AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
Structural Engineering Department

SEISMIC BEHAVIOR OF PRECAST SELF-CENTERING HAMMER HEAD BRIDGE BENTS

A dissertation submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy in Civil Engineering
(Structural Engineering)

By

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Master of Science in Civil Engineering
(Structural Engineering)
Faculty of Engineering, Ain Shams University, 2014

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Date: July 2019

STATEMENT

This thesis is submitted to Ain Shams University in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Civil Engineering (Structural).

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

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THESIS SUMMARY

Construction of bridges sub-structure using traditional monolithic construction method has been the common strategy till last few decades when precast construction method started to be used in the purpose of accelerating bridge construction. Precast construct method has been successfully used in zones with low seismic action, but still cannot be used safely in zones with moderate to high seismic action due to lack of research on the behavior of this system under high seismic action specially at interfaces between precast elements.

This research presents an experimental and analytical investigations on the cyclic load response of hammer-head bridge piers. Five-hammer head bridge piers with a constant total height of 2.00m height from foundation surface to the top surface of the cap-beam were fabricated and tested under quasi-static cyclic loading (monotonic vertical load and a lateral cyclic displacement). The experimental matrix consisted of one conventional monolithic bridge bent as a reference specimen and four precast self-centering hammer head bridge piers. All specimens were tested to evaluate the hysteretic response of the precast post-tensioned connection in terms of failure modes, hysteretic load-displacement loops, dissipated energy and residual displacement were observed. Main variables between precast piers were the extension of column main reinforcement through footing and cap-beam of the bridge bent and level of post-tensioning used to assemble each precast self-centering bridge bent.

Experimental results showed that the proposed construction method of precast self-centering bridge piers is capable of enhancing the cyclic load response characteristics in terms of increased ultimate lateral load capacity,

reduced residual displacements, delayed damage states and reasonable energy dissipation capacity when compared with same bridge piers but with conventional monolithic bridge pier. The use of hysteretic energy dissipation rebar leads to a significant increase in the lateral strength of the piers with energy dissipation rebar accompanied with increased residual displacement. Energy dissipation rebar resulted in much higher hysteretic energy dissipation due to plastic deformation of the ED rebar. Although the level of post-tensioning force increases the displacement level at which this ultimate strength is achieved with reduction in the residual displacement. Specimens of the precast self-centering construction method generally achieved less residual displacement through most cycles when compared with traditional monolithic construction method

In general, precast self-centering construction method may be viewed as a viable alternative to traditional monolithic construction in seismically active regions as the system poses desirable structural merits necessary for these regions

Results of experimental tests were used to verify the Finite Element Model (FEM) developed in this study. Traditional reference bridge pier was first modeled using the ABAQUS platform and was subjected to same loading criteria of quasi-static loading as in the experimental test. Finite element model of monolithic bridge pier showed comparable results with the experimental tests. Thus, the FEM was improved to model precast self-centering hammer head bridge piers by defining unbonded post-tensioning strands and the interaction behavior at discrete surfaces between assembled elements. FEM was able to predict the hysteretic behavior of modeled bridge piers with an acceptable degree of accuracy. In addition, FEM confirmed the experimental

observations and showed that precast self-centering piers system is able to withstand large lateral displacements before achieving maximum lateral load.

Sensitivity analyses were conducted to investigate the effect of mesh size and bond-slip interaction on the hysteretic response of the modeled bridge piers. Developed FEM was found to be sensitive to mesh size; as higher static push over curve and more dissipated energy were resulted from larger mesh size with no significant effect on the residual displacements but with fatter loops that indicates the increase of the dissipated energy with the increase of the modeled mesh size. Also using bond-slip interaction between column main reinforcement and surrounded concrete influenced the hysteretic behavior of the modeled bridge piers as more pinched hysteretic loops and lower skeleton curves were generated when considering the effect of reinforcement-concrete bond-slip interaction.

A parametric study was conducted to investigate the effect of construction method, energy dissipation rebar ratio and socket depth on the hysteretic response of the modeled bridge piers. As expected monolithic specimens achieved more energy dissipation than specimens with proposed construction method and residual displacements. Piers with less energy dissipation rebar ratio achieved lower push over curve and more pinched hysteretic loops, thus less energy dissipation. Existence of socket downward footing of pier and upward the cap-beam is the main reason of high residual displacements when compared with same piers without sockets. Increase of socket depth makes piers with proposed construction method tend to behave as the conventional monolithic specimen especially when reaching a socket depth of 1 to 1.33 of the column diameter.

This analytical study reveals that FE analysis using the developed model can be applied to explore the hysteretic behavior of structural elements subjected to quasi-static loading. The model can be used in determining the appropriate range of applied post-tensioning force; energy dissipation rebar ratio and socket (socket) depth. Finally, fragility analyses were conducted to investigate the effect of post-tensioning level and ED rebar on seismic fragility behavior of precast self-centering construction method. Fragility analyses indicated that seismic vulnerability is reduced with adding ED rebar or increasing post-tensioning level especially in case of severe and collapse damage states.

Keywords: Finite Element, Bridge Piers, Seismic Behavior, Discrete Interface, Unbonded Post-Tensioning, Self-Centering, Fragility.

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