

Data Acquisition for a Bridge Collapse Test

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ABSTRACT - Researchers at the Ferguson Structural Engineering Laboratory successfully collapsed a 120-foot bridge with an intentionally fractured girder to study behavior and safety. It required three rounds of testing before the damaged bridge finally failed under an applied load of more than 360,000 pounds. The bridge, tested to determine its vulnerability to collapse following the fracture of a girder, withstood about 4.5 times the maximum legal truck load. Nearly 300 strain gauges and displacement transducers as well as recorded how the bridge reacted in this extremely damaged condition to incrementally increasing loads during the two rounds of testing. Wireless data acquisition modules were used to monitor the condition of cranes used to apply loads. This presentation is an overview of the methodology used to determine whether or not this design is fracture critical as is commonly assumed.

Introduction

The Texas Department of Transportation and the Federal Highway Administration funded a large-scale research project through the Ferguson Structural Engineering Laboratory at the University of Texas to develop methods for evaluating the redundancy of fracture critical steel bridges. (Figure 1) As part of the research project, a full-scale twin box-girder steel bridge representative of fracture critical bridges in Texas was decommissioned from the highway system in Houston, rebuilt at Ferguson Lab, and prepared for testing. (Figure 2)



Figure 1. Twin box-girder steel bridge (Ferguson Structural Engineering Laboratory)

A series of three experiments were performed on the test-bridge to observe its response to a fracture of one of its bottom flanges. The AASHTO (American Association of State Highway Transportation Officials) Bridge Design specifications define a fracture-critical member as a component in tension whose failure is expected to result in the collapse of a bridge. To avoid the catastrophic collapse suggested by the specifications, bridges with fracture-critical members are subjected to frequent and stringent evaluation and inspection. Texas with over 166 twin box-girder steel bridge units has never found a fatigue related fracture.

Instances of such two-girder bridges that have experienced fracture without collapse have prompted research to determine the level of redundancy that can be expected in twin box-girder bridges. The data gathered during the test were compared to the calculated response from the model to verify the predictive capabilities of the model. If able to predict response accurately, a computer model could be used during design to indicate the presence of redundancy and the decreased need for frequent inspection of this type of bridge resulting in significant savings to the bridge owner. The test set-up and corresponding models represented a worst-case scenario for loading on the structure at the time the simulated fracture was initiated.



Figure 2. Test Bridge at Ferguson Structural Engineering Laboratory

First Full-Scale Test

The first test on October 21, 2006 used explosives to induce a complete fracture in one of the bridge's bottom flanges. (Figure 3) Despite having a load equivalent to a 76,000 lb. truck positioned directly above the mid-span fracture location, the fracture did not propagate into the webs of the girder, minimal deflections were observed, and there was no significant degradation in the capacity of the structure despite the loss of a fracture critical element. (Figure 4)



Figure 3. Explosive shaped charge applied to test bridge



Figure 4. Bridge fracture after explosion.

As important as executing the full-scale test safely and to specification was ensuring that data were acquired during the experiment so that the behavior of the bridge could later be analyzed. The instrumentation plan was designed and implemented to measure deflections and material strains, which could then be used to help quantify material stresses along portions of the hypothesized redundant load paths. Strain gages attached directly to bridge components took measurements of material deformations.

Wires connected to each piece of instrumentation were run to the southern end of the bridge where a small hut housed all of the data-acquisition equipment (Figure 5). For the first full-scale test, a high-speed data-acquisition system was configured for all 127 channels of instrumentation (Figure 6). Because the loading and subsequent bridge response was expected to be dynamic, it was important to sample the data rapidly, accurately, and in a synchronized manner. The system used for the test employed equipment from National Instruments and was set up to sample data simultaneously from all 127 channels, 1000 times each second. The wires from the 127 instrumentation channels were connected into sixteen National Instruments SCXI-1314 8-channel terminal blocks. Each terminal block hooked into its own SCXI-1520 8-channel universal strain module. Two SCXI-1001 12-slot chassis were used to

house the sixteen modules.. The two chassis were connected through a PC that was equipped with a National Instruments PCI-6250 data acquisition card. LabVIEW was used on the PC to view and organize the incoming data.



