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Behavior of Exterior Beam Column Joints with Diagonal Cross Bars and Headed Bars

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Abstract

Beam column joints are one of the most critical components of a reinforced concrete structure, especially if the structure is likely to be subjected to lateral loads. Failure of beam column joint during earthquake is governed by bond and shear failure mechanism, which is brittle in nature. Unsafe design and detailing within the joint region jeopardizes the entire structure, even if other structural members conform to the design requirements.

Use of standard 90^0 and 180^0 hooked bars up to required development length often results in steel congestion, difficult fabrication and construction, as well as poor concrete placement. Use of the headed bar can offer a potential solution for these problems and may also ease fabrication, construction, and concrete placement. This paper presents the experimental work carried out on four different arrangements of reinforcement of beam column joints. The aim of the research is to investigate the pull-out behaviors such as strength, failure mode, and crack patterns of different arrangements of reinforcement in exterior beam column junctions. All joints were tested by using reversed cyclic loading. In the first arrangement, the beam bars are extended in the column for distance Ld+(10xDia) from the inner face of column. In the second arrangement the beam bars are crossed diagonally in the beam column junction. In the third arrangement headed bars are provided with all heads in two parallel planes, whereas in the fourth arrangement, the heads are provided in two orthogonal planes.

Keywords: Keywords- Beam-column joints; headed bars; hysteresis loops

1. Introduction

The all reaction forces of columns and beams in RC structures subjected to strong ground motions concentrate in the joint, because of that beam-column joints are crucial regions of structures. Joints are point of weakness due to lack of adequate anchorages for bar entering the joint from the beam and column. In the design and detailing of beam column joints, it is desired to prevent the brittle shear failure of the joint so that the integral capacity of the connecting beams and columns can be developed. It is also necessary to provide proper confinement to the joint core to maintain the integrity of the joint core and to reduce the stiffness degradation. Proper anchorage of reinforcement is essential to reinforced concrete structures to ensure composite action between reinforcement and concrete to resist the member design forces. In general, anchorage is achieved by a combination of bond and bearing on hooks. Failure of beam column joint during earthquake is governed by bond and shear failure mechanism, which is brittle in nature. Unsafe design and detailing within the joint region jeopardizes the entire structure, even if other structural members conform to the design requirements [1].

In conventional practice to reduce development length of bar, bends are required for effective transfer of load. In normal practice 90^0 and 180^0 hooks are provided. These are generally known as conventional anchorages.

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Bend reduces length of bar because of increase in frictional resistance at the bend due to confinement of concrete inside the bend by radial components of bar in tension. Hanson et al tested corner joint, side joint and interior joint specimens with conventional anchorage system [2]. Alva et al studied cyclic behaviour of RC connections experimentally and concluded that concrete compressive strength is the major factor that governs the joint shear capacity. The experimental results also indicated that joint transverse reinforcement affects the load-displacement response of such connections [3]. Scott investigated strain distribution of beam column junctions with conventional anchorage system of reinforcement. The author also focused on location of plastic hinge formation [4]. Asha et al evaluated seismic resistance of exterior beam column joints with detailing as per IS 13920-1993 [5].

Some researchers used diagonally crossed bars in exterior beam column junctions and found that diagonal bars had improved the ductility and energy absorption capacity than the specimens with arrangement of 90^0 hooks [6]. Even for interior beam column junctions diagonal bar arrangement had shown improved results [7].

There are lots of disadvantages of such conventional anchorages. Use of standard hooks often results in steel congestion, difficult fabrication and construction, as well as poor concrete placement. Use of the headed bar offers a potential solution for these problems and may also ease fabrication, construction, and concrete placement.

Headed bars are formed by attachments of plate at the end of straight reinforcing bar. Such bars are anchored by combination of bond along straight bar length and direct bearing at the head. Like hook bars they can develop effective within short distance but they do not create much congestion. However headed bars have not been widely used in other structure such as bridges, building, or other traditional structures. Chun et al tested some beam column junctions with headed bars and found that headed bar has enough anchorage capacity in the exterior beam-column joints [8,9]. In their study all heads are kept in one plane. There is little guidance currently available for the design of headed bar anchorage either in the form of code provisions or published research.

This study attempts to investigate the pull-out behaviors such as strength, failure mode, and crack patterns of different arrangements of reinforcement in exterior beam column junctions. In the first arrangement, the beam bars are extended in the column for distance Ld+(10xDia) from the inner face of column. In the second arrangement the beam bars are crossed diagonally in the beam column junction. In the third arrangement headed bars are provided with all heads in two parallel planes, whereas in the fourth arrangement, the heads are provided in two orthogonal directions.

