



## Go Live!

*Live Load Test Proves Seattle Floating Bridge is Ready for Light Rail*

By Scott Kuebler, P.E., S.E.

In assessing an existing structure's ability to support a new class of live load, conventional analytical tools are typically sufficient. However, for the Interstate 90 Homer Hadley Floating Bridge in Seattle, a full-scale load test proved to be the right approach in evaluating the structure's ability to support a proposed light rail train (LRT) system.

Initiated by the regional public transportation authority Sound Transit and carried out by the Washington State Department of Transportation's Bridge and Structures group (WSDOT) and Seattle structural and civil consulting engineering firm KPFf, the load test was the final step in the assessment of the structural capacity of the bridge to support the addition of Sound Transit's proposed light rail train system.

The Homer Hadley Floating Bridge, built in 1989, is the fourth longest concrete floating bridge in the world at 5,811 feet long. It is one of three concrete floating bridges that span Lake Washington to provide general purpose and high-occupancy vehicle traffic lanes eastbound and westbound. The bridge consists of prestressed concrete pontoons joined together to form a continuous floating structure that is anchored to the bottom of the lake. Steel girder transition spans at each end of the floating bridge provide flexible transitions to fixed structures on shore, allowing the bridge to flex under load as well as to respond to changes in lake water levels.

Concrete floating bridges are unique structures in that they behave more like permanently moored marine structures rather than conventional fixed bridges. In addition to carrying traditional vehicular traffic, they must also remain water tight. Advanced hydrodynamic modeling is typically required to estimate the structure's response to traffic loads in combination with environmental loads such as wind and waves.

In 2001, Sound Transit requested that WSDOT perform a preliminary analytical study to assess the feasibility of adding a light rail system to the bridge's reversible roadway on the south side of the floating structure. The preliminary study performed by KPFf included utilizing a two-dimensional beam-on-elastic-foundation model to predict global bridge response to LRT loading. While the results of the preliminary study

indicated that adding light rail may be feasible, it was determined that more advanced analysis was required. Given the magnitude of the decisions to be made from the results of further evaluation (i.e., whether or not to propose to voters the idea of building light rail across the lake), a full scale load test was selected in lieu of more analyses. The key advantage to performing a load test is the elimination of unknowns and assumptions inherent to any analytical study. That is, the response of the bridge to LRT loading could be directly observed and measured, rather than estimated through computer modeling.

### Test Overview and Load Simulation

The test program involved closing the bridge and performing full-scale load tests to compare measured response to that predicted by the two-dimensional analytical studies. Flatbed trucks loaded to a gross weight of approximately 148,000

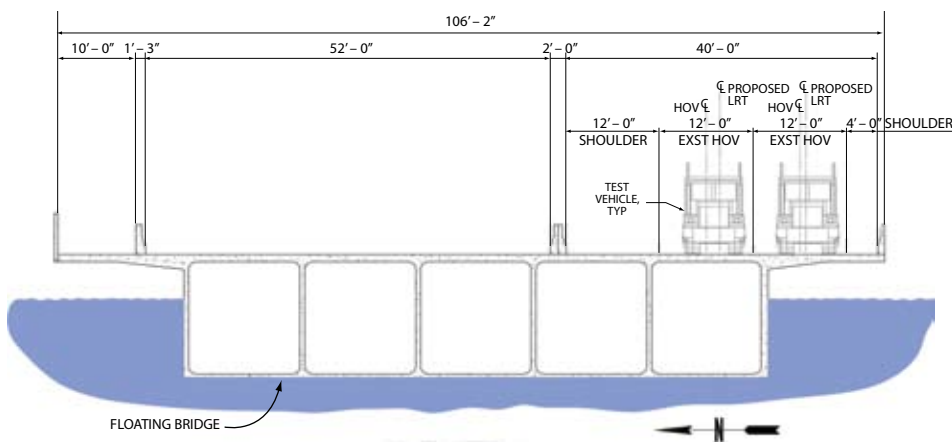


Figure 1: Typical Test Vehicle Placement.

pounds were used to simulate the weight of the light rail trains. (For comparison, the typical legal load limit for highway travel is 80,000 pounds.) A “train” of test vehicles consisted of four trucks spaced evenly apart to apply a live load of approximately 1,600 pounds per lineal foot over 370 feet. Two trains of test vehicles were arranged at various locations within the existing HOV lanes of the bridge at mid-span and near the west transition span expansion joint. Train locations matched those used for the previous analytical studies. *Figure 1* shows a cross-section of the bridge with the test vehicles in the same location as the proposed LRT system.

