RESEARCH NOTES

September 2010

Caltrans

Stability of Bridge Column Rebar Cages

RESULTS:* A series of experimental and analytical studies on bridge column rebar cages were conducted at the University of Nevada, Reno (UNR) through a research project funded by the California Department of Transportation (Caltrans). The purpose of the study was to develop guidelines to enhance the stability of bridge rebar cages and minimize their collapse. The project included the designing and testing two full scale rebar cages under lateral loads in additions to testing hundreds of tie wire connections under various types of loading. Based on calibrated computational models, it was concluded that the internal braces in rebar cages play an important role in their stability. Without these braces, rebar cages have low lateral stiffness and are vulnerable to collapse under accidental loading. The guidelines include the required number, spacing, and end details of the braces, the type of tie wire connections, and the number of template hoops.

Why We Pursued This Research

Collapse of rebar cages during construction causes schedule delays, cost overrun, and sometimes, injuries and deaths. This research investigated the behavior of rebar cages under lateral loading resulting in an understanding of their lateral stiffness to minimize their collapse.

Assembly of Rebar Cages

Four longitudinal bars forming the shape of a square are normally identified as "pick-up bars" during the assembly of a rebar cage. These bars are tied at every intersection with transverse reinforcement using "double-snap" tie wire connections. Along the length of the cage, transverse hoops, identified as "template hoops", are spaced at intervals of about 10-feet. The intersections between these hoops and the longitudinal bars are connected with "double-U" tie wire connections. The region between the "template hoops" is identified as a "field-zone" where the intersections between the longitudinal bars and transverse reinforcement are usually tied with "single-snap" tie wire connections. Different states have various requirements for the number and the type of connections in the "field-zone." For example, the State of California requires 20% to 30% of the intersection joints to be tied with "single-snap" connections, whereas the states of Arizona and Nevada require every intersection joint to be tied with "double-U" connection. Depending on the length and diameter of the cage and the fabricator's experience, internal braces **may** be placed inside the cage. These internal braces vary in detail and location from one fabricator to another. Two common braces used in California are X-braces and square braces. The X-braces are normally four #8 bars, bent in Z-shapes and welded to two inner rings at the ends of the bars. They are attached to the longitudinal bars and spaced at 10-feet along the length of the cage. The square brace uses eight #8 bars that are bent similar to the X-braces and placed at the edges of the cage. The square brace is preferred by many contractors because it allows concrete to be poured in the cage through a 'tremi-tube" without interrupting the X-braces.

At the construction site, the rebar cage is stabilized using at least four guy wires so that it can be attached to the bottom reinforcement mat of the footing. In order to place the prefabricated forms on the rebar cage, two of the guy wires are normally released from the cage. At that instant the stability of rebar cage depends on the lateral stiffness and strength of the cage itself. Any accidental loading may cause the cage to collapse.

Based on information that was collected and tallied by the authors, the collapsed column cages are fixed base columns with a minimum height-to-diameter ratio equal to 8.0. Their longitudinal reinforcement ratio, ρ, ranged from 1% to 2%, lateral reinforcement ratio, ρ_s, ranged between 1% and 2%, and contained no internal braces. Figure 1 shows a collapse of a rebar cage.

Figure 1: Example of rebar cage collapse

What We Did

Two full scale rebar cages were fabricated at Pacific Coast Steel and tested to failure at the University of Nevada, Reno. The main objective of these two full scale experiments was to determine the collapse mechanism of rebar cages in a controlled and instrumented environment. Thus, computational models were calibrated to investigate the effect of various components of the rebar cage on the lateral stiffness. Figure 2 shows the rebar cage before and after the experiments. The height of both specimens was equal to 34-feet and they were constructed for a column diameter of 4 ft. Thus, the height-to-diameter ratio of both experiments specimens was equal to 8.5. Assuming a 2-in clear cover, the outside diameter of the specimens was equal to 3'-8". For Specimen I, the longitudinal and transverse reinforcement ratios were equal to 1% and 1%, respectively. For Specimen II, the longitudinal and transverse reinforcement ratios were equal 2% and 2%, respectively. The height of the braces was equal to 9'- 4", and they were spaced at 10'- 6". The braces used in Specimen I were X-type made of four #8 bars, while the braces for Specimen II were square braces made of eight #8 bar.

