

Quasi-static testing on RC Frame retrofitted with Haunches

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Abstract — Two reinforced concrete models of 1:3 reduced scale were tested using quasi-static loading conditions. One model was control model and the other one was haunch retrofitted model. Both the models were built with lower concrete strength. The joints were missing the ties. Haunch retrofitting of the deficient model was done to shift the damage from joint to beam and was connected through external bolts/anchors. The haunch retrofitting technique substantially increased the strength of the model with some cracking/damage shift towards the beam.

Keywords-Haunch retrofit technique; beam-column joints; under-designed frames; cyclic loading; seismic performance.

I. INTRODUCTION

Worldwide earthquakes can be considered as the main reason of damage to buildings and other structures, as observed in the past earthquakes. The damage is more prominent to structure either designed according to old codes with no proper seismic provisions or having some deficiencies during construction due to bad workmanship, unsuitable material etc. Occurrence of earthquakes is a natural phenomenon and cannot be stopped but measures regarding the proper design and construction of structures can be made better in case of new structures and strengthening/retrofitting can be adopted for already built up structures. Beam-column joint is one of the most critical part of a building as the load of all the floors resting on beams is transferred through beam-column joints from beam to column. Though a critical part, beam-column joints were wrongly assumed to work elastically during an earthquake event, as the joints designed as per old codes with improper seismic provision, or with construction deficiencies experienced brittle failure in the past earthquake events making it a very vulnerable part of such building structures [1]. Some of the well-known earthquake damages are shown in the figure 1 and 2.



Figure 1. 1999 Chi-Chi Earthquake (Taiwan)



Figure 2. Wenchuan earthquake 2008

During ground shaking shear stresses are induced in the joint region due to the moment and shear forces of opposite signs at the beam and column interface with the joint. Due to the combine effect of shear forces in the joint and axial compression forces of the column, principal compression and tension stresses are generated in the joint core that, when exceeds its capacity results into joint shear failure [2]. In the past joints were assumed to behave elastic during the seismic activity its thought was limited to be just able to achieve anchorage requirements of the beam longitudinal reinforcement ending in the joint. But when joints were studied due to its brittle behavior during the past earthquakes, it was observed that its behavior depends on some other factors like strength of concrete, reinforcement steel detailing and strength, geometry and loading pattern. It was also suggested to avoid damage in joints as gravity load is carried by joints, it has lesser ductility and difficult to repair [3]. For buildings designed as per old codes with no/improper seismic provision and/or construction deficiencies, to work properly during an earthquake activity needs to be retrofitted. Retrofitting can be global or local at member level or a combination of both depending on the scenario. If a certain member or component of structure is deficient/weaker than other usually in such cases retrofitting at local level i.e. of that particular component of the structure is more suitable. Many member level retrofitting techniques have been studied in the recent past with reasonable level of effectiveness, where each has its own use, limitations, merits and demerits.

Considering the above [1], proposed haunch retrofit for deficient reinforced concrete beam-column joints to prevent joint shear failure and shifting to beam, to make this technique economical, fast and easy to implement, its attachment to the structure was modified to post-installed anchors by [4], but as the possibility of anchors failure is attached with the fully fastened haunch retrofit solution, attachment of the haunch diagonal element using through bolts/ anchors will be studied in this work.

II. EXPERIMENTAL PROCEDURE

2.1 Introduction

In order to study the usefulness of steel haunches in improving the capacity of weaker beam-column joint regions with no joints stirrups and low concrete strength representative of joints in common deficient structures. Two RC models having such joint assemblies were fabricated with one used as control model and the other one with haunches installed. The member dimensions, material and details of reinforcement are shown in table 1 below. Both the models were 1:3 reduced scale simple model idealized and tested under cyclic loading conditions.

Table 1: Dimensions of Members and reinforcement details.

