RESEARCH news

Iowa Department of Transportation

BUREAU OF RESEARCH AND TECHNOLOGY MARCH 2010

Iowa's bridge diagnostic load testing program

Most bridge engineers rely exclusively on traditional theoretical analysis when determining bridge capacity. Typically, this provides reliable means for assessing the condition of common bridge types. However, based on traditional methods, some bridges with a history of good performance that have marginal load capacity (older bridges designed using outdated specifications or those with unknown design history) require additional assessment to more accurately determine true load capacity. In these cases, diagnostic load testing has proven an effective evaluation tool.

Load testing bridges can be a cost-effective way to avoid rehabilitation, replacement and additional costs (incurred by the traveling public). Calculating additional costs for a restricted bridge is not easy, yet, when trucks must use longer alternate routes due to load restrictions, additional costs are incurred.

In the late 1990s, the Iowa Department of Transportation (Iowa DOT) identified the need to develop a diagnostic load testing program and began seeking innovative solutions to supplement traditional analysis techniques. The goals were to:

- ✓ Re-evaluate older bridges based on new specifications.
- ✓ Determine capacity for bridges with unknown or insufficient design data.
- ✓ Evaluate the need to impose temporary load restrictions on damaged bridges.
- ✓ Reduce the number of bridges restricting a reasonable flow of overweight trucks.
- ✓ Verify effectiveness of new strengthening techniques.
- ✓ Remove load restrictions imposed on additional bridges due to implementation of new weight laws.
- ✓ Load test to determine the behavior of structures under heavy loads with calculated load ratings below anticipated capacity needs.

In early 2000, the Iowa Highway Research Board (IHRB) approved funding for development of a diagnostic load testing program. With help from the Bridge Engineering Center (BEC) at Iowa State University (ISU), a bridge load testing system was acquired from Bridge Diagnostic Inc. (BDI). The load testing system consisted of hardware, software, training, and testing for several Iowa bridges. The BEC's researchers conducted the field load testing and performed all necessary analysis (Figure 1).

Currently, the Iowa DOT's Office of Bridges and Structures identifies structures to be tested and is responsible for determination of final capacity and ratings based on load tests. In addition to capacity and rating determinations, data from load tests are used by the Iowa DOT's rating section to aid in permitting superloads and resolving design issues.

Figure 1 - *An instrumentation and data collection system that allows time efficiency and effective monitoring is critical to a load testing program.*

Usually, Iowa DOT bridge engineers rely on live load distribution performance data (determined from load testing) as a main factor when deciding if load restrictions should be lifted for a bridge. Load tests are also used when building computer models for bridges to evaluate specific loading conditions when live load distribution is not enough to fully evaluate a bridge's behavior. The distribution of live load to individual structural elements is assumed during design and rating of a bridge. Distribution is also generalized in design specifications for different types of structures and load combinations. Generalizations are conservative because there are a wide variety of bridge types with differing structural elements within every category of bridges.

In a high percentage of bridges evaluated, load test results allowed for removal of load restrictions. The live load distributions determined by the Iowa DOT's testing program have been equal to or better than those used in original rating calculations. For example, load testing has shown that curb-and-rail systems contribute significantly to a bridge's capacity. Quantifying the contribution of curb-and-rail systems for a bridge through hand calculations is subjective, and not normally done during design or load rating due to uncertainty of the calculation. Load testing is a mechanism for quantitatively assessing the curb-and-rail contribution.

A bridge's overall condition is taken into account when considering a load test. A bridge with deterioration affecting load capacity is difficult to instrument. If a load test is performed on a deteriorated bridge, the useful life of test data may be short because bridge conditions are changing. The cost-to-benefit ratio must be considered. Overall success of the load testing program in Iowa has shown a reduction in the number of restricted bridges on the Primary Road System, and contributed to better use of repair and replacement funds because some bridges were safely kept in service longer due to greater than expected capacity.

Instrumentation, equipment and load testing

Effective diagnostic testing utilizes specialized hardware and software. The BDI testing equipment used by the Iowa DOT's testing program is an integrated system allowing fast instrumentation placement and, similarly, allowing connection to the data acquisition system in minimal time (Figures 2 and 3). The placement location of strain gauges on a bridge is critical to accurately assess structural performance.

Figure 2 - *Preparation of surface for bonding sensors requires more effort on painted steel than on concrete; the paint and primer must be completely removed on steel and surface made flat for good bonding.*

Figure 3 - *Quick-setting adhesive applied to "footprints" on sensors allows bonding to a concrete beam in a region previously cleaned by surface grinding.*

Generally, to address issues and concerns identified during evaluation of existing condition data, an instrumentation plan is designed (Figures 4 through 6). The plan should incorporate the collection of data that may impact attributes of any subsequent analysis performed. Common issues may include girder-end, rotational restraint conditions, the presence of composite action, lateral live load distribution, etc.

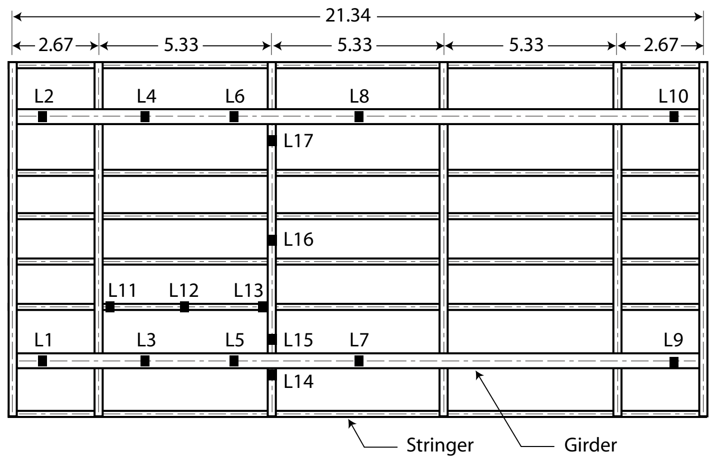


Figure 4 - *Representative instrumentation layout for a diagnostic load test of a two-girder bridge system with floor beams and stringers*

