

Strength Study and Behavior of RCC Interior Beam to Column Joints

Aditya Dawale¹, Mayur Lanjulkar², Prasad Ghongate³, Shubham Wanare⁴, Rushikesh Khodke⁵, Prof. M. S. Sindhikar⁶

^{1,2,3,4,5} Student, Department of Civil Engineering, Padm. Dr. V. B. Kolte College of Engineering, Malkapur

⁶ Assistant Professor, Department of Civil Engineering, Padm. Dr. V. B. Kolte College of Engineering, Malkapur

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ABSTRACT

Beam column joint is an important component of a reinforced concrete moment resisting frame and should be designed and detailed properly, especially when the frame is subjected to earthquake loading. Failure of beam column joints during earthquake is governed by bond and shear failure mechanism, which are brittle in nature. Therefore, current international code of practices gives high importance to provide adequate anchorage to longitudinal bars and confinement of core concrete in resisting shear. Modern codes provide for reduction of seismic forces through provision of special ductility requirements. Details for achieving ductility in reinforced concrete structures are given in IS 13920-1993. In the present study, a two bay five storey reinforcement cement concrete moment resisting frame for a general building has been analysed and designed in STAAD Pro as per IS 1893-2002 code procedures and detailed as IS 13920-1993 recommendations. An interior beam column joint has been modeled to a scale of 1/5th from the prototype and the model has been subjected to cyclic loading to find its behavior during earthquake. The experimental program consists of two interior beam-column specimens, namely, CS, and HS1. Specimen CS represented a control specimen, detailed as per IS 13920-1993 recommendation. Specimen HS1 is strengthened by haunch effect at beam column junction, detailed as per IS 456-2000 recommendation. The interior beam – column joints are examined in terms of load carrying capacity, Load-deflection behavior, stiffness degradation factor, energy dissipation capacity, Ductility factor and cracking characteristics. Based on the experimental results important conclusions are drawn and the advantage of using haunch effect in the beam-column joint region has been established.

Keywords:- Reinforced Concrete, Beam to Column Joint, shear Resistance, Periodic Loading and Haunch Effect.

1.INTRODUCTION

In RC buildings, portions of columns that are common to beams at their intersections are called beam-column joints. Since their constituent materials have limited strengths, the joints have limited force carrying capacity. When forces larger than these are applied during earthquakes, joints are severely damaged. Repairing damaged joints is difficult, and so damage must be avoided. Thus, beam-column joints must be designed to resist earthquake effects. Under earthquake shaking, the beams adjoining a joint are subjected to moments in the same (clockwise or counterclockwise) direction. Under these moments, the top bars in the beam-column joint are pulled in one direction and the bottom ones in the opposite direction as shown in Fig 1. These forces are balanced by bond stress developed between concrete and steel in the joint region. If the column is not wide enough or if the strength of concrete in the joint is low, there is insufficient grip of concrete on the steel bars. In such circumstances, the bar slips inside the joint region, and beams lose their capacity to carry load. Further, under the action of the above pull-push forces at top and bottom ends, joints undergo geometric distortion; one diagonal length of the joint elongates and the other compresses. If the column cross-sectional size is insufficient, the concrete in the joint develops diagonal cracks. Problems of diagonal cracking and crushing of concrete in the joint region can be controlled by two means, namely providing large column sizes and providing closely spaced closed-loop steel ties around column bars in the joint region. The ties hold together the concrete in the joint and resist shear force, thereby reducing the cracking and crushing of concrete. Providing closed-loop ties in the joint requires some extra effort. Indian Standard IS: 13920-1993 recommends continuing the transverse loops around the column bars through the joint region. In practice, this is achieved by preparing the cage of the reinforcement (both longitudinal bars and stirrups) of all beams at a floor level to be prepared on top of the beam formwork of that level and lowered into the cage. However, this may not always be possible particularly when the beams are

long and the entire reinforcement cage becomes heavy.

