Seismic Assessment and Retrofitting of Non-Seismically Designed RC Structures – Consideration of realistic joint behavior – PhD Thesis by Margaritis Tonidis

Natural disasters such as earthquakes keep posing a threat to society due to their potentially devastating impact on civil infrastructure and the associated loss of life and property. Many reinforced concrete (RC) structures in the past have displayed poor seismic performance, in some cases leading to complete collapse. In particular, beam-column connections play a significant role when it comes to the lateral load-carrying capacity and deformational response of RC moment-frame structures. Existing structures that were designed without consideration for seismic loading, commonly referred to as non-seismically designed (NSD) structures, are particularly vulnerable during earthquakes. In light of this, there is a pressing need for the seismic reassessment and potential retrofitting of such structures worldwide.

There is an increasingly prominent trend toward performance-based structural analysis, where structures are evaluated not only in terms of strength but also with regard to their displacement behavior, extent of damage and sequence of damage. In this work, a practical and relatively simple nonlinear, spring modeling approach has been developed for the seismic assessment of NSD beam-column joints susceptible to joint shear failure. To better reflect real-life conditions, special emphasis was placed on capturing three-dimensional (3D) effects, including the influence of transverse beams, monolithic slab behavior, and bidirectional loading.

Fully Fastened Haunch Retrofit Solution (FFHRS) offers a relatively low-invasive, economical, and practical retrofit technique, in which diagonal steel haunches are connected to beams and columns using post-installed anchors. The primary objective of this retrofit is to reduce shear stresses in the beam-column joints and promote a flexural failure due to reinforcement yielding in the beams. A defining characteristic of this solution is the seismic performance of the anchors connecting the haunch. In this work, a new spring modeling approach is proposed for beam-column joints retrofitted with the FFHRS. The proposed model adopts a displacement-based approach for representing the anchor group, accounting for base plate flexibility and the redistribution of forces among the anchors. The haunch itself is modeled through the inclusion of a diagonal uniaxial spring, therefore satisfying both accuracy and simplicity requirements.

The methodology of this work includes the experimental testing on five full-scale exterior 3D beam-column joint subassemblies without and with retrofitting subjected to cyclic loading. The test series also includes corner joints subjected to bidirectional loads. For the first time, FFHRS has been experimentally examined in a corner joint retrofitted with FFHRS in both loading directions. In these tests, the presence of the haunches led to an approximate increase in load-carrying capacity of 100 %.

Furthermore, seismic tests under cyclic quasi-static loading were performed on two full-scale, two-story 3D RC structures. The first structure, tested in its as-built condition, exhibited extensive damage in all beam-column joints. A second, identically detailed structure was subsequently constructed and retrofitted with FFHRS at all joints. In this case, joint shear failure was successfully eliminated due to the effective performance of the anchors. However, the presence of the haunches ultimately shifted the failure mode to shear failure in the columns. These results indicate that a combined retrofit strategy, strengthening both the joints and the columns, may represent an optimal solution for enhancing the seismic performance of existing NSD structures.