Both static and dynamic load tests were performed. Static load conditions were simulated by slowly moving the test vehicles onto the bridge and parking them at predetermined locations. Dynamic load conditions were simulated by driving the test vehicles in train formation at 30 miles-per-hour along the length of the bridge. For both the static and dynamic tests, the trains were located to represent critical load conditions that are expected to routinely occur while the LRT system is in service. These include trains traveling in opposite directions and bypassing at mid-span and toward the end of the bridge. In all, 10 static tests and 11 dynamic tests were performed.

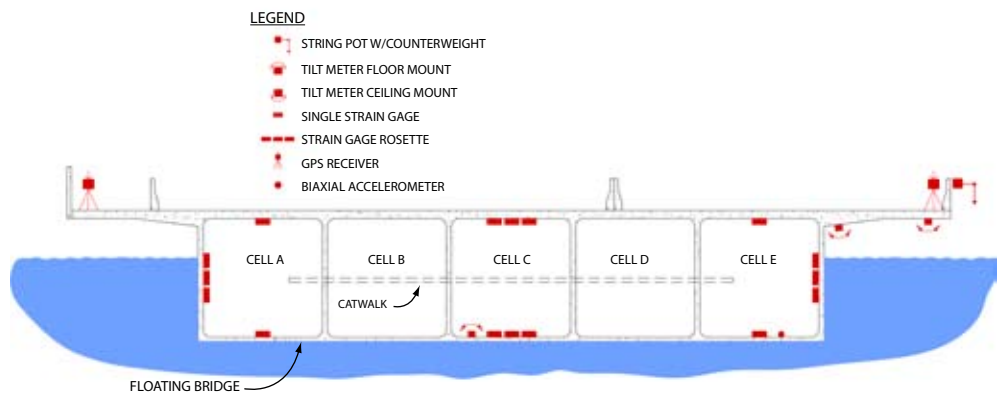
Bridge response was measured in real time for all tests as the vehicles moved along the bridge. Response parameters measured include:

- Freeboard loss.
- Bridge rotation.
- Horizontal and vertical deflections at the expansion joint.
- Vertical and horizontal accelerations.
- Global pontoon strain due to combined moment, torsion, and shear.

