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Haunch Retrofitting of Exterior Beam-Column Connection

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Abstract: Three beam-column joints sub-assemblies of 1/3rd reduced scale was tested under monotonic loading conditions. The beam-column connections were comprised of one control model having low concrete strength and having no joint ties, another similar model with diagonal hooks in the joint, and a retrofitted model using energy dissipating haunch. Haunch retrofitting of the deficient model was done to shift the damage from joint to beam and was connected through external anchors to avoid anchors failure. The haunch retrofitting substantially increased the strength of the model with some cracking/damage shift towards the beam but damage in the joint could not be prevented due to delayed action of the haunch that was due to lose attachment of the anchors.
Keywords: Haunch retrofit technique, monotonic loading, beam-column joints.

I. INTRODUCTION

Earthquakes causes huge damage every year to a large stock of buildings 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.

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. 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.

The damage is more prominent to structure either designed according to old codes with no proper seismic provisions or with some deficiencies due to bad workmanship etc. The first part related to nature i.e. occurrence of earthquakes cannot be stopped but measures regarding the proper design and construction of structures can be improved in case of new structures and retrofitting/strengthening can be adopted for already constructed structures.

Beam-column joint is one of the most critical part of a building as the total load of 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 extremely vulnerable part of such building structures (Pampanin et al. 2006). During an earthquake event, shear stresses are induced in the joint region due to the bending moment and shear forces 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/cracking (Akanshu Sharma2010). For buildings designed as per old codes with no/improper seismic provision and/or construction deficiencies, to work properly during an earthquake event needs to be retrofitted. Retrofitting can be global or local at member level or a combination of both depending on the situation. If a certain member or a 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. But due to limited access to joint region most of the common member level retrofitting techniques cannot be properly used in case of joints, which arises the need of studding newer technique specialized for joint retrofitting to be studied ***(Akanshu Sharma2010)***. Considering the above Pampanin et al. (2006) proposed haunch retrofit for deficient reinforced concrete beam-column joints to prevent joint shear failure and shifting to beam, to make this technique less invasive, fast and easy to implement, it attachment to the structure was modified to post-installed anchors by Genesio, G. (2012). 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 will be studied in this work.

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II. EXPERIMENTAL PROCEDURES

A. Introduction

To study the effectiveness of energy dissipating haunches in enhancing the capacity of beam-column joint assembly with weaker joints having no shear reinforcement in joints and lower concrete strength which is the representative of joints in common deficient structures. Three such joint assemblies were fabricated with one used as an as-built model, another one with haunches installed and the third one with 135/diagonal hooks of the beam longitudinal reinforcement in the joint as opposed to the 90 hooks in case of the first two models to check the effect of hooks on Beam-Column assembly performance. The dimensions and details of reinforcement are shown in Table (1) below. All the three models were 1/3rd reduced scale simple model idealized and tested under monotonic loading.

Table (1); dimensions and details of reinforcement are shown below.

S. No	Member Dimensions (in)	f_c' (Psi)	f_y (Psi)	Long. Reinf.	Tran. Reinf.	Joint Ties	Hook
Model 1	Beam: 4 x 6 Column: 4 x 4	3000	60000	Beam: 4#2 Column: 6#2	Beam: #1 @ 3in Column: #1 @ 3in	No Ties	90°
Model 2		3000	60000	Beam: 4#2 Column: 6#2	Beam: #1 @ 3in Column: #1 @ 3in	No Ties	135°
Model 3		3000	60000	Beam: 4#2 Column: 6#2	Beam: #1 @ 3in Column: #1 @ 3in	No Ties	90°

B. Haunch Design and Application

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:

$V_{c, \text{beam-hinge}} \leq \Phi_1 V_{c, \text{column-hinge}} \leq \Phi_2 V_{c, \text{joint shear}} \leq \Phi_3 V_{c, \text{column-shear}} \leq \Phi_4 V_{c, \text{beam-shear}}$.

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.

C. Test Methodology, Setup And Loading Protocol

The three beam-column joints assemblies were tested by applying monotonic loading through a loading frame with 20 tons of loading capacity and 6 inches (150mm) of displacement capacity. The loading jack was attached to the beam at a location of 2 feet from the face of the column which is equal to the half of the column and beam height i.e. point of contra flexure. Similarly, the column above and below beam were attached at its ends with connection replicating the condition of hinge at the top column and a roller support at the end of the column below the beam. Load applied by the loading frame was recorded through a load cell while a displacement gauge attached to the beam at the point of application of load was used to record the displacement. Loading was increased incrementally until the model fails.

III. RESULTS

A. Damage Behaviour

1) *Control model:* By applying the load at the beam, a small hairline crack appears at the top side of the beam at beam-column interface due to the concrete reinforcement bond failure resulting into slippage of the beam top longitudinal reinforcement due to the lower concrete strength. By increasing the load further, a hairline diagonal crack appears at the joint as the principal tensile stresses surpasses the principle tensile strength of the joint core concrete due to the combine effect of concrete with lower compressive strength and no ties in the joint. By increasing the load further widening in the existing cracks is observed that is followed by the creation of a few smaller new cracks along the sides of the single major diagonal joint shear crack. This increase in the width of the diagonal crakes shows the development of strut mechanism in the joint due to exceedance of principle joint compressive stresses then the principle joint strength ultimately leading to spalling and showing clear joint shear failure.

Figure; (1) Initiation of joint shear cracking.

Figure; (2) Joint shear failure.

