Retrofitting of Damaged Gravity Designed Reinforced Concrete Exterior Connection using Energy Dissipating Haunch

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Abstract

This research aims to compare the seismic response parameters of gravity designed model tested by Rizwan et. al (2018) by introducing novel haunch retrofit technique in already damaged exterior reinforced concrete connection. The model tested by Rizwan et. al was 1/3rd scale bay 2 story RC frame with deficient connection design. Scaled testing was performed on a quasi-static assembly installed at Earthquake Engineering Centre (EEC), UET Peshawar.

Dissipating haunches were installed by first removing damaged concrete from the joints. Afterwards, damaged portion was replaced with rich concrete and haunches were anchored in them to reduce demand on beam-column joints.

The Quasi static cyclic load was applied to damaged beam-column assembly by deforming the structure from elastic to inelastic state under displacement control condition. The ACI ITG-5.1-07 protocols were used as loading history, in which different target roof displacements equivalent to target drifts were applied. The structure force deformation capacity curve was derived, for the computation of Response Modification Factor (R) and global structure ductility (μ). The comparison of the retrofitted and as-built model shows that the retrofitted model not just regained its capacity but increased its stiffness, ductility, strength and response modification factor by 70%, 20%, 40% and 70% respectively.

Keywords: beam-column joint, haunch retrofit technique, response modification factor, quasi-static.

1. INTRODUCTION:

Severe deficiencies have been found in moment resisting frames (MRF) built before 1970s owing to inadequate shear resistance of their beam-column connections. In many developing countries, the RC structures are still constructed without considering the design guidelines for beam-column joints provided by their respective building codes. This is primarily due to the unfamiliarity, lack of skill workmanship and cost insinuation as shown in **Figure 1-1** and **1-2**. The gravity load designed structures are not designed for lateral actions due to earthquakes and also there is no such load transfer mechanism available in these structures to resist the lateral actions.

Figure Error! No text of specified style in document.**-1:** Manual batching and mixing

Figure Error! No text of specified style in document.**-2:** Bent Reinforcement and Non-Seismic Hooks

2. EXPERIMENTAL PROCEDURES:

2.1 Test Specimen

Rizwan et. al (2018) tested five scaled RC portal frames amongst which only one was code compliant RC portal frame, designed according to the BCP-SP 2007. The other four frames were incorporated with some deficiencies in reinforcement detailing and material strength. For the purpose of this research, the model designed for gravity loads was considered for retrofitting.

2.2 Retrofitting of Model:

The retrofitting process of damaged RC portal frame consists of four steps i.e. removal of concrete, model repositioning, concrete replacement and haunch installation. Initially the model was supported by applying jacks to both the floors and lateral support was provided to avoid the collapse of model during retrofitting process as shown in Figure 2-1(a). The damaged concrete from the joint region, columns and adjacent beams was removed up-to 2 times the depth of the joining members as shown in Figure 2-1(b) and 2-1(c). Repositioning was performed with the help of belts to remove the out of plane tilt from the model. Joint concrete was replaced with rich concrete (34.5 MPa) in order to increase the joint's shear capacity and to provide better anchorage to the haunch element by joining members Figure 2-1(d) and 2-1(e).

Figure 2-1: (a) Damaged Frame, (b)Damaged concrete removed from joints, (c) Joint after concrete removal

(d) Formwork for concreting, (e) Joint after replacing damaged concrete

2.3 Haunch Design:

Design of energy dissipating haunch used in this research work was based on the design procedure specified in the research work of Genesio (2012). The idea of haunch retrofit technique revolves around relocation of the plastic hinge from the joint region. Application of haunch to the joint region will reduce the flexural moment at the beam-column interface with the goal of reducing the shear stress in the joint region. Considering the structural and architectural requirement, the length of the haunch element is kept in range of 0.1 to 0.2 times the length of the beam (Sharma et al, 2012). In design of haunch element, certain geometric parameters of trial haunch member are considered i.e. projected length (L'), angle of haunch (α) and haunch stiffness (K_d). The strength hierarchy of the mechanisms involved in beam-column joints are given from least severe to most severe on the structure:

Vc, beam-hinge $\leq \Phi_1$Vc, column-hinge $\leq \Phi_2$Vc, joint shear $\leq \Phi_3$Vc, column-shear $\leq \Phi_4$Vc, beam-shear.