Figure 5. Wires connected to instrumentation



Figure 6. Data Acquisition System

The static deflections of the intact and fractured girders were relatively small. The mid-span of the intact girder deflected downward 0.5 in. under the initial application of the simulated truck live load, then deflected an imperceptible amount following the fracture of the opposite girder, and finally rebounded 0.25 in. when the live load was released. The deflection of the mid-span of the fractured girder follows a similar pattern. It first deflected downward 1.25 in. under the live load, then deflected a very small amount following the fracture of its own bottom flange, and finally rebounded 0.4 in. when the live load was released. A total deflection of 1 in. 2 in. across a 120 ft. span is considered small. The bridge performed exceedingly well relative to the AASHTO fracture critical designation. (Figure 7)

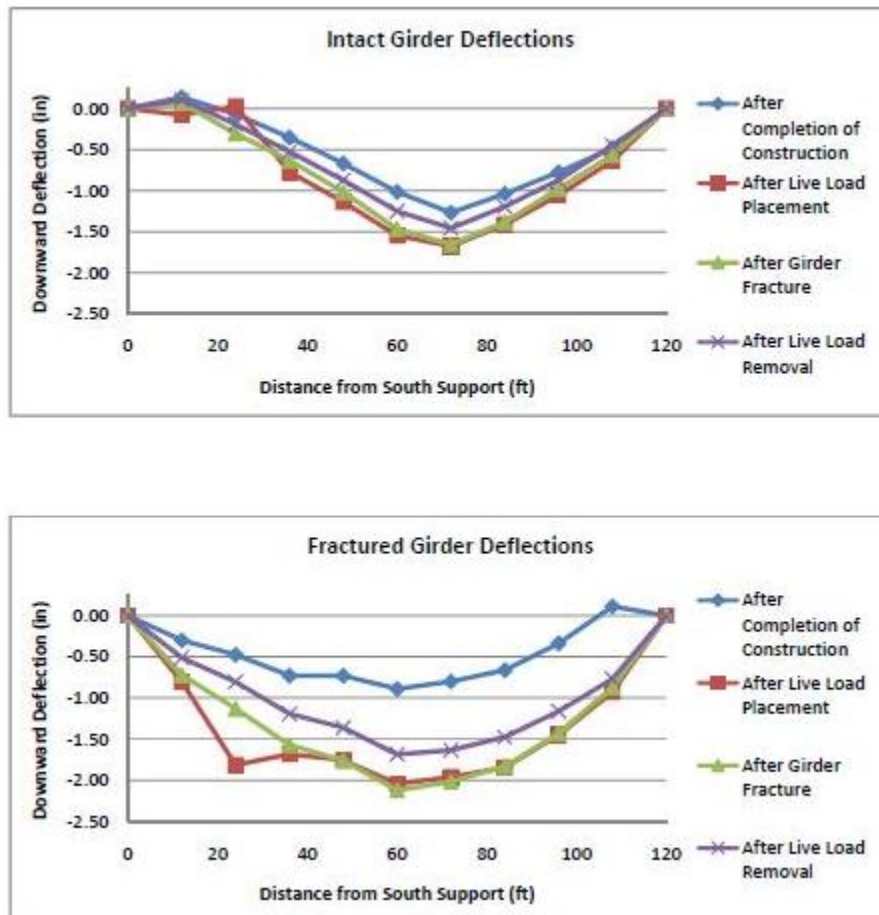


Figure 7. Girder deflections for test 1.

The Second Full-Scale Test

The second test shored the damaged girder while the fracture was manually extended to the full depth of the webs. Afterward, the same design load of approximately 76,000 lbs. used in the first test was placed above the location of the full-depth fracture. The shoring system was removed nearly instantaneously with the use of explosives, and the bridge was allowed to respond dynamically to its damaged condition. Substantial deflections and damage were observed, but the bridge resisted collapse and maintained complete serviceability.

The data-acquisition system used for the 127 channels from the first test was expanded to accommodate the addition of 117 channels for the second test, bringing the total number of channels to 244. National Instruments manufactured all of the hardware used. The two 12-slot SCXI-1001 chassis used in Full-Scale Test 1 were both filled to capacity with a total of 24 SCXI-1520 8-channel universal strain modules.

