

# **Field Testing and Condition Evaluation of a Steel-Stringer Bridge for Superload**

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## **ABSTRACT**

The largest truckload (883,488 lbs., total load) in recorded Ohio history was scheduled to cross an important local river crossing near Marietta in the Summer of 2001. A new power plant was being constructed nearby and huge pieces of equipment were to be transported to the site. However, a BARS-based software analysis conducted by the Structural Engineering Office of the Ohio Department of Transportation revealed possible overload conditions in connection with this load/structure combination. A permit would not be issued without further evidence of the actual load capacity of the bridge.

The bridge (designated WAS-339-2013) is a 2-lane, 6-span, 650-foot steel-stringer bridge with a reinforced concrete deck, built in 1963, crossing the Muskingum River. The university was contracted to instrument the bridge with strain transducers and to conduct a series of controlled experiments with loaded dump trucks to determine the actual condition and load capacity of the structure. Linear superposition was used to then evaluate and verify the safety of WAS-339-2013 for the superload passage.

The event was monitored and liveload predictions were within 10% of the measured responses to the superload. A maximum stress of 10 ksi occurred at the piers and midspans of the bridge, with some temporary loss of the unintended composite action between the steel girders and the concrete decking. Minor permanent damage was observed (e.g., transverse cracking in the roadway). The load arrived without incident.

## **INTRODUCTION**

The University of Cincinnati Infrastructure Institute (UCII) was contracted in June 2001 in order to help the Ohio Department of Transportation (ODOT) evaluate the safety of a steel-stringer bridge (WAS-339-2013, located in Beverly, OH in ODOT District 10) for a superload passage. This effort was to augment a BARS model-based analysis conducted by ODOT's Structural Engineering Office. The load in question was a generator to be used in the construction of an electric power generation facility by Duke Energy. The load gross weight was 829,000 lbs., the largest truckload in recorded Ohio history. Burkhalter Rigging, Inc. was the hauler contracted for the load.

The bridge under consideration here is a 2 lane steel-stringer bridge with a reinforced concrete deck, built in 1963, crossing the Muskingum River in ODOT District 10. Its gross attributes are given as follows:

- The bridge consists of 6 spans (89', 118', 118', 118', 118', 89') for an overall length of 650 feet with a skew of 24 degrees.
- The superstructure consists of a system of 5 variable depth, welded girders (4'8.5" to 7'10.5") spaced at 8'3", stub abutments, and rocker bearings at each pier and abutment.
- The deck consists of an 8.5" reinforced concrete slab 39' wide (30' curb-to-curb) including a 1" monolithic wearing surface.
- The current visual inspection overall condition rating is 7.

The load under consideration has a configuration given in Figure 1 and may be summarized as follows:

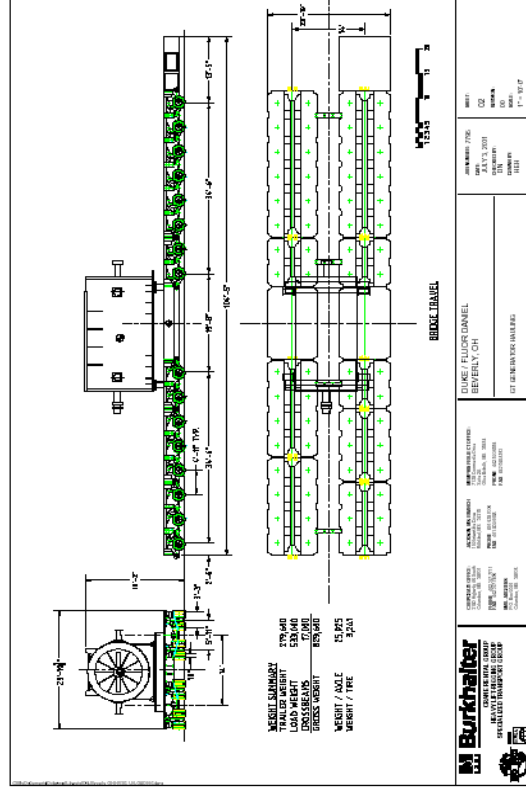
- The load consists of a 15-axle tractor/trailor configuration with an overall length of 142'2" and width of 20'4".
- The tractor consists of 3 axles with 2 tires per axle and axle loads of 17 Kips, 32 Kips, and 32 Kips, respectively.
- The trailor consists of two groups of 6 axles. Each group has an axle spacing of 4'11", 16 tires per axle, and axle loads of 66.9 Kips each.

