Repair and retrofit of beam-column joints of a damaged two story RC-frame

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Abstract

A 1/3rd reduced scale two story reinforced concrete frame tested on shake table was repaired and retrofitted using steel haunches, to check the efficiency of haunch retrofitting in restoring seismic capacity. Repairing was done by removal of damaged concrete from the joints and replacement with rich concrete. Haunches were installed at each joint to change the hierarchy of strength from brittle shear damage in joints to ductile flexure damage in the beam. Testing was performed using quasi-static cyclic loading setup. From the comparison of the tests it was observed that the repaired and retrofitted frame showed a ductile failure mechanism of beam flexure cracking as campaired to joint shear cracking in as-built frame. Also a substantial increase in the seismic response parameters of the retrofitted frame was noted showing the effectiveness of the repair and haunch retrofitting technique.

Keywords: Haunch retrofit technique, quasi-static cyclic loading, seismic response parameters.

1. INTRODUCTION:

Due to earthquakes every year a large stock of buildings is damaged in addition to the loss of many human lives. The risk of damage to the buildings and lives is increased further if non-seismically designed or some type of construction deficiency is found in it, which is the case of a huge stock of buildings in developing countries. Mostly attributable to non-seismic design and construction deficiencies, the Kashmir 2005 earthquake killed more than 73,000 people in addition to severely injuring 70,000 people, while making 2.8 million people homeless. According to an estimate some US$5.2 billion loss to the economy was attributed to the Kashmir earthquake (Asian Development Bank and the World Bank, (2005)).

The study in this work will consider such deficient structures with beam-column(BC) joints in focus, as in past beam-column joints were assumed as to behave in an elastic nature during an earthquake event, that assumption proved to be wrong as when the joints were observed to be one of the most vulnerable part of a structure and become the reason for brittle failure of many structures, either designed as per old colds with improper seismic provision, or with construction deficiencies (Pampanin et al. 2006). Either by increasing the seismic capacity or decreasing the demand on BC joints its brittle failure mechanism in the form of shear cracking can be prevented. To prevent the shear failure of joints many techniques were developed, the applicability of which depends on materials, expertise, cost considerations, architectural and aesthetics requirements. Haunch technique due to its less expensiveness, less invasiveness and easily applicability was proposed by Pampanin et al. (2006) for reinforced concrete(RC) BC joints, while for the haunch technique to be faster, easier and lesser invasive post-installed anchors were used for fastening of the diagonal haunch with the beam and column by Genesio, G. (2012).

2. EXPERIMENTAL PROCEDURES:

2.1 Introduction:

For the purpose of investigating the effectiveness of haunch retrofit technique in restoring seismic capacity of a deficient structure and already damaged during shaking table test performed by Rizwan et al (2018) on the as-built model to be repaired and retrofitted, was tested under quasi-static cyclic loading conditions. In addition to a two story control frame designed according to Seismic Provision of BCP-SP (2007) by Rizwan et al (2018) four other frames were constructed considering the deficiencies found in field practices. The model frame considered in this study was the one with reinforcement details (Figure 1) as of the control frame with concrete strength of 2000psi as campaired to the design strength of 3000psi. The frame constructed and tested, were 1/3rd reduced scale simple model idealized.

2.2 Model Repairing:

The damaged frame was repaired by firstly repositioning the frame from the induced tilting due to testing, then the removal (Figure 2) of damaged concrete from joint and the adjacent beams and column region, which was replaced (Figure 3) with rich concrete of 5000psi of compressive strength. Concrete of higher strength was used in the joints to increase its shear strength, and in the adjacent parts of the beams and columns for better anchorage of the haunches to the beam and column.

