DRISI
Caltrans Division of Research,
Innovation and System Information

Research Results

Seismic

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Project Title:
Structural Behavior of Column-Bent Cap Beam-Box Girder Systems in Reinforced Concrete Bridges Subjected to Gravity and Seismic Loads

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Optimizing Bent Cap Capacity Design

Better calculations for bent cap strength can reduce reinforcement costs and improve seismic performance

WHAT IS THE NEED?

For seismic bridge design, according to the capacity design philosophy, all damage during extreme events is directed to the bridge columns, which are designed to be ductile to prevent brittle modes of failure and overall collapse. On the other hand, the bridge superstructure, joints, and bent cap beams, designated as capacity-protected members, are designed to remain elastic when the columns reach their over-strength capacity. Applying this capacity design philosophy requires calculating the moment capacity of the superstructure components, such as the bent cap beams. Determining integral bent cap beam capacity is difficult in reinforced-concrete, box-girder bridges because the box-girder soffit and deck slabs contribute to the cap beam capacity that results in a flanged bent cap beam section. Obtaining
a reliable estimate provides two benefits: The possibility to reduce reinforcement in the cap beam for seismic capacity and reduce damage to the superstructure component by increasing the effectiveness and reliability of the column retrofit. In addition, box-girder soffit and deck slabs contribute to the integral cap beam capacity of stiffness. An accurate bent cap stiffness determination, as contributed by the box girders, is essential for status quo bridge modeling, which uses line elements for the bridge components. The current Caltrans Seismic Design Criteria need to be evaluated to determine reliable calculations for bent cap beam capacity and stiffness in terms of the effectiveness of bridge analysis, evaluation, design, repair, and retrofitting.

WHAT WAS OUR GOAL?

The goal was to investigate the behavior of bridge column-superstructure systems to recommend the capacity of the integral cap beams in reinforced-concrete box-girder bridges.

WHAT DID WE DO?

Caltrans performed a bidirectional cyclic test on a one-quartered-scaled model of the cap beam, box-girder, column subassembly, designed according to the Caltrans Seismic Design Criteria provisions to verify the capacity design approach. The plastic hinge in the subassembly column failed, but the bent cap beam and superstructure remained elastic. The researchers investigated the effectiveness of repairing the damaged column using a rapid carbon-fiber–reinforced polymer (CFRP) method, which was successful in partially restoring the subassembly capacity and increasing the stiffness of the damaged subassembly in transverse and longitudinal directions. The researchers then retrofitted the column of an identical subassembly with CFRP repair to try to migrate the damage from the column to the bent cap beam, quantify the box-girder contribution to the bent cap beam capacity, and evaluate the effectiveness of a CFRP retrofit. The team created a 3D finite element model and calibrated the model using the test results. This finite element model was used to explore the effect of reducing the bent cap reinforcement on overall system behavior and to investigate the box-

WHAT WAS THE OUTCOME?

Some of the findings produced by this research include:

- The 12 x slab thickness (ts) code value for the integral bent cap effective slab width in the bridge transverse direction is unnecessarily conservative. Instead, a value of 18 ts is recommended for the box-girder soffit and deck slab contributions to the integral bent cap stiffness and strength.
- Transverse deck and soffit slab tension reinforcement within the revised effective slab width should be included in the bent cap capacity estimation.
- The bridge dead and live (traffic) loads typically govern the bent cap beam load and resistance factor design. Any additional reinforcement required for seismic design is added to increase the bent cap beam capacity to ensure that it is larger than 1.2 times the column capacity. The box-girder slab contribution must be accurately considered to avoid unnecessary use of bent cap reinforcement.
- An accurate bent cap capacity estimate should be an integral part of the repair and retrofit designs for resilient infrastructure to avoid undesirable failure modes, leading to prolonged downtime and uneconomical post-event repair in extreme earthquake events. An accurate estimate is particularly critical for older bridges that were not designed using the strong-beam weak-column capacity approach.

WHAT IS THE BENEFIT?

Based on the updated estimate of the integral bent cap beam effective slab width, structural and bridge engineers can reduce bent cap beam reinforcement needed to withstand a seismic event, leading to savings in construction costs. The updated parameters enable structural engineers to better identify the flanged section and compute the capacity and stiffness of the line elements that represent the bent cap beams in their analytical models.

LEARN MORE

To view the complete reports:
http://www.dot.ca.gov/research/researchreports/reports/ 2015/CA16-2171A_FinalReport.pdf
http://www.dot.ca.gov/research/researchreports/reports/ 2015/CA16-2171B_FinalReport.pdf

IMAGES

Figure 1: Cap beam, box-girder, column subassembly before bidirectional cyclic tests (left). Identical column repaired using a rapid carbon-fiber-reinforced polymer method during testing (right).

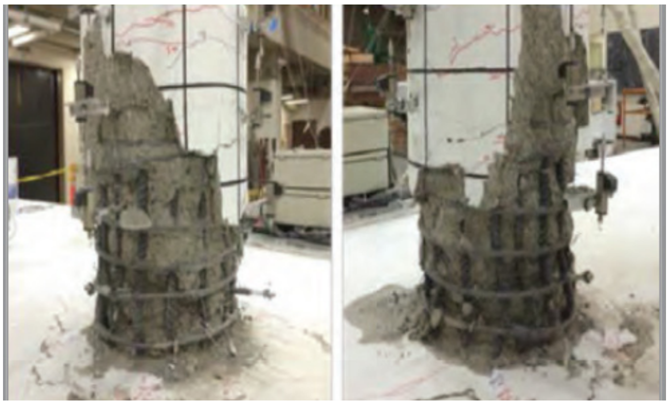

Figure 2: Column damage after cyclic tests

Figure 3: Cap beam concrete crushing and column flexural cracks (CFRP jacket removed) after hybrid simulation tests