RESEARCH NOTES
THE EARTHQUAKE ENGINEERING GROUP
June 2008
Caltrans

Seismic Response of Precast Segmental Bridge Superstructures: Analytical and Experimental Results

***RESULTS:* In collaboration with the University of California, San Diego, Caltrans investigated the seismic performance of a superstructure-column subassembly and parameters that affect the seismic response of segmental superstructures. Results indicate that vertical earthquake motion and the pre-earthquake stress state of the superstructure significantly affect joint response of these bridges, requiring changes to current design standards to improve joint performance during a seismic event.**

Why We Pursued This Research

Precast segmental construction methods can accelerate bridge construction and minimize the cost of bridges in highly congested urban environments and environmentally sensitive regions. While the popularity of precast segmental bridge construction has increased throughout the world, its use in seismic regions of the United States has been hampered by a lack of research on the seismic response to verify the reliability of these structures under a seismic event. The California Department of Transportation (Caltrans) has supported a research program since 1997 to study the seismic performance of a superstructure-column subassembly and to study the parameters that affect the seismic response of segmental superstructures.

What We Did

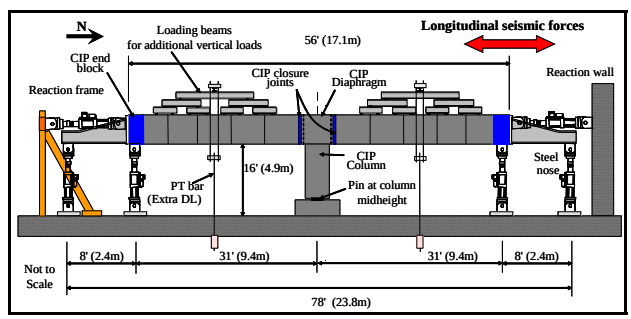
A half scale segmental bridge superstructure and column system was constructed and tested. The objectives of the experiment were to study the performance of the system under combined gravity and seismic loads and to study the performance of the systems when inelastic response was allowed in the superstructure. A suite of two-dimensional (2D) computer simulations were performed to study the parameters that affect the longitudinal and vertical seismic response of segmental bridges.

Description of the Work

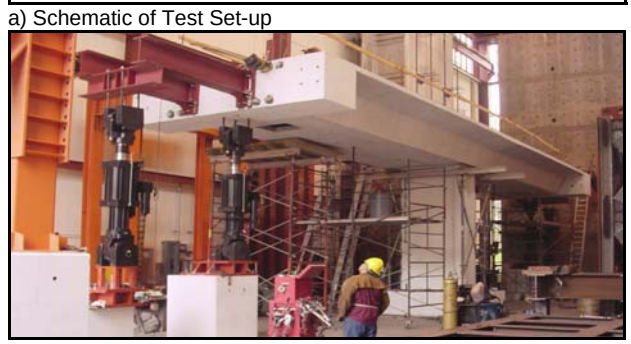
The half scale segmental superstructure-column system experiment consisted of ten precast superstructure segments and a cast-in-place column and diaphragm (see Figure 1). The experiment modeled a prototype structure between midspan of adjacent spans and the column down to the mid height inflection point. The experiment consisted of two loading stages.

The objective of the first stage of loading was to study the response of the column-superstructure system when the segment joints were not expected to open during a seismic event. This represented the current state of practice for segmental bridges in seismic regions. The test unit was subjected to fully reversed longitudinal cyclic loading up to a system displacement ductility of 4.

Upon completion of Stage 1 testing, the configuration of the test unit was altered. The vertical load was increased by 75% to simulate a vertical earthquake acceleration of 0.75g. In addition, the longitudinal PT in the superstructure was reduced to approximately 75% of that of Stage 1 by removing the unbonded tendons. Longitudinal fully reversed cyclic loading continued with a single cycle of system ductility 4 and then increased up to ductility 8. The objective of the second stage of loading was to investigate the performance of a column-superstructure system where non-linear elastic behavior of the superstructure was expected.



a) Schematic of Test Set-up



b) Under Construction

Figure 1: Phase III - System Test

In addition to the large-scale experiments, two finite element models of actual bridges were developed to study the seismic response of superstructure segment

joints: one with nominal interior span lengths of 300 feet (see Figure 2) and the other with spans lengths of 525 feet. The models were developed based on design and construction details from segmental bridges recently constructed in California and were subjected to a suite of twenty near field earthquake ground motion records.

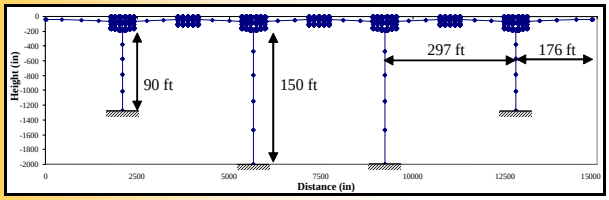


Figure 2: 300 Foot Span Model

Research Results

During stage 1 loading, the top of the pier developed a plastic hinge and experienced significant inelastic response and protected the superstructure from any appreciable damage. A hairline crack opened at the closure joint adjacent to the pier at ductility 4 (see Figure 3).