Two new SCXI-1000 4-slot chassis were used. Filling the eight new slots were five additional SCXI-1520 8-channel universal strain modules, and three SCXI-1121 4-channel isolation amplifiers. SCXI-1314 8-channel terminal blocks were connected to each of the twenty-nine SCXI 1520 modules, and three SCXI-1321 4-channel terminal blocks were connected to the SCXI-1121 isolation amplifiers. All four of the chassis were connected through the National Instruments PCI 6250 data acquisition card into the PC, configured with LabVIEW.

The second full-scale test was designed to produce a dynamic response of the test bridge after it had been held in position while damage comparable to what it would have sustained in the event of an actual fracture was induced. Preparations for this test were extensive. A scissor-jack system was designed, constructed, and installed to raise the mid-span of the fractured girder 0.25 in. and support it while damage was induced on the bridge. (Figure 8)

The support structure was also capable of immediate collapse when a critical link was severed with explosives. Coordinating for the appropriate and safe use of the explosives was an integral part of the test preparations. 244 channels of instrumentation equipment were prepared to gather data that would help characterize the response of the bridge to the simulated dynamic fracture event. (Table 1)

Gage Type	# of Gages / Channels	
Reinforcing Bar	22	22
Shear Stud	14	14
Girder (Uni-axial)	12	12
Girder (Rosette)	36	108
End Diaphragm (Rosette)	4	12
Interior Diaphragm (Uni-Axial)	4	4
Top Deck (Transverse)	40	40
Top Deck (Longitudinal)	12	12
Exterior Railing	6	6
Linear Potentiometer	13	13
String Potentiometer	1	1
Total	164	244

Table 1. Sensors used for the second full-scale test.

The second full-scale test was executed and successfully loaded the test-bridge after it sustained a full-depth fracture in one of its girders. The downward deflection of the fractured girder was as much as 7 in. in locations, and the bridge sustained significant damage to the shear stud connections between the top flanges of the fractured girder and the concrete deck. (Figures 9 and 10) Despite the displacements and damage sustained, the test-bridge resisted collapse, maintaining complete serviceability in its fractured state with the design truck load positioned directly above the fracture location.

