Demonstration of Load Rating Capabilities through Physical Load Testing: Ida County Bridge Case Study

BRIDGE ENGINEERING CENTER

Final Report 2 of 3
August 2013

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16. Abstract The objective of this work, Pilot Project - Demonstration of Capabilities and Benefits of Bridge Load Rating through Physical Testing, was to demonstrate the capabilities for load testing and rating 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 and rating. This report documents one of three bridges inspected, load tested, and load rated as part of the project, the Ida County Bridge (FHWA #186070), including testing procedures and performance of the bridge under static loading along with the calculated load rating from the field-calibrated analytical model. Two parallel reports document the testing and load rating of the Sioux County Bridge (FHWA #308730) and the Johnson County Bridge (FHWA #205750). A tech brief provides overall information about the project.			
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DEMONSTRATION OF LOAD RATING CAPABILITIES THROUGH PHYSICAL LOAD TESTING: IDA COUNTY BRIDGE CASE STUDY

Final Report 2 of 3
August 2013

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INTRODUCTION

The US is heavily dependent on its transportation system for the quick and efficient movement of people, goods, and military assets. While the bulk of traffic volume utilizes state routes, agricultural industries are dependent on both the state and local systems for their travel. With that said, 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.

Currently, the rating and potential posting of bridges is completed by bridge engineers who rely on theoretical analyses based on codified approaches. By no fault of their own, codified approaches must be widely applicable and, as a result, many assumptions must be made. Therefore, while the techniques provide a reliable means for assessing the safe load-carrying capacity, they are, by their very nature, sometimes conservative.

An alternative approach is to create an analytical model that represents the behavior of a specific bridge—as opposed to a code-specified, generic bridge—based on field test results from the bridge itself and subsequently perform the load ratings using the calibrated model.

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. In addition, several counties across Iowa have utilized the same approaches to evaluate the need for load restrictions.

This report documents one of three bridges inspected, load tested, and load rated as part of the project, the Ida County Bridge (FHWA #186070), including testing procedures and performance of the bridge under static loading along with the calculated load rating from the field-calibrated analytical model. Two parallel reports document the testing and load rating of the Sioux County Bridge (FHWA #308730) and the Johnson County Bridge (FHWA #205750).

OBJECTIVE AND SCOPE

The objective of this work was to demonstrate the capabilities for load testing and rating 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 and rating.

BRIDGE DESCRIPTION

The Ida County Bridge (FHWA #186070) is a two-lane, three-span, continuous steel girder bridge located on gravel road Orchard Avenue, approximately one mile west of Arthur, Iowa over Odebolt Creek (approximately 60 miles west of Sioux City). The bridge was built in 1949 as a two-lane bridge with four girders and a roadway width of 20 ft curb to curb as shown in Figure 1.

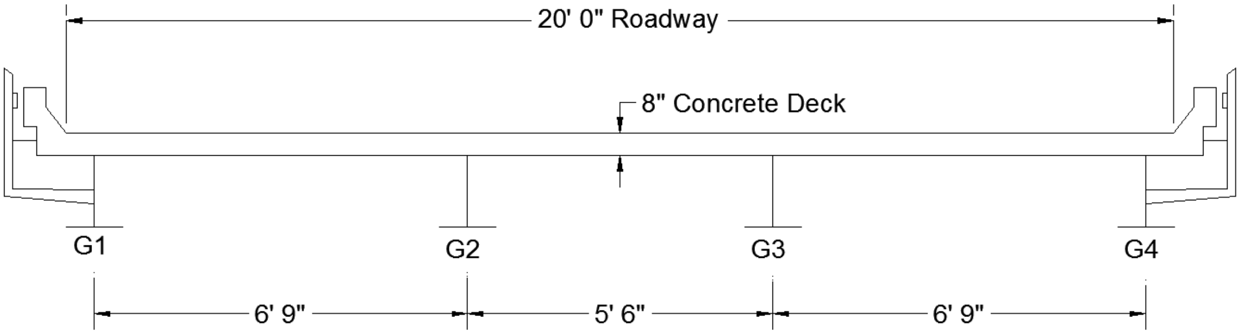

Figure 1. Two-lane Ida County Bridge FHWA #186070

Figures 2 and 3 show end and elevation views, respectively, at the time of testing in 2013.

Figure 2. Two-lane Ida County Bridge end view

Figure 3. Ida County Bridge elevation view

The current load posting for the bridge is shown in Figure 4.

Figure 4. Ida County Bridge load posting

The bridge substructure consists of concrete abutments/backwalls and concrete piers. Seven in. curved plates provide the bearing at the abutments and rockers provide the bearing at each pier as shown in Figure 5.

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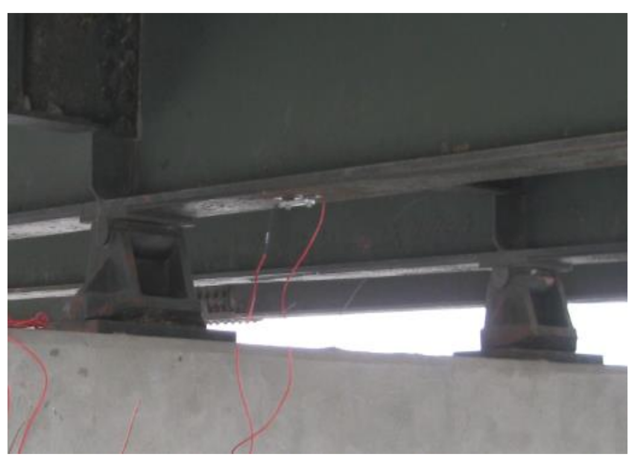
a. Abutment bearing



b. Pier bearing

Figure 5. Ida County Bridge bearings

As previously noted, the bridge superstructure is a three-span continuous steel girder bridge with two 45 ft 9 in. center-to-center of bearing end spans and a 58 ft 6 in. center-to-center of bearing center span, for a total length of 150 ft. Figures 6 and 7 illustrate the bridge plan and profile views, respectively.