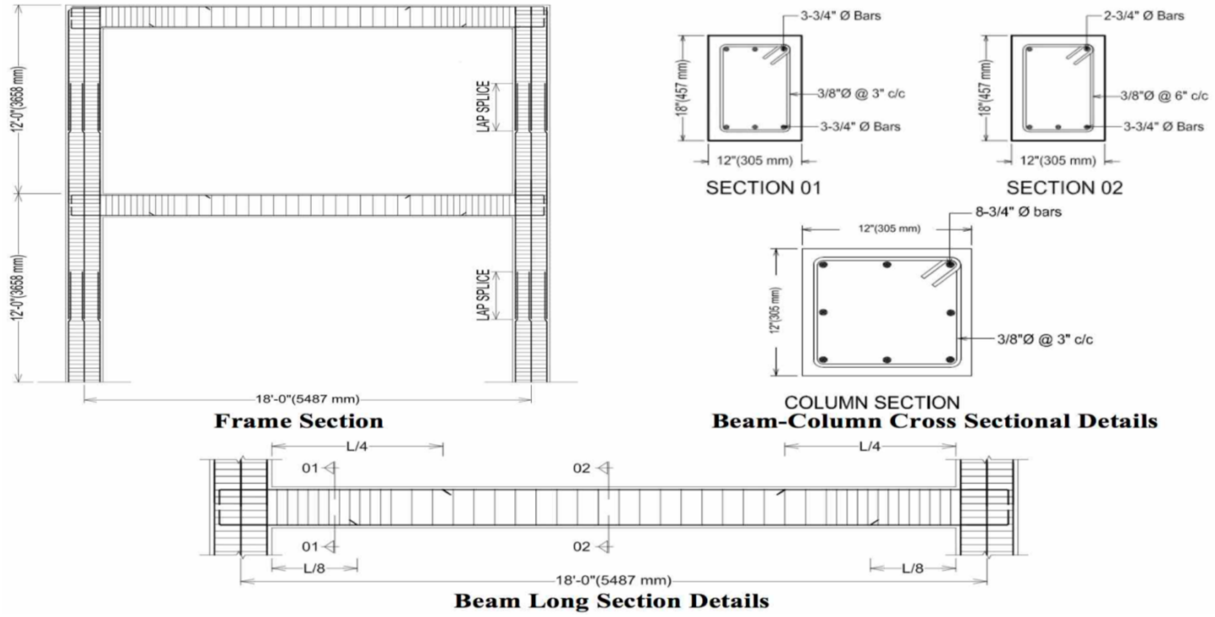

Figure 1: Steel reinforcement details of control frame used by Rizwan et al (2018) as well as candidate model in this study.

Figure 2: Removal of damaged concrete.   Figure 3: Replacement with rich concrete.

2.3 Haunch Design and Application:

The haunch design performed in this study was based on the procedure of fully fastened haunch retrofit solution (FFHRS) introduced by Genesio, G. (2012), that intern is an extension to the procedure used by Pampanin et al (2006). The effectiveness of the haunches in diverting the shear demand from the joint towards the beam depends on length, the angle it makes with the beam and stiffness of the haunch element, where the stiffness of the haunch element depends on its dimensions, material and also anchors stiffness. The dimensions, geometry, and material properties of members that connects with the joint in addition to the trial haunch element and stiffness of the anchors, were the parameters used for designing of the FFHRS. The haunches were connected to the beam and column by drilling of holes, where the anchors passing through the haunches base plates are bonded to the concrete using epoxy.

Table 1: Details of the haunches used for retrofitting.

Haunch Parameters	**Anchorage details**	**Anchorage details**
Haunch Diagonal (Lh)=353mm	Anchorage type=Bonded anchors	Fc'=34MPa
Projected Length of Haunch (L')=250mm	Number of anchors(n)=6	Fy=414MPa
Haunch angle=45^{o}	Anchors effective depth(hef)=60mm	
Es=200GPa	Anchors diameter(dnom)=8mm	
Cross sectional area of Haunch(Ad)=1080mm^2		
Haunch Stiffness (Es.Ad/Lh)=612KN/mm		

