Post-Earthquake Damage Repair of Reinforced Concrete Bridge Components

RESULTS: The objective of the study was to develop repair methods for earthquake damaged reinforced concrete (RC) bridge components with different damage levels. The present study was conducted at the University of Nevada, Reno (UNR) through a research project funded by the California Department of Transportation (Caltrans). Six apparent damage states were defined and their applicability to different bridge components was assessed. To expedite decision making process, no other criterion involving destructive or non-destructive evaluation techniques was used to define bridge element condition. Repair methods to repair bridge components such as: shear keys, girders, abutment walls, and joints were developed depending on the damage level using carbon fiber reinforced polymer (CFRP) fabrics. Repair of bridge columns has been addressed through other research projects. Finally design recommendations and examples were developed to aid bridge engineers in quickly designing the repair and the number of CFRP layers based on the apparent damage state. In cases where the extent of damage precludes an economically feasible repair, reconstruction of damaged bridge component was recommended.

Project Website: http://wolfweb.unr.edu/homepage/saiidi/caltrans/earthquakerepair.html

Why We Pursued This Research

Highway bridges need to be restored after earthquakes as soon as possible to minimize the societal and economic impact of the earthquake. Based on post-earthquake inspection of bridge elements, engineers have to decide whether the bridge is repairable within a reasonable cost and time frame, or if it needs to be replaced. It has been seen that most of the bridges constructed before 1971 were not designed to meet the current seismic design standards. Vulnerability of pre 1971 bridges was particularly evident in the San Fernando Earthquake (1971), Loma Prieta Earthquake (1989), and Northridge Earthquake (1994) in California. Bridges designed as per current seismic standards are also expected to sustain damage to their structural components under extreme earthquake events depending on their type and operational functionality. Replacing the entire damaged bridge is cumbersome, time consuming, and expensive. Therefore, appropriate bridge repair needs to be carried out to restore the bridge within a reasonable time frame.

Previous earthquake damage reconnaissance reports show that, damage to bridge components varies from minor cracks in cover concrete to bar fracture. Different types and degree of damage to bridge components require different repair methods. The fastest method to assess the post-earthquake condition of bridge components is the visual damage because it does not require specialized tools. For the majority of bridges visual damage is the only feasible mean to assess the condition of the bridge rapidly. A variety of destructive and non-destructive techniques are available for detailed evaluation of bridge components but their use is warranted only for specific, perhaps critical bridges. It is, therefore, necessary to quantify the earthquake damage in terms of a series of damage states (DS’s) indicating the extent of apparent damage and then develop repair methods for each.

What We Did

Repair methods developed were based on the visual damage evaluation with no non-destructive testing involved to expedite decision making. Repair of columns is presented through other studies (Vosooghi and Saiidi 2013 and Saiidi et al. 2013). Similar to the previous research on repair of bridge columns, carbon fiber reinforced polymers (CFRP) were used due to their high strength and ease of installation.

In this study repair methods to repair bridge components such as: shear keys, girders, abutment walls, and beam-column joints were developed. The study was conducted in three different stages: (1) conduct a detailed review of damage and repair in past earthquakes to identify repair methods that can be readily adopted and to determine gaps in repair methodologies, (2) develop practical methods to access the condition of earthquake damaged bridge structural components in terms of apparent DS’s, and (3) develop repair design recommendations and examples to aid bridge engineers in quickly designing the repair and the number of CFRP layers based on the apparent DS. In the first phase of the study, detailed review of past earthquake damage and repair practice was conducted. There was a relatively large amount of information available for repair of bridge columns compared to other bridge components. In addition to columns, an attempt was made to obtain records of post-earthquake damage repair for other bridge components around the world. The past bridge repair work documented by Caltrans in various bridge books was found to be the most comprehensive. In other countries post-earthquake damage repair methods and repair objectives were not generally documented. Even though repair methods and records could not be obtained from other countries, the bridge earthquake damage records and their evaluation methods were reviewed. Finally, all past earthquake damage and repair data that were reviewed presented in various tables to categorize and rate the extent by

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which they can be used in development of a general repair guideline and to identify gaps in repair methods.

In the second stage of this study practical methods were developed to access the condition of earthquake damaged bridge structural components in terms of apparent DS’s. Upon consultation with Caltrans engineers, a uniform definition of apparent DS’s that had been developed for bridge columns in a previous study at UNR (Vosooghi and Saiidi 2010) was used as the framework for other bridge components, with the understanding that not all DS’s are applicable to all components. The damage states were: flexural cracks (DS1), first spalling and shear cracks (DS2), extensive cracks and spalling (DS3), visible lateral and/or longitudinal bars (DS4), start of concrete core failure (DS5), and fractured bars (DS6).

The third stage of this study consisted of developing repair design recommendations and examples to aid bridge engineers in quickly designing the number of CFRP layers and the necessary bond transfer length based on the apparent DS. Unidirectional CFRP fabrics were used to develop repair methods. Because ACI 440.2R method of calculating the effective strain in CFRP for side bonded FRP fabrics was iterative and time consuming, a new simple equation was developed and evaluated to calculate the effective strain in the CFRP. Figure 1 shows few repair examples of earthquake damaged bridge components under the given damage state.

Recommendations and Conclusions

While Caltrans bridge books provide many cases of post-earthquake bridge damage repair, the documented repairs are described in very general terms, and the specific efficacy of these repairs are not mentioned. Repair data collected from Japan was informative with respect to column repairs. However, there was a lack of systematic step-by-step repair procedures for other bridge components.

- No information was included in the available documents about residual capacity of bridge components at a given damage level to guide repair design.
- Because bridge columns generally undergo a wide range of apparent damage, uniform definition of damage states that had been developed for columns served as a useful platform for other bridge component assessment.
- The proposed non-iterative equation to determine the effective strain in CFRP provides results that were very close to those from iterative ACI 440.2R-08.
- In general, repair recommended for minor damage (minor flexural/diagonal cracks in cover concrete) was epoxy injections while unidirectional CFRP fabrics were utilized to repair bridge components subjected to moderate to significant damage levels. In cases where the extent of damage precludes an economically feasible repair, reconstruction of damaged bridge component is recommended.
- In shear keys under DS6, repair was presented to achieve two objectives: one to restore the shear capacity of the shear key and the second to change the mode of failure from diagonal shear failure extended into the abutment wall to sliding shear friction failure with the purpose of limiting shear demand on the superstructure.
- In abutment repair, unless there is significant reduction in the wall height due to failure and significant permanent rotation due to out of plane bending, walls with fractured bars (DS6) may be repaired by replacing fractured or buckled portion of the bars using new bars and service couplers as defined by Caltrans. A simpler alternative is to use CFRP fabrics in lieu of the damaged bars. Unidirectional CFRP fabrics with fibers either in horizontal or vertical directions are recommended to to restore the shear capacity.

References


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Figure 1- Repair of bridge components