PennState | Center for Integrated Asset Management for MultiModal Transportation Infrastructure Systems

PROJECT SUMMARY

BRIDGE LOAD RATING AND EVALUATION USING DIGITAL IMAGE MEASUREMENTS

This document is a technical summary of the report, *Bridge Load Rating and Evaluation Using Digital Image Measurements,* funded by the Center for Integrated Asset Management for MultiModal Transportation Infrastructure Systems.

INTRODUCTION

The objective of this study was to implement a procedure for load testing using non-contact, nondestructive sensing technologies to reliably determine the actual load-carrying capacity of a bridge. Bridge load testing has historically involved mounting multiple discrete sensors to the structure, and measuring the deformations as load crosses the bridge, typically involving bulky equipment, need to access hard-to-reach locations, and time to setup and run the test (Figure 1). Using digital imaging or video-based measurements to capture deformations in a non-contact manner benefits end-users in two main ways: (1) saves time by minimizing the need to mount sensors and access the structure, especially for bridges that traverse waterways; and (2) enables one to post-process data in real-time and re-analyze data using the video-based imaging stored from a completed test. However, methods to quantify deformations in a non-contact manner at full-scale and considering environmental and logistical conditions during load testing have been less studied and show promise for condition assessment of aging and deteriorating bridges in the United States.

Figure 3: *Loaded truck crossing bridge during a load test*

In this study, we deploy relatively low-cost, non-contact sensing technologies that rely on digital image correlation (DIC) techniques and compare them to conventional mounted sensor arrays. Three main sensing technologies are used: (1) video-based DIC system, (2) video-based computer vision, and (3) 3D point cloud (Figure 2). The measurements are compared to string-potentiometers attached to the bridge and strain gauges from Bridge Diagnostics Inc. (BDI) attached to the bottom flange of a bridge girder. The non-contact measurements collected from bridge live-load tests are analyzed and used to generate finite element models based on the strain and displacement measurements obtained from a commercial, vision-based digital image correlation system—Imetrum with VideoGauge™ software. Distribution factors generated from load tests and bridge models are compared to AASHTO methodology for determining live load distribution factors (LLDF). In addition to using these measurements to calibrate more refined finite element models, strain and displacement distributions are compared and show similar distributions for the studied bridges, which may be used to inform bridge load rating and evaluation, which are typically based on strain not displacement measurements, as described in the *Manual for Bridge Evaluation* (MBE) (AASHTO, 2018). The broader impact of the sensing technologies used in this study could make load testing more routine to better understand the existing capacity of bridges to support inspection and maintenance strategies. Moreover, the anticipated results can aid decision makers on how to best invest infrastructure funds where needed and support strategies for asset management, especially since almost 40% of the 614,387 bridges within the National Bridge Inventory (NBI) are 50 years old or older. With an increasingly more technological world, digital imaging has given end users the ability to enhance data capture of multiple points of interest as well as a means for repeatable post-processing using sensing technologies.

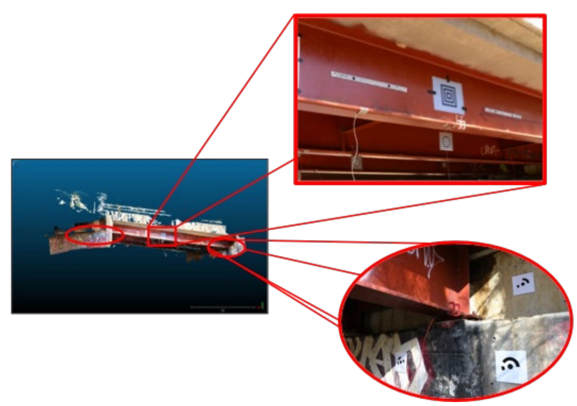


Figure 2: *Placement of fiducial elements for sensing technologies for bridge load testing.*