Truck, proof, or other load testing of highway bridges has usually been reserved as an area of academic research due to the complexities, cost, and disturbance to service of such a field experiment. However, when a structure's computed capacity is less than the desired level of performance, it is usually beneficial to the owner to objectively identify the actual structural response to controlled loading experiments. The constructed bridge will have many inherent mechanisms to resist the applied load and which are generally not considered in the analysis of its capacity. These identified mechanisms include the actual load distribution, impact factor, unintended composite action, participation of superimposed deadload, material properties, unintended continuity, participation of secondary members, effects of skew, effects of deterioration and damage, unintended bearing restraint, and environmental effects such as thermal stresses.<sup>1</sup> The AASHTO *Manual* envisions the future use of diagnostic tests under truckloads for load rating.<sup>2</sup>

## **PROJECT PLAN AND RESULTS**

The university was contracted to instrument the bridge with strain transducers and to conduct a series of controlled experiments with loaded (and weighed) dump trucks in order to determine the actual condition and load capacity of the structure. These experiments (along with visual inspection) indicated that the bridge was in good condition with extensive yet minor cracking in the wearing surface and locking at the abutment interface with the approach. Load distribution was found to be 0.56, as compared with AASHTO specification of 0.75.

**Figure 1: WAS-339 Superload**



One conceptual signature that represents bridge condition and can be determined from a truckload test is the fundamental structural parameter of the unit influence line (UIL), the characteristic response at any instrumented bridge node due to the position of a unit load. Here, the unit load is defined to be a truck axle of one kip total weight and the loading path is considered to be that of a typical tandem or semi truck driven in the marked lane(s). Due to the concept of linear superposition, an influence line is especially helpful to a bridge engineer to understand the effects of various loads at different positions and/or orientations (e.g., point load, uniform load, etc.). For example, the response to a slowly moving vehicle can be determined by adding the weighted sum of influence lines corresponding to each axle weight, and vice versa:

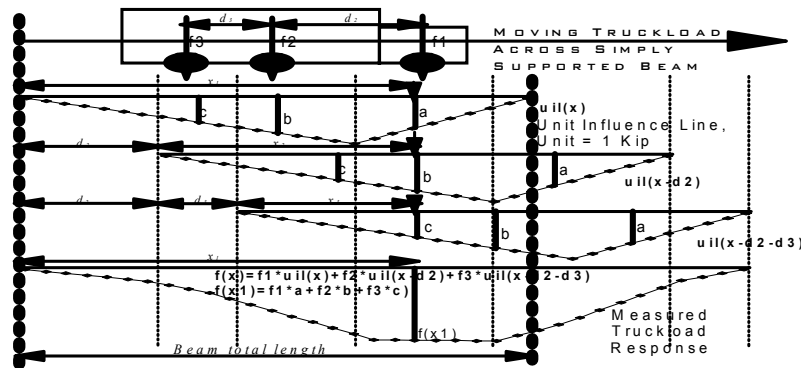


Figure 2: Truckload Response by Linear Superposition of Unit Influence Line

UCII has demonstrated in past projects that the strain (or stress) influence line is a damage sensitive index by conducting truckload tests on decommissioned steel-stringer bridges that were loaded to various damage states.<sup>3,4,5,6</sup> UCII has also shown that the influence line and its utility to estimate the future effects of proof or “superloads” can provide an accurate and conceptual health index for a structure.<sup>3,4,7,8</sup> This project has further exemplified how the influence line can be reliably identified from several controlled loadings conducted weeks or months apart in order to track the condition of the structure. Most importantly, this project demonstrated how the measured truckload data can be used immediately (i.e. near real-time) after the experiment to provide a capacity rating for the instrumented section based upon the relevant AASHTO codes using custom software run on a laptop computer.

Several overloads were scheduled for this project, with two of the Superloads scheduled for late Summer. A series of truckload experiments were conducted immediately before and after the first overload; in addition, the overload was monitored by UCII with the installed strain gages. Figures 3 and 4 illustrate the maximum recorded responses for the positive and negative moment regions. Given the axle weights and spacings of the overload, the UILs were then used to simulate the overload responses with good results (see Figures 3 and 4). Simulations were within 10% of actual stresses for the bottom flange of the critical regions, which indicates good predictive capabilities as well as a consistent linear behavior of the member. Some damage did occur to the unintended composite action between the girder and the decking which lead to increased stresses in the top flange at some of the pier bearings (Figure 7). Hence, all capacity ratings were calculated without composite action, as the bridge was designed.