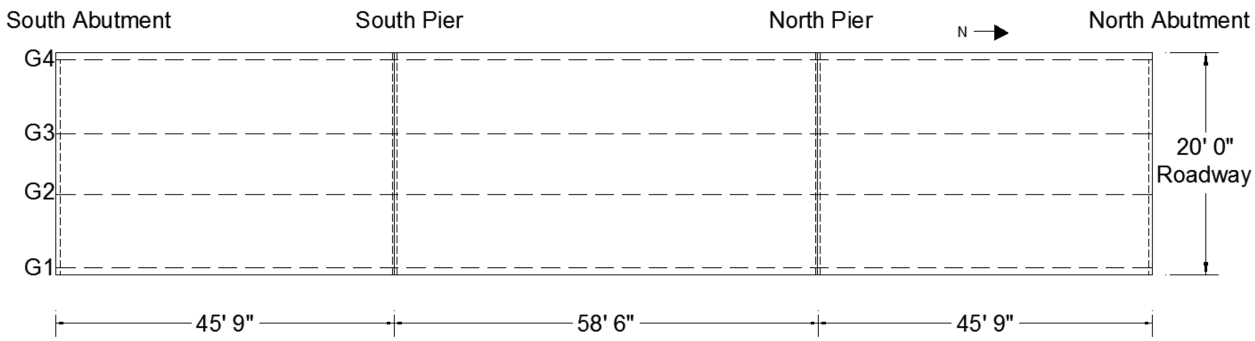


Figure 6. Ida County Bridge plan view

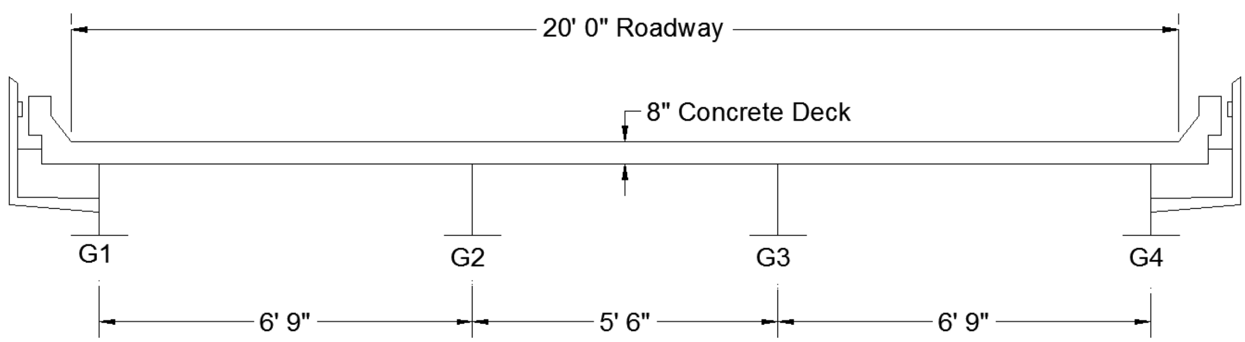


Figure 7. Ida County Bridge profile view

The interior two girders of the bridge (girders G2 and G3 in Figure 7) are W27x94s, and the exterior girders (girders G1 and G4 in Figure 7) are W24x68s. In addition, cover plates are present on all girders in the negative moment regions on both the top and bottom flange. Cover plates are centered over the piers and are sized as follows (width x thickness x length/span): G1 and G4 – 8.0 in. x 0.5 in. x 9 ft, G2 and G3 – 9 in. x 0.5 in. x 9 ft. The interior girders, G2-G3, are spaced at 66 in., and the exterior girders, G1 and G4, are equally spaced 81 in. outside the interior girders. The deck for the superstructure consists of an approximately 8 in. thick concrete slab with concrete curbs and a steel beam/rail guardrail as illustrated in Figure 7.

FIELD TESTING

Methodology

The bridges selected for inclusion in this work were selected 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. After bridge selection, preliminary information including as-built plans, photographs, inspection reports, and geometrical data were collected, if available, from the bridge owners (in this case, the Ida County Engineer's Office). 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. For the Ida County Bridge, the instrumentation plan included the use of strain transducers at critical locations and three transversely-spaced load cases. 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 the bridge as a controlled and known load crossed the bridge. 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.

Instrumentation

The instrumentation plan was developed based on the following: suggested critical sections as specified by the Office of Bridges and Structures (in this case, midspan of the end span was determined to be the controlling section) and the information necessary to create and calibrate an accurate model of the bridge.

Based on these two criteria, strain transducers were installed on the top and bottom flange of each girder at the following cross-sections, as shown in Figures 8 and 9 in plan and cross-section views, respectively: A) a distance d, depth of girder, from the face of abutment, B) midspan of one end span, C) a distance d, depth of girder, from the face of pier, and D) midspan of the center span. Girders are labeled G1 through G4 from east to west. An image of a typical instrumentation installation is shown in Figure 10.

