ANALYSIS METHODS FOR SEISMIC EVALUATION OF INFILLED REINFORCED CONCRETE FRAMES STRENGTHENED WITH FRPS

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Recent earthquakes in Turkey (Kocaeli 1999, Duzce 1999, Bingol 2003) have demonstrated the vulnerability of existing structures to large seismic demands that were not accounted for in their design. Efficient and reliable upgrade methods are needed in order to mitigate the expected seismic loss. Most of these deficient structures in the building stock are reinforced concrete frames with infill walls. The post earthquake reconnaissance surveys [1, 2] showed that lack of lateral strength together with insufficient ductility to withstand seismic deformations is responsible for collapse in most cases. At the verge of rebuilding and retrofitting the infrastructure, practical methods and relevant design procedures are needed for building rehabilitation.

Fiber reinforced polymers have been used in strengthening infill and masonry walls in a number of studies [3, 4, 5]. Both in plane and out-plane behavior of strengthened walls have been investigated in these studies. Recently, a novel technique that makes use of fiber reinforced polymers (FRPs) in the upgrade of reinforced concrete frames with infill walls was developed as a part of a NATO sponsored extensive research project [6]. Quasi-static cyclic tests were performed on multi-bay multi story structures in order to experimentally validate the effectiveness of the FRP strengthening system [7, 8, 9]. The proposed method was found to be effective due to speed and ease of application with little or no disturbance to the occupants. In order to design and detail FRPs based on the results of experiments, analysis and design procedures need to be established. The objective of this study is to fill this gap and propose analysis methods for FRP strengthened infill walls for use in seismic evaluation methods such as the demand-capacity spectrum method.

When a reinforced concrete frame with infill walls is subjected to lateral deformations, the infill wall acts as a diagonal strut, while the separation of the infill occurs on the opposite side. The idea of the FRP retrofit scheme is to reduce interstory deformation demands by using FRPs to act as tension ties. In order to achieve this, diagonal FRPs bonded on the infill wall is tied to the framing members using FRP anchors as shown in Figure 1. In this way, a tension tie contributes to the load carrying capacity in addition to the strength provided by the compression strut formed along the infill diagonal. Experiments conducted on FRP strengthened reinforced concrete frames [7, 8, 9] with infill walls revealed that there are two dominant failure modes (Figure 1). First mode initiates with the failure of the FRP anchors in the form of a combined pull-out and slip failure. As soon as the anchors fail, the load carried by the FRP is transferred to the diagonal compression strut and failure of the infill wall occurs due to corner crushing. Second failure mode occurs because of FRP debonding from the infill wall surface. After FRP debonding, previously formed horizontal cracks start to open and when the tie action of FRP is lost, sliding shear failure of the infill wall occurs. First failure mode is mainly due to insufficient anchor depth and can be avoided by increasing the depth and...
number of anchor dowels [9]. However, the second failure mode marks the limiting strength of the strengthened infill. Tests have shown that beyond a strain level of about 0.006, FRP debonding took place resulting in a sliding shear failure mode followed by a sudden drop of strength [9]. These observations obtained from the experiments are used to develop structural models for the FRP strengthened RC frames with infill walls.

The analytical model of a strengthened frame proposed in this study is a structural one rather than a continuum model as shown in Figure 2. Critical regions of frame elements (i.e. plastic hinge regions) are modeled by discretizing the section into a number of fibers. Unconfined and confined concrete fibers are modeled with commonly used appropriate nonlinear stress-strain models. Steel reinforcement is modeled as an elastic perfectly plastic material model. The advantage of fiber models is the consideration of axial load-moment interaction during analysis and avoiding the need of performing sectional analysis separately. Plastic hinge length, which is the length of the region where inelastic action is expected, is taken equal to the depth of the member. Effective cracked stiffness equal to the 75% of the gross section properties and modulus of elasticity of concrete are used between the plastic hinge regions to model the elastic portion of the frame elements.

Infill wall strengthened using FRPs is modeled using a compression strut and a tension tie, which adequately represents the load transfer mechanism. A trilinear stress-strain response is proposed for the truss members to simulate the behavior of the infill wall (Figure 2). FRP, infill material and plaster on the infill wall surface contributes to the stiffness of the tension tie. Cracking stress and strain are computed based on the cracking of mortar and plaster. The ultimate capacity of the FRP tie is calculated based on an effective strain limit observed in the experiments. The width of the compression strut for the infill is based on the work by El-Dakhakhni et al. [10]. The ultimate strength of the diagonal compressive strut is computed based on the minimum of the two capacities, namely sliding shear, and corner crushing. Corner crushing capacity is computed using an empirical equation calibrated with test results and proposed by Flanagan and Bennett [11]. Models described above have been compared against a number of test results presented by different researchers at different institutions. One such comparison is presented in Figure 3 for the test results presented by Akguzel [9].

Estimated total base shear plotted against roof displacement values are compared...
with experimental results. It can be observed that estimations of stiffness and strength of all the test specimens reasonably agree with the measured response.

The proposed model for inelastic static analysis of FRP strengthened reinforced concrete frames can be used to in seismic evaluation where pushover analysis is required to obtain a capacity curve. It is believed that the outcome of this research will help structural engineers in making a decision on the retrofit scheme and conducting parametric studies, since the models developed have proven to provide reasonable estimates of strength and deformation capacities.

Figure 2. Structural Model and Stress-strain Behavior of Struts and Ties

Figure 3. Comparisons of Experiments conducted by Akguzel [9] with Analysis Results (Points are the experimental points, lines are analytical estimations)
References


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