2) *Haunch Retrofitted Model:* Similar to the control model hairline cracking appears at the top side of the beam at beam-column interface due to the slippage of the beam top longitudinal reinforcement with a slight increase in stiffness and strength in the initial phase as compared to the control model. It was followed by joint shear cracking and the widening of the existing cracks. But after reaching the maximum in term of strength that is usually and, in the control, model followed by a drop in the strength, a rise in the strength is observed in the retrofitted model that gets stepper with further increase in the deformation as shown in the load deformation behaviour. This unique behaviour of the retrofitted model can be explained as, due to improper/loose attachment of the haunches to the model it influences the joint assembly by increasing the initial stiffness and strength by just a small margin, but as when the deformation increases and subsequently the haunch become more effective as its connection tightens due to the deformation in the model removing the free space the haunch takes the load and so transferring the stresses away from the joint towards the beam which the haunch was designed for. As the haunch diverts any further increase in stress in the joint with the increase in deformation towards the beam as intended a hairline flexure crake appear in the beam at the end of the haunch base plate that increase with further increase in the load and deformation up-to the maximum applied displacement.

Figure: (3) cracking in joint.

Figure: (4) cracking in beam.

3) *Diagonal/135 Hooks Model:* In the case of hooks bent diagonally making angle of 135^ that position it transverse to the potential principal tensile crakes to help increase the joint principle tensile strength. After the application of load beam-column interface cracking was observed that widened reasonably before any diagonal joint shear crack was observed. The diagonal joint shear cracking started with multiple cracks showing compression strut failure due to principal compression stresses as opposed to the other models where cracking started with a single crack and converted to multiple cracks. This type of damage behaviour shows that the diagonal hooks increased the principal tensile strength of the joint thus delaying the occurrence of diagonal shear cracking and an overall increased strength of the joint assembly.

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Figure: (5) Initiation of joint shear cracking.

Figure: (6) Joint shear failure.

B. Load-Displacement Relationship

In the case of control model yielding in the Load-displacement graph, starts at 3mm of applied displacement with applied load of 0.33 tons corresponding to the beam-column interface cracking in the joint assembly. Followed by the strain hardening region up-to a maximum load capacity of 0.43 tons corresponding to joint peak shear strength, where the joint fails under principal compressive stresses. After joint shear failure the strength degradation starts up-to the ultimate displacement of 35mm and load of 0.26 tons.

With the diagonal hooks in the joints a small increase in initial stiffness was observed. A little drop in the stiffness in the stiffness was observed due to the initial cracking at the beam-column interface but this drop was not substantial as in control model, as in this model interface cracking was not directly followed by initial joint shear cracking that in control model load-displacement graph could be seen in the form of clear yielding mechanism/drop usually followed by strain hardening. The joint assembly reaches to its maximum strength of 0.55 tons at 17mm of applied at the joint peak shear strength representing 22% of maximum strength increase, where the joint shear failure occurs in the form of joint core crushing due to principal compressive stresses. A 21% of strength drop was observed at the application of 25 mm of displacement

In case of the joint retrofitted with haunches a small increase in the initial stiffness and strength is observed as compared to the control model, otherwise a similar load-displacement behaviour was observed up-to applied displacement of 8mm. This small difference/behaviour 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. More than 180% of strength increase was observed up-to the application of 45mm of displacement.

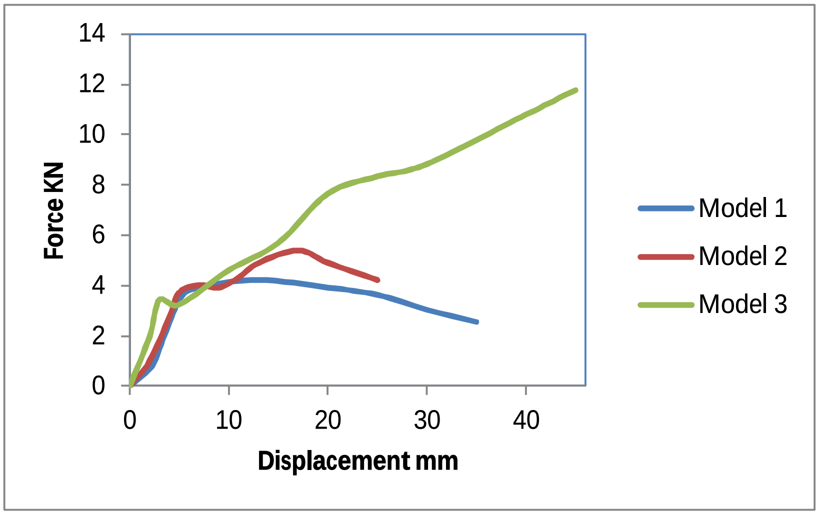

Figure (7); Load displacement behaviour.

IV. CONCLUSION

The haunch retrofitting marginally increased the initial stiffness and the strength by more than 180% but due to the delayed action of action as the haunch was improper/loosely attached the objective of eliminating brittle joint shear cracking could not be achieved with intended beam flexure cracking occurring at the later stage of loading. The diagonal hooks also increased the initial stiffness marginally and the maximum strength by 22% but the damage behaviour was more brittle with faster strength degradation after reaching maximum strength in this case as compared to the control model. The significant increase in the strength and the occurrence of beam flexure cracking at the later stage of the loading shows the effectiveness of the proposed retrofitting technique in increasing the seismic capacity of deficient/weaker beam-column joints. But as joint damage could not be prevented due to improper haunch attachment it is recommended to further investigate the haunch connection part that can be improved with more precise haunch fabrication specially its connecting base plates so that it can be attached fully and smoothly that can be done by taking inti consideration the actual as-per site dimension and angle the model member make rather than design drawings. Also, the extent up-to which the connection bolts should be prestressed.

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