The Indian Standard IS:13920-1993 requires building columns in seismic zones III, IV and V to be at least 300 mm wide in each direction of the cross-section when they support beams that are longer than 5m or when these columns are taller than 4m between floors (or beams). The American Concrete Institute recommends a column width of at least 20 times the diameter of largest longitudinal bar used in adjoining beam. Several techniques were employed to strengthen the beam column joints including concrete jackets, bolted steel plates and jacketing with corrugated steel sheets. These strengthening approaches have been found to improve the joint shear strength and ductility. However, a major difficulty in strengthening of beam column joints is ensuring effective confinement in the joint region.

The strengthening of joints is necessary due to

Poor detailing of reinforcement.

Deficient constituents materials and inadequate anchorage length of bars.

Improper confinement of joint region.

Changes in current design detailing.

Variation of loads due to frequency of earthquakes and hence alteration of earthquake zones. The shear failure of beam column joints is the primary cause of collapse of many non-seismically designed framed buildings due to earthquake forces.

1.1 Beam Column Joints

The functional requirement of a joint, which is the zone of intersection of beams and columns, is to enable the adjoining members to develop and sustain their ultimate capacity. The demand on this finite size element is always severe especially under seismic loading. The joints should have adequate strength and stiffness to resist the internal forces induced by the framing members.

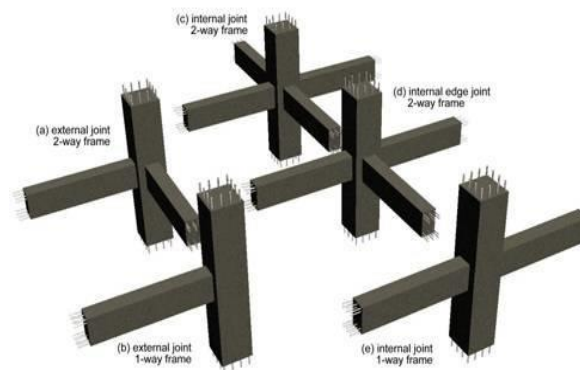


Fig.1 Types of Joints in a Moment Resisting Frame

The joint is defined as the portion of the column within the depth of the deepest beam that frames into the column. In a moment resisting frame, three types of joints can be identified viz. Interior joint, exterior joint and corner joint (Fig.2). When four beams frame into the vertical faces of a column, the joint is called as an interior joint. When one beam frames into a vertical face of the column and two other beams frame from perpendicular directions into the joint, then the joint is called as an exterior joint. When a beam each frames into two adjacent vertical faces of a column, then the joint is called as a corner joint. The severity of forces and demands on the performance of these joints calls for greater understanding of their seismic behavior. These forces develop complex mechanisms involving bond and shear within the joint.

1.2 Principle of haunch effect at Beam Column Joint

The reinforcement details of beam column joint in pre-1970 buildings, the longitudinal reinforcement in beam is discontinuous and in columns, the reinforcement is lap spliced with short length above the floor level. The transverse reinforcement is not proportioned to prevent the shear or lap-spliced in joints, and the details show wide spacing, open stirrups, and hoops with 90-degree bends. No joint transverse reinforcement is observed. These deficiencies reduce the joint strength and lateral displacement ductility. Haunch effect is one of the seismic strengthening techniques for reinforced concrete beam column connection. In this method, the beam column joint is two-dimensionally enlarged by cast in-situ concrete. The in-situ cast joint expansion can be independently installed in transverse and longitudinal direction. The method is economical and architecturally acceptable. No slab perforation is required. In terms of architectural concern, the planer joint expansion can be hidden in infill walls or nonstructural walls with less than 5% coverage area. The main objective of strengthening is to avoid joint shear failure and to encourage beam flexural failure. RC joint expansion with 100x100mm triangular shape was fabricated around bottom corners of specimen. This method is applicable to both new constructions and retrofitting works. Like any strengthening technique, although the joint expansion

method is effective to prevent joint shear failure and to encourage plastic hinge in beam, it has limitation. The method may produce undesirable shear failure in beam and column due to shortened member length. The strength, stiffness, energy dissipation and ductility of strengthened specimens were greatly improved in this method.