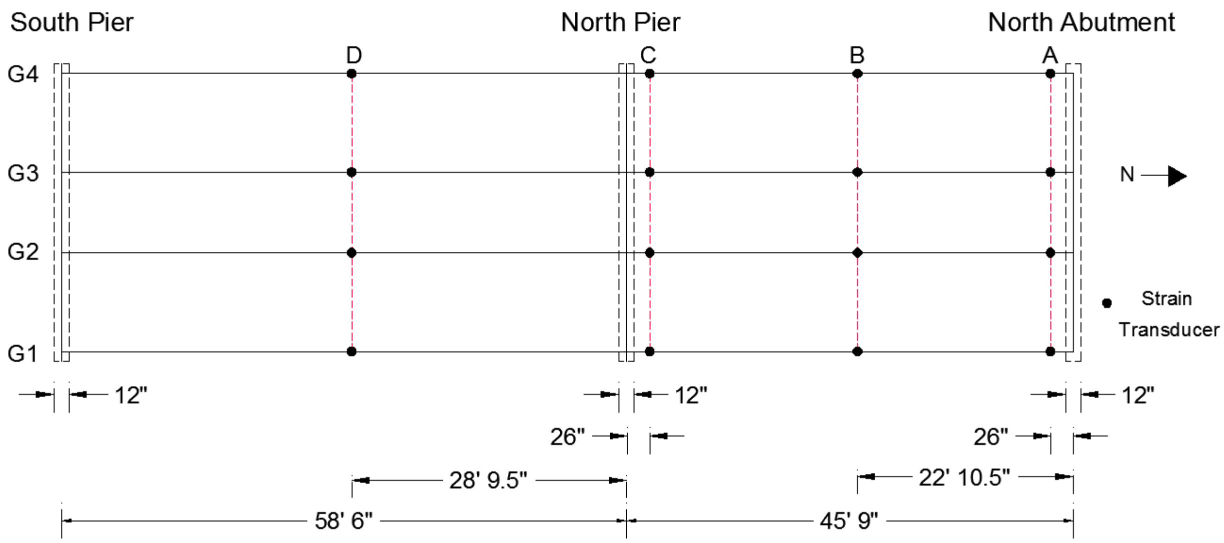


Figure 8. Ida County Bridge plan view of strain transducer locations

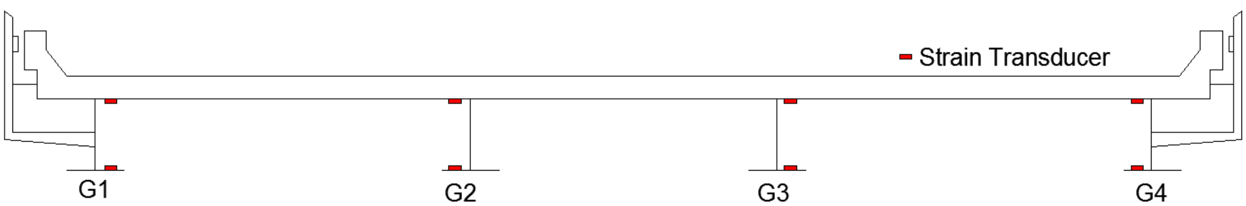


Figure 9. Ida County Bridge cross-section view of strain transducer locations

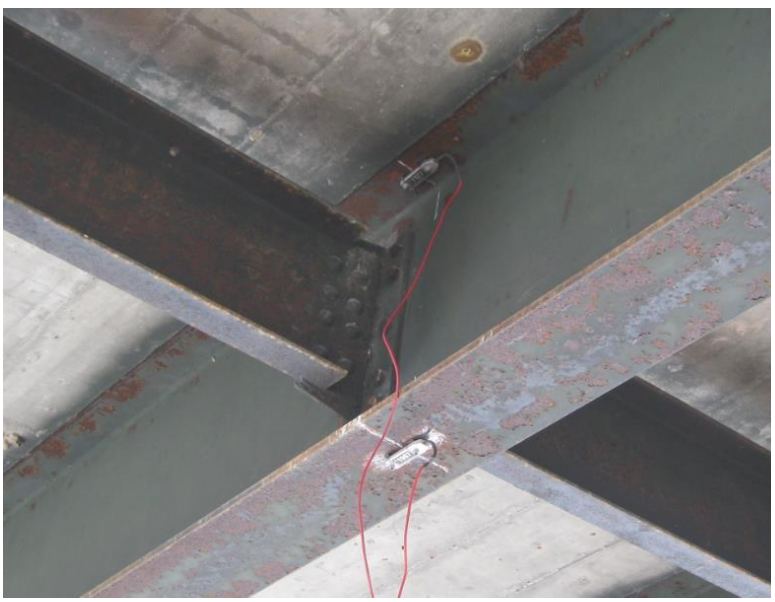


Figure 10. Ida County Bridge instrumentation setup

Static Loading

Loading of the structure was completed using a loaded and known tandem axle dump truck provided by Ida County, shown in Figure 11. Figure 12 shows the load truck dimensions and axle weights at the time of testing.

Figure 11. Ida County Bridge test truck

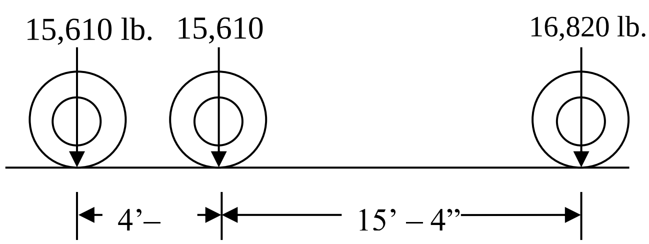


Figure 12. Ida County Bridge truck configuration and axle loads

The total weight of the truck was 48,040 lb., with front and rear axle weights of 16,820 lb., 15,610 lb., and 15,610 lb., respectively. The front and rear axle wheelbase were 7 ft and 6 ft, respectively; the rear axle spacing was 4 ft 3 in. center to center, and the distance from the forward most rear axle to the front axle was 15 ft 4 in.

Selection of truck positions for the three load cases was based on meeting the goals of this project and general bridge engineering concepts. The three load cases are illustrated in Figure 13.

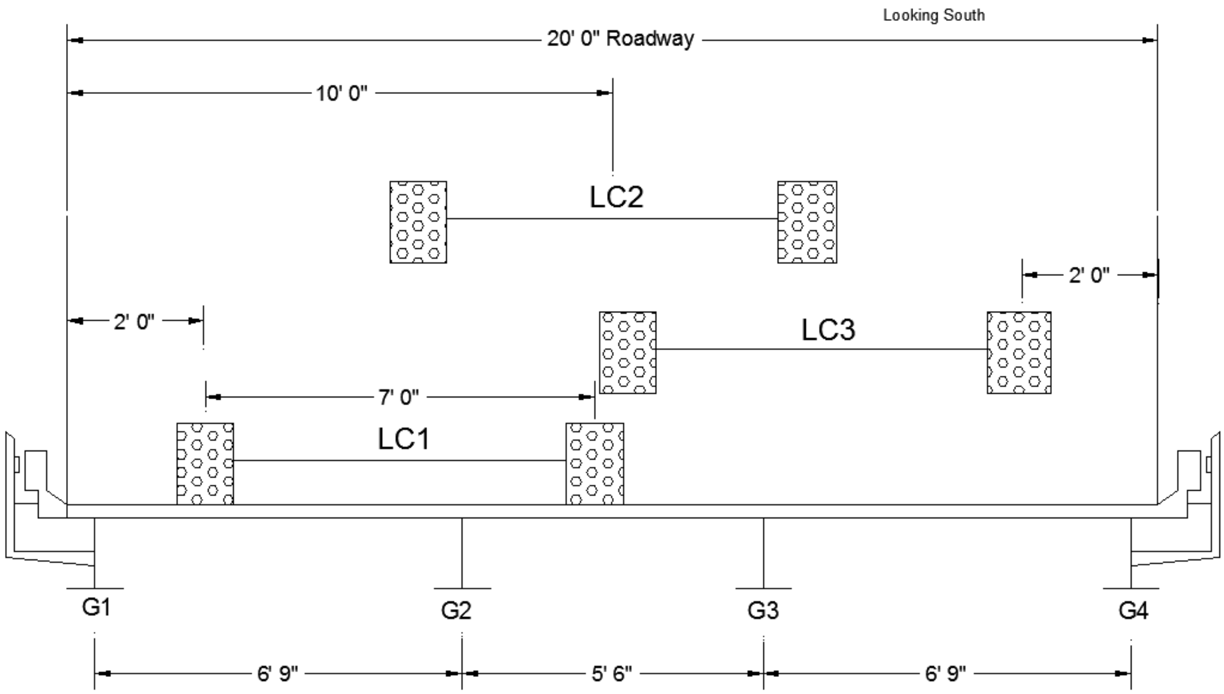


Figure 13. Transverse load position for Ida County Bridge testing

For the first load case, the truck was driven south at crawl speed with the centerline of the driver-side wheel line offset from the east curb 2 ft. The second load case consisted of the load truck driving south at crawl speed with the middle of the truck centered on the longitudinal centerline of the bridge. The third and final load case involved the load truck driving south at crawl speed with the passenger-side wheel line offset from the west curb by 2 ft.