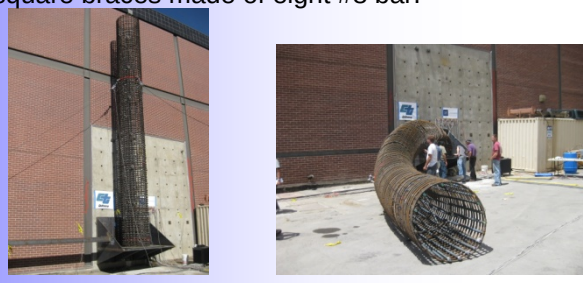

Figure 2- Specimen II before and after the experiment

Research Results

The experimental and analytical results are summarized in the form of resultant cable force-displacement. The response curves obtained from the experiments and from the analyses of the calibrated computational models for specimens I and II are presented in Fig. 3.

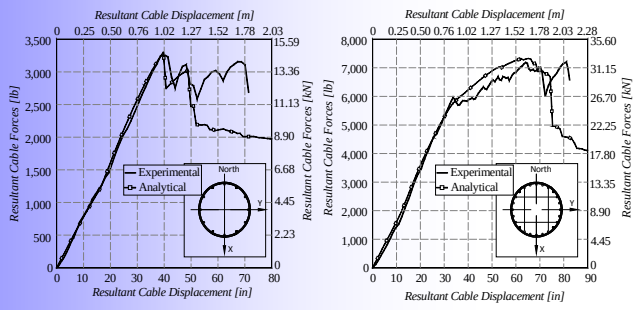

Figure 3: Experimental and analytical results for specimens I and II

It should be noted here that the computational model used the experimental results of the tie wire connections to model the connection of three translational and three rotational flexibilities. The calibrated models were used to establish the behavior of rebar cages with and without braces. Figures 4 and 5 show the results for cages with and without X and square-braces. These figures show the effect of bracing on the lateral stiffness and strength of rebar cages.

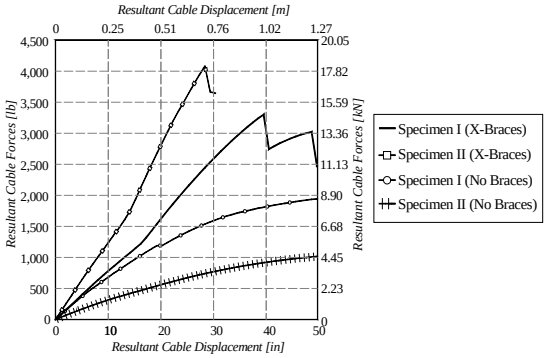

Figure 4: Comparison between X-braced and unbraced cages

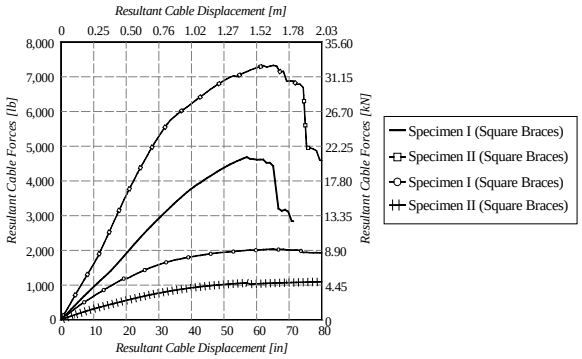

Figure 5: Comparison between square braced and un-braced rebar cages

Based on the research results, the following preliminary recommendations are proposed [1]:

1. Tie wire connections shall use #15 gauge, soft annealed steel with min F_u=40 ksi.
2. At least four vertical "pick-up" bars that form a square shall be tied at every intersection with double wire ties.
3. Hoops (template rings) shall be tied at every intersection with double wire ties at a maximum of ten feet increments.
4. At least 20% of the remaining reinforcement intersections shall be tied with at least single wire ties. Ties shall be staggered from adjacent ties.
5. Internal braces with box configurations with 8 bars (min #8) tied to the "pick-up" bar and interlocking hoops at the ends shall be provided at a maximum of ten feet increments.

Reference

1. Builes-Mejia, J.C., A. Itani, and H. Sedarat, "Stability of Bridge Rebar Cages ," University of Nevada, Reno, Report. CCEER, in preparation.