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PERFORMANCE EVALUATION OF RETROFITTED RC BEAM-COLUMN CONNECTIONS USING STRUT AND TIE METHOD

Seyed Ahmad NEZAMI
M.Sc. Student, Faculty of civil Engineering, Shahrood University of Technology, Shahrood, Iran
s.ahmad.nezami@shahroodut.ac.ir
Jalil SHAFAEI
Assistant Professor, Faculty of Civil Engineering, Shahrood University of Technology, Shahrood, Iran
jshafaei@shahroodut.ac.ir

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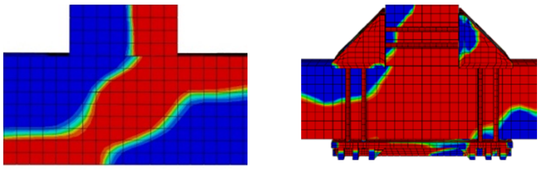
Recent earthquakes in Iran, and particularly the 12 November 2017 Kermanshah earthquake, caused numerous fatality and financial losses due to the failure of reinforced concrete (RC) structures. Post-earthquake inspections of damaged RC buildings have demonstrated that poorly detailed beam-column joints can suffer serious damage (Elwood et al., 2012). A retrofit technique called “joint enlargement using prestressed steel angles” was experimentally investigated and found to be an effective and practical technique for the seismic retrofit of non-seismically detailed reinforced concrete beam-column joints (Shafaei et al., 2014). In the current study, a strut and tie model is conceptually presented, implemented and validated by experimental results, to evaluate the joint shear strength and seismic performance of retrofitted beam-column joint. A strut and tie model was used to evaluate the joint shear strength and seismic performance of retrofitted beam-column joint. For constructing strut and tie model and to identify the flow of principle stresses in the joint enlargement region, 3D Finite element analysis was conducted. Based on principal stress pattern obtained from finite element analysis, strut and tie model was constructed to analyze the retrofitted beam-column joints. The model was verified and calibrated with experimental results of four retrofitted beam-column joint with various reinforcement details and various size of joint enlargement. The model was verified and calibrated with experimental results from four retrofitted beam-column joint with various reinforcement details and various size of joint enlargement.

Figure 1. Collapse of the RC buildings due to the failure of beam-column connections in recent earthquake (12 November 2017) in Kermanshah-Iran with magnitude of 7.3.

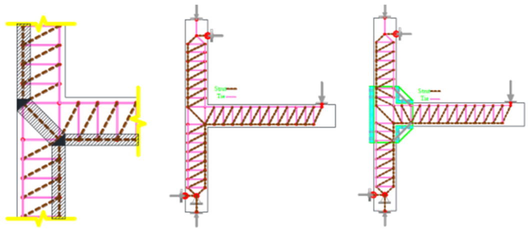
The plot of principal stress in finite element model is shown in Figure 2. In the control specimen, the compressive struts develop in joint panel. In retrofitted specimens, the compressive struts develop in joint panel, beam sections within joint enlargement and the enlarged areas. In the enlargement parts, the compressive struts form diagonally along the edge of the two opposite enlarged areas. These compressive struts provide additional load bearing mechanism that reduces the compressive stress in the joint panel main strut.

The strut-and-tie model representing the stress fields within an external beam-column joint was developed based on the results of force flow in the finite element analysis. Truss idealization of an exterior beam-column joint before and after retrofit is shown Figure 3.



(a) Control specimen (b) Retrofitted specimen

Figure 2. Finite element principal stress plots in two opposite direction loading.



(a) Main strut in the joint region (b) STM of control specimens (c) STM of retrofitted specimens

Figure 3. Truss idealization of an exterior beam-column joint.

As shown in Figure 4, the strut-and-tie model predicts the ratio of compressive stress to concrete compressive strength in the joint panel main strut to be 1.55 and 0.48, in control and retrofitted specimens respectively. This indicates that the enlargement reduces force in the joint panel struts and change the failure mode from joint failure in non-seismically detailed specimens to beam plastic hinging in retrofitted specimens. For retrofitted specimens, the strut-and-tie model predicts yielding in tension tie at the edge of joint enlargement and predicts reduced tension force in the tie at the column face. This prediction agrees well with experimental result.

(a) control specimen NS-C (b) Retrofitted specimen

Figure 4. Detailed view of forces in critical strut-and-tie element in enlarged joint region for control and retrofitted specimens.

Based on the results of strut-and-tie model, it can be concluded that the STM can capture the non-uniform distribution of shear stress in the joint enlargement area. Strut-and-tie model is demonstrated to be a mechanical model that can qualitatively capture the essential behaviors of strengthened specimens. However, the quantitative prediction is not perfect, for example, the model underestimates the horizontal shear force carried by the joint panel. The refinement of the strut-and-tie model for a better precision is needed to build a rationally mechanical model for designing the joint enlargement.

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