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Haunch Retrofitting of Deficient Beam-Column Joint

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Abstract: Three beam-column joints sub-assemblies of 1/3rd reduced scale were tested under monotonic loading conditions. These comprised of a control model with lower strength concrete and no joint ties, another similar model with diagonal hooks in the joint, and a haunch retrofitted model. 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 loose attachment of the anchors.

Keywords: Haunch retrofit technique, monotonic loading, beam-column joints.

I. INTRODUCTION

All around the world earthquakes can be considered as the most prominent reason of damage to buildings and other structures, as observed in the past earthquake events. 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. In addition to other members of a building 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 colds 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 (Pampanin et al. 2006).

During an earthquake 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/cracking (Sharma, A. 2014). As mentioned earlier that joint were assumed to behave elastically during an earthquake event its consideration was limited to be just able to fulfil 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 behaviour depend on factors like geometry, concrete strength, reinforcement detailing 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 (Panjwani, P. 2015).

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(Sharma, A. 2014). 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.

II. EXPERIMENTAL PROCEDURE

A. Introduction

To study the effectiveness of steel haunches in enhancing the capacity of beam-column joint assembly with weaker joints with no joints stirrups and lower concrete strength 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 B-C assembly performance. The dimensions and details of reinforcement are shown in table (01) below. All the three models were 1/3rd reduced scale simple model idealized and tested under monotonic loading.

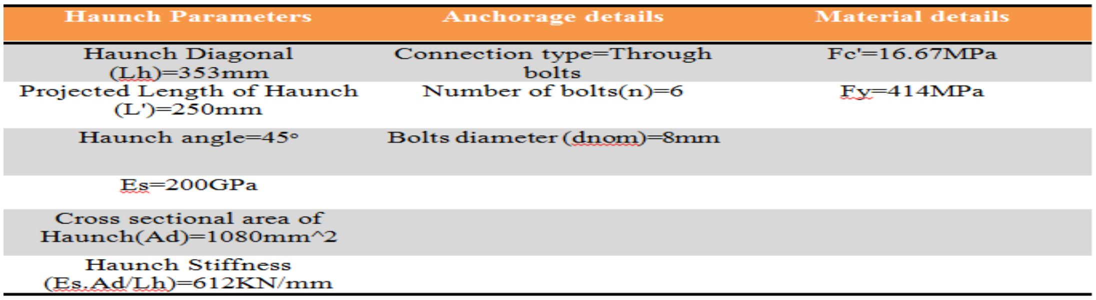
Table 01: Dimensions and reinforcement details.

S. No	Member Dimensions (in)	f_c' (Psi)	f_y (Psi)	Long. Reinf.	Tran. Reinf.	Joint Ties	Hook
Control Model	Beam: 4 x 6 Column: 4 x 4	2400	60000	Beam: 6#2 Column: 8#2	Beam: #1 @ 1in Column: #1 @ 1in	No Ties	90°
Diagonal Model		2400	60000	Beam: 6#2 Column: 8#2	Beam: #1 @ 1in Column: #1 @ 1in	No Ties	135°
Retrofitted Model		2400	60000	Beam: 6#2 Column: 8#2	Beam: #1 @ 1in Column: #1 @ 1in	No Ties	90°

B. Haunch Design and Application

Complete haunch design including the haunch diagonal element and anchors was performed according to the procedure explained in detail by Genesio, G. (2012) for the design of a fully fastened haunch retrofit solution (FFHRS) for non-seismically designed B-C joints. Though Genesio, G. (2012) in his retrofit solution attached the haunches to the beam and column through drilling of holes and then anchoring, but also highlighted the highly negative effect of anchorage failure which is likely in such a connection. Considering this possibility and its negative effect the connection of haunch diagonal element with the members was made by using through bolts passing along the sides of beam and column in this 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 location in the beam. The haunches were attached to the beam by using through bolts passing along the beam and tightened using bolts with the base plat of the haunch on the other side of the beam, and connected to the column in a similar way to a simple plate on the back side of the column.