Crawl speed indicates the load truck was moving across the bridge at less than 5 mph. At this low speed, any dynamic effects that may be induced in the structure are negligible. The location of the truck was recorded using the front axle as a reference point by creating a data spike for every 10 ft traveled. This allowed the data to be presented and evaluated as a function of known truck position.

LOAD TEST RESULTS

Following load testing, all field data were reviewed graphically to provide a qualitative assessment of the structure's live-load response. Some common assessments include strain history reproducibility for tests on common load paths, elastic strain response (strains return to zero after truck exits bridge), transverse load distribution, and axle signatures in strain data from gauges close to the load.

Figure 14 illustrates a strain history plot versus truck position for two tests of Load Case 2 on the bridge.

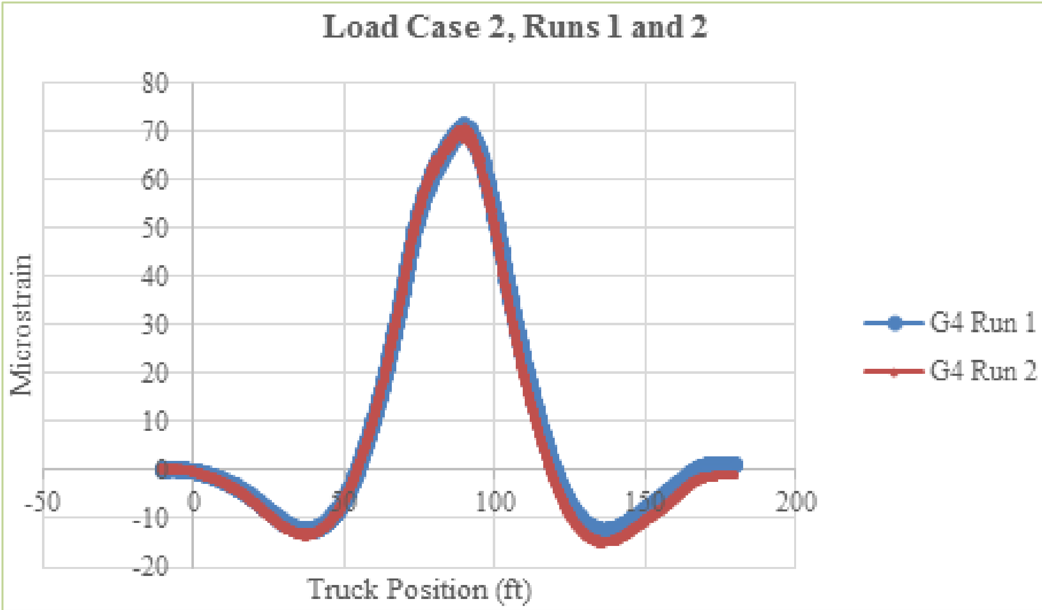


Figure 14. Data reproducibility for Ida County Bridge test

Comparison of the two data sets in Figure 14 indicates good reproducibility in the data. Returns to approximately zero after passage of the load truck suggests elastic behavior in the response. All load cases had similar response histories with respect to the degree of reproducibility and elastic behavior; therefore, one data set from each load case was selected for further, more in-depth, evaluation.

Approximations of the transverse load distribution characteristics of the structure were obtained using the measured strains from the load tests. Using the measured strains and equation 1, distribution factors (per wheel line) were calculated for each load case at midspan of both the center span and the approach span and are presented in Figure 15 and 16, respectively.

$$DF = \left(\frac{\varepsilon_i}{\sum_{i=1}^{n} \varepsilon_i} \right) * 2$$, decimal percentage of a single wheel line **(1)**

where:

ε_i = maximum measured bottom flange strain from ith girder.

