Pilot Project - Demonstration of Capabilities and Benefits of Bridge Load Rating through Physical Testing

tech transfer summary

This project demonstrated the capabilities for load testing bridges in Iowa, developed and presented a webinar to local and state engineers, and produced a spreadsheet and benefit evaluation matrix that others can use to preliminarily assess where bridge testing may be economically feasible given truck traffic and detour lengths.

Problem Statement

The US is heavily dependent on its transportation system for the quick and efficient movement of goods, people, and military assets. While the bulk of traffic volume utilizes state routes, agricultural industries are dependent on both the state and local systems. The more than 4,000 load-restricted (i.e., posted) bridges on the secondary road system represent potential reductions in the efficiency of the movement of farm goods. This inefficiency has the potential to reduce the cost-competitiveness of the US agricultural industry.

Background

In general, bridge engineers rely on theoretical analyses based on codified approaches. While these techniques provide a reliable means for assessing the safe load-carrying capacity, they are, by their very nature, sometimes conservative. By no fault of their own, codified approaches must be widely applicable and, as a result, many assumptions must be made. Another approach is to create an analytical model that represents the behavior of a specific bridge—not a code-specified, generic bridge.

In early 2000, the Iowa Highway Research Board and the Iowa State University Bridge Engineering Center (BEC) embarked on a project to enhance the bridge assessment capabilities of the state. To do this, they invested in bridge load testing hardware and software. Since that time, the load testing program in the state has become quite mature.

Ida County case study bridge

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RESEARCH PROJECT TITLE

Pilot Project - Demonstration of Capabilities and Benefits of Bridge Load Rating through Physical Testing

SPONSORS

Soy Transportation Coalition
Iowa Department of Transportation
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CO-PRINCIPAL INVESTIGATORS

Brent M. Phares, Director,
Bridge Engineering Center
Iowa State University
515-294-5879
bphares@iastate.edu

Travis Hosteng, Bridge Research Specialist
Bridge Engineering Center
Iowa State University
515-294-7197
kickhos@iastate.edu

Zach Hans, Research Engineer
Institute for Transportation
Iowa State University

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
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Johnson County case study bridge

Currently, the Iowa Department of Transportation (DOT) Office of Bridges and Structures identifies structures to be tested and is responsible for determining capacities and ratings based on the load test results. In addition to determining ratings, the Iowa DOT uses data from load tests to aid in permitting superloads and to resolve design questions. Several counties across the state have utilized the same approaches to evaluate the need for load restrictions.

Generally, the first step in the load testing process is to design an instrumentation scheme. The instrumentation plan should strategically place sensors in areas that may impact subsequent analyses. Commonly, the instrumentation scheme is established to answer questions related to end restraint, level of composite action, lateral live load distribution characteristics, and other important attributes. Testing is then completed by installing the pre-designed instrumentation plan and monitoring the performance of the bridge as a controlled load crosses the bridge. BEC engineers then evaluate the data and extract vital information that aids in the creation of a modified load rating.

In many cases, basic modification to codified parameters allows Iowa DOT engineers to arrive at a reasonable solution. In other cases, BEC engineers create and calibrate a more elaborate finite element model using the field test data. This calibrated model is then used for direct calculation of an updated bridge rating.

Project Objectives

The objectives of this project were to demonstrate the capabilities for load testing bridges in Iowa, study the economic benefit of performing such testing, and perform outreach to local, state, and national engineers on the topic of bridge load testing/rating.

Research Description and Methodology

Three bridges were selected as case studies by the Iowa DOT Office of Bridges and Structures with the assistance of the BEC and the Soy Transportation Coalition based on the criterion specified in the proposal:

- Ida County FHWA # 186070
- Johnson County FHWA # 205750
- Sioux County FHWA # 308730

After bridge selection, preliminary information including as-built plans, photographs, inspection reports, and geometrical data were collected, if available, from the bridge owners. In addition, information related to any critical sections within the bridges was collected from the Iowa DOT Rating Engineer.

Once the basic bridge geometry information and photographs were obtained, an instrumentation scheme was developed such that all critical and necessary data could be collected during load testing. Each instrumentation plan was developed based on suggested critical sections as specified by the Office of Bridges and Structures and the information necessary to create and calibrate an accurate model of the bridge. Based on these two criteria, strain transducers were installed as appropriate.

Transducers were installed on all three bridges to record strain magnitude, transverse load distribution, and support restraint. For the two girder bridges (Ida County and Sioux County), transducers were also installed for neutral axis measurements. Strains were collected using Bridge Diagnostics, Inc. (BDI) strain transducers and the BDI Structural Testing System (STS).

Load testing was then completed by monitoring the performance of each bridge as a controlled and known load crossed the bridge. All three bridges were tested in January 2013.

Sioux County case study bridge during load testing

Ida County Bridge load posting

The collected data were then evaluated and used in the creation and calibration of an analytical model. This calibrated model was then used for direct calculation of bridge rating factors using the rating and legal loads.

Investigation of Bridge Load Restriction Impacts

Two approaches were employed to investigate the possible financial impacts of removing bridge load restrictions. The first approach investigated the change in truck traffic volumes on secondary road bridges where a load restriction had been removed. The second approach estimated the out of distance travel costs associated with bridge load restrictions.

