel. Ultimately, this situation can lead to significant maintenance costs and/or safety concerns. Because of this, some early users of adjacent box beams now only allow them on low-volume roads where salt application does not occur.



Box beam bridge in Buena Vista County, Iowa

Even with the known issues associated with adjacent box beams, they can still result in an economical short- to medium-span bridge that is generally quick and easy to construct. The Iowa Department of Transportation (DOT), in principal cooperation with HDR, Inc., has been working to develop a new set of bridge standards particularly targeted toward use by counties.

As is widely known, counties have a large number of bridges in their systems that must be constructed and maintained. As such, they are increasingly in need of low-cost bridge concepts.

For many counties, the ideal construction strategy is one that can be executed using resources available to them. Due to these constraints, the utilization of prestressed and heavy-weight members are not plausible.

During a meeting on May 2, 2014, interested parties (from the Iowa DOT, the Federal Highway Administration/FHWA, designers, counties, and academia) discussed possible concepts for the desired bridge standard. Because the decision had previously been made (based on preliminary work completed by HDR) to use a box beam shape, the discussion principally centered on needs associated with this concept.

Of particular importance was information presented by Ben Graybeal with the FHWA, who has been conducting testing on adjacent box beams at the Turner-Fairbank Highway Research Center. The results of that work include a connection detail that appears to perform well.

The main drawback associated with that connection detail (from a county perspective) is the fact that ultra-high performance concrete (UHPC) is needed. This material tends to be very expensive and requires a high level of expertise for proper mixing, placement, etc.

Thus, it was discussed that perhaps work could be done to develop alternatives that would have sufficient performance when placed in the right locations. This is frequently termed context-sensitive design and was the main focus of this research project.

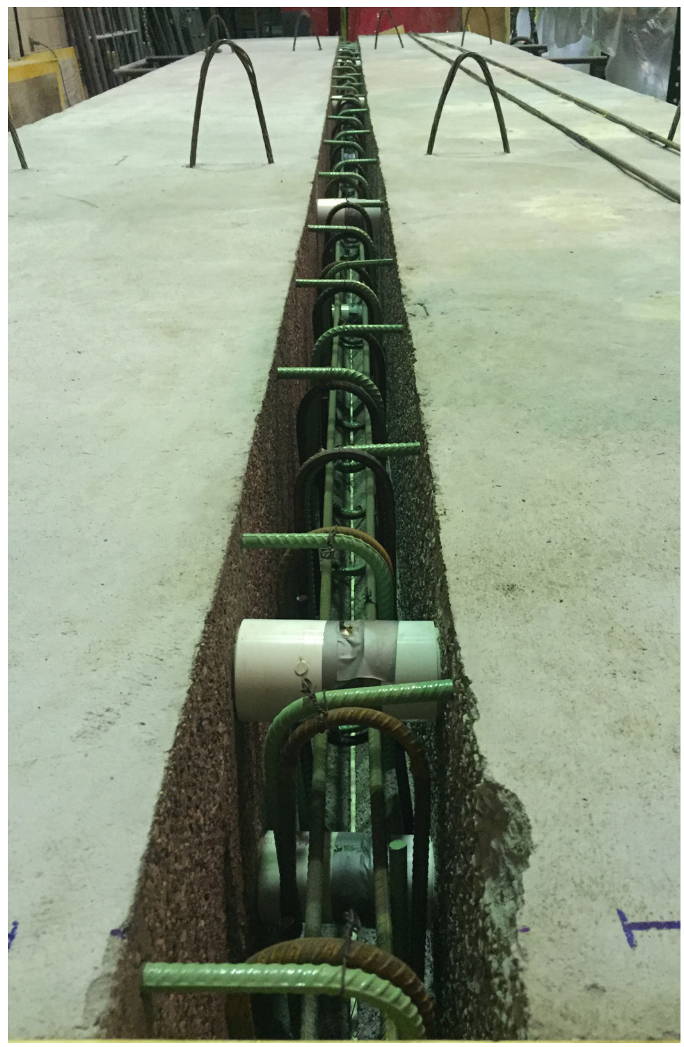
Research Description/Methodology

The researchers inspected two box beam bridges previously constructed on the Iowa county road system for cracks in the joints. They also conducted a comprehensive literature review on cracking in the joint between adjacent box beams to collect relevant information and help guide subsequent work on the project.