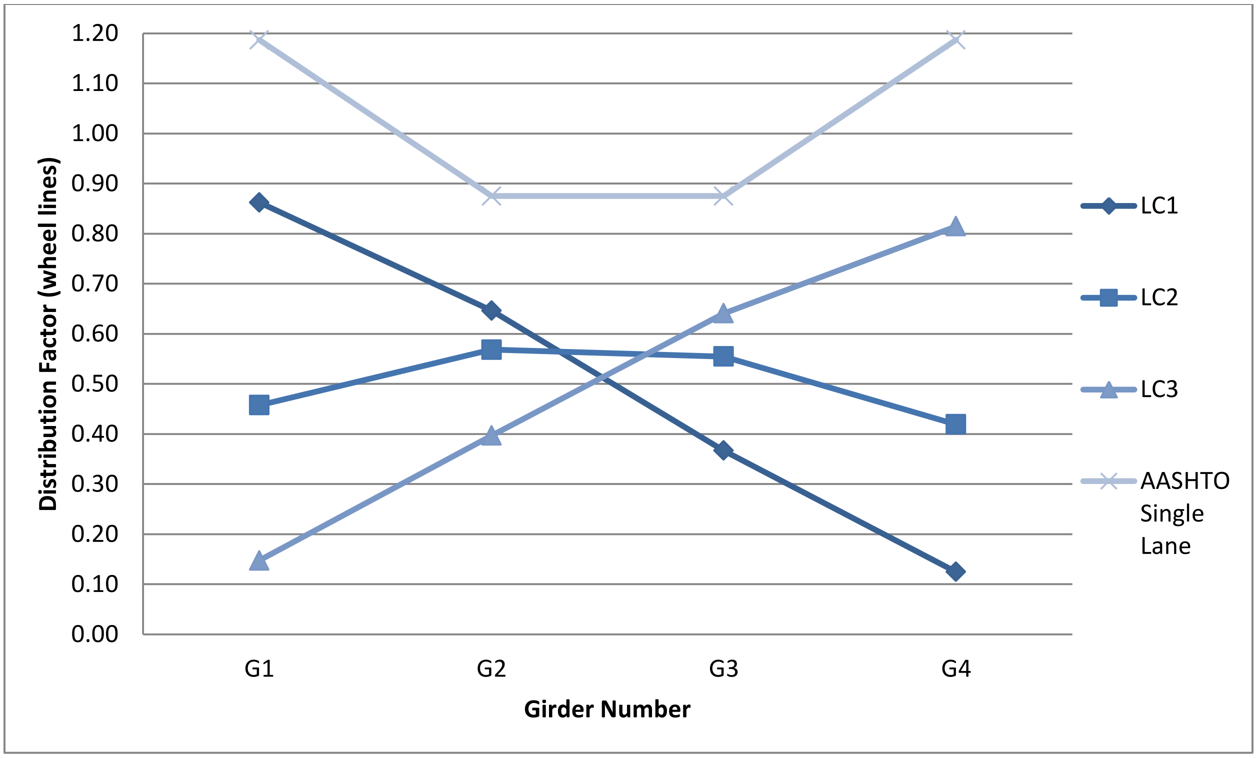


Figure 15. Ida County Bridge center span distribution factors

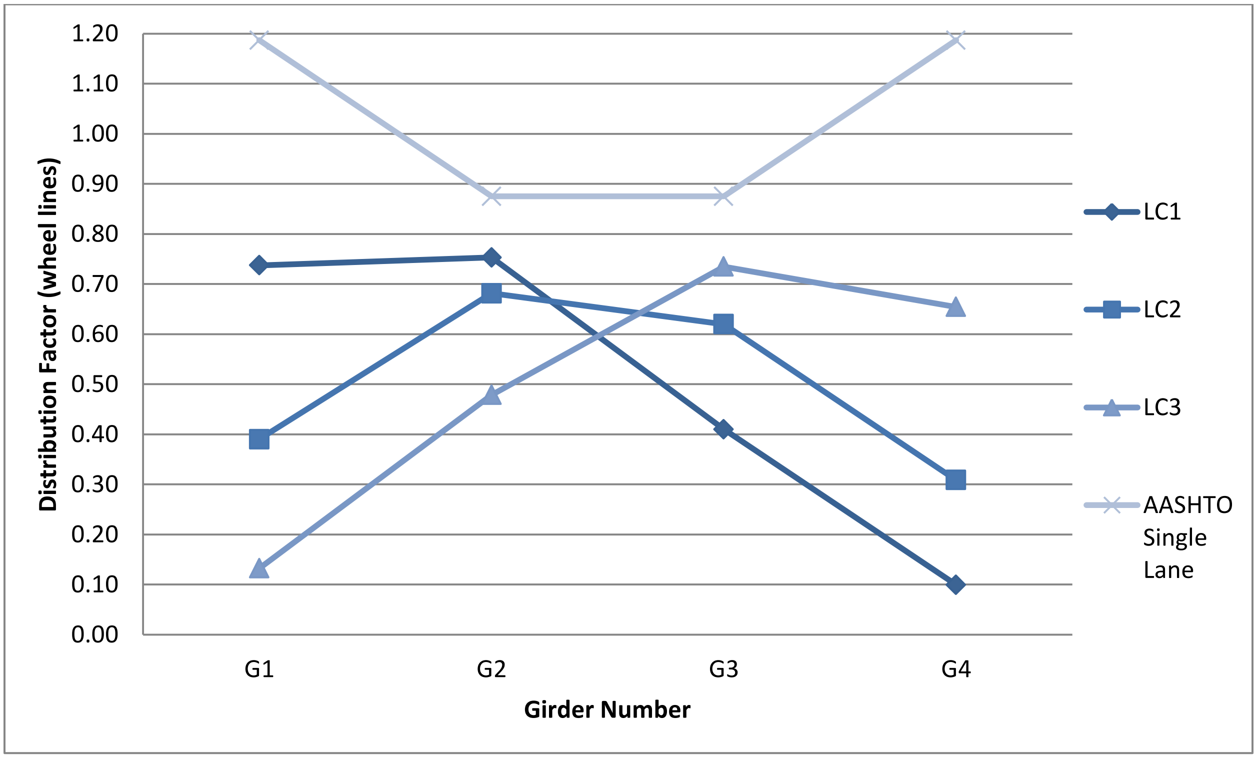


Figure 16. Ida County Bridge approach span distribution factors

In addition to the calculated distribution factors from the field strains, the American Association of State Highway and Transportation Officials (AASHTO) Standard Specification (1996) load distribution factors are also presented for comparison. In all cases, the field-measured distribution factors are less than those calculated using the code-specified equations.

Based on the information available from the inspection reports and plan sheets, it was believed that shear connectors were not utilized on the original structure. With that said, evaluation of the top and bottom strain magnitudes for each girder was completed to determine the location of the neutral axis and therefore the presence and degree of any unintended composite action. The field-calculated neutral axis information was then utilized during the model calibration discussed in the next section. Figure 17 illustrates the top and bottom flange strains measured on girder G3 for Load Case 2.

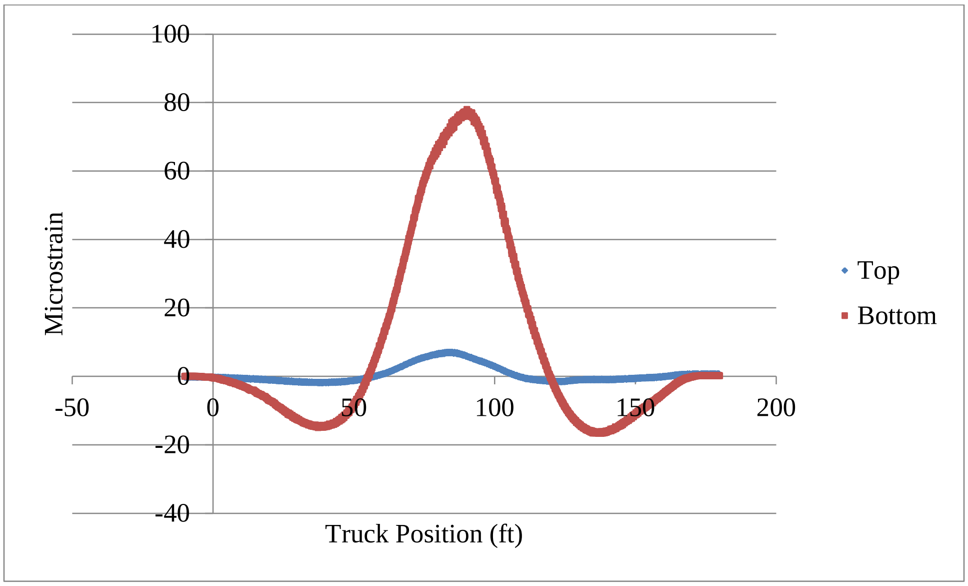


Figure 17. Ida County Bridge top and bottom flange strains on Girder 3 for Load Case 2

Similar plots were generated for all girders at both midspan cross sections (sections B and D in Figure 8), for evaluation of the neutral axis location at each location. Based on the data illustrated in Figure 17 and similar plots for all girders, it was determined that the Ida County Bridge exhibited some degree of unintended composite action at all girder locations. The exterior two girders, G1 and G4, displayed the least significant amount of composite action.