Table 02: Haunch dimensions and connection details.



Haunch Parameters	Anchorage details	Material details
Haunch Diagonal (Lh)=353mm	Connection type=Through bolts	Fc'=16.67MPa
Projected Length of Haunch (L')=250mm	Number of bolts(n)=6	Fy=414MPa
Haunch angle=45°	Bolts diameter (dnom)=8mm	
Es=200GPa		
Cross sectional area of Haunch(Ad)=1080mm^2		
Haunch Stiffness (Es.Ad/Lh)=612KN/mm		

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 applied till the failure of the models.

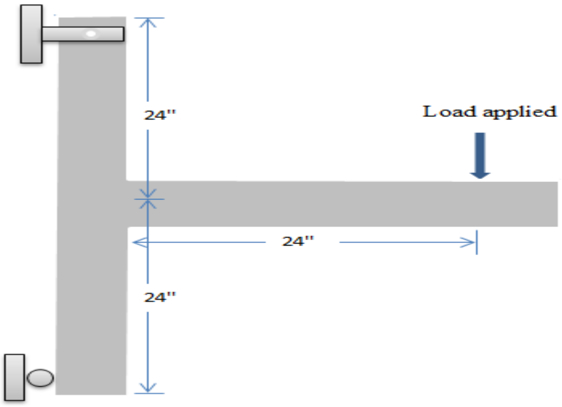


Figure 1: Test setup.

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 2: Interface and joint shear cracking.

Figure 3: 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 4: Beam flexure cracking.

Figure 5: Joint shear cracking.

3) *Diagonal/135° Hooks Model:* In the case of hooks bent diagonally making angle of 135°, that places 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.

Figure 6: Initiation of cracking.

Figure 7: 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 3.8 KN corresponding to the beam-column interface cracking in the joint assembly. Followed by the strain hardening region up-to a maximum load capacity of 5.4 KN 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 4.2 KN.

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 7.5 KN at 10 mm of applied at the joint peak shear strength representing 38% of maximum strength increase, where the joint shear failure occurs in the form of joint core crushing due to principal compressive stresses. A 20% of strength drop was observed at the application of 28 mm of displacement

In case of the joint retrofitted with haunches a small increase in the initial stiffness and strength is observed as campaired to the control model, otherwise a similar load-displacement behavior 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 200% of strength increase was observed up-to the application of 40mm of displacement.

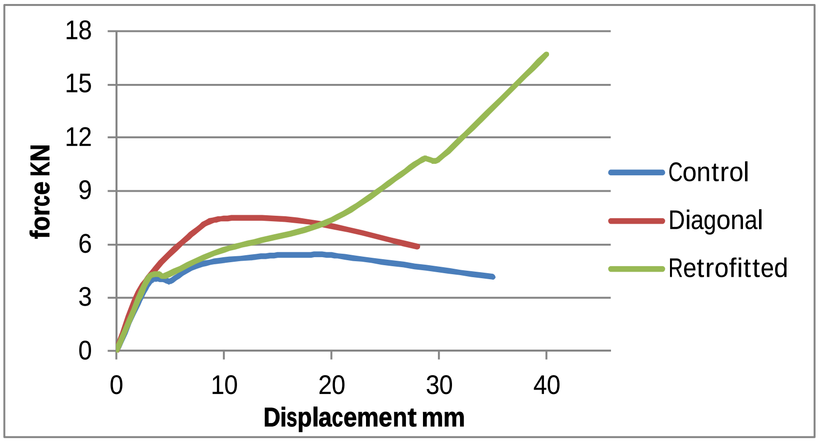


Figure 8: Load-Displacement behaviour.

IV. CONCLUSION

The haunch retrofitting marginally increased the initial stiffness and the strength by more than 200% 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 38% but the damage behaviour was more brittle with faster strength degradation after reaching maximum strength in this case as campaired 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.