Haunch element consists of a dog-bone specimen which is enclosed in a steel cylinder which is then filed with rich mortar to resist buckling during compression of the haunch element subjected to lateral loading. Figure 2-2 shows the designed haunch element diagrams.

Haunches were placed both at top and bottom of the beam in order to get a better performance in resisting the lateral loads Figure 2-3 shows the haunch placement scheme.

The type of anchorage used in this research is through anchorage. It consists of 6 bolts passing through steel plates at both sides of the column and beam Figure 2-4.

Table 1: Haunch element details

Haunch Parameters	**Anchorage details**	**Anchorage details**
Haunch Diagonal (Lh)= 353mm	Anchorage type= Through Anchors	Fc'= 34 MPa
Projected Length of Haunch (L') = 250mm	Number of anchors (n)= 6	Fy= 414 MPa
Haunch angle (α)=45°	Anchors diameter(d_{nom})= 6 mm	
Es= 200GPa		
Cross sectional area of Haunch (Ad)= 30 mm^2		
Haunch Stiffness (Es.Ad/Lh)= 16.9 KN/mm		

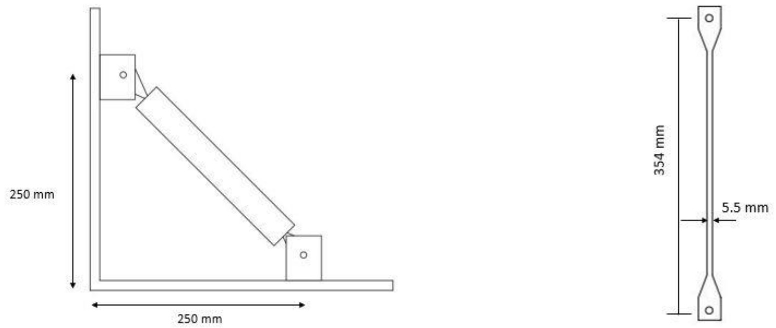


Figure 2-2 Haunch schematic diagrams

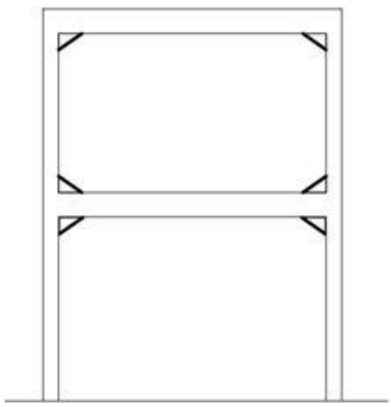


Figure 2-3 Placement scheme

Figure 2-4: Through Anchorage in beam and columns

2.4 Test Setup and Loading Protocols

Quasi static lateral cyclic load was applied to the test model with the help of displacement-controlled hydraulic actuator. The actuator consists of a ram and load cell having capacity of 50 tons and having ± 6in (150 mm) displacement capacity of the shaft. The hydraulic actuator is connected to the vertical distribution beam at 1/3rd span from the top end, to apply lateral loads simulating triangular lateral force distribution. The test setup of the retrofitted specimen is shown in **Figure 2-5**.

The loading history consists of series of three cycles at increasing level of target roof drift (0.4%, 0.5%, 0.7%, 1%, 1.5%, 2%, 2.5%) prepared as per ACI ITG-5.1-07 protocols (Figure 2-6). To record the in-plane lateral displacement, two displacement transducers were attached to each floor, while one displacement transducer was attached to the base pad of the structure in order to record any sliding in the structure. The applied load was recorded by the load cell attached to the hydraulic actuator.

Figure 2-5: Test Setup

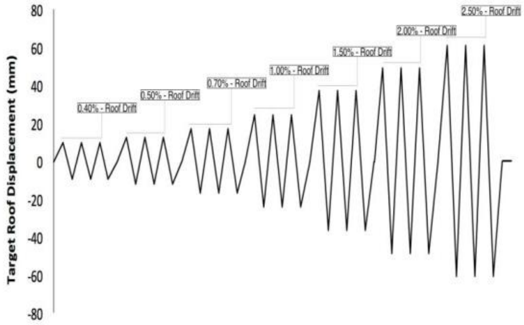


Figure 2-6: Loading History

3. RESULTS:

3.1 Damage Behaviour:

Damaged behaviour was observed in relation to story drift. At 0.4 % drift, pre-existing cracks reopened in columns. Further increase in drift to 1% led to development of shear cracks in joint region. At 1.5% drift, haunch fractured at ground storey while further increase to 2% led to further widening of shear cracks in column base and joint. Widening of flexural and shear cracks continued at 2.5% drift accompanied by severe damage to column base.