Figure 5 - *Two-girder bridge system with cover plates and strengthening angles on the two girders*

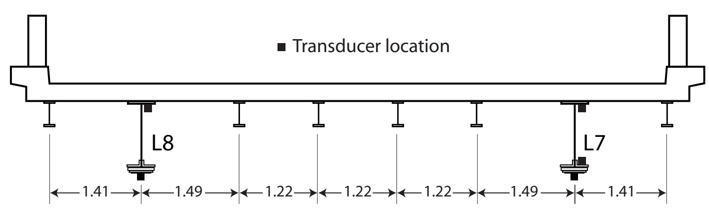


Figure 6 - *Example cross section of an instrumentation layout for a diagnostic load test*

The testing process utilizes a controlled test truck crossing the structure at a crawl speed (documented weight and position on bridge must be known). The truck's position can be determined using a device mounted to its tire and fender (Figure 7). The data acquisition system uses software allowing researchers to see plotted strain vs. truck position during actual testing (Figure 8). This ensures data is collected properly.

Figure 7 - *A test truck crosses the bridge at 5 mph in predesignated driving lanes. To automatically record the truck's position during a load test, hardware devices are mounted to its wheel and fender.*

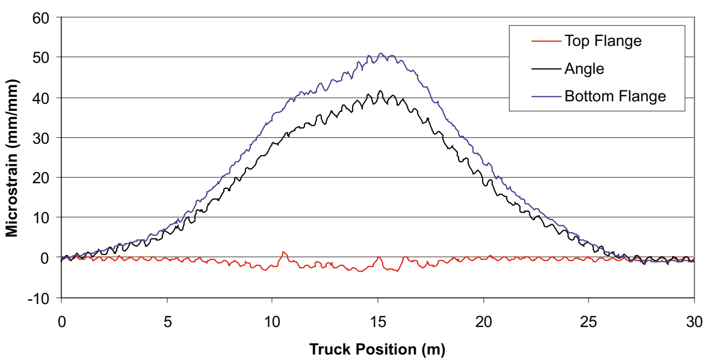


Figure 8 - *Typical plot of strain time history for a test truck load path. Strain data is shown for one of the girders that had been strengthened using a bolted structural angle near the bottom flange.*

Software associated with the integrated testing system allows plotting of data in different formats after testing is complete. Typical processing of test strain data includes calculating the lateral live load distribution and identifying the maximum live load strains in bridge components. A modified initial bridge rating can be created using this data. If a desirable solution is not reached, integrated testing system software can be used to create a validated analytical bridge and vehicle model for direct calculation of a bridge rating.

Embargo evaluation

Codified parameters are the conventional foundation used in load-rating calculations for bridges, subsequently used in the process of maintaining bridge inventory. Frequently, diagnostic load tests reveal strength and serviceability characteristics exceeding predicted codified parameters. More accurate load ratings resulting from diagnostic field load testing frequently result in increased rating factors. In addition, Iowa's recent modifications to legal vehicle specifications require that some bridges be posted (embargoed) after conventional rating calculations have been performed.

Sixteen critical (embargo) bridges previously posted in Iowa and identified as negatively impacting the flow of traffic were re-evaluated using diagnostic load testing procedures to determine if load ratings would justify removing the postings. Subsequently, the Office of Bridges and Structures was able to justify removal for the majority of postings. Typical evaluation of an embargoed bridge initiates with OBS, providing the BEC with load rating information for:

✓ Critical sections.
✓ Spans or members.
✓ Lateral load distribution.
✓ Determination of effects for composite action and end restraints.

Strain gauge instrumentation is placed at predetermined critical locations and test trucks representing loads similar to legal vehicles (selected by the OBS) are used to conduct load tests. Visual inspections are performed as needed (as part of the testing and evaluation) to identify bridge deterioration or damage.

Using data collected from a load test, OBS can more accurately determine the load rating for a bridge, and in the case of embargo bridges, potentially reduce or eliminate posted limits as a result. The following case study on an Interstate 80 (I-80) slab bridge near Grinnell, Iowa, illustrates the evaluation process.

I-80 bridge near Grinnell, Iowa

In 2006, an I-80 slab bridge near Grinnell was load tested (Figures 9 through 11). The three-span, slab bridge consists of 34-foot-3-inch end spans and a 44-foot interior span. The bridge has two lanes with shoulders on both sides for a total width of 43 feet. Strain gauges were installed on the bottom of the midspan slab at one end, on interior spans, and on one pier and abutment. Gauges were oriented so the lateral load distribution, maximum positive and negative bending strains and end restraint were calculated.

Figure 9 - *Slab bridge on I-80 near Grinnell*

Figure 10 - *Iowa DOT tandem-axle load test truck*

Figure 11 - *Strain gauges attached to bottom of slab, midspan of end span*

An Iowa DOT tandem-axle dump truck (59,200 lbs.) was used as the load vehicle and driven from east to west at a crawl speed (2-5 mph). Several load paths were investigated (including single- and two–lanes loaded) made possible by superpositioning two single-lane load cases (Figure 12).

Strain profiles for six strain gauges located midspan (at the end span oriented longitudinally) for Load Case 1 and Load Case 3 show that, as predicted, strain magnitudes were highest when the truck was closest to a single gauge (Figures 13 and 14). The shape of plots was as predicted. Only one traffic lane was closed for testing, which resulted in data spikes (after the 70-foot mark when ambient traffic crossed the bridge).

