DRISI

CALTRANS DIVISION OF RESEARCH, INNOVATION AND SYSTEM INFORMATION

TRANSFORMING IDEAS INTO SOLUTIONS

Research Notes

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Project Title: Primary Vertical Rebar Cutoffs for Reinforced Concrete Bridge Columns

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Primary Vertical Rebar Cutoffs for Reinforced Concrete Bridge Columns

Mitigating Mid-Height Plastic Hinge Formation through Integrated Seismic Analysis and Testing of Vertical Reinforcement Termination Limits in Bridge Columns

WHAT IS THE NEED?

During the 2023 Mw 7.8 earthquake in Turkey, multiple examples were observed of reinforced concrete cantilever column plastic hinges forming above the critical column/ footing interface where moment demand is largest and seismic details are provided for nonlinear and plastic behavior. This has significance to California bridges because Turkey closely follows the California Department of Transportation (Caltrans) seismic bridge design specifications and best practices. Caltrans' direct interest in this unusual column behavior and damage in Turkey is that Caltrans' current earthquake specifications allow primary rebar cutoffs up the column height. Plastic hinges that form a significant distance up the length of the columns of a single-column-bent bridge structure can result in instability and complete loss of the bridge.

While it is expected that having primary vertical rebar cutoffs up the column height is the main reason for column plastic hinges forming part-way up the column, there is another potential contributing factor; a moment demand for a cantilever bridge column that is not linear over its height. Under a simple lateral load, applied at the column top, the moment demand increases linearly from zero at the top of the column to a maximum at the column/footing interface. However, under a real bridge earthquake response, the column moment diagram can shift over time due to many factors, such as the bridge being curved in plan view or the rotational mass inertia of the superstructure, which can be significant and apply moments to the column top at its own natural period.

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WHAT ARE WE DOING?

The research started with development of a new analysis tool that will be able to realistically capture the lateral behavior to failure of a reinforced concrete cantilever bridge column with any configuration of rebar cutoffs up the column height. Then this tool will be used to assess a matrix of different column designs with various vertical and transverse steel percentages, and axial load ratios, as well as pattern and number of rebar cutoffs, including multiple sections up the column height where bars are cutoff.

Following completion of the computer program, and multiple analyses of column designs using this program, as discussed above, a series of cantilever column tests will be conducted in the laboratory to failure, under cyclic quasi-static loading. These will be at both ¼-scale and ½-scale, with ¼-scale preferable since it allows many more columns to be built and tested within the contract budget. With more column tests, there will be many different rebar cutoff configurations that can be physically tested, allowing verification of the computer program as well as real-world observations of columns with bar cutoffs.

The final part of this research will be to develop seismic design specifications and seismic design details for reinforced concrete bridge columns that have primary vertical rebar cutoffs. This will allow bridge design engineers in California, and elsewhere, to safely include rebar cutoffs in their column designs for future bridge structures.

WHAT IS OUR GOAL?

The goal of this research is to develop seismic design specifications and seismic design details for vertical rebar cutoffs of reinforced concrete bridge columns, based on the combined analyses and physical tests to failure. This will ensure plastic hinges form at the intended column/footing interface and not part-way up the columns for future bridge designs that include vertical rebar cutoffs.

WHAT IS THE BENEFIT?

The benefit to California is safer bridge structures for the traveling public and more economical designs, benefiting all California citizens. Bridge structures should not collapse under major earthquake loading, and the on-going research contributes significantly to this philosophy, preventing column plastic hinges from forming part-way up the columns in regions that are not designed or detailed for this. Such column plastic hinge offsets for single-column-bent bridges could result in instability and complete collapse of the bridge frame. Results from this research will also directly impact/benefit Turkey as they intend to adopt the findings from this research into their bridge designs.

WHAT IS THE PROGRESS TO DATE?

A computer program has been developed that currently performs moment-curvature analysis for circular reinforced concrete column cross-sections, for any number of primary vertical rebar and transverse hoops. This will be the primary program to evaluate the force-displacement behavior of cantilever bridge columns with vertical rebar cutoffs up their height, regardless of where the plastic hinge forms, and to ensure the plastic hinge develops at the desired column/footing interface (in subsequent analysis). At this point in the program creation, different section moment-curvature analyses can be conducted over the column height, correctly modeling the various amounts of vertical and transverse rebar after bar termination. Passing vertical rebar slip information from one section to the next is the current activity on this program, which will allow overall column force-displacement behavior to be realistically modeled for any arrangement of vertical rebar cutoffs.

In addition to the local column modeling discussed above, global bridge structures are being modeled. This is to better understand the changing column moment demand diagram over time for a single-column-bent bridge under earthquake loading. Five bridge structures were designed; each with five spans, but different radius (horizontal curve) in plan view - one bridge is straight and the other four have radii of 10,000 ft, 5,000 ft, 2,000 ft and 1,000 ft. Otherwise, the bridge frames are the same, with primary span lengths of 150 ft and end spans of 113 ft. Spectral and nonlinear time-history analyses are being conducted using SAP2000 to capture column moment demands versus time for single-column-bent bridge frames under severe earthquake loading. Global bridge modeling would allow any affects to the column moment profile from a horizontal bridge curve and the superstructure rotational mass inertia to be assessed, especially from nonlinear time-history analyses.