S. No	Description	Member Dimensions (inch)	f_c' (Psi)	f_y (Psi)	Long. Reinf.	Tran. Reinf.	Joint Ties
1	Control Model	Beam: 4 x 6	2400	60000	Beam: 6#2 bars Column: 8#2 bars	Beam: #1 @ 1inch Column: #1 @ 1inch	No Ties
2	Haunch Retrofitted Model	Column: 4 x 4	2400	60000	Beam: 6#2 bars Column: 8#2 bars	Beam: #1 @ 1in Column: #1 @ 1in	No Ties

2.2 Fabrication of models

For simplicity and due to the fact that scaling stress-strain properties of both concrete and steel re-bar materials for model fabrication are quite demanding and expensive, a simple model idealization was considered in which the materials' stress-strain properties essentially remained the same for both the full scale and their reduced scale models [5]. Following the simple model idealization all the linear dimensions of beams and columns and diameter of the steel re-bars were reduced by a scale factor of 3. The procedure for mix design of concrete [6], was followed for the preparation of concrete for the control and haunch retrofitted models. The construction of models was done stepwise in series under the supervision of civil engineer. Stepwise method for model fabrication is shown in figure 3 below.

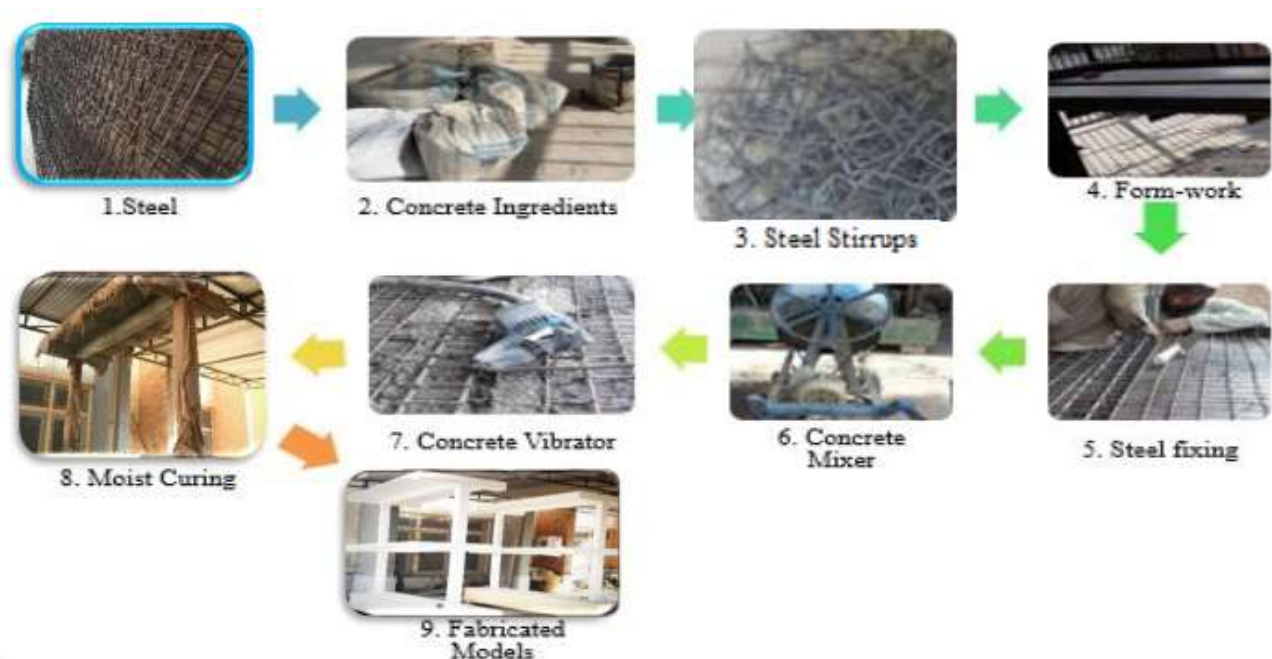


Figure 3. Fabrication of models

2.3 Haunch Design and Application

Haunch design including the haunch diagonal element and anchors was performed according to the procedure explained in detail by [4] for the design of a fully fastened haunch retrofit solution for non-seismically designed Beam-Column joints. Though they in their retrofit solution attached the haunches to the beam and column through drilling of holes and then anchoring, but also highlighted the highly undesirable effect of anchorage failure which is likely in such a connection. Keeping in view this possibility and its adverse effect the connection of haunch diagonal element with the members was made by using bolts passing along the sides of beam and column in this research study. The angle of the haunch element with the beam and its stiffness that in-turn is dependent on its material properties, dimensions and stiffness of the connection are the factors that how effective it will be in transferring the stresses from the weaker joint to the intended region in the beam.

Table 2: Haunches dimensions and connection details.

S.No.	Haunch Parameters	Anchorage details
1	Inclined Length, L=345mm	Type=Through bolts
2	Projected Length=240mm	Diameter=12mm
3	Angle=45°	fy=60,000 psi
4	Cross sectional area=1000mm ²	
5	Stiffness=600KN/mm	

2.4 Test methodology, setup and Loading Protocol

The two RC models were tested under the cyclic loading using a loading frame with 30-tons of load capacity and 6 inches (150mm) of total displacement capacity (Figure 4). Loading applied is shown in figure 5. To record the horizontal displacement of the structure displacement gauges were attached. A load cell was attached to the loading frame for recording the load applied. Loading was applied till the failure of the models.

