Seismic assessment and retrofitting of non-seismically designed reinforced concrete structures considering realistic joint behavior – A numerical study

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The easy construct and inexpensive feature of frame structures make them one of the most popular construction types in the world. At the same time, old (pre 1970) non-seismically designed (NSD) reinforced concrete frame structures characterized by their poor seismic performance and sensitivity are still present all around the globe and a replacement of such is not intended due to economic reasons. For this reason, the existing structure needs to be correctly assessed in order to realistically predict its performance under seismic action to later on adapt the retrofit solution if needed. The assessment is done by performing numerical simulations with accurate and correct models where the inelastic behavior of the structure is captured. The strengthening method of a frame structure basically involves the strengthening of the individual beam-column joint in the structure. Since the economic aspect plays a major role, the retrofit measure used should be feasible and as uncomplicated as possible.

This work focuses on the assessment of three-dimensional beam-column joint sub-assemblies exposed to horizontal excitations, simulating earthquake conditions. In contrast to gravity loads, the beam-column joints exhibit moments of opposite sign, which in turn results in high shear stresses in the joint core. If the shear stresses reach a certain value diagonal cracking and concrete spalling occur due to insufficient amount of reinforcement, which is characterized by a low lap length, low/missing anchorage lengths, insufficient shear reinforcement and large spacing of stirrups in the area of possible plastic hinge formation (joint core). Given all these conditions, a premature brittle failure, where the stability of the building is no longer guaranteed, occurs. Nevertheless, non-seismically designed frame structures can support a certain amount of seismic loading without resulting in a complete collapse. However, in order to simulate the behavior of joints as realistically as possible, the three-dimensional effect must be taken into account. This effect describes the phenomenon where, unlike for gravitational loads, slab and transverse beams take part in the load transfer. The three-dimensional beam-column joint sub-assemblies consist of beam, column, joint, slab and transverse beam. However, most studies on frame structures found are based on two-dimensional models, in which the contribution of slab and transverse beam is not considered in the load transfer. For this reason, the simulations on 3D beam-column joints represent the crucial part in this work. The study was done on various models of exterior and interior beam-column joints, in which different parameters were analyzed on their contribution to the seismic performance of the sub-assemblies. In order to avoid a premature failure of the structure due to a brittle joint shear failure, a retrofit solution is needed which preferably induces a ductile failure while protecting the joint core. The Fully Fastened Haunch Retrofit Solution (FFHRS) has been proven to be an effective method in the strengthening of poorly detailed joints. This retrofit solution consists of a steel diagonal welded onto two plates and anchored to beam and column ensuring a good connection. The input parameters for modeling the 3D spring model of the sub-assemblies were adjusted, using the available 2D spring model from literature. The spring model used includes different springs where each spring represent a different mechanism in the joint. For example, the shear spring represents the shear deformation that occurs in the column, while the flexure that occurs in the beam is characterized by a flexural spring. Once the input parameters are known, the springs can be modeled, and the behavior of the connection can be captured as accurately as possible. The numerical simulations were first performed at component level (beam-column connections), in which the influence of different parameters on the performance of the joints were investigated and evaluated. Finally, the study was completed by simulating the entire frame structure, once without and once with the retrofit solution.