2. Experimental Investigations

2.1 Material Properties and Concrete Mix Design-

The materials required for the experimental work were tested in the laboratory to get necessary data for mix design. 53 grade Pozzolana Portland cement was used. Natural river sand with specific gravity 2.69 and fineness modulus 3.5 which conforms to grading zone II was used as fine aggregate. Crushed basalt with maximum size of 20mm and specific gravity 2.79 is used as course aggregate. Concrete Mix design is carried out for concrete grades M30 for medium workability. The mix proportions are finalized after taking some trials for target strength determined by considering standard deviation equal to 5.

Reinforcement- Thermo mechanically treated ribbed bars of diameter 12mm were used (TMT-TISCON). Three bars were tested for mechanical properties. For all the bars ultimate stress was in the range 650 to 665 N/mm^2 and 0.2% proof stress was in the range 515 to 525 N/mm^2.

2.2 Details of Specimen-

Exterior beam column joint was considered for experimental work. In the test model the dimension of beam was 200 x 165 mm with length of 400mm and column size was 220 x 165 mm with total height of 800mm.

2.3 Reinforcement Details-

In all the specimens main reinforcement provided in the beam was 3-#12 at top and 3-#12 at bottom. In column 4-#12 + 4-#10 reinforcement was provided. In beam #6 @ 75 mm C/C stirrups were provided whereas in columns #6@ 75 mm C/C ties were provided.

- Specimen S1- The reinforcement details of beam column joint are shown in fig.1. The arrangement of the reinforcement is provided according to IS 13920-1993[10]. The beam bars are extended in the column for distance Ld+(10xDia) from the inner face of column.

- Specimen S2- The reinforcement details of beam column joint are shown in fig. 2. All four corner bars of the beam are extended in the column for distance Ld+(10xDia) from the inner face of column. For 12 mm diameter this length is 660 mm. The top and bottom middle bars of the beam are extended diagonally in the column.