LOAD RATING

This section briefly discusses the model calibration, validation procedures, and calculated rating factors for the Ida County Bridge.

Model Calibration

Information gathered from the bridge and the load test data evaluation was utilized to generate an initial two-dimensional, finite element model of the bridge using BDI's WinGEN modeling software as illustrated in Figure 18.

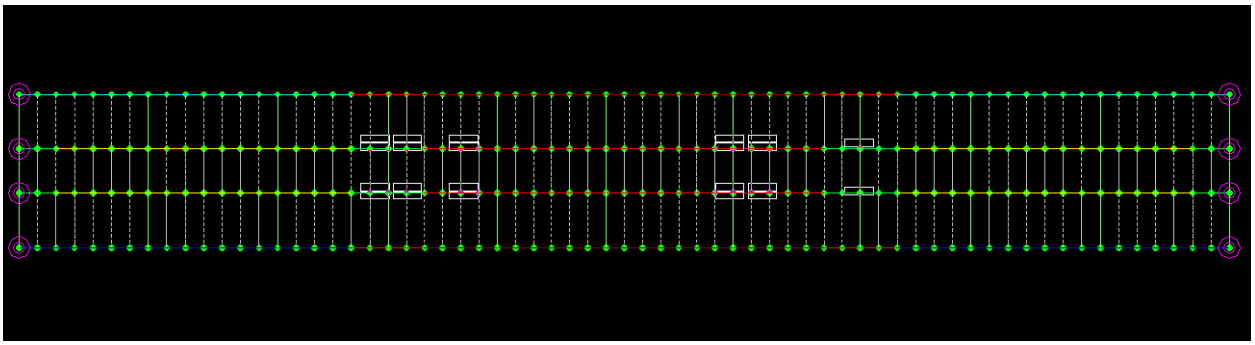


Figure 18. Finite element model of Ida County Bridge with modeled test truck footprint

Overall bridge geometry, girder and deck dimensions, approximate boundary (support restraint) conditions, neutral axis information from the field data, along with known and calculated material properties (modulus of elasticity, moment of inertia, etc.) were input for the basic model generation. Once the model was generated, a two-dimensional footprint and corresponding axle loads of the test truck, along with the load test data files, were input into the software.

With the initial model created, the load test procedures were reproduced analytically using BDI's WinSAC structural analysis and data correlation software. The software accomplishes this by moving the analytical truck footprint of the test truck across the model in consecutive load cases simulating the truck paths used during field testing. The analytical responses of this simulation were then compared (both statistically and graphically) to the field responses to validate the model's basic structure and to identify modeling deficiencies.

Model calibration continued until an acceptable level of correlation between the measured and analytical responses was achieved. This calibration involved an iterative process of optimizing material and stiffness properties (both cross-sectional and boundary conditions) until they were quantified realistically and the analytical model test results closely matched those from the field test results.

For bridges of this type and configuration, an acceptable level of correlation is on the order of less than 10 percent error. In the case of the Ida County Bridge, the majority of the calibration effort was spent optimizing the approximate end restraint and stiffness characteristics observed in the test data.

Calibration Results

At the conclusion of the model calibration, the final model produced a 0.9631 correlation and approximately 8.5 percent error with the measured responses, which can be considered an excellent match for a continuous steel girder structure such as the Ida County Bridge. The final model was found to closely match the member strains in magnitude and strain history as shown in Figure 19.

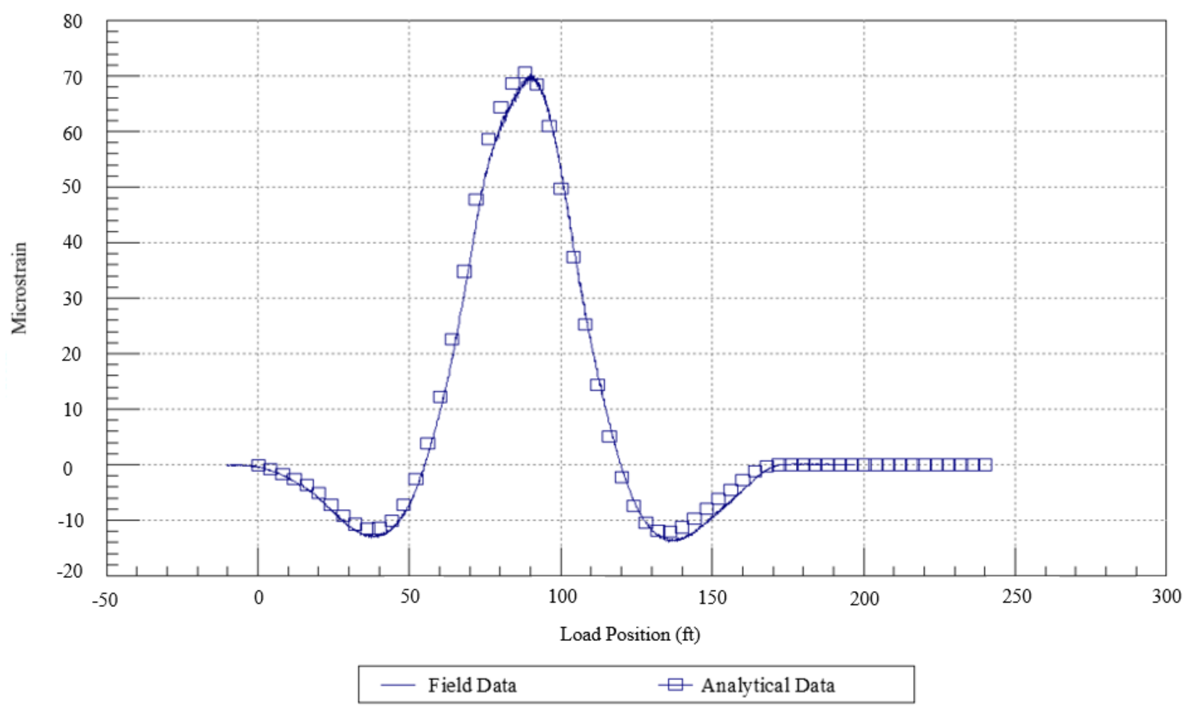


Figure 19. Ida County Bridge member strain comparisons on G2 for LC2

In addition, the model's midspan lateral distribution of strain closely matched that of the actual structure as shown in Figure 20.