To investigate the possible impact on truck traffic, the locations of 462 secondary road bridges that had been load restricted previously, but replaced recently (2009 through 2012), were identified, as well as all available traffic data from 2001 through 2011. The primary objective was to identify bridges possessing single unit (SU) truck and/or multiple trailer (combination) truck average annual daily traffic (AADT) data both before and after bridge replacement.

A secondary objective was to determine the average out of distance travel necessitated by a bridge load restriction. Review of a 10 percent sample of the replaced bridges yielded an out of distance travel range of two to nine miles, with an average distance of 3.4 miles. These distances, as well as the number of trucks rerouted, are critical components in determining out of distance travel costs.

A Microsoft Excel spreadsheet was developed in cooperation with the Iowa DOT Office of Systems Planning to estimate out of distance economic costs for SU and combination trucks.

While detour length and rerouted trucks are necessary inputs, other factors must also be considered while estimating the operating costs, driver pay, and roadway usage costs resulting from out of distance travel. These factors include the following:

- Baseline truck operation costs
- Incremental travel costs
- Stop-start driving condition costs
- Vehicle speed
- Driver pay and benefits while rerouted

Many of these factors, which may be adjusted, require assumptions. All assumptions were provided, with documented sources, by the Office of Systems Planning. Based on these assumptions, the estimated detour length, and number of rerouted trucks, out of distance travel costs are output.

Key Findings

A separate report documents each of the case study bridges and associated load test and rating results.

Overall, the live load response data recorded during field testing for the three case study bridges revealed no abnormalities. The test data exhibited response magnitudes and shapes typical of their corresponding structures.

Following testing of the structures, a two-dimensional finite element model of each structure was created using the collected structural information, and subsequently calibrated until an acceptable match between the measured and analytical responses was achieved. A very good correlation between the measured and computed response was obtained for each bridge during the modeling process.

Johnson County Bridge instrumentation setup

The calibrated models were then utilized to conduct load ratings for each bridge by applying the American Association of State Highway and Transportation Officials (AASHTO) rating vehicle and Iowa legal loads to the models. Comparison of the input member capacities with the model-generated moments resulted in output rating factors for all vehicles. Physical tests generally revealed that bridge performance exceeds that predicted by codified approaches.

The load rating results were controlled by the ultimate flexural capacity of the girders near midspan of the center span for the two girder bridges and by the ultimate flexural capacity of the slab section near midspan for the slab bridge. The results indicated all three bridges had satisfactory operating level ratings for all standard AASHTO design and rating loads. However, results for the inventory rating criteria varied some as detailed in the three final reports.

Bridge Load Restriction Impacts

Unfortunately, more than half of the 462 secondary road bridges that had been load restricted previously, but replaced recently, did not have any truck AADT data available, and only 20 bridges possessed both before and after truck AADT. Of these 20 bridges, half experienced a net increase in SU or multiple trailer truck AADT. However, based on the available data, definitively attributing changes in traffic volumes to load restriction removal was not possible.

Again, review of a 10 percent sample of the replaced bridges yielded an out of distance travel range of two to nine miles, with an average distance of 3.4 miles. This distance, as well as the number of trucks rerouted, are critical components in determining out of distance travel costs.

Preliminary analyses suggested that a modest number of rerouted trucks, over a relatively short detour, could result in fairly-significant costs, compared to the cost of physical bridge testing. For example, the economic cost of 10 rerouted combination trucks daily over a 3.4 mile detour may be approximately $28,000 annually.

Conclusions

- Physical testing is the single best way to understand how bridges resist traffic loads
- Physical tests generally reveal bridge performance exceeds that predicted by codified approaches
- Physical test costs can be justified if only a modest number of trucks can avoid even short alternative routes

Implementation Readiness and Benefits

Outreach/Webinar

The research team developed an hour-long webinar to summarize the project, demonstrate the load testing and rating process, and present the bridge load restriction impact information, spreadsheet, and benefit evaluation matrix that were developed. The team and the Iowa Local Technical Assistance Program (LTAP) at Iowa State's Institute for Transportation hosted the webinar as a technical seminar with engineers participating both in person and via the internet on August 1, 2013.

Benefit Evaluation Matrix

Given the possible sensitivity of the economic costs to the out of distance travel assumptions, and the generally low and/or seasonal truck traffic volumes on secondary roads, the aforementioned spreadsheet served as the basis for developing a benefit evaluation matrix.

The rows of the matrix represent the estimated number of trucks rerouted per year. This allows the spreadsheet user to address the fact that secondary roads may not experience consistent truck traffic, and to perform a more-refined analysis based on more-realistic traffic conditions.

The columns of the matrix represent the estimated detour length. All calculations, represented as matrix cells, are the estimated economic benefit of removing a bridge load restriction, based on the out of distance travel assumptions and corresponding truck traffic and distance values. Spreadsheet users may make changes to any of the underlying out of distance travel assumptions and immediately see the impact.

In addition, to take costs into consideration, users may make assumptions regarding the potential cost and frequency of bridge testing as well as any costs related to depreciation and loss of useful life of the bridge. Through conditional formatting, those cells with an out of distance benefit less than these costs can be highlighted.

In general, this matrix can be used to preliminarily assess where bridge testing may be economically feasible, given truck traffic and detour lengths. More detailed economic analysis may be warranted when specific sites are considered.