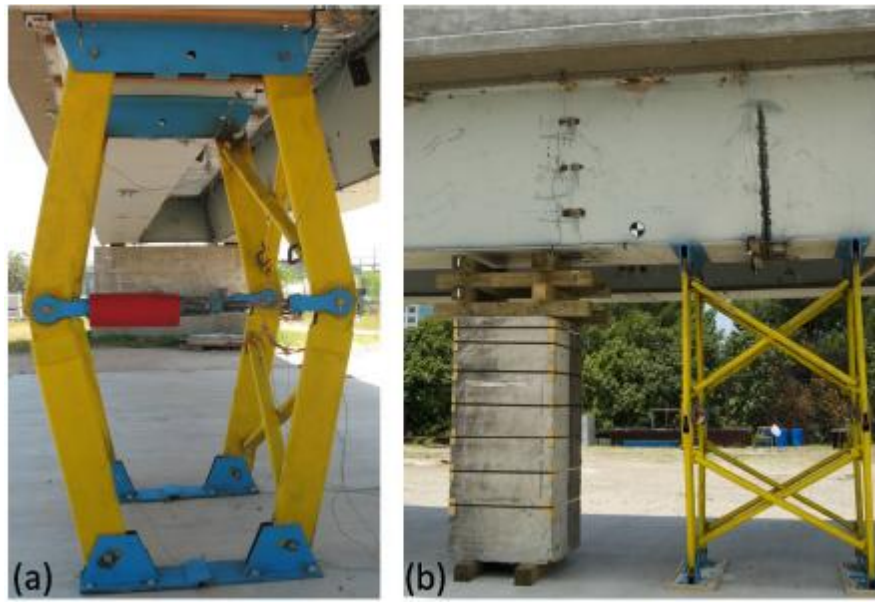


Figure 8. Scissor jack system used to shore up bridge for test 2

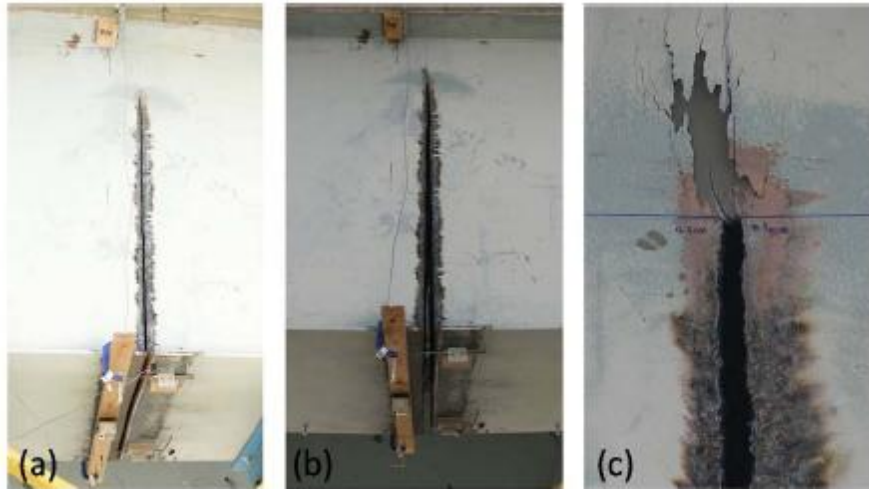


Figure 9. Fractures after release in test 2.

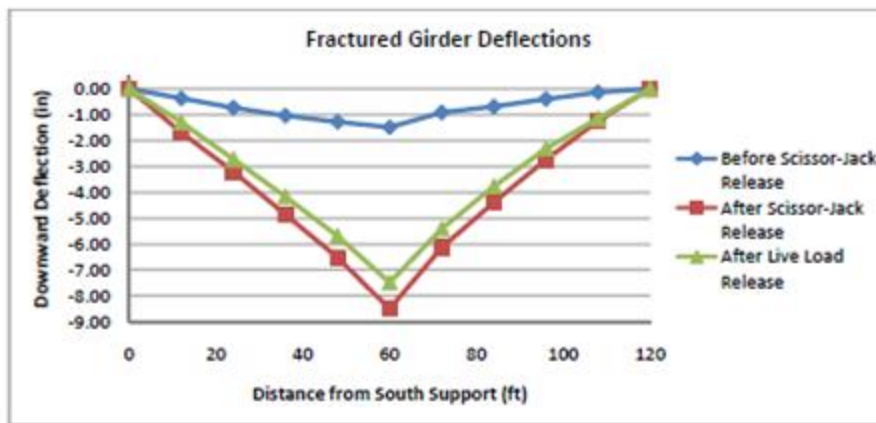
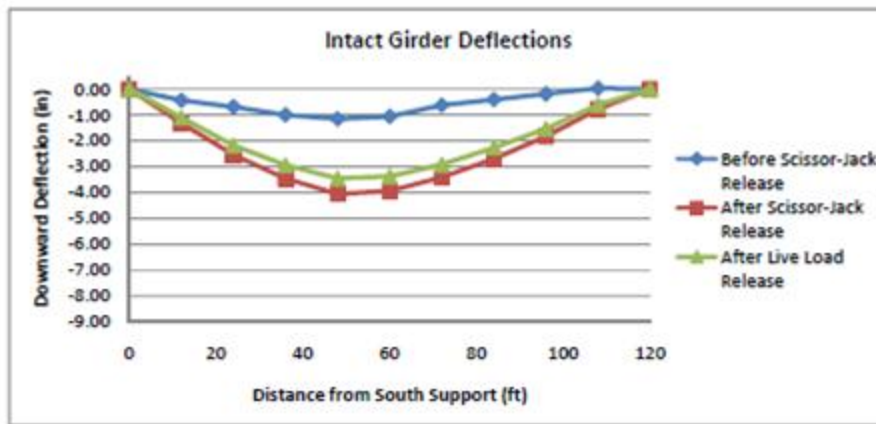


Figure 10. Girder deflections in second full-scale test.