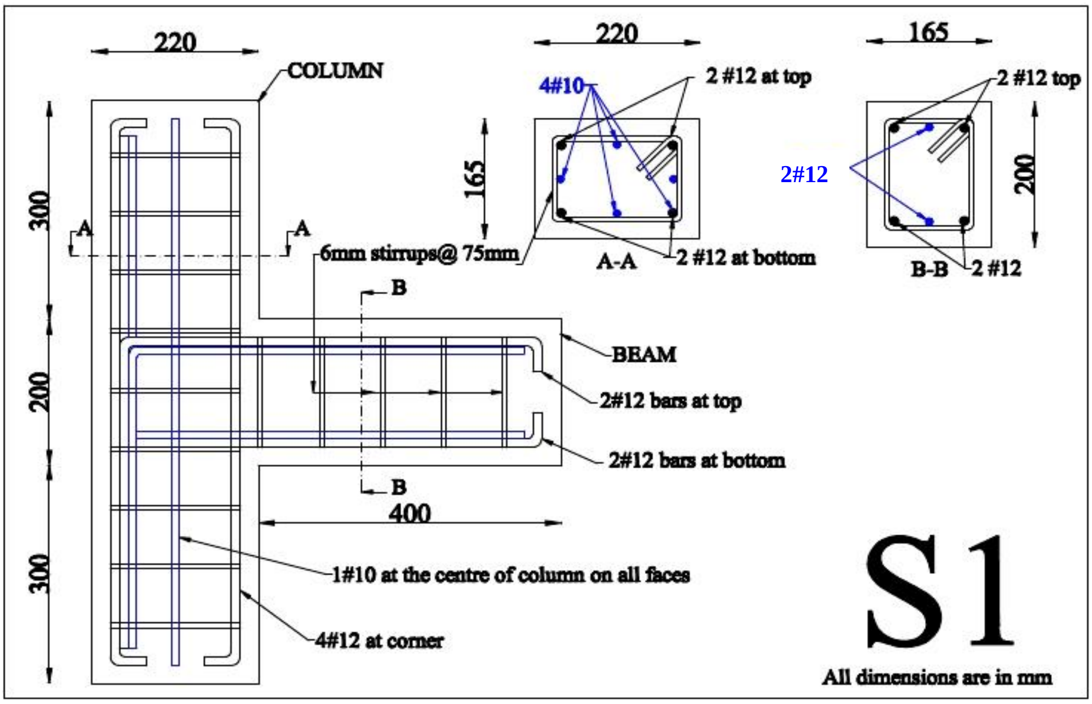

Fig.1. Reinforcement arrangement as per IS 13920

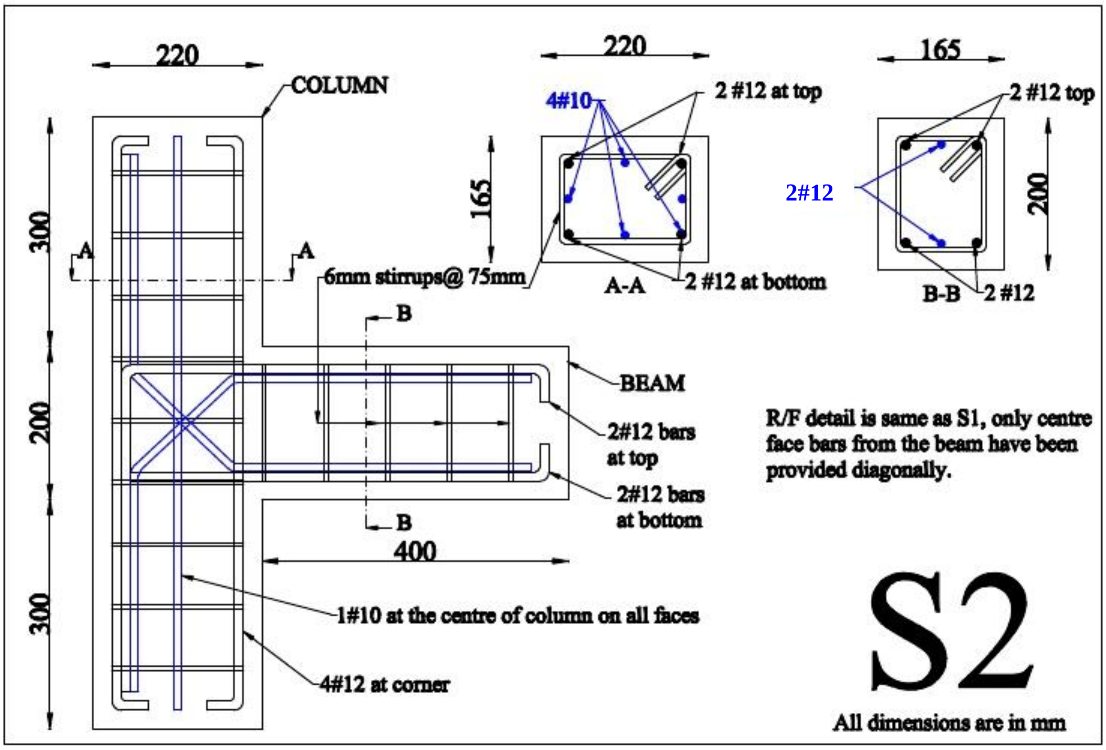

Fig. 2. Reinforcement arrangement with diagonally crossed bars

- Specimen S3- The reinforcement details of beam column joint are shown in fig. 3. All the beam bars were provided with heads of diameter 50.4mm and thickness 12mm. The head was drilled centrally. The bar was inserted in the hole and welded from both the faces. All six head plates were kept in two parallel vertical planes. The head plates of the corner bars are touched to the column bars of outer face. The head plate of the middle bar was kept 50mm above the head plates of the corner bars.