1.3 Objectives of the study

- a) To study the behavior of RC beam column joint designed and detailed as per IS 13920 recommendation. To prepared a $1/5^{\text{th}}$ scale model of the beam column joint. To study the behavior of the beam column joint subjected to seismic loading.
- b) To strengthened the beam column joint by haunch effect at bottom portion of joint detailed as per IS 456-2000.
- c) Important conclusion is to be received at the end of the experimental work related to load deflection characteristics, hysteric characteristics, stiffness, energy absorption etc.

2. ANALYSIS AND DESIGN OF BEAM COLUMN JOINT

An interior beam-column joint of a multistory reinforced concrete building in Salem Zone falling under the seismic Zone – III has been analyzed using STADD.pro. The specimens were designed for seismic load according to IS 1893(Part-I): 2002 & IS 13920: 1993. The structure is a five storey, two bay frames including 1.5 m foundation depth. The plan and elevation view of two bay frames as shown in fig.1. Seismic loads corresponding to the zone III has been applied and the analysis is carried out. Fig 4 shows two sequences of load applications. The maximum moment is occurred at the ground floor roof level as shown in fig 5. The beam-column joint has been modeled to a scale of $1/5^{\text{th}}$.

3. EXPERIMENTAL INVESTIGATION:

An experimental investigation has been carried out on the $1/5^{\text{th}}$ model of interior beam-column joint with and without haunch effect under the reverse loading.

3.1 Details of specimen

The experimental program consisted of two interior beam-column specimens, namely, CS and HS1. Specimen CS represented a control specimen, detailed as per IS 13920 recommendation. Specimen HS1 is strengthened by haunch effect at beam column junction detailed as per IS 456 -2000 recommendation. The test specimen was reduced to $1/5^{\text{th}}$ scale to suit the loading arrangement and test facilities. Prototype specimen having beam dimension of 305 X 460 including slab thickness and column dimension of 305 X 460. For experimental model, the dimension of beam was 120 X 170 mm without slab thickness and beam length of 450mm, that column size was 120 X 230 mm. Height of the column was 600mm, and length of beam is 450mm. The dimension of haunch provision is $h_h \times h_v \times b_p$ in triangular. The width b_p is set equal to beam width that is 120mm, h_h is equal to 100mm and h_v is equal to 100mm.

3.2 Description of the formwork

To cast the specimen, two wooden moulds were fabricated and using 12mm thick plywood sheet made to suit the dimension of the model. The size of the beam was 450mm x120 mm x170 mm and the column size was 600 mm x120 mm x230 mm for all specimens (CS & HS1). For haunch specimen (HS1), extra haunch effect is given at bottom of ordinary joint having dimension of 100 x 100 x 120mm (triangular shape), as shown in Fig 2&3.