3.2 Comparison of As-Built and Retrofitted Structure:

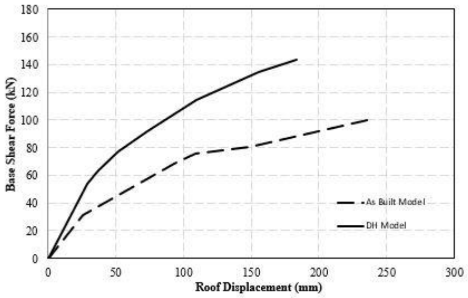
The as-built structure of Rizwan et al (2018) was not designed for any kind of lateral loading so it withstood 50% of intensity of Northridge accelerogram and showed very lower stiffness and severe joint panel damage due to lateral loading conditions. Due to the use of lower strength concrete and the lack of stirrups in the joint region, it has very less tensile strength resulting in a brittle failure mechanism in the form of joint shear cracking which ultimately led to lower overall lateral load capacity of the structure.

Structural Properties	**As Built Model**	**DH Model**	**% Increase**
Stiffness (N/mm)	817.51	1399.87	71.24
Ductility (μ)	1.65	1.99	20.46
Ductility Factor (Rμ)	1.65	1.99	20.46
Overstrength Factor (Rs)	1.73	2.46	42.15
Response Modification Factor (R)	2.86	4.89	71.24
Strength (KN)	90.85	129.18	42.15

In the retrofitted structure with rich concrete and haunch retrofit technique, slight shear cracks were observed in joint region. The observed ultimate mechanism was hinging and the core concrete crushing at the base of the columns under large lateral displacement cycles. The haunch retrofit technique significantly improved the seismic performance of a damaged reinforced concrete gravity designed structure.

3.3 Force-Deformation Capacity Curve

The force-deformation capacity curve was developed from the recorded data of the quasi-static testing of the retrofitted frame. The capacity curve shows that severe pinching effect (Figure 3-2) reduced the energy dissipation in the structure. Both the positive and negative lateral roof displacement and lateral loads were plotted and then



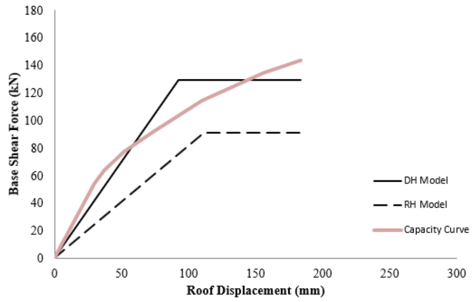


Figure 3-1(a): Roof Displacement, **(b)** Comparison with Rizwan et al

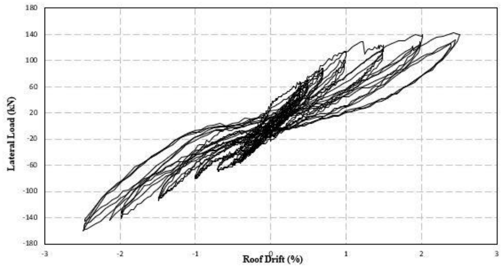


Figure 3-2: Hysteretic Curves

averaged to obtain the mean capacity curve for the prototype structure shown in Figure 3-1(a). The retrofitted structure shows substantial increase in the lateral load carrying capacity as compared to the as-built structure. In order to compute the structural response parameters, bilinear idealization of the capacity curves was performed using equal area principle. Figure 3-1(b) compares the bilinear idealized curves for as-built and retrofitted structure.

4. CONCLUSIONS:

The following conclusions are derived from this research work:

- The retrofitting technique substantially improved the strength and stiffness of the retrofitted structure by approximately 42% and 71% respectively as compared to the as-built structure.
- The retrofitting technique increased the overall response modification factor (R) of the structure by 70%.
- The proper anchorage design made the retrofit technique more effective. Through anchorage was provided in this research. The drilling through the members is risky, if not done properly can weaken the members internally by introducing pre-test damages and is ultimately the failure of the retrofit technique.

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