BEHAVIOR OF POST-INSTALLED CHEMICAL ANCHORS UNDER COMBINED LOADING

Devyani Tewatia
Research Scholar
Department of
Earthquake Engineering
IIT Roorkee

P. C. Ashwin Kumar
Assistant Professor
Department of
Earthquake Engineering
IIT Roorkee

INTRODUCTION

Retrofitting Reinforced Concrete (RC) frames using internal steel braces is suitable for maintaining or improving seismic performance. Internal steel bracing is placed inside the RC frame and is connected to the beam and column members directly to transfer the forces. They also help to increase the stiffness of the building, especially in the case of the Open Ground Story frame, where the stiffness irregularity is present due to the absence of a masonry wall on the ground floor.

However, for the steel braces to develop the desired performance as a part of the retrofitting scheme, the connection between steel and RC plays a crucial role. Currently, a well-defined procedure for designing these connections does not exist and the limited guidelines might result in over-designed connections leading to higher redundancy or maybe under-designed, which can lead to premature failure of the connections.[1,2] These anchors at the beam-column joint are subjected to combined tension and shear loading while transferring the axial forces from the brace. The failure modes of anchor in tension include steel failure, concrete pull-out, concrete breakout, bond failure and concrete splitting. In shear, the failure modes have been identified as steel failure, concrete pry-out and concrete breakout. As can be observed, failure in concrete is mostly the governing mode and it is necessary to check the quality and strength of existing concrete before selecting anchors for connections.

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ACI 318-19 [3] provides design against various failure modes in anchorage to concrete based on the concrete capacity method but is restricted to anchors placed in plain cement concrete on a planar surface instead of reinforced concrete making this code's design method highly conservative. Hence, as a part of developing design guidelines for the connection of steel braces to RC beam-column joint, an experimental investigation has been carried out to assess the capacity of the anchors, specifically the post-installed chemical anchors. The post-installed chemical anchors have been chosen for this study as they are the least invasive and less labour-intensive compared to other steel-RCC retrofitting techniques like peripheral steel frames. An RCC beam-column sub-assembly has been prepared and attached to the brace, similar to the actual retrofitting scenario. Thereafter, these joints have been tested under force-controlled conditions to assess the capacity of anchors and governing failure modes.

EXPERIMENT

A beam-column joint subassembly having a cross-section size of 230 mm x 350 mm has been cast as per the details in Table 1. To connect the steel brace to RC beam-column joint Hilti HIT-V-5.8 anchor bolt with HIT RE 500 V3 epoxy has been used as post-installed chemical anchors due to their seismic pre-qualification in accordance to ETAG001. [4] The concrete surface has been initially cleaned, and holes of the required diameter have been drilled. Thereafter, the holes have been filled with chemical epoxy before inserting the anchor rods as per guidelines. [5] The anchor plate placed over these bolts has been designed to remain elastic throughout the test.

Table 1: Beam-column sub-assembly detail	
Item	**Detail**
Beam size	230 mm x 300 mm
Column size	230 mm x 300 mm
Beam - longitudinal reinforcement	4 nos-16ϕ bars (1.15%)
Column - longitudinal reinforcement	6 nos-12ϕ bars (1%)
Beam, column transverse reinforcement	8 mm dia. bars @150 mm c/c
Material	
Concrete	M25
Reinforcement steel	Fe500

Uniform Force Method has been used to evaluate the forces on the gusset plate. [6,7] In this study, steel brace and gusset plate have been designed to remain elastic such that the capacity of concrete-anchor connections can be assessed along with the mode of failure. Servo-hydraulic actuator having 500 kN capacity and a stroke length of ±250 mm has been utilized to apply the monotonically increasing force.

Force-controlled test

A hollow circular steel brace having a cross-section of 165 mm and a thickness of 5 mm has been welded with gusset plates on both ends. The gusset plate is welded with an anchor plate, which is then bolted to the concrete surface as per Fig. 1.