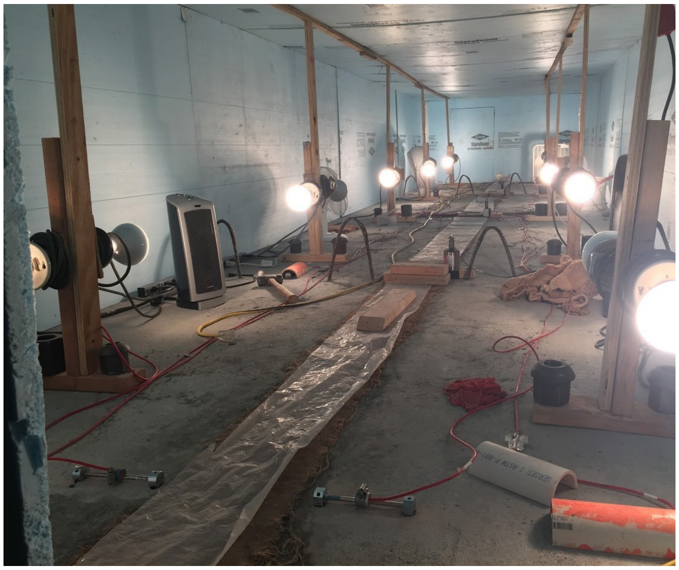
Some potential solutions noted by previous research include the use of low-/zero-shrinkage material, increased bond strength and shear strength, and additional reinforcement in the joint. Incorporating these potential solutions and other concepts, an innovative joint was designed with the following unique details:

- Wide joint dimensions (about 6.5 in.)
- Use of shrinkage-compensating cement for the joint concrete
- High surface roughness for the interface between the joint material and the box girders
- Use of commercially available reinforcing steel couplers to connect the joint material and box beam materials to provide both transverse strength and stiffness

The research team constructed and tested a 30 ft long specimen consisting of two concrete box beams with the innovative joint between them in the laboratory. The researchers performed laboratory tests on the joint, replicating previous FHWA UHPC joint testing, including temperature loading and cyclic vertical loading. During the testing, strain, displacement, and temperature were collected using the following devices: vibrating wire strain gauges (VWSGs), displacement transducers, and thermocouples.



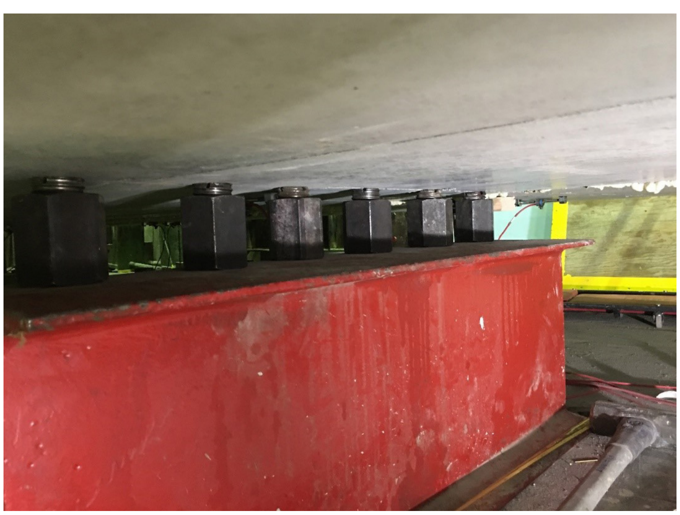
Two box beams placed side-by-side with roughened interface surfaces for the joint material and reinforcing steel couplers during construction of the innovative wide joint specimen in the laboratory



Temporary temperature isolation room on top of the specimen allowed for the application of heat that would simulate normal thermal radiation consisting of heating of the top surface (Note the joint concrete down the center was covered with burlap, with plastic over that, while the material cured)

The temperature loading was applied during the early age of the joint concrete in conjunction with concrete expansion, heat of hydration, and concrete hardening. During the early-age testing of the innovative joint that was developed in this work, the daily temperature loading simulated a 40 °F vertical temperature gradient through the depth of the specimen. The test continued for seven days.