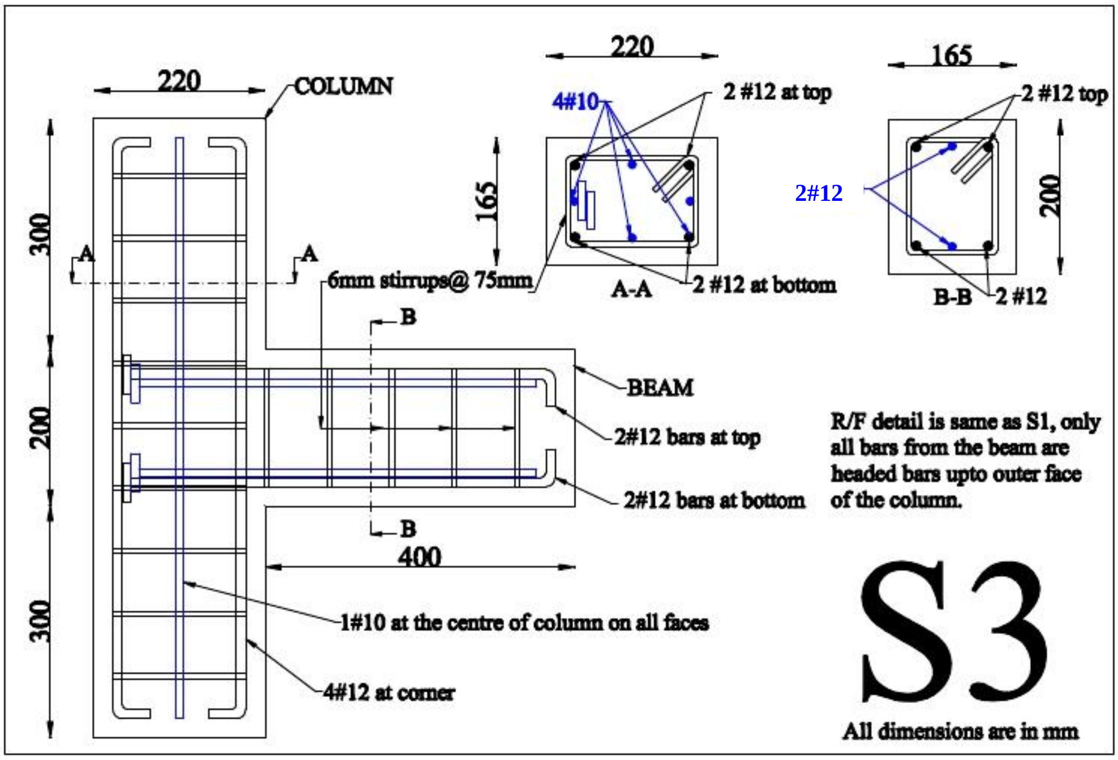

Fig. 3. Reinforcement arrangement with headed bars (Head Plates in parallel planes)

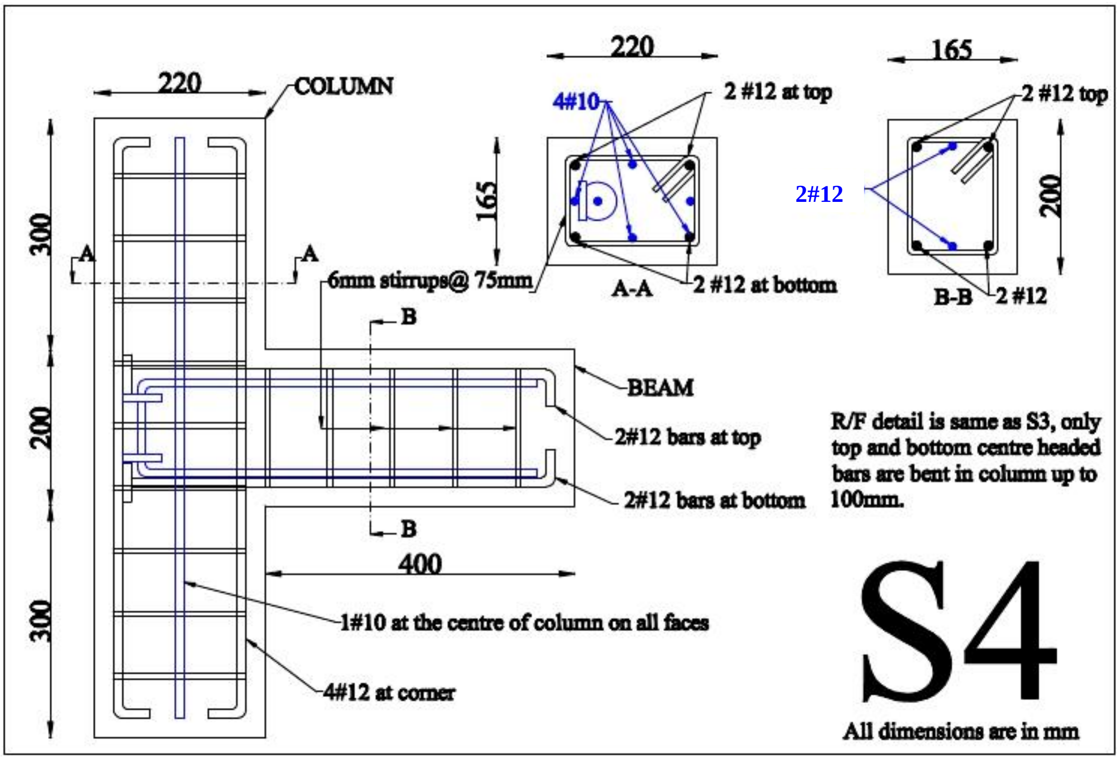

Fig. 4. Reinforcement with headed bars (Head Plates in orthogonal planes)

- Specimen S4-The reinforcement details of beam column joint are shown in fig. 4. All the beam bars were provided with heads of diameter 50.4mm and thickness 12mm. The head plates of the corner bars are touched to the column bars of outer face. These four plates are kept in vertical plane. The remaining middle top bar and middle bottom bar were bent through 90º for 100 mm length. At the end of these ‘L’ bent head plate were welded. Now these two head plates were in horizontal plane.