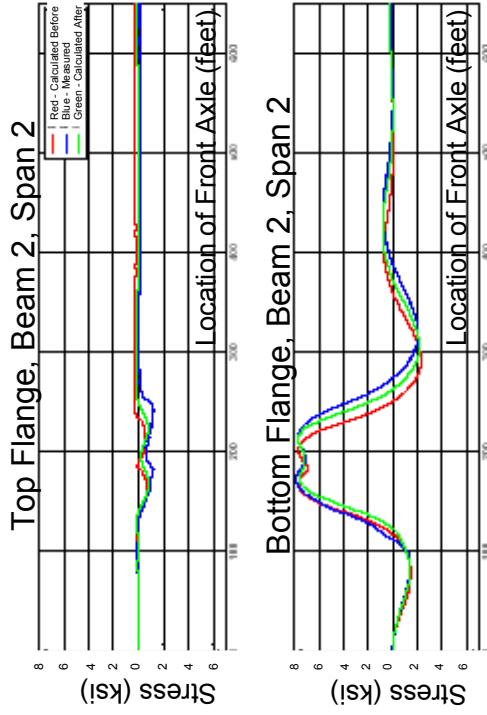


Figure 3: Comparison of Predicted and Measured Load Response at Span 2

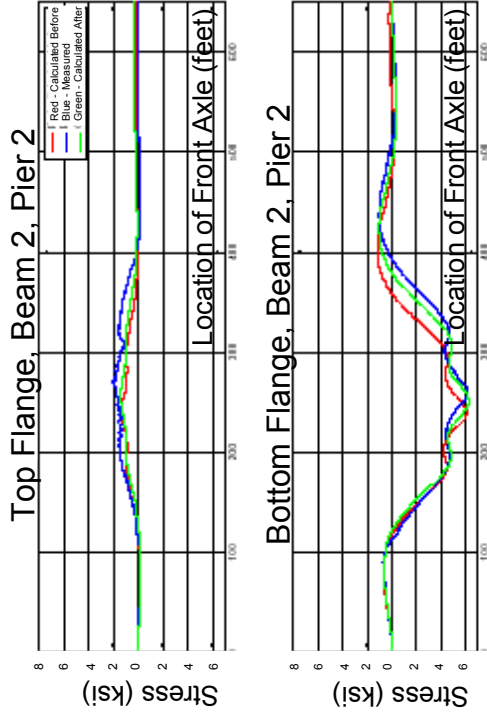


Figure 4: Comparison of Predicted and Measured Load Response at Pier 2

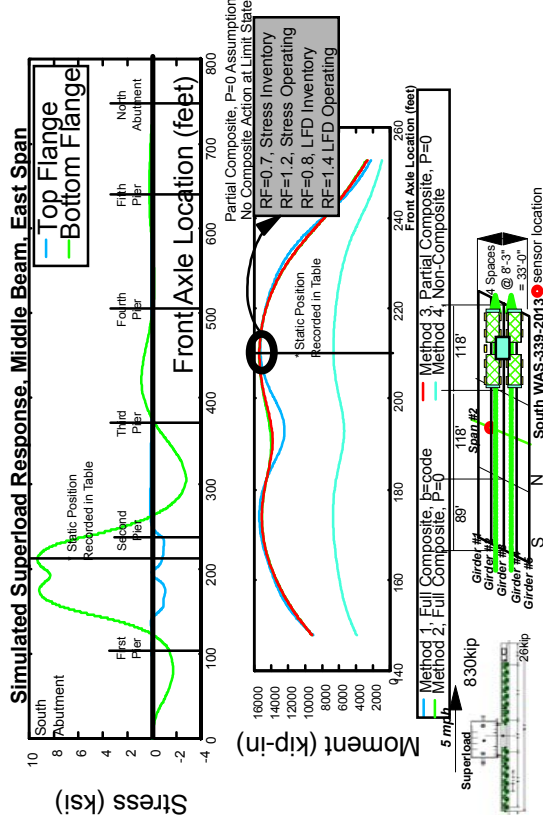


Figure 5: Predicted Superload Responses at Span 2 (Critical Positive Moment)