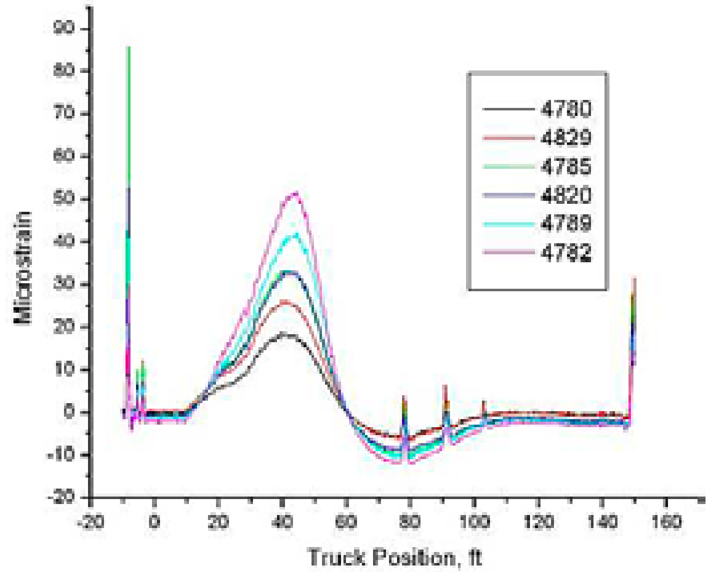


Figure 13 - *Strain profile for Load Case 1 - midspan of end span*

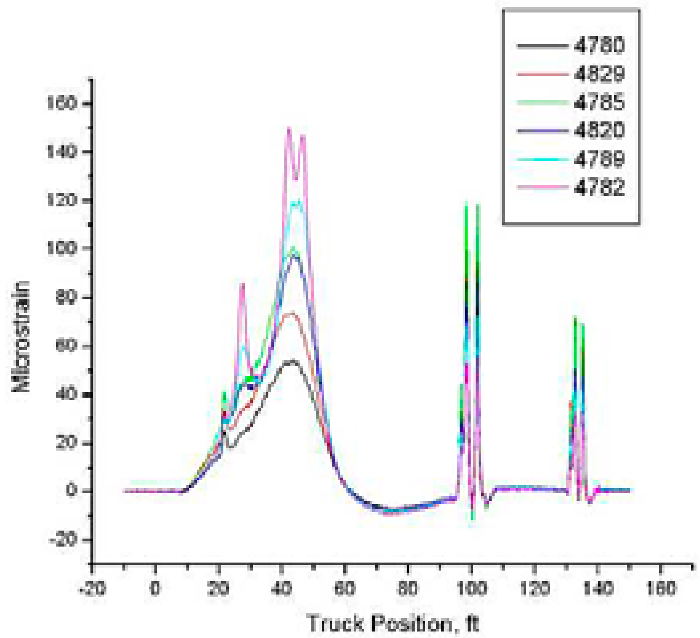
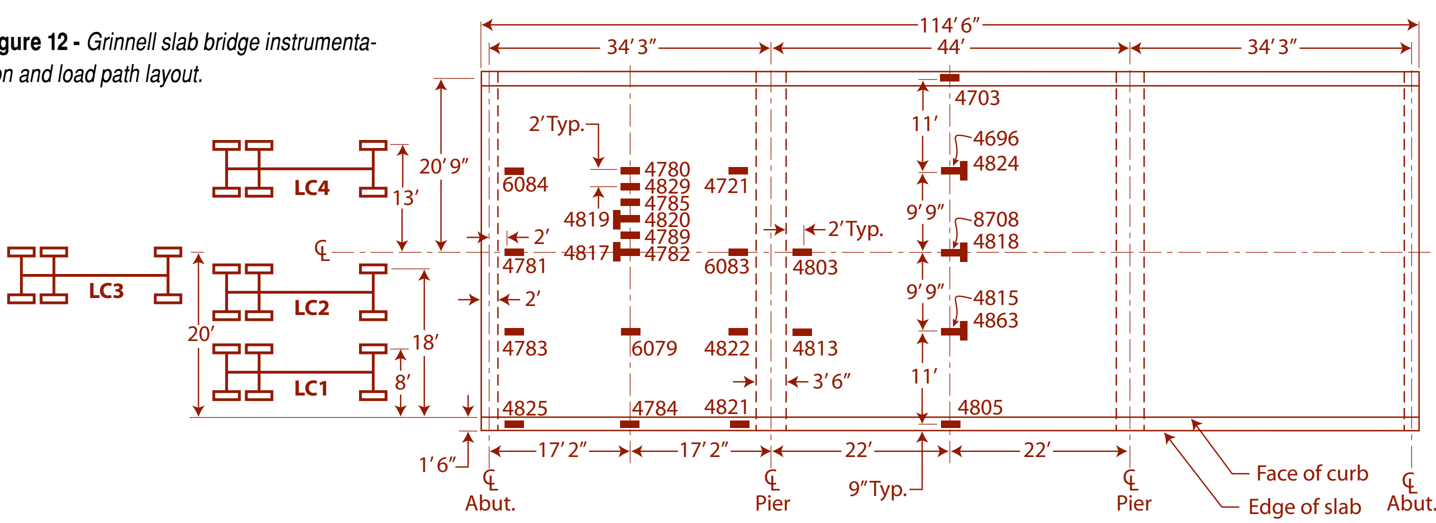


Figure 14 - *Strain profile for Load Case 3 - midspan of end span*

Figure 12 - *Grinnell slab bridge instrumentation and load path layout.*



To calculate the equivalent width of longitudinal strips per lane for both shear and moment, the following equation was used.

$$E \text{ (Equivalent strip width)} = \frac{\sum_{i=1}^{n} (\text{strain}_i \times d_i)}{\text{strain}_{max}}$$

Where (n) is the total number of strain sensors, $strain_i$ is the strain reading of the width sensor, $strain_{max}$ is the maximum strain measured by the sensors, and d_i is the spacing of adjacent strain gauges. A graphical representation of the procedure is shown (Figure 15).