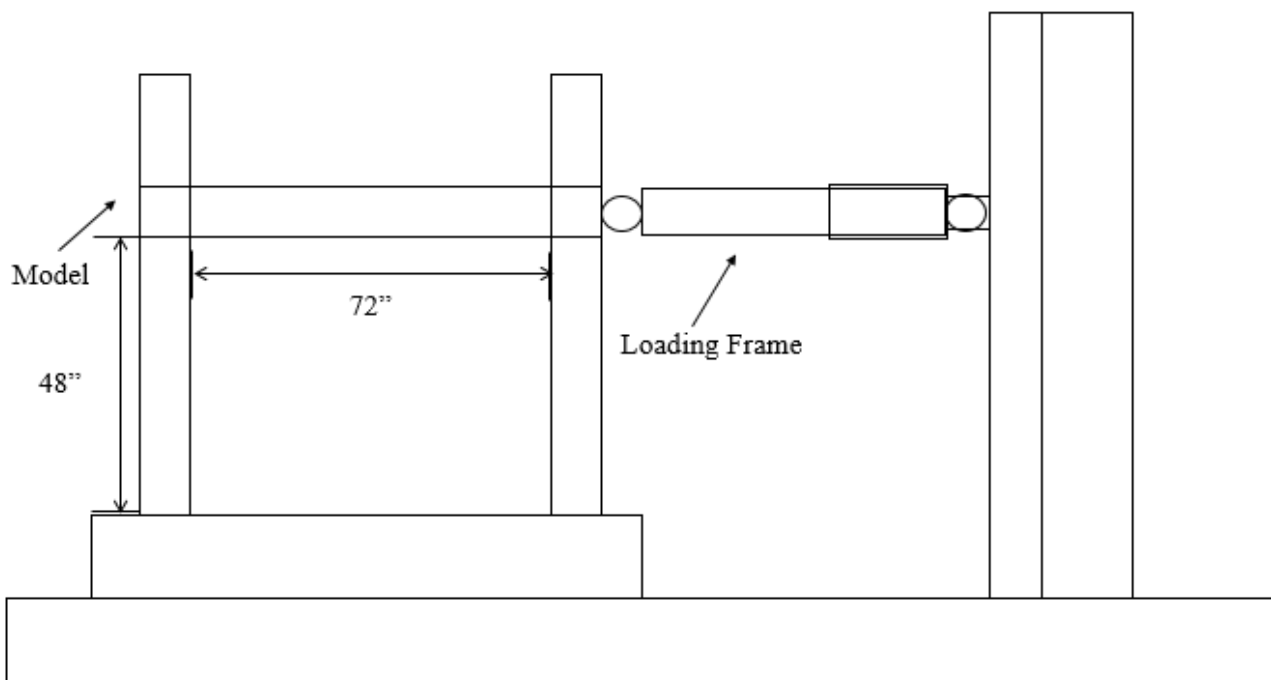


Figure 4. Test Setup

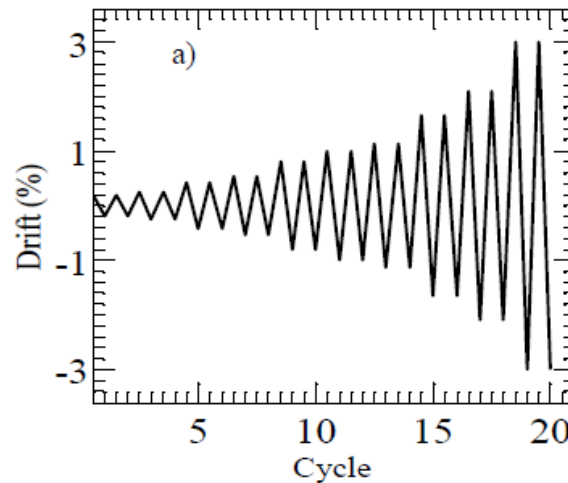


Figure 5. Loading Protocol

III. RESULTS ANALYSIS AND DISCUSSION

3.1 Damage behavior

3.1.1 Control Model

By applying load initially only small thin line cracks were observed in the beam. By increasing the load beginning of cracking in the joint panel were observed. By further increasing the load starting of flexure cracks at column top during joint opening in the inner side of column. By further increasing the load starting of flexural crack in beam were seen. Beginning of more cracks in the joint panel under the closing of connection were observed as the load was increased further. During the pull cover spalling at the base region of column were observed. By further increasing the load existing cracks further increased and widened.



Figure 6. Cracks in the beam-column joint area

3.1.2 Haunch Retrofitted Model

By applying load initially only small thin line cracks were seen. By increasing load small flexure cracks were observed in beam. By further increasing the load flexure cracks were seen in the column member. By further more increasing the load existing cracks further increased resulted in critical cracking.



Figure 7. Observance of flexural cracks in the beam

3.2 Results comparison

The data gained from the experimental tests is analyzed and by using the equations the data is converted to the full scale of the test models as in full scale RC structure and the force-displacement graphs of both the Control and Haunch retrofitted model are plotted and the results are then compared with each other.

In the case of Control model yielding in the Force-displacement graph, starts at 43mm of applied displacement with applied load of 110 KN. Followed by the strain hardening region up-to a maximum load capacity of 157 KN at an applied displacement of 109mm. After joint shear failure the strength degradation starts up-to the ultimate displacement of 120mm and load of 135 KN.

In case of the Haunch retrofitted model at the start of the test a small increase in stiffness and strength was observed as compared to the control model, otherwise a similar load-displacement behavior was observed up-to applied displacement of 9mm. This small difference can be attributed to less effectiveness of the haunch at smaller applied displacement due to the loose connection of the haunches to the joint assembly.

As the applied displacement increases haunches become effective as the loose connection tightens, this can be observed in the clear increase in the strength and stiffness in the later stage of the load-displacement graph. In this case yielding in the Force-displacement graph, starts at 31mm of applied displacement with applied load of 180 KN. The maximum load capacity of 220 KN at an applied displacement of 53mm. After this the strength degradation starts up-to the ultimate displacement of 132mm and load of 160 KN.