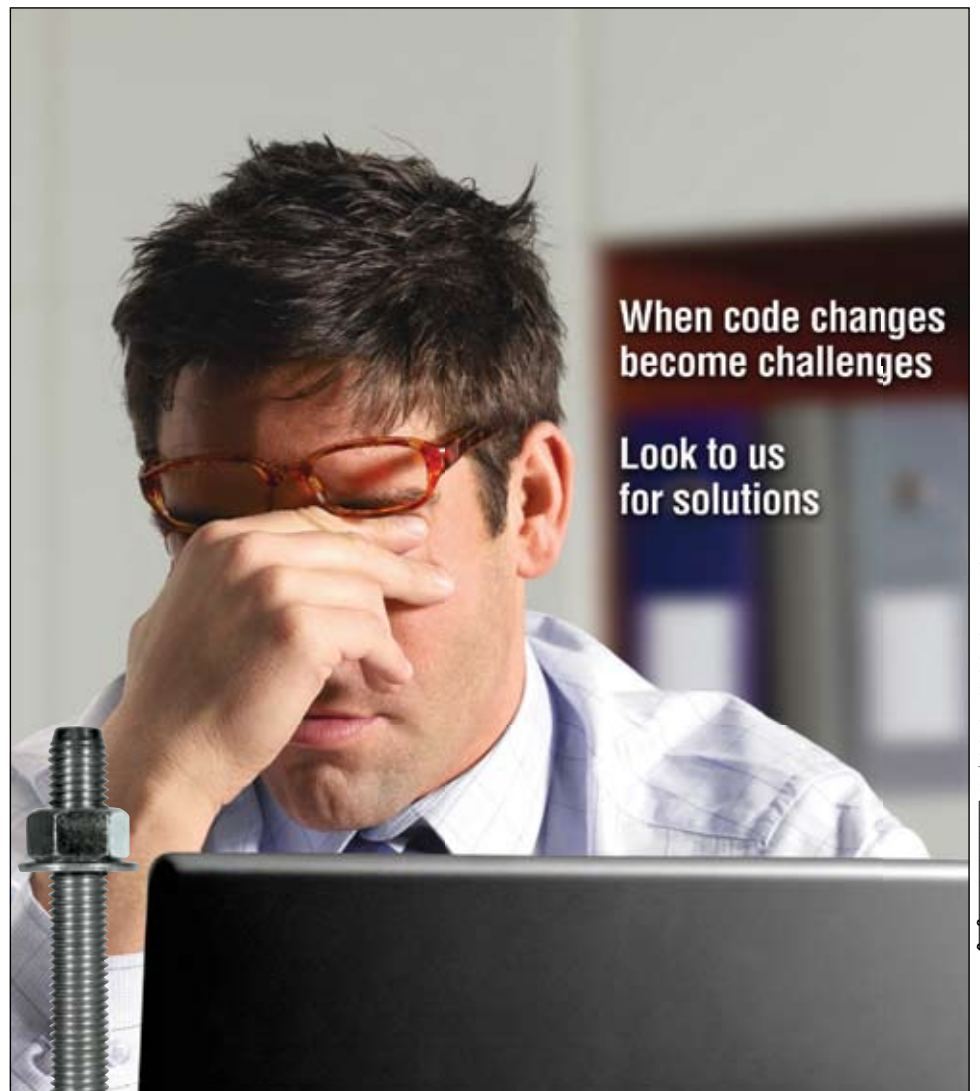
## Measuring Bridge Response

Bridge response to simulated LRT live loading was measured by instrumentation installed at five stations located on the west half of the bridge. Since the floating pontoons are essentially symmetrical about the centerline of the bridge, global response of the entire bridge was evaluated by instrumenting only one-half of the structure. Factors influencing the selection of instrumentation locations included bridge response predicted in the previous analytical studies, bridge accessibility and interior/exterior obstructions.

Instrumentation installed on the bridge included strain gages (rosette and single) to measure bending, shear, and torsional stresses; tilt meters to measure bridge rotation; triaxial accelerometers to measure global acceleration; and string potentiometers for determining freeboard loss and expan-



*Figure 2: Typical Bridge Pontoon Instrumentation.*



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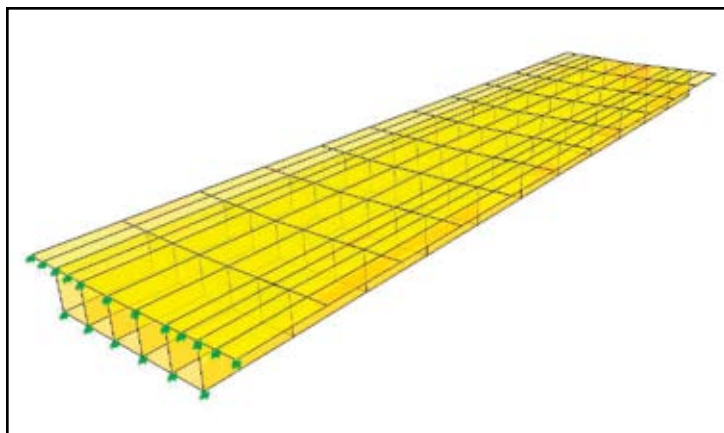
sion joint movements. A network of GPS receivers was also installed to measure bridge movement both vertically and horizontally. The GPS system, in combination with the other installed components, provided a redundant data collection system that enabled cross-checking of collected data.

Sensor readings were collected continuously via a wireless data acquisition system that was synchronized to a common time reference. During the tests, the response of the bridge was viewed in real time on laptop computers. After the tests, the data was imported into Excel spreadsheets for reduction and interpretation. All instrumentation, except the GPS system, was installed and operated by CTL Group of Skokie, IL. WSDOT installed and operated the GPS data collection system. A typical cross section of the bridge showing the installed instrumentation is shown in *Figure 2* (page 17).