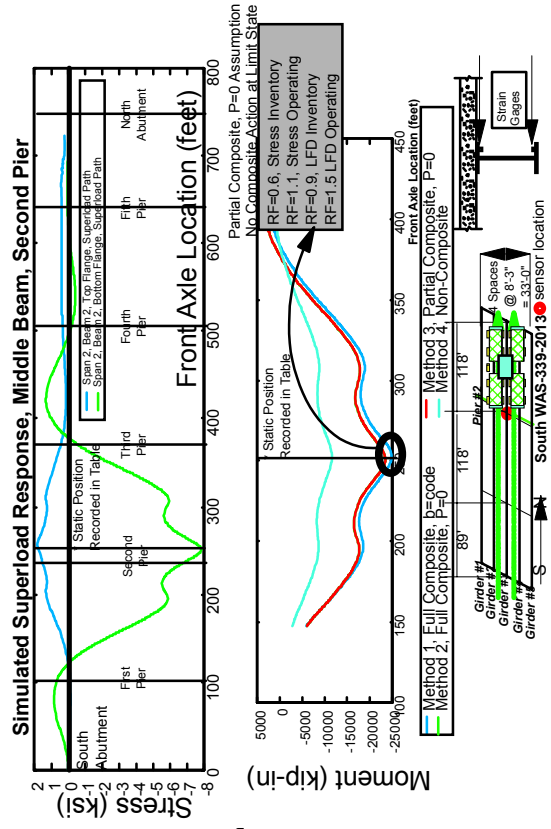


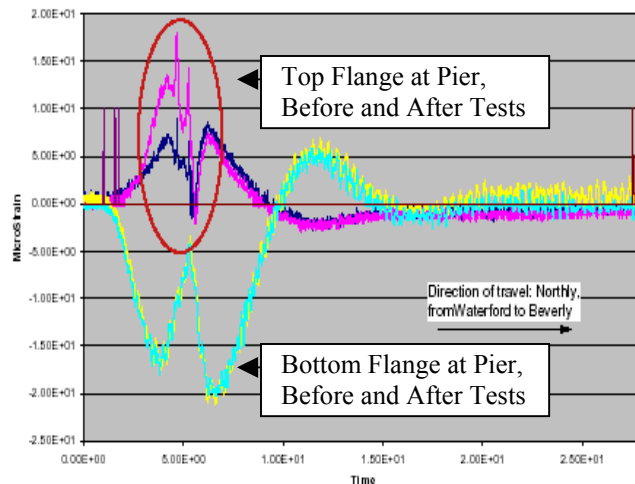
Figure 6: Predicted Superload Response at Pier 2 (Critical Negative Moment)

A finite element (FE) model was developed from the bridge plans and calibrated with the identified UILs.<sup>6</sup> This analytical redundancy allowed verification of the experimental results and interpolation to all of the other members that were not instrumented. The critical sections of the bridge were rated for Superload capacity by the Allowable Stress and Load Factor methods (see Figures 5 and 6) according to AASHTO Specifications.<sup>3</sup> Custom software was developed to calculate the structural capacity of the instrumented sections from the measured truckload data using the concept of linear superposition. The software runs on a laptop almost instantaneously. All methods indicated an operating rating slightly greater than one for the Superload passage. A permit was granted by ODOT.

Based upon FE model simulations, recommendations were provided by UCII for possible measures, retrofits, etc. to help mitigate damage by the Superload and any other overloads for this project. These included the best route, speed, and configuration of the trailers for the various planned loads; several of these loads, including the Superload, were then monitored using the installed sensors and followed by more truckload tests.

For each Superload, we were asked to conduct a truckload test the day before the scheduled move, to check for any interim damage, and to again verify the capacity ratings. On the day of the Superload passage, we were asked to conduct a pre-test to verify system and structure status, to continuously monitor and report the structural condition during the load, and to perform a post-test to check for any damage by the Superload and to again verify the capacity ratings. A maximum stress of 10 ksi was measured at the critical regions during the Superload. Simulations by unit influence line for bottom flange liveload were again within 10% of actual measurements. Some top flange responses could not be predicted due to the nonlinear loss of composite action.

With each overload, additional damage was observed at various locations on the bridge. Audible pings could be heard and some small debris was observed to fall from the bridge into the river below. The deck cracking became somewhat more pronounced. All of this is ascribed to the further loss of composite action, which was evident in the measured data near the supports during the overloads. The capacity rating for the Superload became progressively worse with each overload, although it never dropped below one. Much of this damage was restored under normal loading conditions; however, some damage was permanent at some locations (Figure 7). Since the composite action was not intended by the bridge design, no compensation was pursued by the state from the owner of the load. In conclusion, the various overloads passed without significant incident.



**Figure 7: Example of Superload Damage, Loss of Unintended Composite Action at the Pier Bearing**

## ACKNOWLEDGMENTS

We gratefully acknowledge the support by and collaboration with ODOT and Burkhalter Rigging, Inc., with special thanks to Amjad Waheed and Don Nolan, respectively.

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