Evaluation of the Performance of a Short-Span T-Beam Bridge

tech transfer summary

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RESEARCH PROJECT TITLE
Evaluation of Performance of a Short-Span T-Beam Bridge in Buchanan County

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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.

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This project evaluated a simple ultra-high performance concrete (UHPC) longitudinal joint with high-strength, corrosion-resistant reinforcing steel bars for T-beam bridges.

Problem Statement

The current literature available on the choice of material and the detailing of longitudinal joints for T-beams is limited. Meanwhile, the development of new materials is inspiring engineers and researchers to develop construction friendly, durable, and smaller sized longitudinal joints.

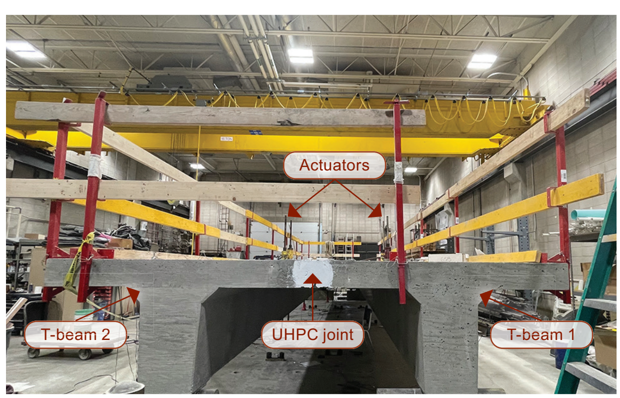
Background

Precast beam elements include box beam girders, deck bulb T-beams, and T-beams. These beams are connected together at their flanges by a longitudinal joint. These longitudinal joints are conventionally designed with complex detailing. Traditional joints involve welded plates in individual T-beams, which are then welded to dowel bars to connect the two beams and make a full system. The complex detailing results in additional stresses and requires regular maintenance and repair activities.

Longitudinal joints are also recommended in wide bridges, although state recommendations vary about the width of the individual bridge decks. These longitudinal joints are a weak spot and result in a reduction of the service lives of these bridges. The common problems associated with these longitudinal joints are cracking within filler materials, reflective cracking, and leakage in the joint. The leakage in the joint allows for chloride-contaminated water to seep through to the reinforcing steel bars and the underlying structure, leading to structural deterioration.

Research Description and Goals

A full-scale experiment and a set of finite element (FE) simulations were carried out to investigate the behavior of an innovative T-beam bridge design with a unique longitudinal UHPC joint. The goal of the experimental investigation was to evaluate a full system using two concrete T-beams joined by an ultra-high performance concrete (UHPC) longitudinal joint.



Full-scale T-beam specimen with longitudinal UHPC joint in Iowa State University's Structural Engineering Research Laboratory

The two T-beams were reinforced with high-strength, corrosion-resistant reinforcing steel bars that have tensile strength greater than 910.1 MPa (132 ksi). The joint detailing was also unique as the joint had no longitudinal reinforcing steel bars, and the reinforcement in the joint was extended from the deck T-beams into the UHPC joint.

The full scale test setup was 46 ft long and 24 ft wide. The longitudinal joint and bridge system were tested under flexural and shear stress under service limit loading. The T-beams were then separately tested to investigate the individual capacity and behavior of the T-beams by cutting through the joint and separating the beams.

The experimental results were complemented by a set of FE models that the researchers created from the laboratory-tested bridge elements using the Abaqus software package to investigate the behavior of full bridge and individual T-beams under the maximum moment created by HL-93 truck loading. The models were validated utilizing the results from the experimental tests.

Key Findings from the Experimental Work in the Laboratory

- The UHPC longitudinal joint was tested under flexure to have tensile stress on top and compressive stress at the bottom face of the joint. The load deflection curves and the load strain curves for deflections at the bottom of the beams at midspan and the strains at the bottom reinforcing steel bars of the beams showed that, within the service limit, the beams responded in a linear elastic range with a small change in slope at 10 kips. No visible cracks were observed within the service limit.

- The transverse strains in the reinforcing steel bars in the UHPC joint were recorded to evaluate the performance of the joint. The resulting strains recorded in the top and bottom reinforcing steel bars of the joint showed that the strains in the joint were tensile on both the top and bottom reinforcing steel bars. This highlights the fact that the beam centerline acts as the pivot for the load, and the inner flanges of the beams pull axially on the joint in tension.

- The bridge system was tested to exert maximum shear stress in the UHPC joint. The load deflection and load strain curves showed that the unrestrained beam behaved linear elastically until 15 kips and showed a small change in slope after that but stayed linear with reduced slope until the service limit loading of 21 kips. The deflection and strain for the movement-restricted beams were negligible, indicating that the supports restricting the movement were performing as intended.

- The two T-beams were separated by cutting through the joint and tested under flexural loading until failure. The load deflection curves for both beams followed the same path, varying only 3% at ultimate capacity. The beams showed a similar load deflection response for deflections at midspan as well as at quarter span.

Key Findings from the Numerical Investigation

The experimental data were utilized to validate the FE models created using the Abaqus software package. The FE models were further explored by placing a full HL-93 truck on the full-scale tested specimen with the UHPC joint and on each of the individual beams.

- The comparison of load deflection curves for deflection at midspan and load strain curves for strains at the bottom reinforcing steel bars of the midspan showed that the strains for the unrestrained case were greater than those for the restrained case. This was explained by the fact that the entire system deflected more when unrestrained, thus resulting in lower strains at the bottom reinforcing steel bars.

- In the unrestrained beam case, the transerve strains at the center of the joint at midspan were tensile in both the top and bottom reinforcing steel bars, while, in the restrained beam case, the top reinforcing steel bars were in tension with the bottom reinforcing steel bars in compression. This highlights the fact that, in a realistic situtation, there will be a sideways pull on the joint rather than a bending in the joint in the transverse direction.

- The individual T-beams were evaluated by placing the HL-93 truck to generate maximum moment. The first cracking started to happen at 21 kips wheel loading, and the reinforcing steel bar strain showed yielding as well. This reflected that the individual T-beams experience some cracking under an HL-93 truck load when placed to generate the maximum positive moment in the beam. However, it should be kept in mind that, when part of a full system, there are no cracks, as observed in both the experiment and in the simulations performed for restrained and unrestrained cases.

Implementation Readiness and Benefits

The development of high-strength materials including UHPC and high-strength reinforcing steel bars is allowing engineers to design simple and durable structural elements, including their joints. The investigations performed in this project showed that the double T-beam system can withstand the service loading demand under maximum HL-93 truck loads.

The results of this research provide novel information regarding the stress distribution within the joint under flexure and shear loading and will aid in the design of UHPC longitudinal joints in T-beam bridges, in particular, and longitudinal UHPC joints, in general. The results will also help in analysis and design calculations for beams reinforced with high-strength reinforcing steel bars.