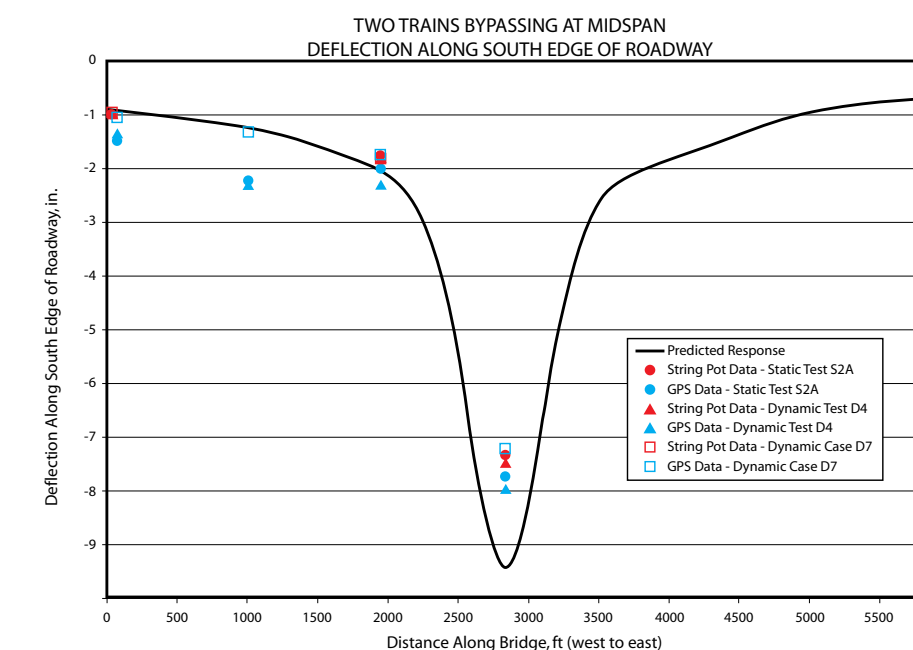
## Test Results

All tests were performed successfully during two consecutive nights of bridge closure, with good correlation between the different methods of measurement. Of the approximately 60 sensors installed on the bridge, only three did not work as expected. The network of redundant components provided enough back-up information to account for the non-functional sensors.

Overall, there was good correlation between measured and predicted bridge response. *Figure 3* shows a comparison between measured and predicted bridge freeboard loss for two trains bypassing at midspan. One key observation that was reflected in a number of other measurements is that the actual response of the bridge was less severe than predicted immediately adjacent to the applied load, but greater than predicted away from the applied load. That is, the measured distribution of pontoon response appears to



*Figure 4: Finite Element Model of Bridge Pontoon.*



*Figure 3: Comparison Between Measured & Predicted Bridge Freeboard Loss.*

be more gradual than predicted, possibly due to the pontoon structure having a greater torsional stiffness than estimated.

Another finding of significance is that there appeared to be no definitive trend when comparing global bridge response due to static loading to that for dynamic loading. That is, no amplification or dampening of bridge response due to dynamic loading was observed.

For evaluation of pontoon stresses based on strain gage measurements, measured strains were converted to stress and compared to stresses predicted using a three-dimensional finite element model. The model was created to predict the stress distribution throughout the pontoon section due to combined moment, shear and torsion at each of the instrumentation stations. Shell elements were used to model the thin-walled cellular construction of the pontoon. A snapshot of the model used is shown in *Figure 4*. The results of the stress

evaluation indicated that the previous analytical methods may have underestimated longitudinal stresses in the pontoons. A scale factor was developed to amplify pontoon stresses predicted using previously applied analytical methods in order to more closely match what was observed during the tests.

## Conclusion

A number of key observations were made through the performance of the full-scale load test that might not have been discovered through more computer modeling. These include the observation of the true torsional behavior of the bridge, the response to static and dynamic loading, and the potential underestimation of longitudinal stresses. Additional analyses of the bridge were performed using the results of the load test in conjunction with wind, wave and traffic load criteria established by WSDOT. The main conclusion drawn was that the floating bridge structure could structurally carry the operational loading from Sound Transit's light rail train system.

Successful execution of this test program provided WSDOT with the information needed to feel comfortable about adding a new class of live loading to their unique structure, and provided Sound Transit with a critical milestone to achieving their long-range goals for transportation in the Puget Sound region. ■

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