2.4 Test methodology, setup and Loading Protocol:

Tests on the repaired and retrofitted frames were conducted by applying quasi-static cyclic loading through a hydraulic actuator of 50-tons of load and 12 inches (300mm) of displacement capacity (Figure 4). Two pin connections were provided with the actuator assembly for avoiding any accidental eccentricity that can be induced due to loading. The actuator was attached at 1/3rd height from the top to a distribution girder attached to the top of first and second stories, so as to create loading conditions equalling to that of code linear triangular load distribution between the floors. Loading history as per ACI ITG-5.1-07 protocols was applied, where 0.4, 0.5, 0.7, 1.0, 1.5. 2.0, 2.5% of roof drift cycles were applied with each drift cycle repeated three times. Based on the code allowed maximum inter story drift for low rise structures, a maximum to be applied roof drift was selected. Load cell to the actuator was attached for recording load, while displacement transducers were attached to the floors for recording displacements. Also to record any horizontal sliding of the retrofitted frame another displacement transducer was attached to its base pad.

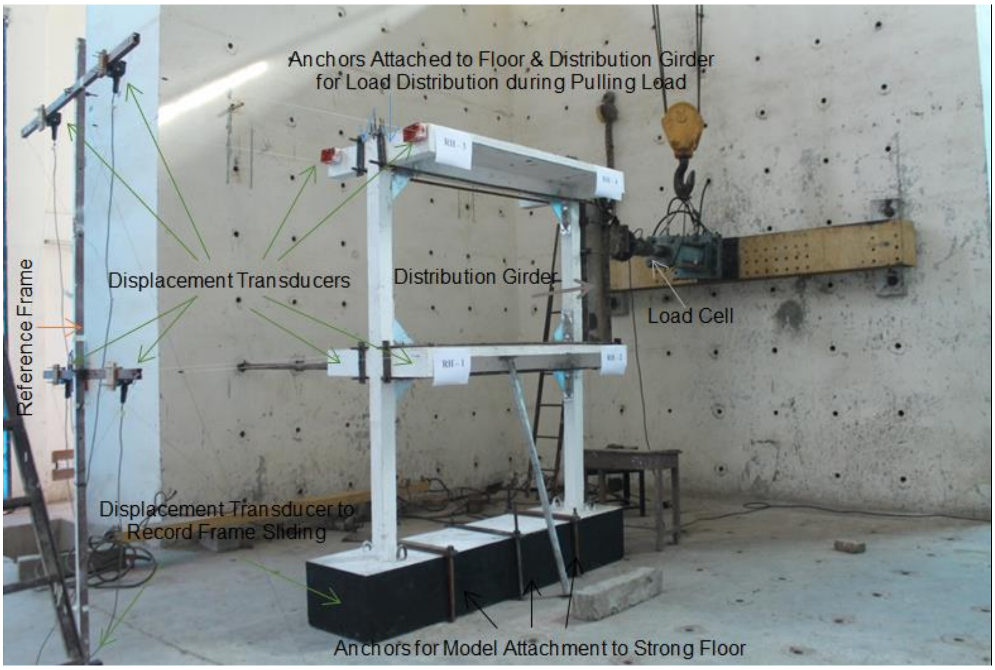

Figure 4: Test setup and instrumentation plan.

3. RESULTS:

3.1 Damage behavior:

By starting with the application of 0.4% of roof drift and increasing to 2.5% as per ACI ITG-5.1-07 protocol, the damage started with hair line cracking in the beam at the end of haunch plates that widened significantly in the subsequent drifts up-to 2.5%. Also some hair line shear cracking in the joints and shear cracking in the columns of ground story at the end of haunch plates was observed during the application of the last drift cycle, which can be attributed to the detachment of the haunches through concrete pry-out that further weakens the substrate member. Also some pinching behavior in the load-deformation response (figure 5) of the frame was observed that can be attributed to the opening and closing of already existing cracks, which can be controlled/minimized by injecting epoxy.