Fig 2&3: Details of formwork

3.3 Reinforcement steel grill details

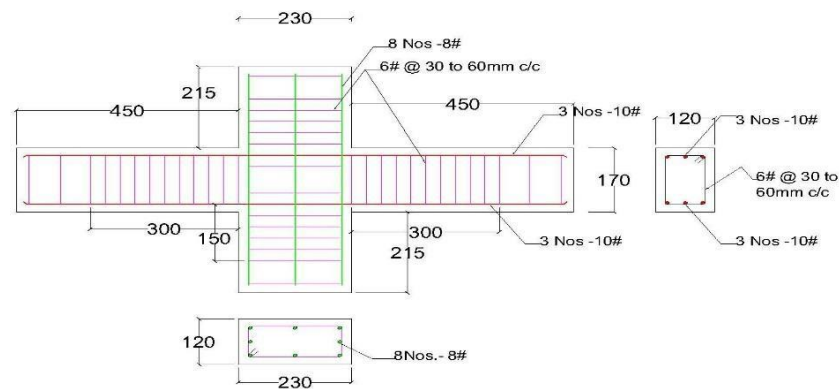


Fig 4: Reinforcement Detail for specimen CS as per IS 13920-1993

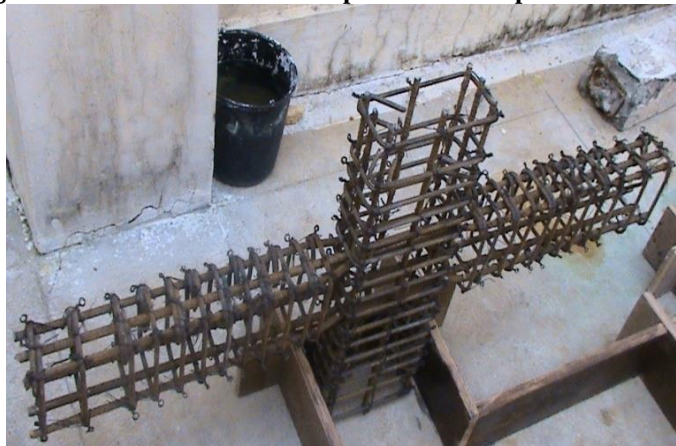


Fig 5: Reinforcement cage for test specimens CS & HS1

3.4 Casting and curing



Fig 6: Casting stage of test specimens CS & HS 1

3.5 INSTRUMENTATION

3.5.1 Test Procedure

All the specimens were tested in a reaction frame of 50 tonnes capacity. Axial Load is applied by means of Hydraulic jack. Load was applied simultaneously in downward direction of right hand side beam top and upward direction of left hand side beam bottom. To record the load precisely a proving ring was used. The load is applied forward cyclic and reverse cyclic and deflection measured from every 3 KN by using dial gauge.

3.5.2 Instrument for measuring deflection

Dial gauge of least count 0.01mm and LVDT of least count 0.001mm was used for measuring deflection at necessary points of the specimen. The positions of deflection meter at measuring deflection at the point above and below the load points are shown in Fig 7&8.



Fig.7&8: Test Setup for specimens CS & HS 1(Forward Loading Position)

4. BEHAVIOUR OF RCC BEAM COLUMN JOINT (CS):

The experimental study of RC beam-column joint under cyclic loading has been represented as control specimen (CS) and detailed as per IS 13920-1993. The parameters like load carrying capacity, ductility factor, energy absorption capacity and stiffness were studied.

4.1 Loading and load deflection behavior:

The interior beam column joint specimen was subjected to quasi-static cyclic loading simulating earthquake loads. The history of load sequence followed for the test was presented in Fig 13. The load was applied using screw jack totally 7 cycles are imposed. The cyclic load versus deflection diagram was presented in Fig 9&10.

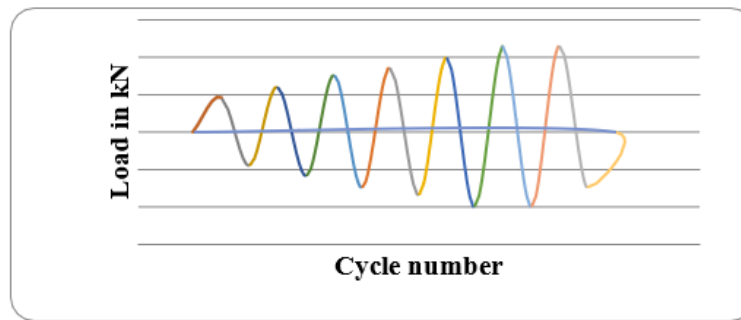


Fig 9: Load sequence diagram

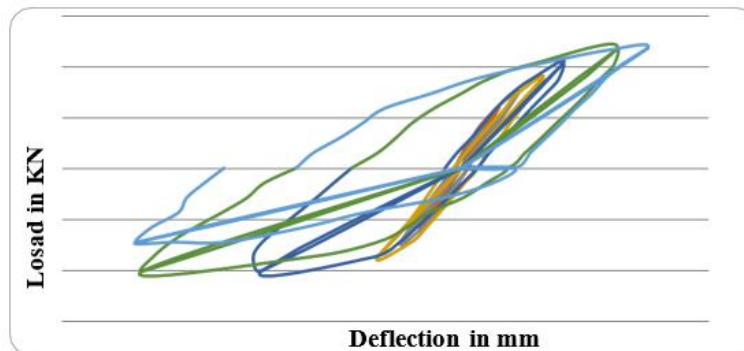


Fig 10: Load-Deflection diagram

The beam-column joint was gradually loaded by increasing the load level during each cycle. The load sequence consists of 3kN, 6kN, 9kN and up to failure load. The deflection measured at center was 1mm during first cycle of loading. As the load level was increased in each cycle, the observed deflection was greater than it was in earlier cycle.