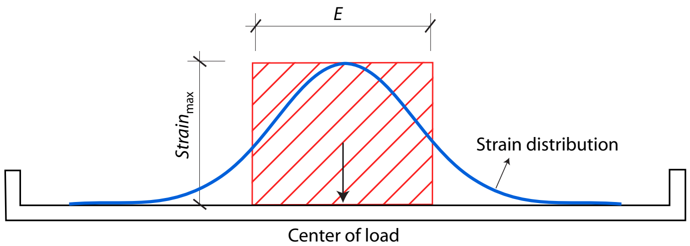


Figure 15 - *Graphical representation of equivalent longitudinal strip width*

Using this concept, peak strain data for Load Case 3 were extracted and plotted with respect to lateral position. (Note: The ‘0’ position is aligned with the truck’s centerline). A graphical representation of this extracted data is shown (Figure 16). Using this data and procedure above, an equivalent strip width was estimated between 8 feet 6 inches and 11 feet.

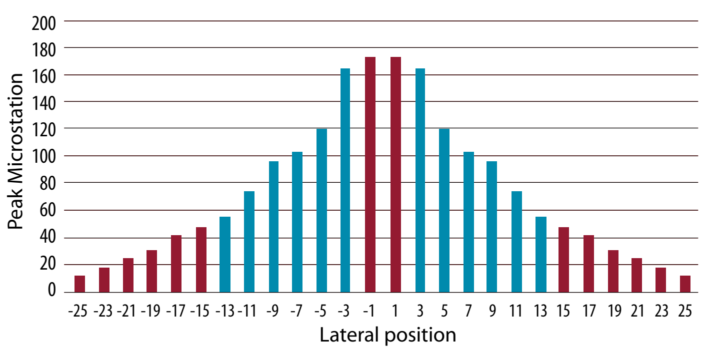


Figure 16 - *Peak strain distribution*

Collision damage evaluation

Diagnostic bridge testing is commonly used to clarify conventional load rating calculations. The Iowa DOT also uses it to evaluate the short-term safety of bridges damaged from collisions involving over-height vehicles. The Iowa DOT has investigated several of these types of incidents over the past five years. The following is a case study at the I-680 bridge near Beebeetown illustrating this evaluation process.

I-680 westbound near Beebeetown, Iowa

In June 1996, an over-height vehicle struck the I-680 westbound structure near Beebeetown causing significant loss of section and cracking (Figures 17 and 18). Severe damage was incurred and concerns over the remaining capacity and long-term durability of two damaged beams resulted in their removal. Just before the girders were replaced, the exterior driving lane was closed to traffic and a load test performed to determine short-term load distribution characteristics of the bridge.

Figure 17 - *View of damaged exterior girder in the center span of the Beebeetown bridge, westbound on I-680 in western Iowa; damage was restricted to the exterior and first interior prestressed girders.*

Figure 18 - *Close-up view of damaged exterior and interior girders; the damage included loss of section properties and severe cracking, as well as damage to prestressed strands.*

Because there was a similar companion bridge at the site for eastbound traffic, a unique opportunity existed to perform an in-place assessment of load distribution between damaged and undamaged bridges. Test vehicles were positioned along the decks of both bridges, and single and dual truck tests were conducted on each. Both deflection and strain instrumentation were used to evaluate local and global structural performance characteristics, including placement of strain gauges on the exposed undamaged prestressed strands (Figures 19 and 20).

Figure 19 - *Load test with two test trucks in adjacent traffic lanes; deflections were measured using displacement transducers on tripods and high-strength wire.*

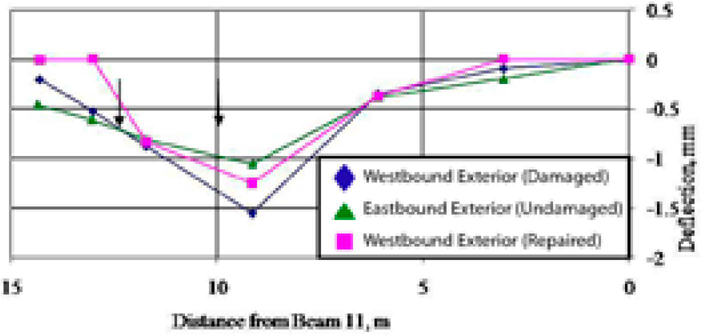


Figure 20 - *Transverse deflected shape, lane 2 loaded - rear axles at P4 and P6.*

Based on experimental test results alone, noticeable differences in structural response were detected between the damaged westbound and undamaged eastbound bridges (Figure 20). Stiffness for the damaged westbound exterior girder decreased. Additionally, redistribution of live loads from damaged girders to adjacent undamaged girders (of the westbound bridge) was shown. Another aspect of this research included analytical modeling of damaged and repaired conditions so the effect of damage on load distribution could be quantified. The models in Figure 20 were calibrated using these experimental results.

Fatigue evaluation

A common problem with multiple steel-girder bridges is fatigue cracking at diaphragm/girder connections, particularly in the negative moment regions when the stiffener is not connected to the top flange. Skew bridges are particularly prone to these problems. Differential deflections of girders from live loading produce forces in the diaphragms that are transmitted to the webs at these connections and create cyclic stresses that may cause fatigue cracking in the web gap regions of diaphragm/girder connections.

The web gap is an area above the stiffener connection and below the flange fillet weld where the stiffener is coped. There are at least several different retrofit methods used to prevent web fatigue cracking, but there have been cases where a crack has reoccurred. The Iowa DOT has explored the effectiveness of retrofit methods through diagnostic load testing.