METHODOLOGY

Description of sensing technologies used for bridge load testing

In this research project, the research team from the University of Delaware and George Mason University performed load tests on two bridges in Delaware, 1-911S and 1-213, using both contact and non-contact, video-based measurement (sensing) techniques to develop methodologies to evaluate the load-carrying capacity (Figure 3). Two DelDOT loaded dump trucks totaling approximately 60 tons (~120 kips) were used, where each wheel load acted as point loads on the bridge (Figure 4). The alignment of the loads along the cross-section of the bridge was initially modeled along the centerline of the two 13-ft-wide lanes but was adjusted, since the trucks may not have been exactly centered in the driving lane. Displacement measurements of girders at midspan and other critical points were monitored to determine lateral live load distribution using the three non-contact sensing technologies: (1) video-based digital image correlation (DIC) system by Imetrum with VideoGauge™ software, (2) video-based computer vision, and (3) 3D point cloud. String potentiometers were mounted to the underside of the girders to measure displacements, and strain gauges were attached the girder flanges to measure strain at discrete locations (Figure 3). Also, 3D point cloud measurements were taken to add another dimension to the notion toward quantifying deformations when performing full-scale structural testing. One of the major benefits of the Imetrum with VideoGauge™ software within the system controller is its video-based image processing technology that deploys algorithms for point-to-point tracking in the camera's field of view.

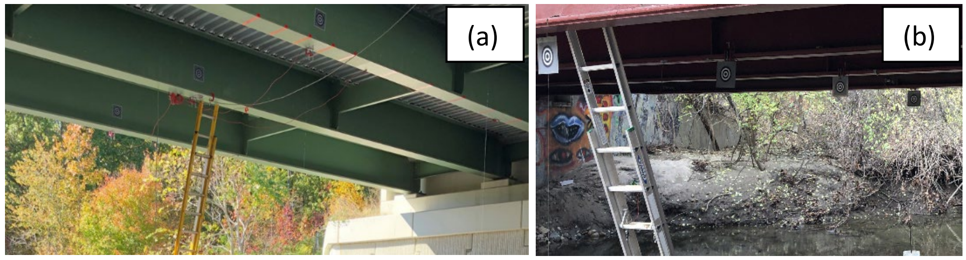


***Figure 4**: Imetrum target locations: (a) 1-911S, (b) 1-213*

For the data collection, two Imetrum cameras collected data and video recordings for all of the rolling truck passes. Two lenses, 12 mm (0.47 in) and 25 mm (0.98 in), were attached to the two Imetrum cameras. The videos were postprocessed within the system controller after calibrating reference measurements within the image to determine displacement measurements of the bridge girders. The Imetrum recordings were complemented with an additional camera that recorded videos for the phase-based optical flow method used for comparative analysis. These videos were postprocessed independently using software generated by the research team. During the static load tests, two additional cameras were used to collect sets of images (not videos) that were then converted into 3D point clouds via photogrammetry. Point clouds before and during static load testing were compared via computational geometric analysis to quantify the static 3D deformation fields. Captured images are first preprocessed to correct for lighting changes. The point cloud of the unloaded bridge (reference point cloud) and the point cloud for the statically loaded bridge (compared point cloud) were generated independently and then scaled and oriented to a global reference frame using calibration targets attached to the structure. The two point clouds were then geometrically aligned and deformations were computed by measuring distances between points in each cloud. Deformations captured by the varying sensing technologies were compared and used to assess how live load is distributed among the bridge girders under flexural load through the computation of live load distribution factors (LLDFs). The Imetrum midspan displacement readings from DE 1-213 were used to calibrate a bridge model generated in ABAQUS/CAE (2019).