2.5 Casting and Curing

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. Concrete mix designed for M30 was used. The concrete was placed into the mould immediately after mixing and well compacted. Control cubes and were prepared for all the mixes along with concreting. The moulds were removed after 24 hours from casting. All the specimens were cured in water for 28 days. After 28 days of curing the specimen were dried in air and white washed.

2.6 Test Setup and Instrumentation

The specimen was tested in a reaction frame. The test setup is shown in fig.5. A 1000 kN capacity calibrated hydraulic jack mounted vertically on the frame was used to apply axial load on the column. A constant load of 100kN, which is about 15% of the axial capacity of the column, was applied to the columns for holding the specimens in positions and to simulate column axial load. Two ends of the column were given an external axial hinge support in addition to lateral hinge support provided at the top and bottom of the column. Another two 500 kN capacity hydraulic jacks were used to apply reverse cyclic load. The load was applied at distance 50mm from free end of the beam face. The load was measured by inserting load cell in between the jack and the beam face. Loading was applied gradually such as 5,10,15,20,…70,75 kN respectively for forward direction and 5,10,15, 20,…70,75 kN respectively for reverse direction. Fig. 6 shows the loading history in terms of applied cycles versus load. Three LVDTs were used to measure deflections. The deflections were measured at the beam free end tip (at loading point), at distance 175mm from column face along beam and at the column top.

Fig. 5 Test Setup

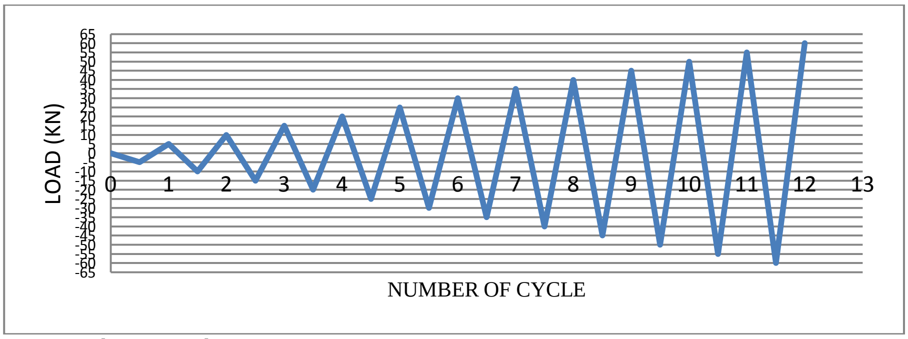

Fig. 6 Load Sequence diagram.

2.7 Test Results

Fig. 7 to 10 show the crack pattern and the loads at which cracks appeared.