One retrofit method that has been evaluated is based on reducing web gap distortion (and associated cyclical stress) by reducing the applied diaphragm forces in the web gap. This is accomplished by loosening the bolts in diaphragm/web stiffener connections while leaving them in place. That way, diaphragms still help distribute lateral load due to wind or collision while providing bracing support for the girders.

I-35 northbound at State Line Road

One bridge tested and evaluated is a skewed, two-lane bridge with five girders supporting northbound traffic on I-35. The bridge has three spans and crosses State Line Road where Iowa borders Missouri. Previously, cracking had occurred at several diaphragms in the negative regions. Drilled-hole retrofits had been implemented, but to no avail at some locations (Figures 21 and 22).

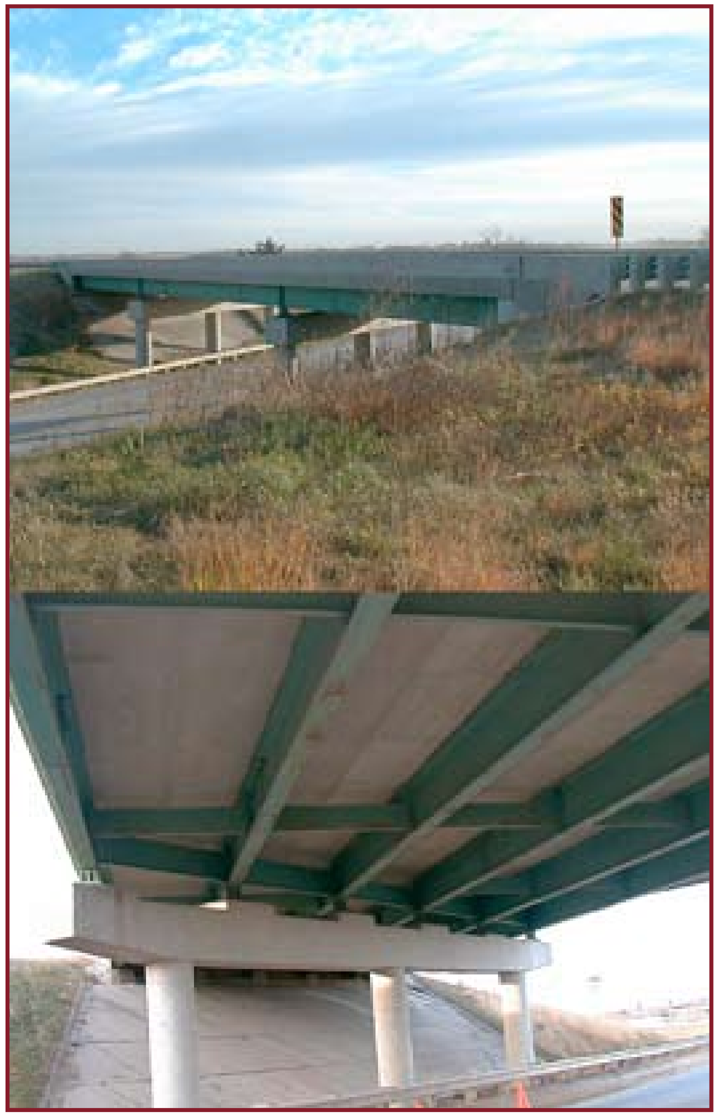


Figure 21 - *A multiple steel-stringer bridge on I-35 in southern Iowa; several web gap locations and associated diaphragms were monitored during a diagnostic load test before and after an implemented retrofit.*

Figure 22 - *A web gap on the I-35 bridge showing previously developed cracks; for the initial retrofit, holes were drilled at the ends of the crack. However, cracking continued to spread beyond the hole retrofit.*

Diagnostic load tests were performed on the bridge using test trucks of known weight and geometry. Single and multiple truck loading was applied to the bridge in various lanes using several diaphragm/stiffener locations (for diaphragm bolts) in an original tight condition and for all bolts loosened in the diaphragm (including bolts in the next interior diaphragm section). Both out-of-plane deflection and strain in the web gap were measured (Figure 23). In addition, strain data was measured on the diaphragms to determine cause and effect between web gap performance and diaphragm forces (Figure 24).

Figure 23 - *The out-of-plane behavior of the web in a typical web gap location was determined by using both displacements and gradient-strain gauges.*

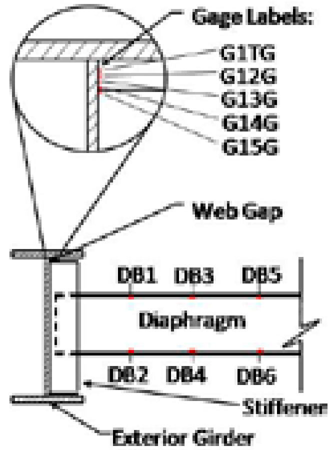


Figure 24 - *A schematic showing the gradient-strain gauge (five separate strain gauges in the gradient) in a web gap and individual strain gauge locations of the associated diaphragm.*

Strain data (Figures 25 and 26) show the comparison of web gap strain (and diaphragm strain) before and after implementing the bolt-loosening retrofit – the reduction in the maximum web gap strain was approximately 75 percent. Additionally, strain values in the diaphragms were almost completely eliminated. These, and subsequent similar results from diagnostic testing, support the bolt-loosening retrofit as an effective solution to fatigue web cracking.