V. ACKNOWLEDGMENT

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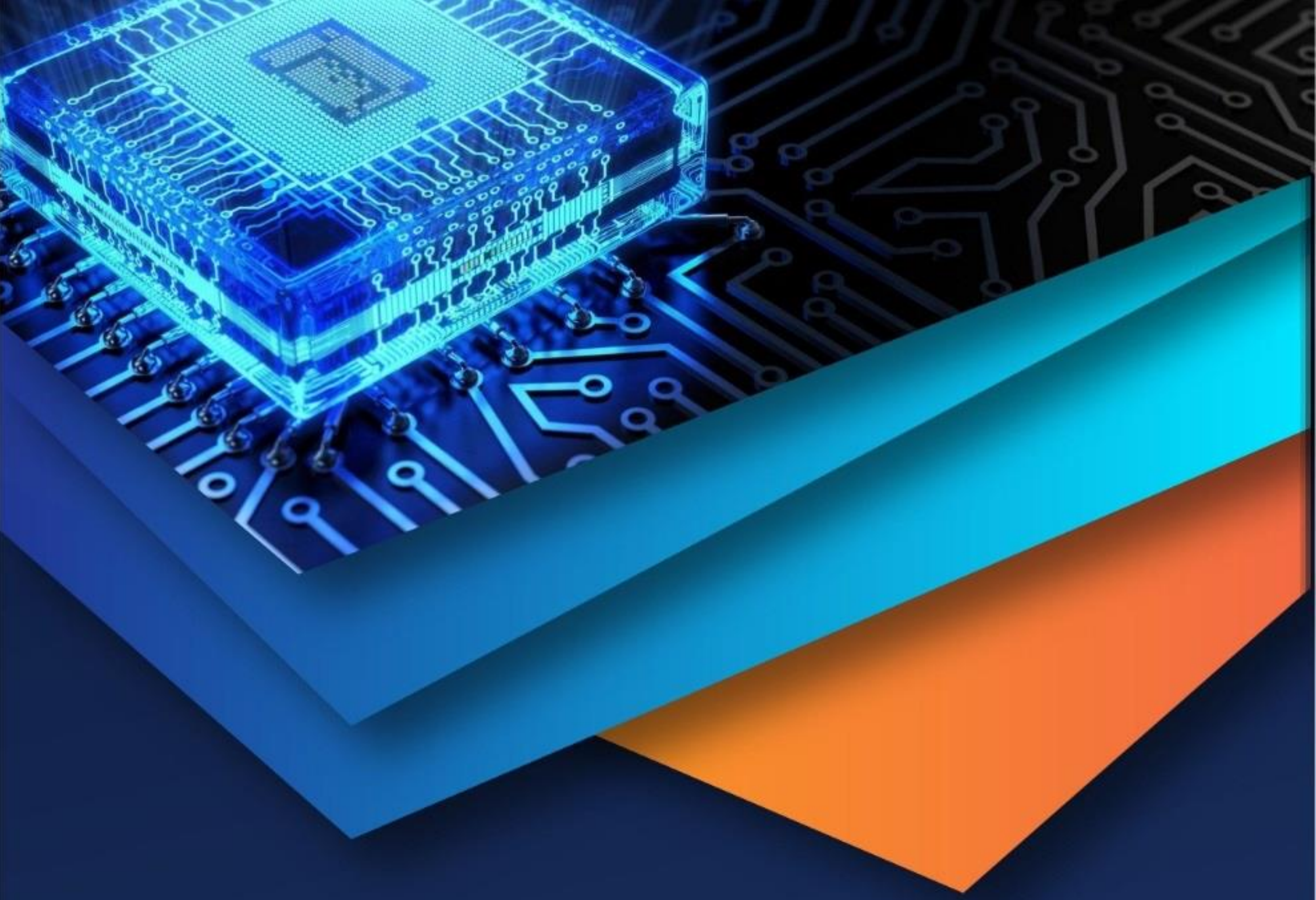

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