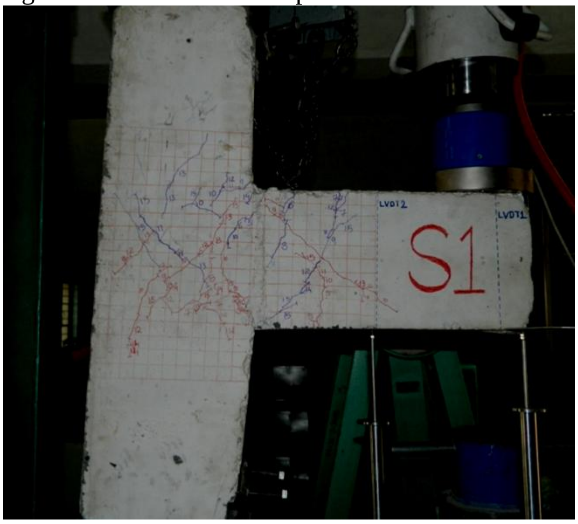

Fig. 7 Crack Pattern of Joint S1

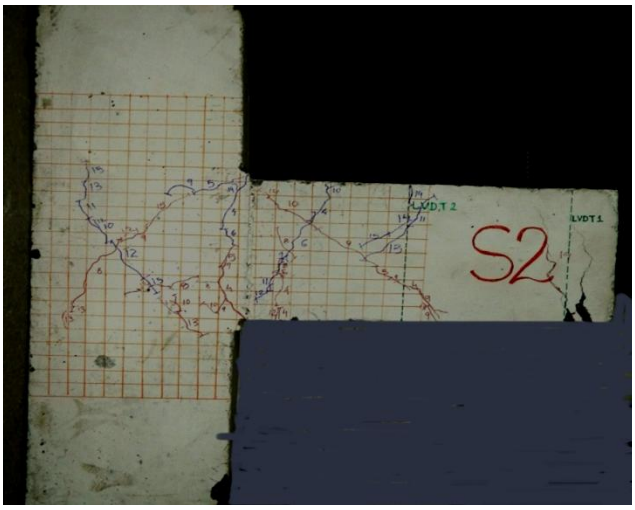

Fig. 8 Crack Pattern of Joint S2

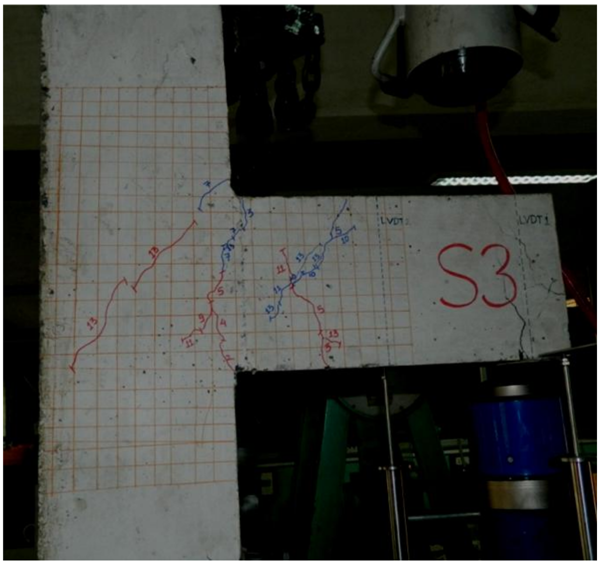

Fig. 9 Crack Pattern of Specimen S3

Fig. 10 Crack Pattern of Specimen S4

Fig. 11 to 14 show the load Vs deflection graphs-hysteresis loops for joints S1, S2, S3 and S4 respectively.

2.8 Discussions of The Test Results

The diagonal first crack at the joint region initiated at 25kN load in joint S1 and S2 whereas in joints S3 and S4 it initiated at 35kN load. The first crack at beam interface initiated at 25kN load in S1, 20kN in S2, 15kN in S3 and S4. With further increase in loading, the cracks propagated further and initial cracks started widening. At each cycle some new cracks formed. In joint S1 the cracks are distributed on entire beam column joint. In specimen S2 major only five cracks occurred, two diagonal '*x*' crack in the joint region, one along the beam interface and two *'x'* cracks in the beam portion. In Joint S3 only four major cracks appeared, one along beam interface, two *'x'* cracks in the beam portion and one diagonal crack in the joint region. The diagonal crack in the joint region which initiated in 7th cycle, propagated further directly in the 13th cycle. The crack pattern of S4 is almost same as that joint S2 with the main difference that the diagonal cracks propagated in parallel lines. This difference in the crack pattern is due the arrangements of heads in orthogonal planes. The cracks in joint S3 had not widened much more as compared to other joints. After occurring initial cracks, increase in load was observed. It may be due to the following reasons. During cyclic loading, when unloading takes place, tip of the crack becomes blunt, and during reloading the specimen, more energy is required to propagate the crack or to change the direction of propagation from the blunt crack tip. This in turn increases the ultimate load [11]. The strength parameters and energy dissipation among different joint specimens are compared and reported in table.1.

Table 1. Ultimate Strength and energy dissipation of joints

Joint Specimen	First crack load at joint region	First crack load at beam Interface	Ultimate Load kN	Energy Dissipation kNmm	Mode of Failure
S1	25 kN	25kN	75	564	J-B
S2	25kN	20kN	75	325	J-B
S3	35kN	15kN	70	230	B
S4	33kN	15kN	75	658	J-B