Collapsing the Bridge in the Third Full-Scale Test

Typical tests at a Structural Engineering lab push the unit under test to failure so it was decided to do this here. The third test incrementally over-loaded the bridge while the progressive failure mechanisms were closely observed. Loading continued until the ultimate load was reached and the bridge collapsed. Because the test-bridge was still capable of supporting additional loads following completion of the second full-scale test, a third full-scale test was planned as a follow-up to extend the results from the dynamic test.

The goal was to observe the sequence of failure mechanisms and to determine the ultimate load required to induce a total collapse of the bridge. The experimental procedure for the third was designed as a load-controlled test, where additional load in excess of the design truck load was applied incrementally and without significant dynamic effects. The first two tests that deployed explosives were monitored by agents from Homeland Security and the FBI. By moving to a load-controlled test, this approval wasn't required.

After placing the concrete girders on the bridge deck, additional load was applied by incrementally dumping material into and eventually around the bin. Road base was chosen as the loading material for its ease of acquisition, low cost, and relatively high density. (Figures 11 - 15)

Obtaining a lifted weight measurement for each crane pass, from the placement of the concrete girders through the placement of each bucket of the road base, was critical. To measure the weights quickly and easily, a load-cell was attached to the crane load line above the lift bucket. A Wi-Fi transmitter was

connected to the load cell so that the load data could be easily read and recorded from across the work-site.

After three days of loading 1500 pounds of road fill at a time, large portions of concrete at the mid-span expansion joint of the exterior railing began to spill when the total load applied to the bridge reached 360,200 lbs. After the onset of major material losses, three additional lift bucket loads were placed on the bridge before the bridge came to rest on the concrete bed below. As the load applied to the bridge increased over the course of the experiment, the bridge components experienced a series of failures. Following these intermediate failures, the bridge was able to redistribute the applied loads, suggesting the contribution of redundant load paths in maintaining equilibrium of the bridge in its progressively damaged state. (Figure 16)



Figure 11. Loading the bridge with road base.



Figure 12. Bridge loaded to collapse.



Figure 13. Remote load cell monitoring.

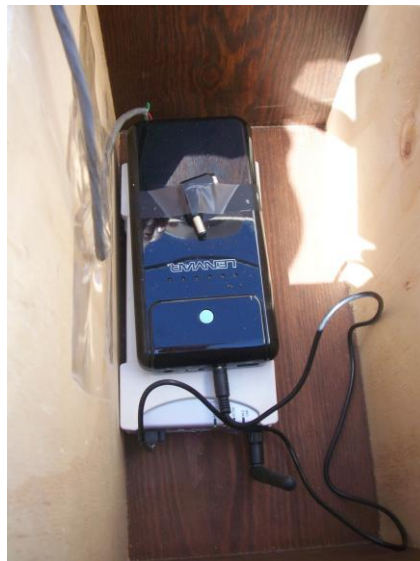


Figure 14. Wi-Fi DAQ module with battery in housing box for measuring load cell



Figure 15. Side view of intact girder.

