Experimental Investigation of RC-Beam column joint strengthening by FRP Wrapping

1Dr.P.Loganathan, 2Dr.P.Subramanian

1Associate Professor, Department of Civil Engineering, Al-Ameen Engineering College, Erode.
2Professor, Department of Civil Engineering, Sengunthar Engineering College, Tiruchengode.

ABSTRACT

Beam-column joints of a reinforced concrete structure need special attention due to their highly complex behaviour under seismic loads, which is marked by a combination of large shear forces, diagonal tension and high bond stresses in the reinforcement bars, all brittle mode of failure. An experimental investigation of the behaviour of Corner beam-column joints with detailing as per IS 13920: 1993 under seismic conditions is presented in this paper. The experimental study on Corner beam-column joint of a multistorey reinforced concrete building (G+ 4 storeys) 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 test specimen is reduced to one fifth model of beam column joint from prototype specimen. Column confinement and beam stirrups are provided closely in joint region according to IS 13920: 1993. The test specimens were evaluated in terms of load-displacement relation, ductility, stiffness, load ratio and cracking pattern.

Key Words: Beam-column joints, seismic loads, stiffness, STADD.pro, prototype specimen

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. 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 mean, 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 also 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.

2. LITERATURE REVIEW


The principles of detailing and the structural behaviour of simple members such as beams and columns are well established. On the other hand, the detailing, strength and behaviour of corner joints, especially opening corners, in reinforced concrete structures has not been conclusively determined. Tests have shown that opening corners in reinforced concrete structures have significantly reduced efficiency, ductility and unacceptable cracks at service loads. Four different detailing systems were investigated. The parameters for investigation were strength measured in terms of joint efficiency, ductility, crack control and ease of reinforcement fabrication.

Paul S. Baglin et al. (2000)

Paul S. Baglin et al. (2000), have presented the application of a non – linear finite element analysis package to the modeling of exterior beam – column connections. The behavior of the finite element model is compared with the results from 19 experimental tests. They conducted that the matched models showed very good correlation with the test specimens and the load deflection characteristics were generally good but modeling of the deformation due to crack growth and dislocation was inhibited by the smeared crack approach.

Shigeru Hakuto et al. (2000)

Shigeru Hakuto et al. (2000) have simulated seismic load test on reinforced one-way interior and exterior beam – column joints with substandard reinforcing details of typical building constructed before 1970s. They indicated form the test results that the seismic performance of the typical interior beam – column joints of pre – 1970s designed reinforced concrete moment – resisting frames without transverse reinforcement in the beam – column joint cores would be poor in severe earthquake. They also studied the jacketing of beam – column joint regions

**Strengthening of Beam Column Joints**

Failures in RC buildings during earthquakes demonstrate that brittle shear failure of beam column joint leads to total collapse. In order to strengthen the weak elements, various retrofit schemes could be designed.
Recently, a simplified analytical model for the joint behaviour has been proposed as a viable tool for extensive parametrical studies on seismic response of the existing building.

Several techniques were employed to strengthen the beam column joint 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 joint is ensuring effective confinement in the joint region. The use of FRP in rehabilitation of RC structure has increased recently due to its quick application, short construction time, and light weight as well as corrosion resistance. FRP wrapping of joints panels improved the shear strength by successful minimization or delay in the shear failure of the joint. Proper anchorage of FRP should be designed to provide confinement to the joint as the joint area is small. FRP laminates as an alternative method to enhance the structural integrity of beam column joints, such as increasing moment capacity and reducing joint rotation.

**Strengthening of Beam Column Joints by ductile detailing as per IS 13920 : 1993**

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. Failures in RC buildings during earthquakes demonstrate that brittle shear failure of beam column joints lead to total collapse. In order to strengthen the weak elements, various retrofit schemes could be designed. Recently, a simplified analytical model for the joint behavior has been proposed as a viable tool for extensive parametrical studies on seismic response of the existing buildings. 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.

In Corner joints the beam longitudinal reinforcement that frames into the column terminates within the joint core. After a few cycles of inelastic loading, the bond deterioration initiated at the column face due to yield penetration and splitting cracks, progresses towards the joint core. Repeated loading will aggravate the situation and a complete loss of bond up to the beginning of the bent portion of the bar may take place.

The longitudinal reinforcement bar, if terminating straight, will get pulled out due to progressive loss of bond. The pull out failure of the longitudinal bars of the beam results in complete loss of flexural strength. This kind of failure is unacceptable at any stage. Hence, proper anchorage of the beam longitudinal reinforcement bars in the joint core is of utmost importance. The pull out failure of bars in exterior joints can be prevented by the provision of hooks or by some positive anchorage. Hooks are helpful in providing adequate anchorage when furnished with sufficient horizontal development length and a tail extension. Because of the likelihood of yield
penetration into the joint core, the development length is to be considered effective from the critical section beyond the zone of yield penetration. Thus, the size of the member should accommodate the development length considering the possibility of yield penetration. When the reinforcement is subjected to compression, the tail end of hooks is not generally helpful to cater to the requirements of development length in compression. However, the horizontal ties in the form of transverse reinforcement in the joint provide effective restraints against the hook when the beam bar is in compression.