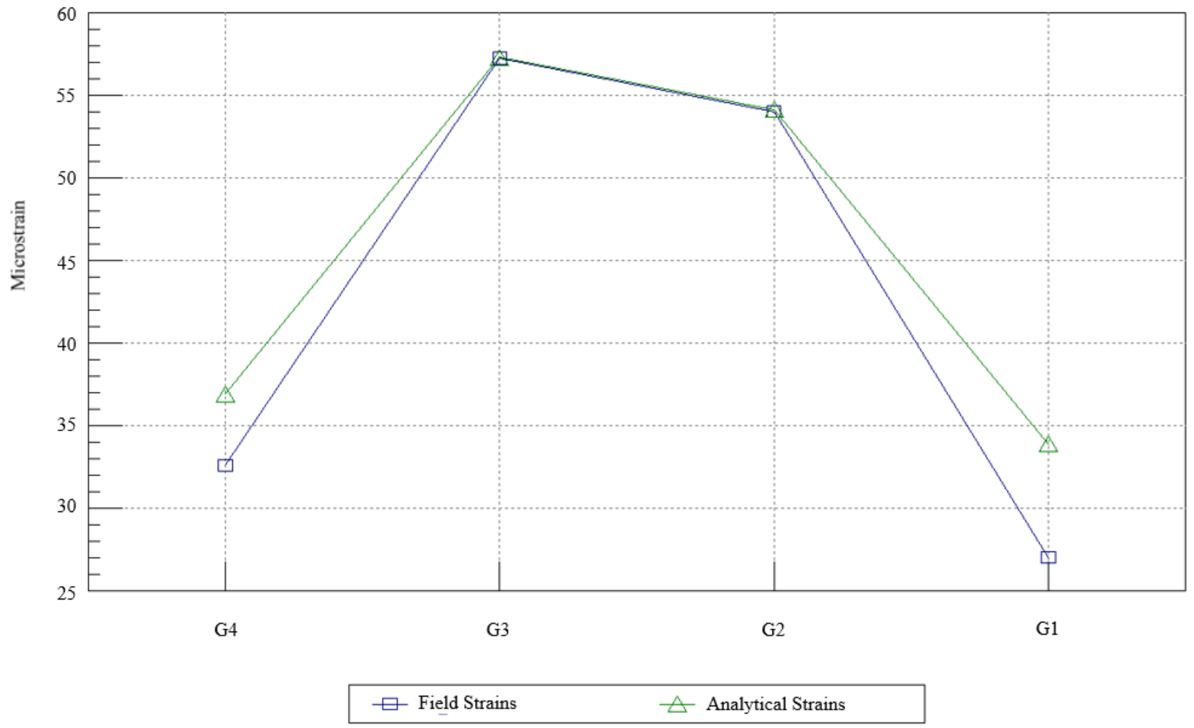


Figure 20. Ida County Bridge midspan lateral distribution strain comparison for LC2

Rating Factors

This section briefly discusses the methods and findings of the load rating procedures for the Ida County Bridge. All appropriate bridge elements were load rated in accordance with the AASHTO load factor rating (LFR) guidelines shown in Table 1.

Table 1. LFR rating factors applied

Factor	Inventory	Operating
Dead Load	1.3	1.3
Live Load	2.17	1.3
Impact Load	1.3	1.3

All structural dead loads were applied automatically by the modeling program's self-weight function. Member capacities were calculated according to the AASHTO Manual for Bridge Evaluation (2013) guidelines and the final calibrated finite-element model provided the structural responses due to the rating and legal trucks. A concrete compressive strength of 3 ksi and a steel reinforcing yield strength of 33 ksi were utilized based on the structure's age.

A library of the rating and Iowa legal loads was generated in WinGEN allowing these vehicles to be evaluated on the calibrated analytical model. Figures 21 and 22 illustrate the AASHTO rating vehicle configuration and Iowa legal load configurations, respectively, used for the Ida County Bridge. Given the 20 ft wide roadway, both one-lane and two-lane loaded scenarios were considered.