4.2 Relative and cumulative energy absorption

When the beam-column joint is subjected to reverse cyclic loading, such as those experienced during heavy wind or earthquake, some energy is absorbed in each load cycle. It is equal to the work in straining or deforming the structure to the limit of deflection. The relative energy absorbed during the first cycle of loading was calculated as 1.676 kN-mm and during 7th cycle of loading 123.75 kN-mm.

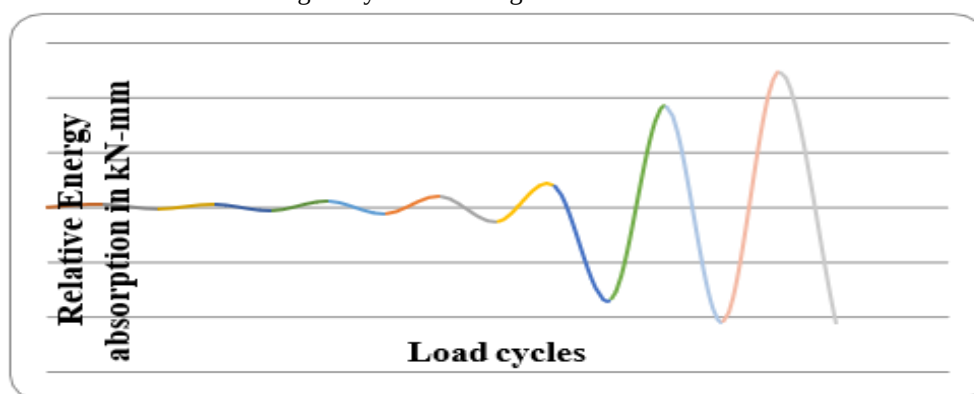


Fig 11: Relative energy absorption for forward and reverse cycle

4.3. Stiffness

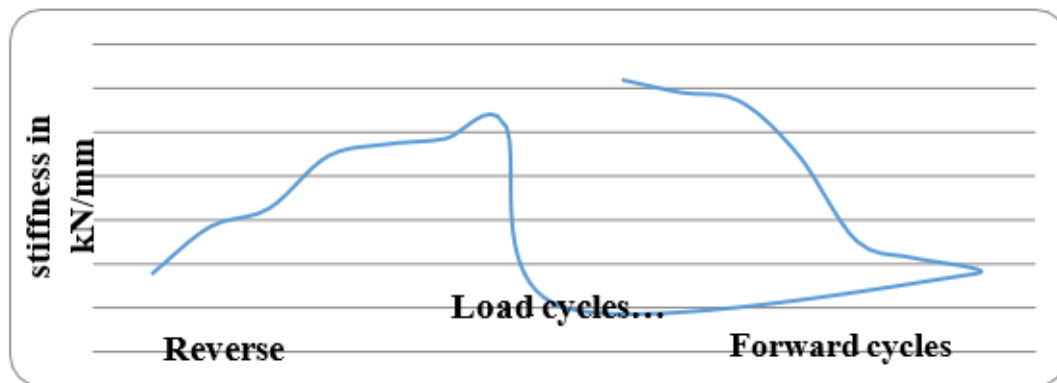


Fig 12: Stiffness degradation for forward and reverse cycle

5. BEHAVIOR OF RCC BEAM COLUMN JOINT WITH HAUNCH EFFECT DETAILED AS PER IS 456 RECOMMENDATIONS (HS1)

This specimen is strengthened by haunch provision at beam column junction, detailed as per IS 456 recommendation, and tested under forward and reverse cyclic loading. Haunch portion is having dimension of 100x 100 x 120mm (triangular shape) and represented as HS1. The parameters like load carrying capacity, ductility factor, energy absorption capacity and stiffness were studied. All factors studied as same as CS. Procedures as same done for CS.