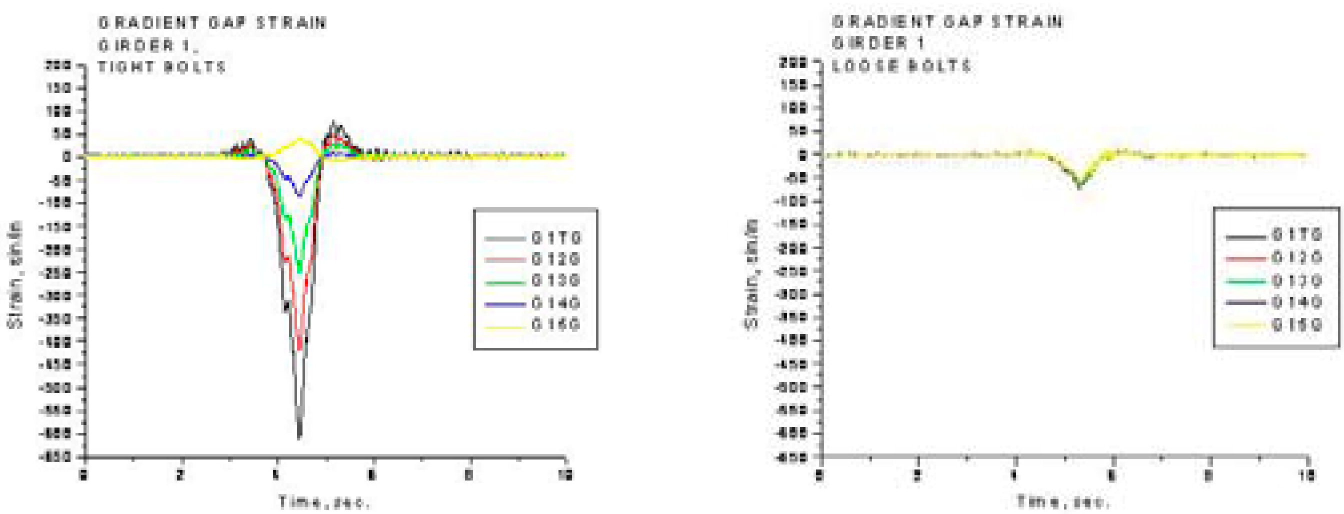


Figure 25 - *Plots of web gap strain (in the same web gap) before and after the bolt loosening retrofit was implemented.*

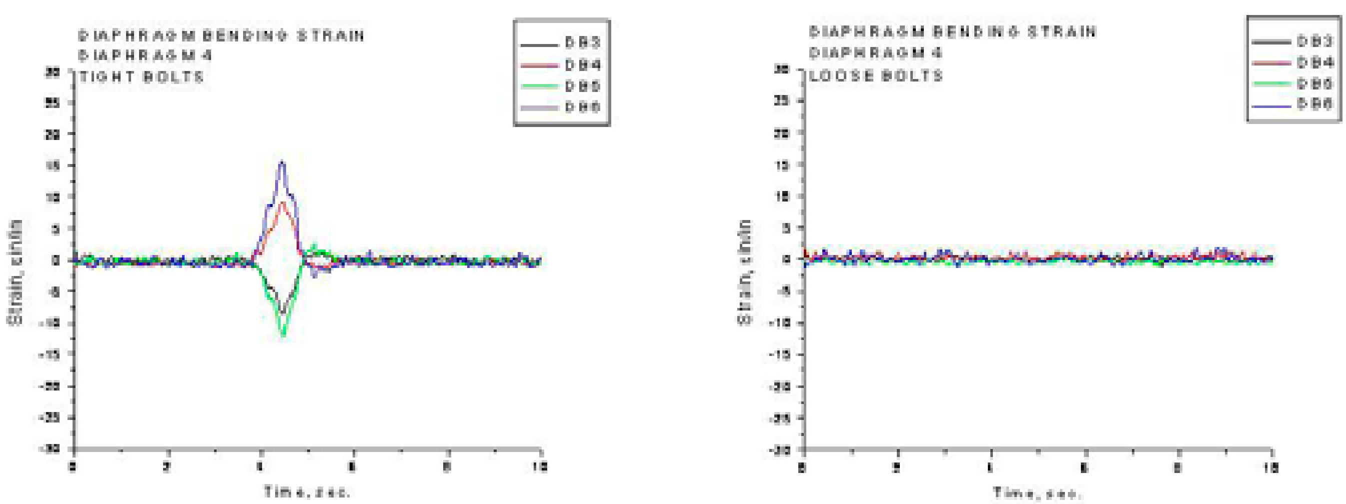


Figure 26 - *Plots of diaphragm strain (on the same diaphragm) before and after the bolt loosening retrofit was implemented.*

Advanced materials evaluation

The OBS has investigated the use of ultra high-performance concrete (UHPC) in two Iowa bridge projects supported by funding through the Federal Highway Administration's Innovative Bridge Research and Construction (IBRC) Program and IHRB. While the program requires testing and evaluation to verify success of the applications, the Iowa DOT strongly supports these goals to validate their design process and identify potential problems with these state-of-the-art bridges.

UHPC is very high strength, does not utilize typical structural steel reinforcing, and has the potential to make bridges more durable and longer lasting. Diagnostic load testing has been used to evaluate the potential benefits of erecting bridges with this new high-performance material.

First UHPC bridge in the United States
Wapello County, Iowa

In Wapello County, the Iowa DOT and Wapello County designed, constructed and evaluated the first road bridge in the United States utilizing UHPC in 2005 (Figure 27). Because no design specifications existed for this material, OBS used both laboratory and field testing to validate design procedures and assess field performance of the bridge. The results provided guidance on standardization for future design procedures and information for improved applications of UHPC use in bridges.

Figure 27 - *Deck placement after UHPC pi-shaped girders are in place; this was the first UHPC bridge designed and constructed in the United States and is maintained by Wapello County.*

First UHPC pi-girder bridge in the United States
Buchanan County, Iowa

Buchanan County and the OBS were also significantly involved with the next generation UHPC girder shape (pi-shape) for a similar demonstration application completed in Buchanan County in 2008. The demonstration project included modification of the initially developed pi-shape; and the bridge was eventually constructed and evaluated through load testing. Once again, this bridge project put Iowa at the national forefront of bridge design, and construction implementation and field evaluation of this UHPC shape (Figure 28).

