POST-EARTHQUAKE RESIDUAL VERTICAL LOAD-CARRYING CAPACITY OF Y-SHAPED PIERS: EXPERIMENTS AND SIMULATIONS

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Extended Abstract

Y-shaped bridge piers (YSPs) have been increasingly adopted in urban viaduct systems because they can support wide bridge decks while reducing land occupation beneath elevated structures. However, the bifurcated geometry of YSPs leads to complex load-transfer mechanisms, and their post-earthquake residual vertical load-carrying capacity (VLCC) has not yet been sufficiently investigated. After earthquakes, bridges are required not only to prevent collapse during seismic excitation but also to maintain adequate residual load-carrying capacity for emergency transportation and rescue operations. Therefore, investigating the residual VLCC of YSPs is important for post-earthquake bridge safety assessment and resilience-oriented design.

In this study, the seismic behavior and post-earthquake residual VLCC of reinforced concrete YSPs were investigated through large-scale experimental testing and finite element (FE) analysis. Based on a typical urban overpass prototype, one YSP specimen and one conventional single-column pier (SCP) specimen were designed and fabricated at a 1/5 scale. A sequential loading protocol consisting of cyclic lateral loading followed by eccentric vertical loading was adopted. First, cyclic lateral loading was applied under constant axial compression until the specimens reached the design-basis earthquake (DBE) damage level. Subsequently, monotonic eccentric vertical loading was imposed until failure to simulate post-earthquake eccentric vehicle loading conditions.

The experimental results presented in Fig. 1 show that the Y-shaped configuration significantly altered the lateral force-transfer mechanism of the bridge pier. For the SCP specimen, seismic damage was primarily concentrated at the pier-base plastic hinge region. In contrast, the damage of the YSP specimen shifted toward the bifurcation region due to the abrupt geometric discontinuity and force redistribution effects introduced by the inclined branches. Compared with the SCP, the YSP exhibited lower lateral strength and energy dissipation capacity during cyclic loading.

During the subsequent eccentric vertical loading stage, the YSP demonstrated superior residual VLCC performance compared with the SCP. The residual VLCC of the YSP was approximately 10% higher, and the specimen also exhibited greater ultimate vertical deformation capacity. The enhanced residual VLCC was mainly attributed to the redistribution of internal forces through the inclined legs, which effectively reduced the stress level and mitigated structural damage of the beam cap. As a result, failure mechanisms were delayed, and the post-earthquake vertical resistance of the YSP was improved.

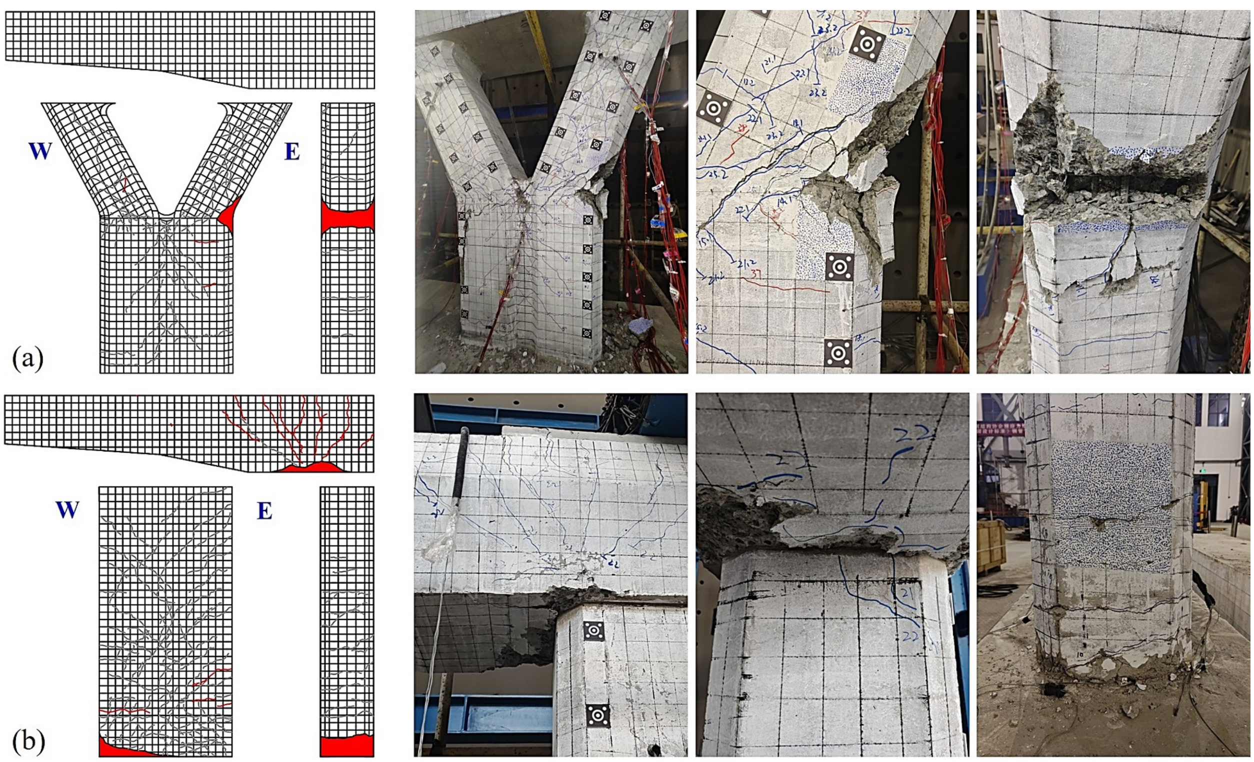

Figure 1- Post-test damage conditions of: (a) YSP specimen, (b) SCP specimen.

Based on the experimental observations, nonlinear FE models were established and validated against the test results. The validated models were further used to investigate the degradation behavior of residual VLCC under different seismic damage levels and eccentric loading positions. The numerical results indicated that residual VLCC gradually decreased with increasing displacement ductility demand and was significantly influenced by the position of vertical loading. Furthermore, a bilinear relationship between normalized residual VLCC and lateral displacement ductility was proposed for different loading conditions. The proposed relationship can serve as a useful tool for post-earthquake performance evaluation of YSP systems.

The findings of this study provide important insights into the seismic damage mechanisms and post-earthquake residual vertical resistance of Y-shaped bridge piers. The results can contribute to the development of more reliable post-earthquake assessment methods and resilience-based design strategies for irregular bridge structures.

Keywords: Y-shaped bridge pier; Residual vertical load-carrying capacity (VLCC); Eccentric vertical loading; Cyclic lateral loading; Finite element modeling.