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Hysteretic cyclic testing of self-centering precast segmental RC bridge columns under diagonal loads

Junfeng Jia[1,2], Kaidi, Zhang[1], Tianning Bai[1], Xiuli Du[1]

1. Key Laboratory of Urban Security and Disaster Engineering of Ministry of Education, Beijing University of Technology, Beijing 100124, China;

2. Department of Civil and Environmental Engineering, University of Nevada, Reno. 89557, USA.

Abstract: Environmentally friendly and advanced structural systems are the promising development trend of next generation bridges by incorporating the design concept of seismic resilience into accelerated bridge construction (ABC) technology. ABC has been widely used in low seismic regions in USA, Japan and China. The advantages of economic and social benefits of prefabricated bridge elements, including girders, abutments, pier columns, cap beams, have attracted more attentions of engineers and scholars. However, insufficient research and design guidelines for seismic evaluation and design method is limiting application of ABC in high seismic zones. Many types of precast bridge columns had proposed and investigated in past ten years. The posttentioned segmental bridge columns combined with ABC techniques and seismic resilience concept is one of the main concerns in this field. On the other hand, it is worth noting that multi-dimensional strong ground motion has been observed and recorded in many past strong earthquakes. Previous studies reveal that inputting direction of ground motions will imposed unique effect on bridge columns, especially these columns with a rectangular section. Therefore, former researches on the seismic evaluation and design of precast segmental bridge columns (PSBCs) have not yet mentioned the effect of loading direction of ground motion. The seismic behavior and design considerations of the effect of multi-directional loads on precast self-centering segmental bridge columns are not clear.

The main objectives of this study are (1) to evaluate seismic performance of a self-centering precast segmental bridge columns with rectangular hollow section; (2) to investigate the effect of loading direction on seismic behavior of the PSBCs; (3) to provide seismic design considerations of PSBCs with rectangular hollow section; (4) to facilitate the use of PSBC in practice in high seismic zone.

Five 1/10-scaled segmental slender pier column models, each of which had six precast segments, were designed. The prototype columns were typical slender pier columns in China. They were designed according to Chinese guidelines. The outer dimension of the cross section of each segment was 550 mm×320 mm, the height of each segment was 500mm. The thickness of each section was 90 mm. The wall slenderness ratio of the segment was 4.11. The effective height of each column model was 3150 mm. Only the loading angle between loading direction and the longer side of the cross section was different in these five models. A loading block with a dimension of 600 mm ×600 mm×300 mm was connected to the loading actuator. The layout of loading block and footing were constant and the cross section of each model was rotated to form different loading direction. The loading direction for each model was 0, 30, 45, 60 and 90 degrees, respectively. They were called C-0, C-30, C-45, C-60, C-90 models in following study. Four unbonded steel tendons were posttensioned after the six segments and loading block were installed to provide axial compressive

force and restoring force during lateral loading. Eight energy dissipation (ED) bars were uniformly installed in each model to provide lateral resistance strength and energy dissipation capacity. Each ED bar was unbonded in 200 mm length at the bottom two joints between segments to avoid premature fracture. The total axial load index (ALI) was 0.13 for each model. A vertical jack was used to provide axial force of 237kN, which was equal to the prestressing force provide by the four posttentiond steel tendons.

Lateral quasi-static cyclic loading was applied in a displacement control mode. There were twelve drift ratio levels totally during the loading process, and two repetitive cycles were performed at each level. The first three lateral load reversals consisted of two cycles at $\delta=0.1\%$, 0.15% and 0.25%, respectively. Subsequent drift ratio levels started from $\delta=0.5\%$ to $\delta=1\%$ at an interval of 0.25%. After that, the loading levels started from $\delta=1.5\%$ to $\delta=3\%$ at an interval of 0.5%. The last drift ratio level was $\delta=4\%$. Thus, considering the subsequent reinforcement process, the largest drift ratio imposed on these specimens was 4%, corresponding to a lateral displacement of 126 mm. two linear differential transducers (LVDTs), labeled as D1 and D2, were horizontally mounted between the specimens and vertically erected pipes to measure the displacement at the loading point and the possible slippage of the footing, respectively. Accordingly, the actual lateral displacement at the loading point equals D1-D2. The corresponding lateral resisting force was measured by a loading cell. Four loading cells, labeled as T1, T2, T3 and T4, were installed under the tapered anchorage to measure the prestressing force during the initially tensioning and lateral cyclic loading process.

Apparent damage of these five models were compared at two stages. The first stage was the damage of cover concrete spalling, the loading drift was 3.0% for C-0 model and C-90 model, but it was 2.0% to 2.5% for the other three models, which were diagonally loaded. The damage mode of each model under lateral drift of 4% were presented, it is shown that more severe damage of two corners, which were far from the center, was formed for these three models under diagonal loading. Most slight joint crack was formed for the C-90 model, which was loaded along the weak axis of the cross section. The lateral force vs displacement hysteretic curves of tested models were presented and it is shown that preferable “flag-shape” loops were obtained for the C-0 and C-90 models. However, self-centering behavior was not evident in the other three models, that is, C-30, C-45 and C-60 models.

Residual displacements of these models were obtained from the force-displacement curves with maximum lateral loading drift of 4.0%. It is obvious that the residual displacement of C-90 model was the minimum, and the next was that of C-0 model. The maximum residual lateral drift along positive and negative loading direction for C-90 and C-0 models was less than 1.2%. The relationship between the moment of pier column bottom and lateral displacement were calculated with or without consideration of P-Δ effect. The results show that P-Δ effect was prominent in these tall pier columns. The energy dissipation and equivalent viscous damping ratio were also obtained and analyzed.

Prestressing forces of steel tenonds in each model were recorded during loading process. From the prestressing force vs lateral loading displacement curves, it is obvious that the prestressing force was linearly increased with the loading displacement. Prestress loss was found in each steel tendon after the model re-centered, which was similar with other results from self-centering structures. The presstress loss should be paid more attention to in self-centering structures with unbonded steel tendons. The loading direction imposed significant effect on prestress loss of steel tendons.