Figure 28 - *New generation pi-shaped bridge girders utilizing UHPC.*

The Buchanan County pi-girder bridge is a 25-foot wide, three-span, 115-feet 4-inch bridge. The two end spans are constructed of conventionally reinforced concrete slab units and the center span (50 feet) was constructed with pi girders (Figures 29 and 30).

Figure 29 - *The center span of the bridge uses pi girders (three individual units tied together) on a 50-foot span.*

Figure 30 - *Pi-girder span of the bridge under construction; three individual pi girders were placed before being connected to each other.*

The pi-girder bridge was instrumented and tested in the autumn of 2008, shortly after construction. Both strain and deflection data were measured during testing to validate design assumptions used for this bridge. This allowed documentation of:

- ✓ Live load sharing between the three adjacent pi girders.
- ✓ Peak deflection and strain magnitudes of critical members.
- ✓ Effectiveness of the bridge diaphragms.
- ✓ Affect of bearing conditions at the pier on bridge performance, etc.

Installation of load testing instrumentation (Figures 31 and 32) and typical plots showing girder strain and deflection (Figure 33) during load testing of the Buchanan County pi-girder bridge are shown below.

Figure 31 - *Single-load test truck used for static and dynamic diagnostic load tests.*

Figure 32 - *Strain instrumentation placed on the pi-girder bridge prior to load testing.*

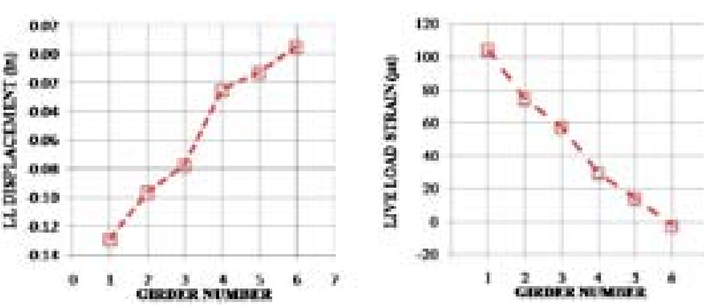


Figure 33 - *Plots of girder strain and deflection for one load position of the test truck*

Permit vehicle evaluation

The most common application for diagnostic bridge testing is clarification of conventional load rating calculations; however, the Iowa DOT also uses it to evaluate requests for permit vehicles (i.e., superloads). The following case study in Floyd County illustrates this process.

Figure 34 - *The first superload vehicle crossing the test bridge.*

Critical bridge superload instrumentation assessment
Floyd County, Iowa

In the summer of 2003, a series of superloads (Figure 34) were scheduled to depart from Waterloo, headed for a location near Mason City. Given the magnitude of the expected loads (600,000 - 900,000 lbs.), the Iowa DOT decided to perform a diagnostic load test to assess the load-carrying capacity of the most critical bridge along the scheduled route. Initial conventional ratings indicated a rating factor of approximately 0.5 was sustained, which was insufficient for approving a permit.

The critical structure is a five-span, prestressed concrete girder bridge with a six-girder cross-section located in Floyd County about six miles east of Mason City. The bridge crosses a small creek and railroad line, has an overall length of about 600 feet, and an overall roadway width of approximately 39 feet. The span of the bridge found to be of greatest concern (using traditional calculations), was about 120-feet 6-inches long (Figure 35).

Figure 35 - *Partial elevated view of the five–span, prestressed girder bridge*

To assist the Iowa DOT in assessing the Floyd County bridge, the BEC conducted a traditional load rating test using various combinations of one or two loaded tandem-axle dump trucks (Figure 36). Strain data were collected at three cross sections of critical span (near the west abutment at midspan and first pier). Four girders were instrumented with two strain gauges each (one on the top and bottom flanges) at the sections near the abutment and pier, and all six girders were instrumented using two strain gauges each (one on the top and bottom flanges) near the midspan section.

Figure 36 - *Test trucks for load rating prior to passage of superload vehicle*

From data collected during this test, a finite element model was calibrated. The final model had less than a 9 percent error-predicting field test result; it was then used to predict the response of the bridge to the first superload (approximately 640,000 lbs). Typical strain results for two bridge girders from the prediction are shown (Figure 37). It was assumed for this analysis that the truck crossed the bridge centered across its width. As expected, a symmetric behavior resulted. From this model and further consultation with the Iowa DOT, it was determined that the bridge had sufficient strength (both flexural and shear) to allow passage of the loads.

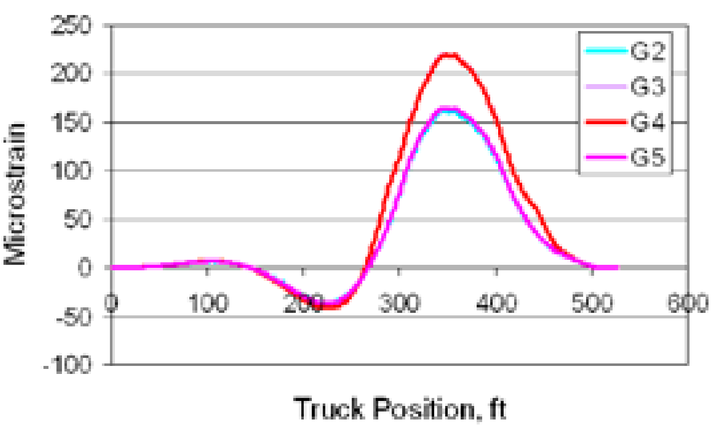


Figure 37- *Analytical prediction of girder strain from passage*

For actual testing of the first superload (Figures 38 and 39), this same instrumentation scheme was installed on the bridge and responses measured. When comparing predicted responses for girders at midspan (Figure 37) with actual results (Figure 40), there is very good correlation. Although not shown here, the predicted strain at the pier was not as accurate as predictions near midspan and the abutment. A brief post-loading visual inspection of the bridge revealed that additional cracking in the barrier wall and deck had occurred. This may account for the less accurate prediction.