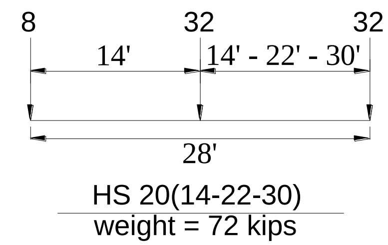


Figure 21. AASHTO load rating vehicle configurations for Ida County Bridge

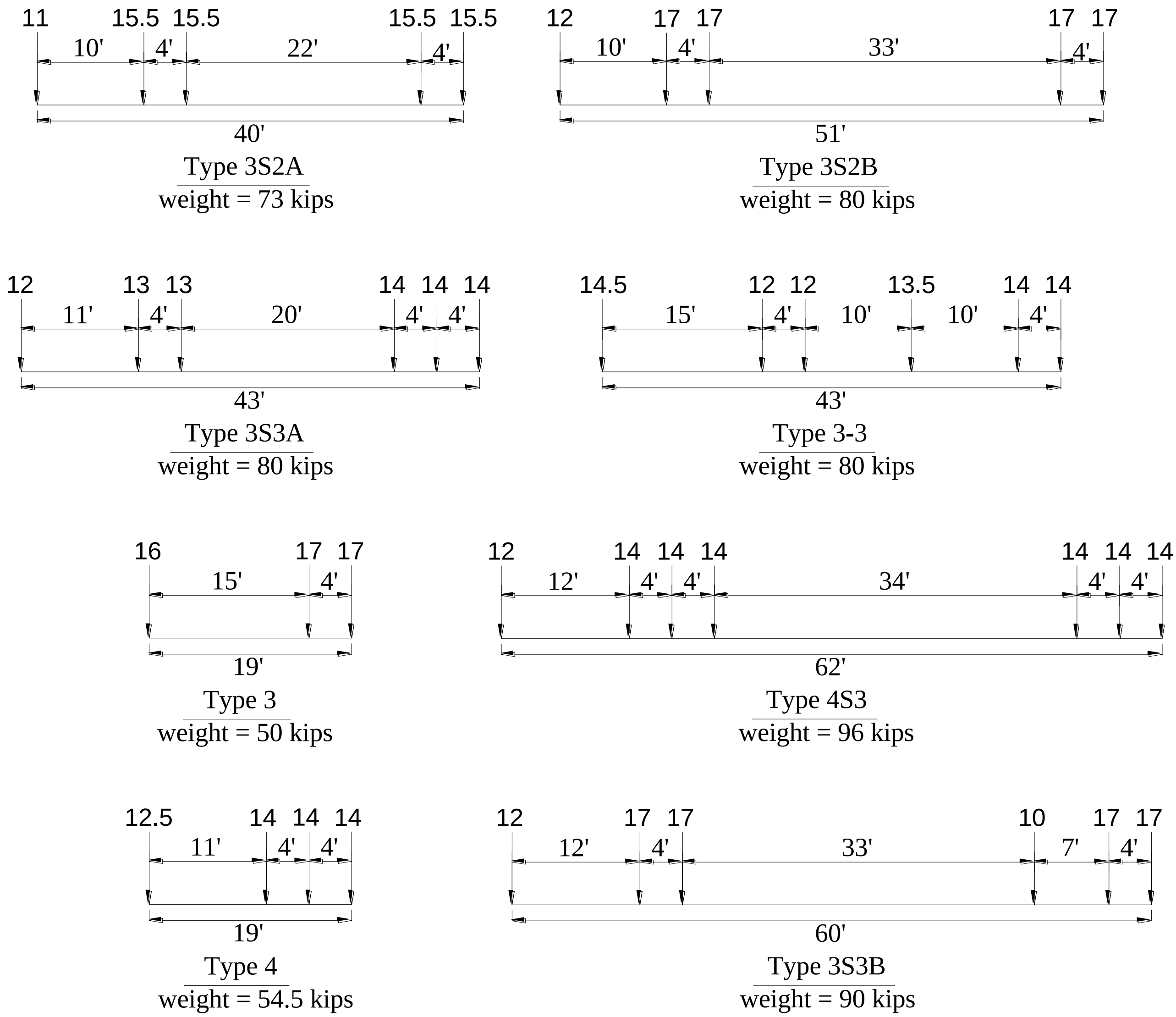


Figure 22. Iowa load rating vehicle configurations for Ida County Bridge

Using WinSAC, all of the rating and Iowa legal loads were applied individually to the structure as outlined in the specifications. Member rating factors were then output for each vehicle and are presented in Table 2.

Table 2. Ida County Bridge critical rating factors

Rating Vehicle	Location/Limiting Capacity	Inventory Rating Factor		Operating Rating Factor	
		Two Lane	One Lane	Two Lane	One Lane
HS-20(14)	Two Lane Interior, One Lane Exterior, Center Span, (+) Flexure	0.80	1.10	1.34	1.84
HS-20(22)	Two Lane Interior, One Lane Exterior, Center Span, (+) Flexure	0.96	1.31	1.60	2.19
HS-20(30)	Two Lane Interior, One Lane Exterior, Center Span, (+) Flexure	1.10	1.52	1.84	2.53
Type 4	Two Lane Interior, One Lane Exterior, Center Span, (+) Flexure	0.92	1.27	1.54	2.11
Type 3S3A	Two Lane Interior, One Lane Exterior, Center Span, (+) Flexure	0.98	1.35	1.64	2.26
Type 3-3	Two Lane Interior, One Lane Exterior, Center Span, (+) Flexure	1.00	1.35	1.67	2.26
Type 3S3B	Two Lane Interior, One Lane Exterior, Pier, (-) Flexure	1.01	1.39	1.69	2.32
Type 4S3	Two Lane Interior, One Lane Exterior, Pier, (-) Flexure	0.94	1.27	1.57	2.12
Type 3	Two Lane Interior, One Lane Exterior, Center Span, (+) Flexure	1.01	1.39	1.69	2.32
Type 3S2B	Two Lane Interior, One Lane Exterior, Pier, (-) Flexure	1.06	1.45	1.78	2.42
Type 3S2A	Two Lane Interior, One Lane Exterior, Center Span, (+) Flexure	1.05	1.44	1.75	2.40
Midspan and Endspan Lane Load	Two Lane Interior, One Lane Exterior, Pier, (-) Flexure	1.15	1.39	1.93	2.32
Both Endspans Lane Load	Two Lane Interior, One Lane Exterior, Pier, (-) Flexure	2.11	2.58	3.52	4.31
Midspan Lane Load	Two Lane Interior, One Lane Exterior, Pier, (-) Flexure	1.62	1.94	2.70	3.23
Single Endspan Lane Load	Two Lane Interior, One Lane Exterior, Pier, (-) Flexure	2.03	2.50	3.39	4.18

The bridge met operational rating criteria (RF>1.0) for all standard design and posting loads for both one and two lanes loaded, as shown in Table 2. The inventory rating criteria (RF>1.0) was also satisfied for the rating vehicle and all Iowa legal loads for one lane loaded. However, the bridge met the inventory rating criteria for all but the HS-20 (14 ft and 22 ft) rating vehicle and Type 4, Type 3S3A, and Type 4S3 Iowa legal loads for two lanes loaded. The critical rating factor for all vehicles was controlled by the flexural capacity of the girders near midspan of the center span.

SUMMARY AND CONCLUSIONS

Overall, the live load response data recorded during the field testing of the Ida County Bridge revealed no abnormalities. The test data exhibited response magnitudes and shapes typical of a three-span continuous, steel girder structure.

Following testing of the structure, a two-dimensional finite element model of the 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 during the modeling process. The calibrated model was then utilized to conduct load ratings for the bridge by applying the AASHTO rating vehicle and Iowa legal loads to the model. Comparison of the input member capacities with the model-generated moments resulted in output rating factors for all vehicles.

The load rating results were controlled by the ultimate flexural capacity of the girders near midspan of the center span. The results indicated the bridge had satisfactory operating level ratings (RF>1.0) for all standard AASHTO design and rating loads for both one and two lanes loaded. Furthermore, the inventory rating criteria (RF>1.0) was also satisfied for the rating vehicle and all Iowa legal loads for one lane loaded. However, the bridge met the inventory rating criteria for all except the HS-20 (14 ft and 22 ft) rating vehicle and Type 4, Type 3S3A, and Type 4S3 Iowa legal loads for two lanes loaded.

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