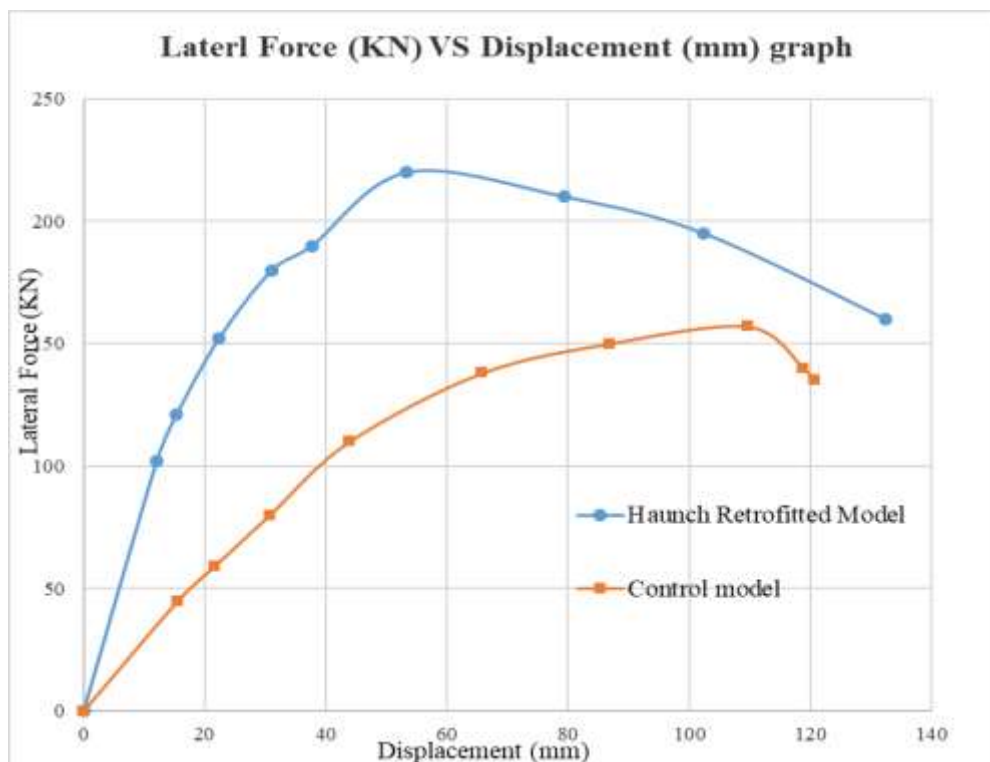


Figure 8. Lateral Force-Displacement graphs of full scale representative of test models

IV. CONCLUSIONS

The study was carried out to observe the usefulness of the haunch retrofitting technique in seismic upgradation of deficient RC structures. The conclusions drawn from this study are listed below:

- The haunch retrofitting technique increased the yield strength and stiffness by 64% and 126% respectively.
- The maximum strength was increased by 40%.
- The ultimate strength was increased by 19%.

REFERENCES

1. Pampanin, S., C. Christopoulos, and T.H. Chen, *Development and validation of a metallic haunch seismic retrofit solution for existing under- designed RC frame buildings*. Earthquake engineering & structural dynamics, 2006. 35(14): p. 1739-1766.
2. Sharma, A., R. Eligehausen, and J. Hofmann, *SEISMIC ASSESSMENT OF RC FRAME STRUCTURES WITH JOINTS RETROFITTED USING FULLY FASTENED HAUNCH RETROFIT SOLUTION*. 2014.
3. Panjwani, P. and S. Dubey, *Study of Reinforced Concrete Beam-Column Joint*. International Journal of Engineering Research, 2015. 4(6): p. 321-324.

4. Genesio, G., *Seismic assessment of RC exterior beam-column joints and retrofit with haunches using post-installed anchors*. 2012.
5. Ahmad, N., et al., *Seismic performance assessment of non-compliant SMRF-reinforced concrete frame: shake-table test study*. Journal of Earthquake Engineering, 2019. **23**(3): p. 444-462.
6. Dixon, D.E., et al., *Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete (ACI 211.1-91)*. 1991.