Structural Identification of a Cantilevered Truss to Inform Live Load Rating

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ABSTRACT: A steel cantilevered truss was found to have unsatisfactory ratings for critical truss members, gusset plates and targeted floor system components. A structural identification (St-Id) program was designed and implemented to compute calibrated load ratings for the critical components via controlled load testing. The cantilevered truss contained a variety of movement mechanisms, including internal releases near the pin and hanger details between the anchor and suspended spans. The St-Id application was used to show that the movement releases performed in a non-linear manner and as a function of the loading vehicle position. This case study documents the application and lessons learned.

Test Structure and Measured Data

A long span steel cantilevered deck truss was subject to routine permit vehicle crossings. The bridge's rating was such that it did not allow the permit vehicles to cross with traffic, rather they required a police escort to close the bridge resulting in an expense to the owner. Thus, the bridge's owner was interested in more accurately establishing the live load rating of the truss to evaluate whether the permit vehicles could freely cross the bridge mixed with general traffic. A live load testing program was developed to measure the load distribution of a known load which would then serve as the basis for an FE model calibration effort.

To better understand the structure, a thorough document review effort was carried out in addition to a site visit. A main objective of the document review was to identify all pieces of information need to construct an FE model, such as geometry, cross sections, material properties, boundary conditions, and any changes in the structure over its life, such as deterioration or retrofits. The bridge was built in the 1950s and consists of fourteen spans, three of which are short multi-girder approach structures with the remaining eleven consisting of long deck truss superstructures. The bridge was designed in a cantilever fashion, with a general assembly of spans as shown below in Figure 1.
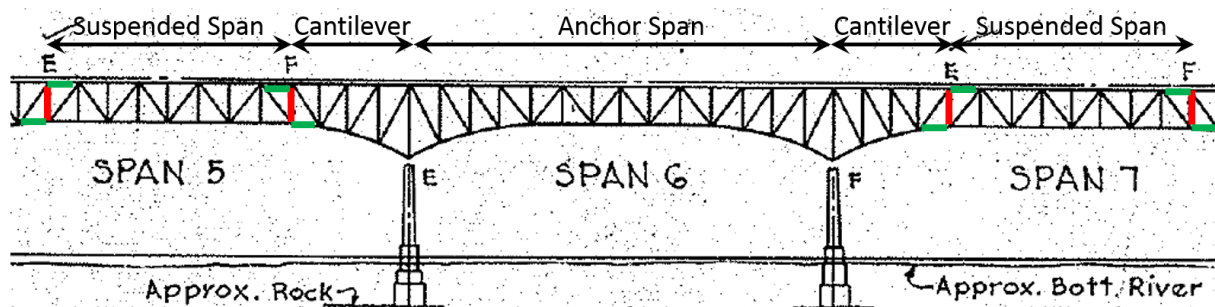

Figure 1: Schematic of Typical Cantilevered Deck Truss Assembly

Each suspended span is simply supported by pin-connected hangers to the adjacent cantilever spans. The designers achieved this while maintaining the continuity of the truss lines by incorporating a series of slotted dummy members which allowed for the free expansion and contraction of the suspended span. As seen in Figure 1 above, the dummy members are highlighted in green with the pin and hanger members highlighted in red. The dummy members were either pinned or slotted depending on the location to allow the suspended span to be simply supported.

An FE model was developed to support the design of an instrumentation plan as well as to eventually compute live load demands to support the calibrated load rating objective. The FE model was developed in Strand7 where truss members and floor system components were represented by beam elements and the deck was represented by shell elements (Figure 3).

The model was evaluated for uncertain components, namely places where the engineer had to make assumptions as to the bridge's actual behavior. An

Figure 2: View of Dummy Member at Suspended Span Hanger Detail

example of an uncertain model component would be the expansion bearings stiffness at the piers. A thorough sensitivity study was then carried out to identify the locations in a typical structural unit which were the most sensitive to not only applied load but also to the uncertain components of the FE model. The interested reader can find more details regarding the uncertain model components and sensitivity study process in Dubbs & Yarnold [1].

Figure 3: Extruded View of 3D FE Model

The truss instrumentation plan utilized a total of thirty-six vibrating wire strain gages to measure the axial forces in three sections of the truss, eighteen truss members in total. Two sensors were located on opposing sides of the welded box sections at the vertical neutral axis. This sensor configuration allowed for the measurement of only axial strains. The three sections of the truss instrumented are shown in red in Figure 4.