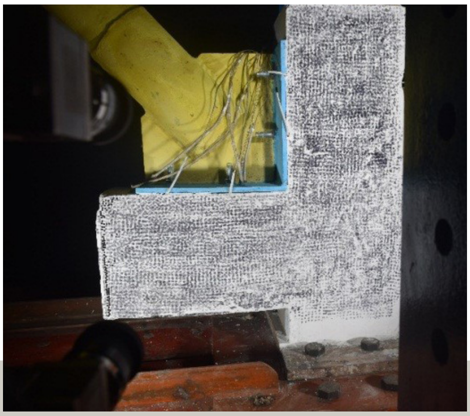

Fig. 1: Beam-column sub-assembly

The RC beam column sub-assembly connected to the steel brace has been tested under force-controlled mono-tonic pull-out protocol. The brace is connected at an angle of 45 degree with the joint. The force transfer between beam and column faces is equally distributed. The loading has been linearly increased at 10 kN intervals at 0.1 kN/sec till connection failure is observed.

RESULTS AND CONCLUSIONS

As expected, during the test, no yielding of brace and gusset plate has been observed. The diagonal cracks started developing in the beam-column joint at an axial force of 160 kN, as shown in Fig. 2. The concrete connection suffered a sudden brittle failure at an axial brace load of 184 kN as shown in Fig. 3. The failure was observed as concrete breakout mostly limited to cover of the beam and column face. The axial force vs displacement curve is seen in Fig. 4. Based on the test results the distribution of forces on each anchor face has been calculated to be 65 kN in tension and

Fig. 2: Diagonal crack at beam-column joint

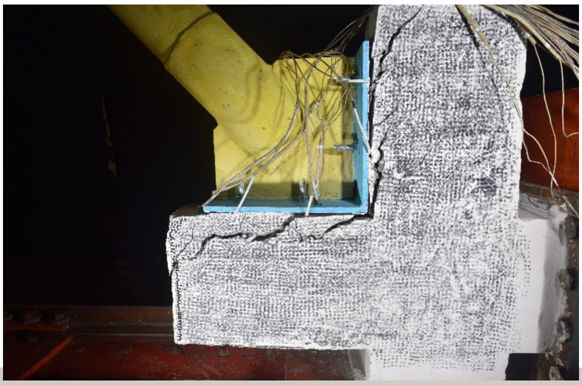

Fig. 3: Beam-column subassembly at the end of experiment

shear at failure. The equal value of tension and shear component is due to the missing RC frame action on the joint which only effectively reduced tension component on each face making shear force component governing in such case. [8] According to tension-shear interaction equation 1 as per ACI318-19, the maximum strength of the anchor group is restricted to 18 kN and 33 kN in tension and shear, respectively, with and without factor of safety.

$$\frac{N_{ua}}{\phi N_n} + \frac{V_{ua}}{\phi V_n} \leq 1.2 \qquad 1$$

The difference between actual failure and expected failure is quite evident. It can be attributed to presence of reinforcement steel in the specimens. Post-installed HILTI anchors have shown to be a suitable choice for connection between steel brace and existing RC beam-column joint.

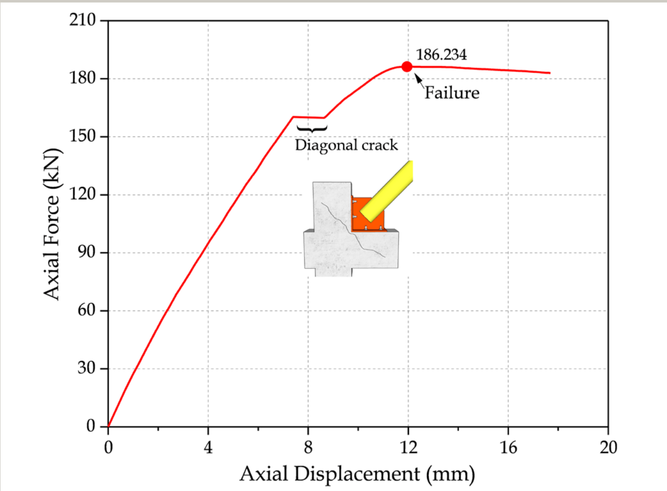

Fig. 4: Axial force vs displacement curve

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