**Strengthening by GFRP in Beam Column Joints**

The GFRP jacketing enhances the shear strength of joint and improves the ductility of the joint. GFRP sheets wrapped around the joint to prevent the joint shear failure, and attached to the beam bottom face to strengthen inadequately anchored steel bars. The joints built without proper Reinforcement detailing suffered brittle shear and bond failures while the rehabilitated joints improved the ductility. GFRP composites possess’ high strength to weight ratio and tensile strength compared to Tor steel. The other enhancing properties of GFRP are it is non reactive for chemicals such as chlorides, alkalis and thermally non conductive in nature and hence durability of structure is increased. This calls for the use of GFRP as reinforcement for concrete structures in which corrosion is primary concern. GFRP composites mats, fabrics and rods can be effectively applied externally and internally over the RC elements for strengthening purposes. Such strengthening leads to improved ductility, energy absorption capacity and increased load carrying capacity of the RC members. These composites are, hence used in larger scale for the rehabilitation of earthquake affected structures.

**Advantages of GFRP**

(i) Low weight leads to reduction in dead loads.
(ii) Immunity to corrosion
(iii) Excellent mechanical strength and stiffness
(iv) Attractive in appearance and architectural beauty of the structures.

**Experimental investigation**

A two bay five storey Reinforced concrete frames has been designed for seismic loads according to IS 1893 and IS 13920. The maximum moment is occurred at ground floor level for the interior and exterior beam column joints. In this experiment study, loading was applied in forward and reverse cyclic loading and strengthening of beam column joint after post yielding using FRP Wrapping and behaviour of joint is studied upto failure loading condition.

**Details of specimen**

The test specimen was reduced to 1/5th scale to suit the loading arrangement and test facilities. For testing model, the dimension of beam was 120 X 170 mm and beam length of 450mm and that column size was 120 X
230 mm. Height of the column was 375 mm. The Fig 1 shows the shape of form work and reinforcement details for test specimen.

Fig 1: Formwork and Reinforcement for test specimen

**Reinforcement details**

The reinforcement details of beam column joint are shown in fig. 2. Main reinforcement provided in the beam was 10 mm diameter bars, 3 Nos at top and 3 Nos at bottom. The stirrups are 6 mm diameter bars at 30 mm c/c for a distance of 2d, i.e. 300 mm from the face of the column and at 60 mm c/c for remaining length of the beam. The longitudinal reinforcement provided in the column was 8 No’s of 8 mm diameter bars equally distributed along four sides of column. The column confinements are 6 mm diameter bars at 30 mm c/c for a distance of 150 mm from the face of the column and at 60 mm c/c for remaining length of the column.

Fig 2: Ductile Detailing of Beam

Column Joint as per IS 13920: 1993
The mould is arranged properly and placed over a smooth surface. The sides of the mould exposed to concrete were oiled well to prevent the side walls of the mould from absorbing water from concrete and to facilitate easy removal of the specimen. The reinforcement cages were placed in the moulds and cover between cage and form provided was 20 mm. Concrete mix designed for M30 (1:1:2.5) and water cement ratio is 0.40. Cement mortar block pieces were used as cover blocks. The concrete contents such as cement, sand, aggregate and water were weighed accurately and mixed. The mixing was done till uniform mix was obtained. The concrete was placed into the mould immediately after mixing and well compacted. Control cubes and cylinders were prepared for all the mixes along with concreting. The test specimens were remolded at the end of 24 hours of casting. They were marked identifications. They are cured in water for 28 days. After 28 days of curing the specimen was dried in air and white washed.

![Casting Stage of Beam-Column Joint](image)

**Test setup and instrumentation**

An axial load of 100KN was applied on the column in order to produce a compressive stress of 0.1f<sub>ck</sub>. Screw jack has been used for applying load on the beam. The load applied was cyclic in nature and deflection is measured for every 3KN of loads by using LVDT. The complete test setup as shown in fig. 4.
Behaviour of Beam-column joints

The experimental results of RC Beam Column Joint under reverse cyclic loading have been enumerated. The parameters like load carrying capacity, Ductility factor, and Energy absorption were studied.

Load carrying capacity

The first crack was witnessed during 2\textsuperscript{nd} cycle at the load level of 12KN. As the load was increased, further cracks were developed in other portions. The Ultimate load carrying capacity of the RC Beam Column Joint was 17KN recorded at 4\textsuperscript{th} cycle.

Load Deflection Characteristics

The Corner Beam-Column Joint specimen was subjected to cyclic loading simulating Earthquake Loads. The load was applied by using screw jack. Totally 6 cycles were imposed. The Beam-Column Joint was gradually loaded by increasing the load level during each cycle. As the load level was increased in each cycle, the observed deflection was greater than it was in earlier cycle.
Mode of failure
The corner Beam Column Joint test specimen was tested under cyclic loading. During the forward loading cracks have been developed at the top of the specimen. As the loading was progressed the width of crack has been widened. And the reversal of load specimen has to be in the reversed positions, cracks have been formed at the bottom tension and the cracks already formed in the tension face have to be closed. This opening and closing of the cracks has been confirmed till the final failure of the specimen takes place. The complete failure pattern of the Beam-Column Joint is shown in fig. 6

Fig 6: Failure at Ultimate load

Conclusion
A model of corner Beam column joint of RC moment resisting frame has been subjected to seismic type cyclic loading the general behaviour and the mode of failure has been studied in this paper. Based on experimental observations it is concluded that additional reinforcements are necessary at corner beam column joint in order to avoid the opening and closing type of joint failure.

Reference
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