6. COMPARISON OF TEST RESULTS

The behavior of controlled RC beam-column joint and haunch effect beam-column joint under forward and reverse cyclic loading are discussed in detail. The load carrying capacity, equivalent static load-deflection behavior, failure patterns, ductility factor, energy absorption capacity and stiffness degradation factor of the specimens CS, HS1 beam-column joints were compared and discussed.

6.1 Load carrying capacity of beam-column joint

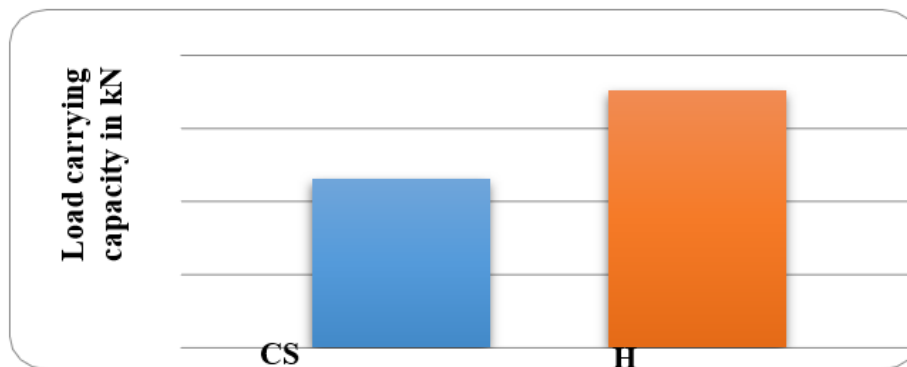


Fig.13: Comparison of Ultimate Load Carrying Capacity of specimens CS & HS1

6.2 Equivalent static load vs. deflection-behavior of beam-column joint

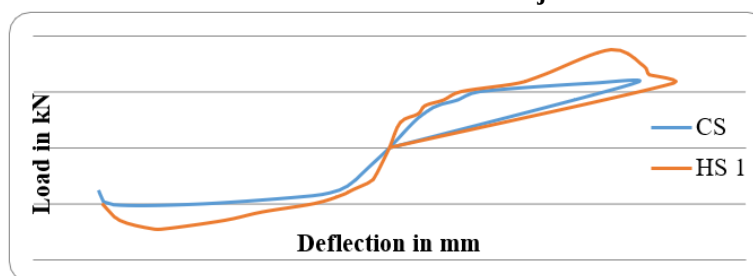


Fig. 14: Equivalent Static Load vs. Deflection Diagram

6.3 Mode of failure

The haunch specimen (HS1) is developing the limited cracks only compared with control specimen (CS). Specimen HS 1 developing minimum shear cracks at joints at ultimate load due to no confinement at joint region. Mode of failures of all specimens as shown in Fig 17.



Fig 17: Failures of control specimen (CS) and haunch specimen (HS 1)

7. CONCLUSION

An experimental study was carried out on two numbers of Beam-Column Joints with and without haunch arrangements were tested under reverse cyclic loading. Based on the investigation reported in earlier chapters, the following conclusions are drawn. They are summarized below.

P1: The first crack load of specimen HS1 is 1.177 times greater than that of specimen CS.

P2: The ultimate load carrying capacity of haunch specimen is 52% more than that of Control Specimen. P3: The load deformation characteristics also improved to large extent in the case of the haunch specimens.

P4: The cumulative Energy absorption capacity of HS1 beam-column joints is 1.26 times than that of controlled RC beam-column joint.

P4: The cumulative ductility factor of HS1 beam-column joints were 1.82 times than that of controlled RC beam-column joint. P5: The provision of haunches at the beam-column joint greatly enhances the overall behavior of beam-column joint, showing very little damage as compare as control specimen (CS).

RC beam-column joint with haunch effect shows overall better behavior in terms of load carrying capacity, ductility, energy absorption and stiffness. Hence it is highly suitable for the structure in severe seismic prone zones.

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