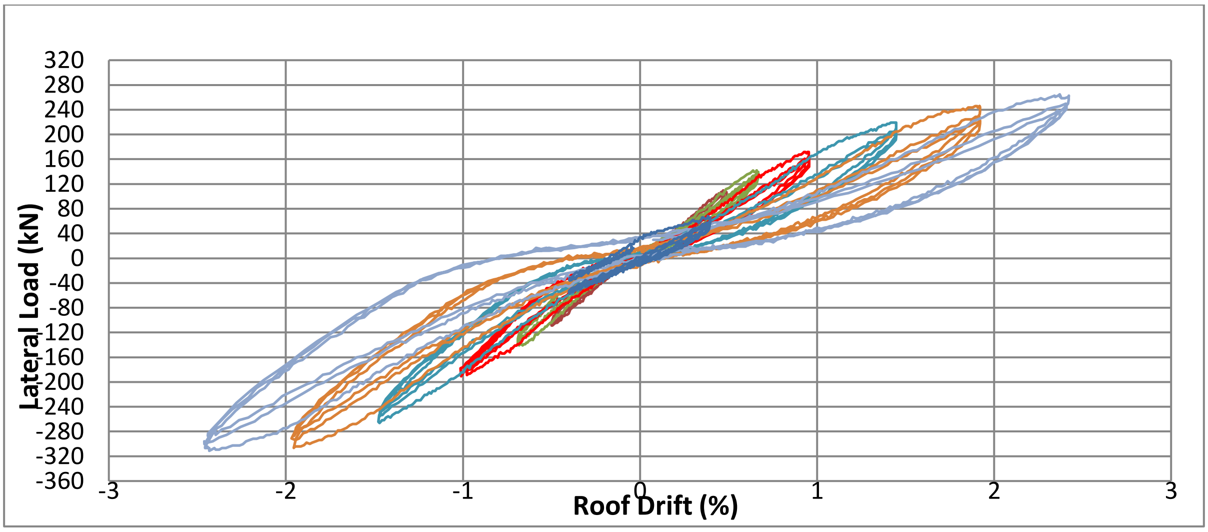

Figure 5: Force-displacement hysteretic response of prototype of retrofitted test frame.

3.2 Comparison between Retrofitted and As-Built RC Frames:

In case of the as-built frame tested by Rizwan et al (2018) through a shaking table, that was built using low strength concrete, had lower load resistance and higher deformation under same loading conditions. This frame has also lower lateral load capacity due to early joint shear failure (Figure 6) due to the use of low strength concrete. The frame when then repaired using higher strength concrete and with haunches installed showed much higher stiffness and lateral load capacity. This can be attributed to the higher joint shear strength due to the use of rich concrete and also due to the shear transfer mechanism produced by the haunches installed at beam-column joints, from joint to the beam. That resulted into flexure plastic hinge (Figure 7) formation in beam as opposed to joint shear damage mechanism in as-built frame.

Figure 6: Damage in joint of as-built frame

Figure 7: Flexure cracking in beam of retrofitted frame.

3.3 Seismic Response Parameters:

The capacity curves were generated from the hysteretic behaviour of the frames and then this capacity carves were bi-linearly idealized using equal energy principal. From the Idealized Elastic-Plastic Capacity Curves the different Seismic response parameters were calculated as per procedure followed by Rizwan et al (2018), so as to have quantitative comparison between the seismic response of the as-built and repaired plus retrofitted frame. From this comparison it was found that the repair and retrofitting not just restored but increased stiffness, strength, ductility and response modification factors of the deficient and damaged frame by 75%, 52%, 15% and 75% respectively.

4. CONCLUSIONS:

The objective of transferring damage from brittle shear cracking in the joint was achieved in the form of ductile flexure cracking in the beam. Due to which a reasonable increase in structure stiffness, strength, ductility and response modification factor was observed. It was observed that the attachment of fully fastened haunches to beam and column, which is through drilling of holes, can further weaken it and in case of earlier detachment of anchor through concrete pry-out can further weaken the beam or column (especially) and can lead to its shear failure. Also as pinching behaviour in the hysteretic response of the structure was observed due to opening and closing of already existing cracks, epoxy injecting is recommend. Additionally to avoid anchors failure and weakening of beam and column due to drilling done for anchors attachment, attachment of haunches through external anchors is recommended.

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