Following full curing of the joint (when the joint concrete was two months old), a series of cyclic live loading tests were conducted on the specimen. Generally, the cyclic loading was applied at a frequency of 2 Hz and the beams were tested with two different boundary conditions: both beams simply supported and one beam restrained (to generate higher stresses in the joint).



Restraints used to restrict deflection under one beam

The maximum applied load was 42 kips, which is equivalent to a design truckload based on AASHTO specifications. In total, more than 5,000,000 cycles of live loading were applied during the cyclic load testing.

After the cyclic loading tests, the joint was intentionally cracked with an artificial horizontal load. The test was repeated at both quarter-span diaphragm locations. The horizontal load test results were compared with the UHPC tests conducted by the FHWA.

Key Findings from the Box Beam Bridge Inspections

- No cracks were found during the joint inspection of the bridge in Madison County.
- Moisture staining was found at the bottom surface of the bridge in Buena Vista County, which indicated that the bridge had cracks and experiences water leakage.

Key Findings from the Literature Review

Based on the findings of the literature review, joint cracks are suspected to be caused by low bond strength between the joint material and box girder, large shrinkage of joint material, stress concentrations near the shear key, and temperature changes.

- Cracking of the shear key between adjacent box beams appears to principally be a service-related problem, as multiple sources indicate that even with a cracked joint, a bridge can continue to effectively distribute loads throughout the primary load carrying members. With regards to cracking, it appears that cracking tends to be most prominent at the interface between the joint material and the box beam due to the low bond strength. Use of a shear key may induce stress concentration in the joint. Further, cracking seems to first initiate near the ends of beams.
- Consistent throughout the literature is the conclusion that joints that use full-depth keyways have the best performance. The use of transverse post-tensioning seems to be the most effective when two ties are used at each location (e.g., one near the top and one near the bottom) with high amounts of force. However, there have been some reported instances where no post-tensioning also performed well.
- Cracking does not seem to be first initiated by the application of live loads. There are, however, differing opinions on the relative contribution to cracking from shrinkage and temperature. Nevertheless, once cracking is initiated by either shrinkage and/or temperature, cracks can continue to grow with subsequent live load application.

Key Findings from the Laboratory Tests

During the tests, no cracking was found in the joint and no trend of increasing differential displacement was found between the two beams.

- During the early-age test, no cracks were found in the joint or at the interface between the joint and the box girder. The lack of any cracking is a very positive indicator that the joint is unlikely to experience cracking later in life as well.
- Immediately after the application of the first cycle loading of 18 kips, transverse cracks occurred on the bottom of the box girder. The cracks were concentrated from one-quarter span to three-quarters span. Almost all of the cracks developed across the width of the specimen and were spaced almost evenly at about 1 ft. During the cyclic load tests, no cracks occurred in the joint.
- Both horizontal load tests ended with failure of the box girder concrete. The maximum horizontal loading was 25 kips at one diaphragm and 45 kips at the other diaphragm. For both tests, no cracks initiated in the joint or at the interface before the box girder concrete failed.

Implementation Readiness and Benefits

This innovative joint design could provide a cost-effective bridge solution that counties can, if desired, construct themselves.

- The wide joint between the roughened interface surface, filled with shrinkage-compensating concrete and reinforced by reinforcement steel, can create a crack-free joint without the utilization of a shear key or transverse post-tensioning.
- This joint is as functional as the traditional cement grout-filled narrow joint with respect to the transfer of the moment and shear between the girders, while also performing better than the traditional joint in resisting joint cracks in both early-age loading and the long-term service life of the bridge.
- At the same time, the test results for the new innovative joint detail appear to compare very well with the UHPC-based joint detail developed and tested by the FHWA. However the UHPC used by FHWA likely has superior permeability characteristics to the Type K shrinkage-compensating cement evaluated in this work.

To further investigate the performance of this joint detail, the researchers recommend that a field trial be completed. During this field trial, the bridge should be monitored and evaluated during early-age concrete curing as well as for a period of at least two years following construction.