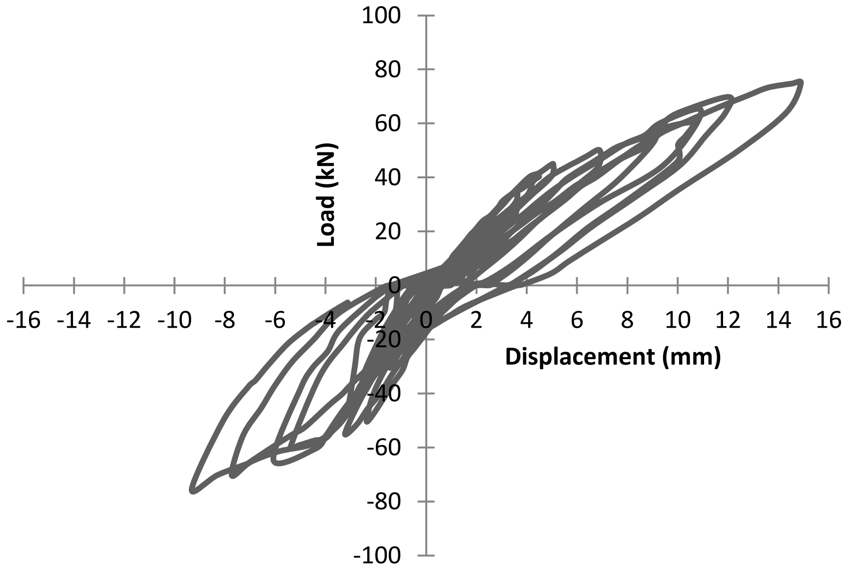

Fig. 11 Load - Displacement hysteresis loops of Joint S1

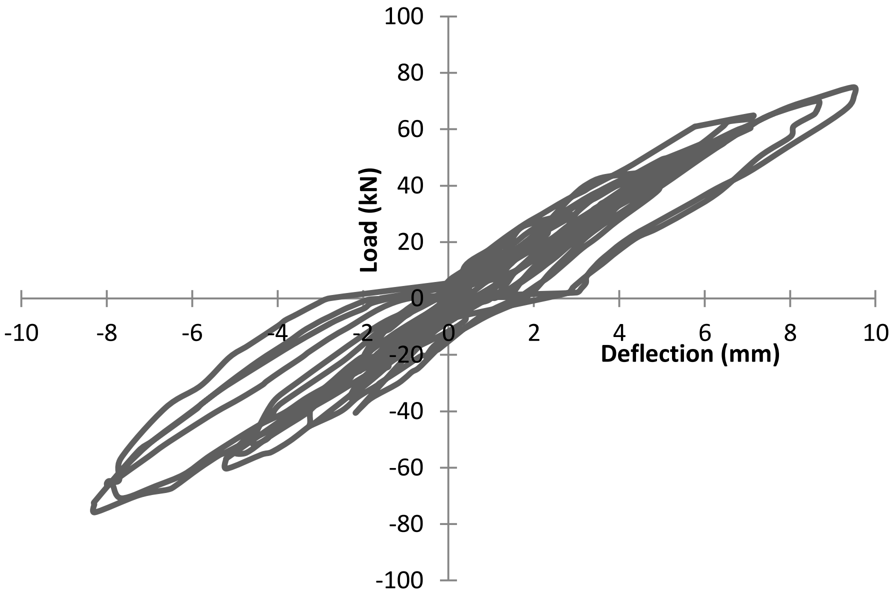

Fig. 12 Load - Displacement hysteresis loops of Joint S2

The seismic design philosophy relies on providing sufficient ductility to the structure by which the structure can dissipate seismic energy. The structural ductility essentially comes from the member ductility wherein the latter is achieved in the form of inelastic rotations. In reinforced concrete members, the inelastic rotations spread over definite regions called as plastic hinges. During inelastic deformations, the actual material properties are beyond elastic range and hence damages in these regions are obvious. The plastic hinges are "expected" locations where the structural damage can be allowed to occur due to inelastic actions involving large deformations. Hence, in seismic design, the damages in the form of plastic hinges are accepted to be formed in beams rather than in columns. Mechanism with beam yielding is characteristic of strong-column-weak beam behaviour in which the imposed inelastic rotational demands can be achieved reasonably well through proper detailing practice in beams [1]. In the present study from the crack pattern, it is observed that the failure mode for joints S1, S2 and S4 is combined joint and beam mode failure, whereas in joint S3, it is beam mode failure.

The maximum deflections attended in 12^{th} cycle were 10.85mm, 5.9mm, 6.94mm and 6.44mm with corresponding