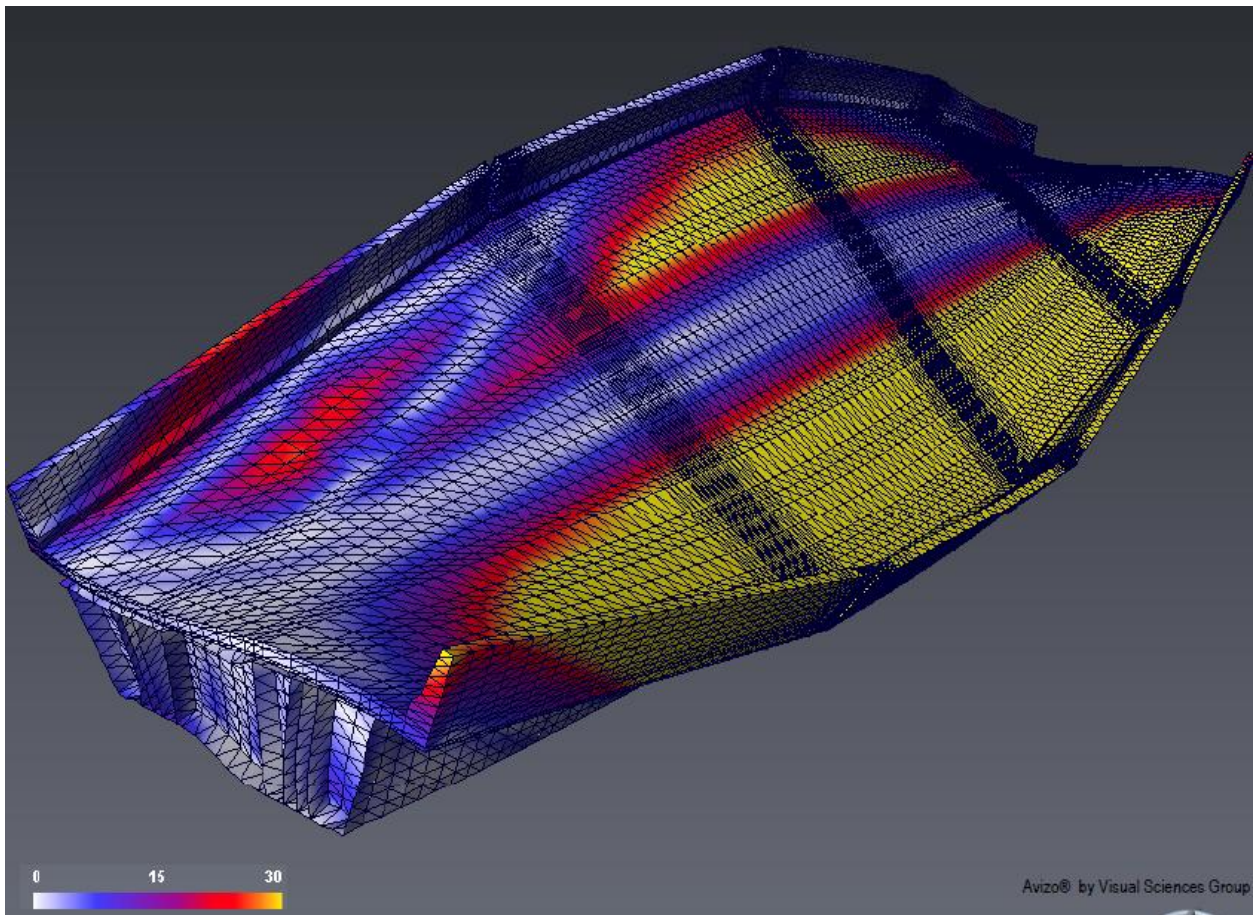


Figure 16. Bridge Model Validation visualization with Avizo

Conclusion

Supported by a number of its elements contributing to create a robust redundant load path, the test-bridge performed extremely well and supported the application of over four times its design load after sustaining a full-depth fracture of one of its two girders. Results obtained from the finite element model indicated that adequate redundancy exists in the bridge design to maintain stability after the fracture of one girder. This was validated in the full-scale tests. The large concrete railing above the fractured girder transmitted force away from the fracture location when bridge deflections resulted in a closing of its expansion joints. The bridge deck also transferred significant loads in flexure, both transversely and longitudinally to the bridge span.

This research may lead to revisions to the current AASHTO specifications that a) can accurately predict the behavior of these bridges following the failure of a critical member, and b) subsequently prescribe appropriate inspection and maintenance requirements. Research at the Ferguson Structural Engineering Laboratory implies that the current requirement for bi-annual detailed inspections does not appear to be an effective use of labor or financial resources.

Acknowledgements

Thanks to the faculty and students of the Ferguson Structural Engineering Laboratory for sharing information about this application. The laboratory, named after Professor Phil M. Ferguson, is located on the Pickle Research Campus of the University of Texas at Austin and is an integral part of the Department of Civil, Architectural and Environmental Engineering. Students and faculty conduct large-scale tests of a broad range of civil engineering structures in this facility. For more information on the "Methods of evaluating the redundancy of steel bridges," visit their web site at :

http://fsel.engr.utexas.edu/research/5498_webinar/index.cfm

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