Figure 4: Instrumented Sections of the Truss

A live load test of one typical structural unit was carried out during a planned overnight bridge closure. The bridge was loaded up to 480,000lbs in a variety of configurations and total weights. The live load testing utilized both crawl speed (5mph) and static positioning of the trucks. The strain gages were sampled at a rate of 20Hz with a Campbell Scientific CDM-VW305 peripheral and a CR3000 datalogger. Due to the interaction of the spans through the dummy members, the crawl speed and static positioning of the trucks was implemented over three adjacent spans to characterize the transfer of loads from the suspended span to the anchor span and what role the dummy members played, if any.

The measured strains were first reviewed for quality control purposes by visually inspecting for obvious spikes or errors. The data was then reduced from its raw time history format (**Figure 5**) into a table of average strain response while a vehicle was at one location. Vehicle locations were documented by toggling a Boolean variable in the data acquisition program, indicated in the figure by the dashed lines.
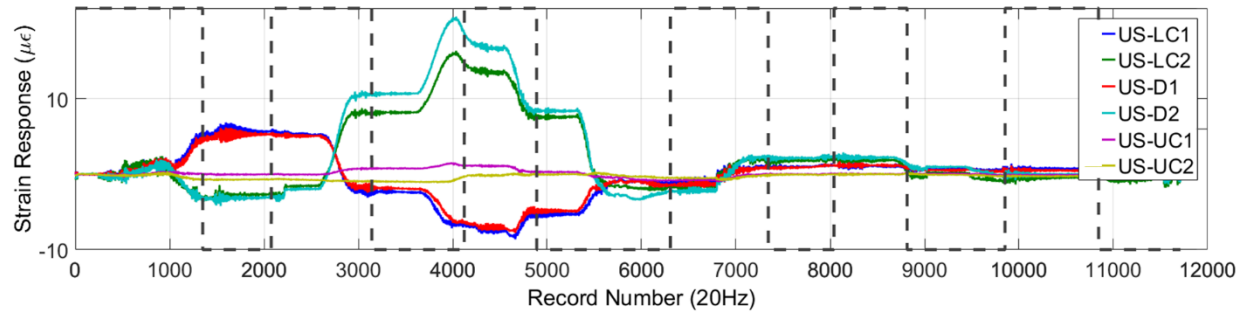
Figure 5: Strain Response in the Truss Members due to a Crawl Speed Load Event

SHM Methodology and Results

The FE model was calibrated by minimizing the difference between the observed strain response per truck location and the FE model prediction of the same loading configuration. The minimization process was carried out in an automated fashion using the computational software MATLAB and built-in optimization functions. The model uncertainties identified earlier in the project were varied between feasible bounds until a globally minimum solution was achieved. The challenge for this bridge was that there was no single global optimum solution; rather there were two. It was found that the dummy members were actually participating in the global load distribution of the structure, but only when the vehicles were in specific positions along the roadway. The interested reader is encouraged to read Dubbs [2] for more details on this optimization challenge.

The two calibrated FE models, representing the active or passive roles the dummy members played in the global load distribution were utilized to compute the live load demands for legal rating vehicles. As a result of this project, it was found that permit vehicles of specific configurations were not required to have police escorts and could travel freely with routine traffic, resulting in a net savings for the bridge owner.

Lessons Learned

The case study presented herein served valuable lessons learned for the author. First and foremost, it is very important to not only consider performance of primary load carrying elements during a load test, but to also consider how the movement mechanisms, if present, will impact the participation of those members over time. For this project, an initial attempt at model calibration utilized strain response from all positions of the truck in the same error function, with very poor results. It was not until the error function was modified to allow for two unique solutions as a function of varying truck positions that it was realized that the dummy member participation was non-linear with respect to vehicle position. It is important to consider this in similar applications.

References

[1] Dubbs, N. C., & Yarnold, M. (2014, August). Optimal Sensor Placement for Condition Assessment of a Cantilever Truss Bridge. In NDE/NDT for Structural Materials Technology for Highway & Bridges (pp. 106-113).

[2] Dubbs, N. C. (2015, April). Interpretation and Reporting of Load Test Results from a Cantilever-Truss Bridge with Internal Movement Mechanisms. In Structures Congress 2015 (pp. 332-344).