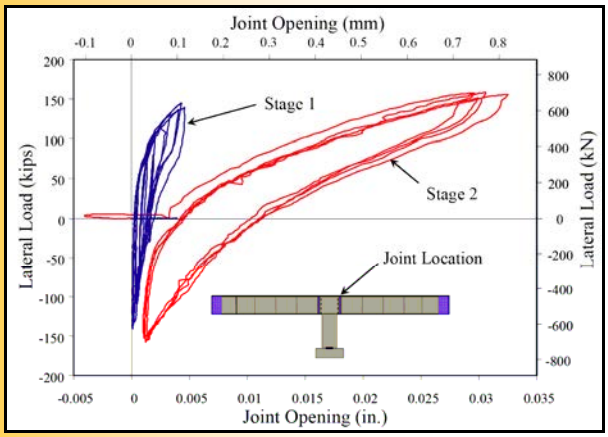


Figure 3: System Test - Longitudinal Force vs. Joint Opening

During stage 2 loading, the superstructure segment joints adjacent to the pier opened due to the increased vertical load and the reduced longitudinal PT in the superstructure (see Figure 3). As the longitudinal displacements increased from a drift ratio of 2% to 4% (i.e. ductility 4 to ductility 8), the gap in the segments joints increased only modestly, implying that the increased lateral displacement increased the rotational demands on the plastic hinge at the top of the piers, and did not significantly increase the demands in the superstructure

In general the results of the computer simulations indicated that the median segment joint rotations exceeded the cracking limit state and opened gaps at the extreme fibers of the superstructure during a significant seismic event. The first joint adjacent to the pier and the joint at midspan exhibited the largest rotation demands. Gap widths adjacent to the piers and near midspan may be up to 0.05 inches and 0.15 inches, respectively. All segment joints closed completely upon completion of the seismic event.

Vertical earthquake motions significantly contributed to the joint response, and increased the peak negative moment joint rotations by over 1000% (see Figure 4), the peak positive moment rotations by at least 250%, yet did not affect the residual rotations. Segment joints in positive bending near midspan experienced the largest rotation increases due to vertical ground motions. These large increases were generated because the vertical ground motion pushed the joints beyond the cracking limit state and into the non-linear range.

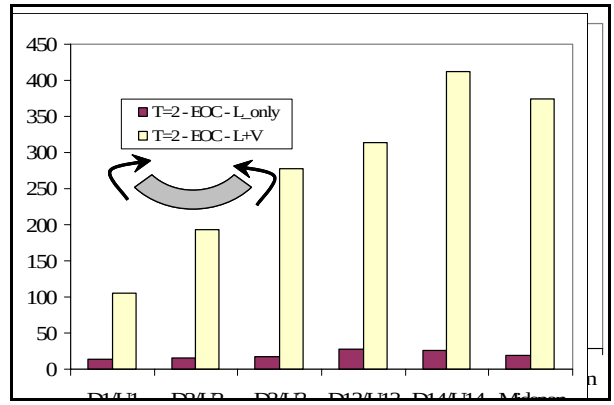


Figure 4: Effect of Vertical Ground Motion on the Median Peak Positive Bending Rotations

The pre-earthquake stress-state can influence the seismic response of segment joints by as much as an order of magnitude, as shown in Figure 5. This finding is contrary to common knowledge that volumetric changes have negligible effects on the structure's response to earthquakes. The extreme stress-states (i.e. -CS and +2CS) generated the largest rotation demands. This was because the extreme stress-state required the smallest seismic rotation demand to exceed a performance limit state.

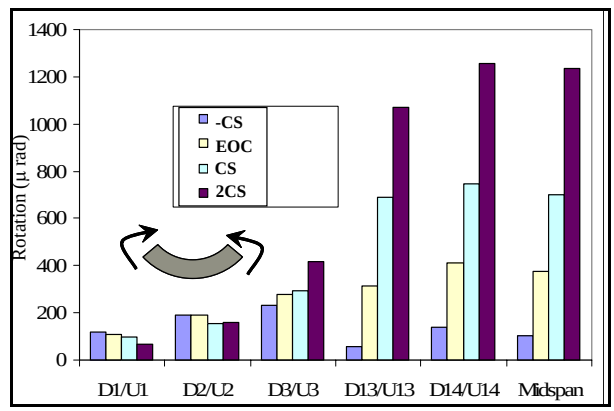


Figure 5: Effect of Superstructure Pre-earthquake Stress State on the Median Peak Positive Bending Rotations

Recommendations

Develop seismic design guidelines for segmental bridges that consider the effects of vertical earthquake motion and the superstructure pre-earthquake stress state.

For More Information on this and other DES research projects, contact:

Charles Sikorsky (916) 227-8759 or
E-mail: csikorsk@dot.ca.gov