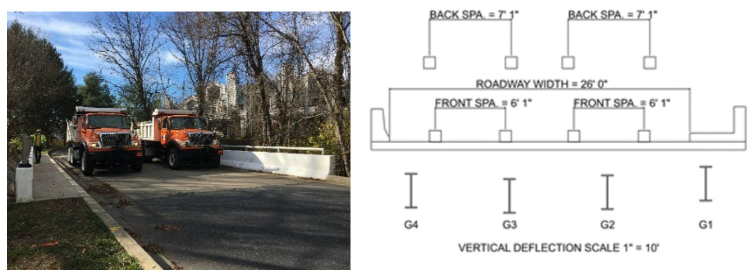


***Figure 4**: Loading position of trucks on DE 1-213 bridge*

***Figure 5**: Underside of bridge superstructure photo (left) and ABAQUS model (right) of DE 1-213*

DATA SUMMARY

Since each truck loading scenario occurred twice, once where one truck was trailing the other and another where the trucks passed through the bridge in tandem, superposition of results from individual girders was easily evaluated. The results from the Imetrum system concurred with superposition measurements, while the string potentiometers did not, revealing some technical issues at times. Figure 6 shows a comparison of the measurement methods for DE 1-911S. The results show noisier data when the camera is farthest from the target regardless of the sensing technologies used.

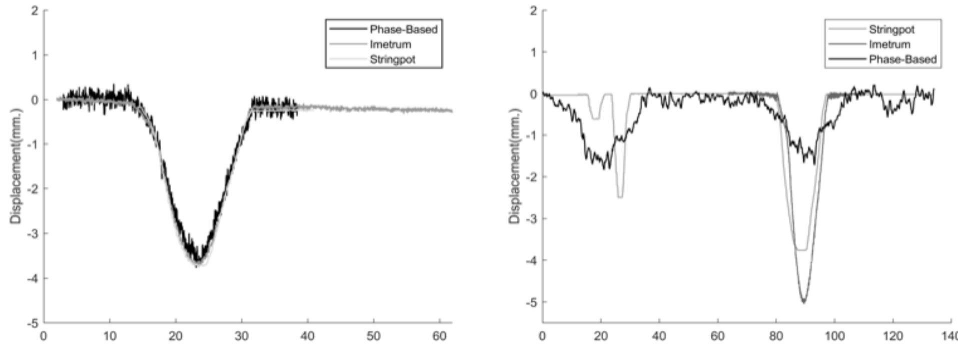
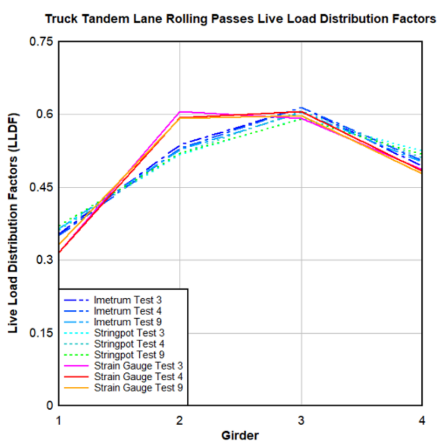


***Figure 6**: Comparison of measurement methods: (a) strong correlation of results for fascia girder nearest to the phase-based camera and (b) inaccurate results for the phase-based approach for girder farther away from the camera for DE 1-911S.*

EVALUATION RESULTS

The lateral distribution of live load from the field test was assessed using both strain transducers located at the midspan of each girder and the Imetrum system, which captured the vertical deflections at midspan using video-based measurements. The displacement data from the string potentiometers and Imetrum system midspan displacement measurements were compared. For all load passes, the Imetrum system measured larger displacement measurements than the string potentiometers. Live load distribution factors for each truck load per beam were calculated using the midspan displacements measurement from the strain transducers placed on the bottom flange of each girder at midspan and from the Imetrum system. LLDFs were also computed using conventional methods per *AASHTO LRFD Bridge Design Specifications* (2020) and the finite element model data for moment and deflection to evaluate the lateral distribution due to live load. The lateral distribution live load distribution factor for each truck load per beam ($LLDF_{truck}$) was calculated and compared.



CONCLUSION AND IMPLEMENTATION

The study led to the following conclusions about sensing technologies used for bridge load testing to reliably determine actual load-carrying capacity:

- From this study, results revealed minimal differences between the measurements from the mounted sensors (i.e., string pots and strain gauges) versus the non-contact sensing technologies to track displacements.
- Results showed how live load distribution factors obtained from strain measurements compared favorably to the distributions obtained from vision-based displacement measurements for two different full-scale load tests, and used to calibrate finite element models.
- However, more research is needed to validate that displacement data obtained from non-contact, vision-based methods can be used to perform load ratings using the AASHTO LRFR rating factors.

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