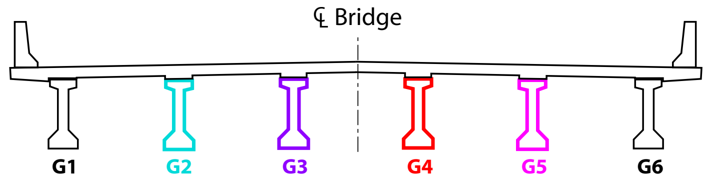


Figure 38 - *Roadway position of superload during load test*

Figure 39 - *Superload crosses prestressed girder bridge during load rating test*

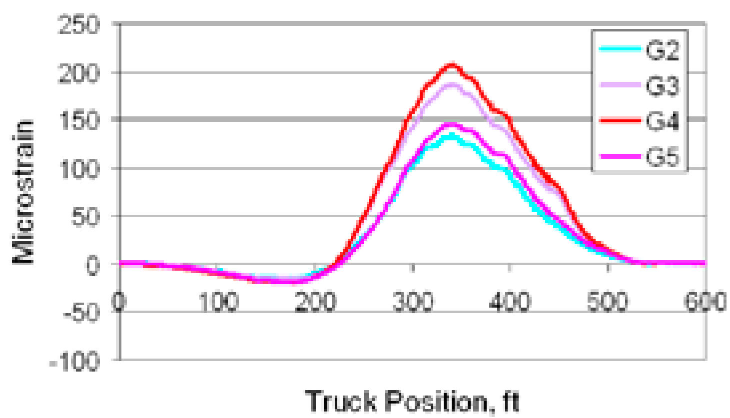


Figure 40 - *Experimental results of girder strain from superload passage*

Implementation team

Implementing a successful load test requires an organized plan and team effort between the Iowa DOT and researchers. For these tests, OBS enlisted the help of ISU's BEC when conducting load tests (Figure 41). In addition to OBS and ISU staff, field staff from the Iowa DOT's district offices provided onsite support.

Figure 41 - *Several BEC staff members placing instrumentation on a bridge*

Several key ISU's BEC staff members (Figure 42) and their primary roles were as follows.

✓ Brent Phares - load test plan, design of instrumentation layout and data evaluation
✓ Terry Wipf - overall load test planning, instrumentation and data evaluation
✓ Doug Wood - instrumentation, data collection and data processing
✓ Travis Hosteng - instrumentation, data evaluation and reporting

Figure 42 - *ISU's BEC staff members (left to right): Brent Phares, Terry Wipf, Doug Wood, and Travis Hosteng*

Continuing goals

During the past 10 years, the Iowa DOT has recognized an ever-increasing need to explore new technologies for assessing the true capacity of bridges. These innovative technologies help bridge engineers determine when to:

✓ Restrict heavy truck loads over deficient bridges.
✓ Permit superloads.
✓ Strengthen damaged members or members during evaluation of innovative materials.

To determine if a bridge's calculated load capacity accurately reflects its true load capacity, the Iowa DOT has begun load testing restricted bridges. A primary goal of the OBS bridge capacity evaluation program is to implement improved methods for load testing that help save lives, time and precious resources, while increasing the dependability and longevity of Iowa's bridges.

Iowa Highway Research Board Research and Development Activities FY 2009

✓ **Project details**
✓ **Progress updates**
✓ **Technology transfer activities**

Find out which IHRB projects received funding or were completed during FY 2009.

The Iowa DOT Research and Technology Bureau has recently published the annual report titled *2009 Iowa Highway Research Board Research and Development Activities FY 2009*. The report, prepared for the legislature, lists active, ongoing and approved IHRB projects, as well as detailed information regarding research, intelligent transportation systems and technology transfer activities.

Iowa Department of Transportation

ANNUAL REPORT
of
Iowa Highway Research Board
Research and Development
Activities
FY 2009

Attachment to
FY 2009 Annual Report
Research, Intelligent Transportation Systems, and
Technology Transfer Activities

DECEMBER 2009

Research and Technology Bureau

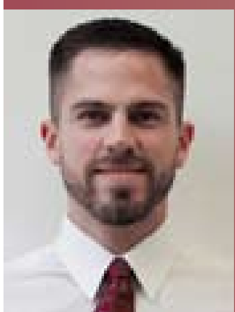
IHRB

To read the report visit www.iowadot.gov/operationsresearch/default.html.

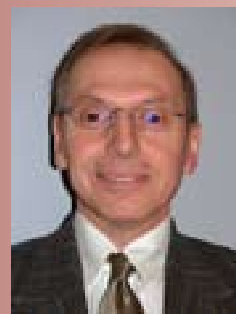
Iowa's bridge diagnostic load testing program

About the authors...

Dr. Terry Wipf achieved his doctorate in mechanics and energetics engineering from the University of Nebraska-Lincoln in 1983. He is currently the director of Iowa State University's Bridge Engineering Center, and a division leader and professor in the department of civil, construction and environmental engineering.



Travis Hosteng, P.E., achieved both his bachelor's and master's (2004) degrees in civil engineering from Iowa State University (ISU). He is currently a bridge research specialist at ISU's Institute for Transportation Research (InTrans), where he works to address timber bridge and other structural engineering needs within the private and public sectors.



Ahmad Abu-Hawash is the Iowa Department of Transportation's (DOT) chief structural engineer in the Office of Bridges and Structures. Abu-Hawash received his bachelor of science in civil engineering from the University of Iowa and his master's degree in structural engineering from Iowa State University. He has worked 25 years for the Iowa DOT in construction and bridge design.

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