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Recent Development of Post-Tensioned Self-Centering Structures for Earthquake Resistance

A post-tensioned (PT) self-centering (SC) structure that uses post-tensioning steel to compress beams against columns or bridge column segments against a footing has been developed as an alternative to a traditional earthquake-resisting system. The approach in seismic design, developed under the U.S. PRESSS program for precast concrete buildings with the SC connections, was verified from a 3/5 scale five-story SC concrete test-building (Priestley 1991, Pampanin et al. 2000). The SC behavior of the test-building was extremely satisfactory without significant strength loss up to drift levels of 4.5%. This posttensioning technology was successfully extended to steel moment-resisting frames (MRFs) by several connection tests (Ricles et al. 2002, Christopoulos et al. 2002). The lateral deformation of the PT frame leads to the opening of the gap at beam-to-column interfaces, so the compression force in the PT beam is affected by the column and slab restraints that oppose the frame expansion. These two issues become sources to hinder the SC behavior expected for this system.

Various conceptual proposals have been made along this line. Recently, Chou et al. (2008) experimentally showed that the PT connection with a continuous composite slab self-centers with low residual deformations as long as the metal deck separates along the column lines and negative connection moments provided by the slab reinforcements are considered in design. Chou et al. (2009) also demonstrated similar cyclic responses between a bare PT connection and a composite PT connection with a fully discontinuous composite slab, which opens freely along the beam-to-column interface. By adopting a concept of the rigid bay to transfer floor inertia forces to the PT frame and accommodate PT frame expansion (Garlock et al. 2006), shake table tests of a 3-dimensional PT frame with a sliding slab demonstrated the SC seismic response and small residual drift of the specimen frame in earthquake loadings (Chou and Chen 2009).

Kim and Christopoulos (2008) outlined the column restraining effect and suggested a pinned boundary condition for upper story columns to estimate column bending stiffness. The assumption of pinned boundary conditions represents a simplified estimate that represents an upper bound of this restraining effect and was suggested to account for the worst case scenario where a structure responds with a high drift at one floor while the drifts in the floors above and below are almost zero. Note that when the structure responds in its first mode shape (common seismic response for regular low-to-medium rise buildings) where all stories have comparable drifts, the restraining effect might be greatly reduced because the columns are pushed out at all floors simultaneously. Therefore, the previously approximate approach is overly conservative in cases where the structure responds in its first mode. Chou and Chen (2009) presented an alternative method for evaluating bending stiffness of the columns and compression forces in the beams based on a deformed column shape that matches the gap-opening at each beam-to-column interface. This method was verified analytically and experimentally through a full-scale one-story PT test-frame (Chou and Chen 2010).

It is easier to apply the posttensioning technology to bridge columns than buildings due to lack of restraints from the superstructure. In the past few years, research activities on the seismic responses of concrete segmental columns have been carried out in the U.S. and in other countries (Billington et al. 1999, Chang et a. 2002, Hewes and Priestley 2002, Chou and Chen 2006, Chou and Hsu 2008, Ou et al. 2007). Several test and analytical results of the PT segmental columns demonstrated the SC capability and good energy dissipation, but the application of this system in high seismic areas is still limited.

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