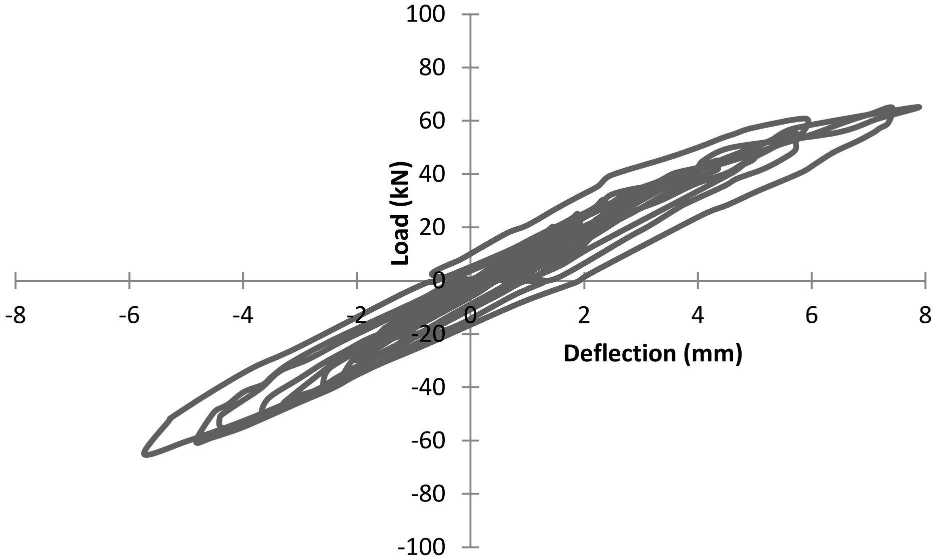

Fig. 13 Load - Displacement hysteresis loops of Joint S3

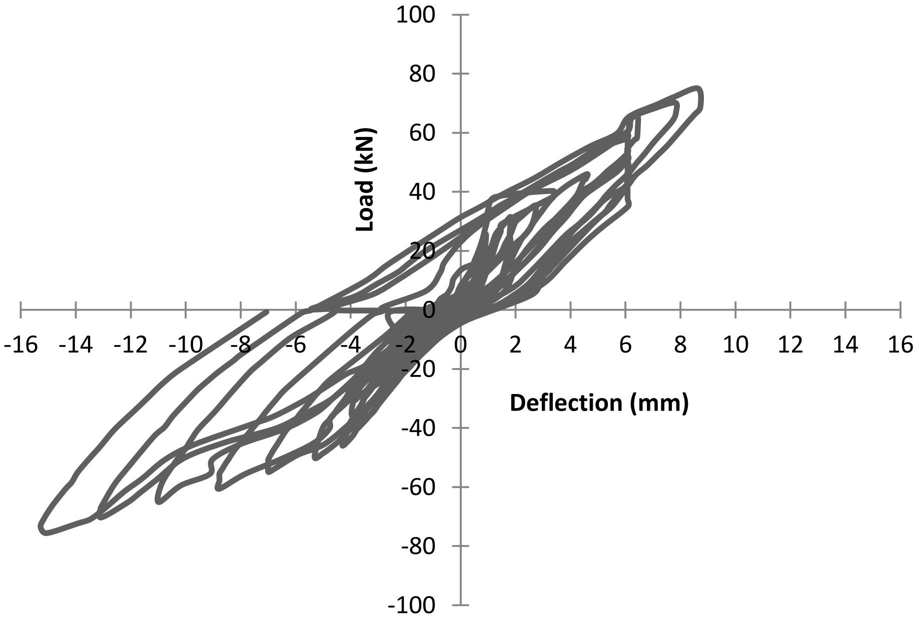

Fig. 14 Load - Displacement hysteresis loops of Joint S4

drift ratios of 2.4%, 1.3%, 1.5% and 1.4% respectively for Joints S1, S2, S3 and S4. The load-displacement hysteresis loop for joint S1, S2 and S4 exhibited almost same ultimate strength, Joint S3 failed at 70kN ultimate load, but the failure was not at the junction or beam interface but in shear at the load point. The loops are much closely spaced for Joint S3. Joint S4 had shown large displacements during downward cycles.

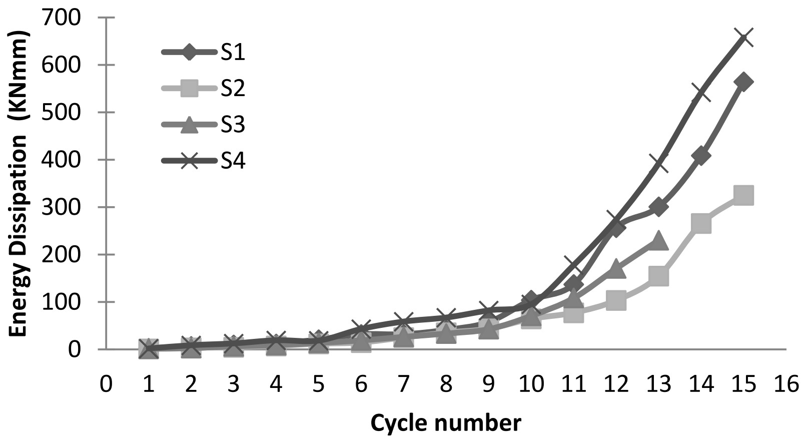

Fig. 15 Energy Dissipation Curves

Energy Dissipation -

The energy dissipated at the beam column joint specimens through plastic deformation was the sum of the area in the beam tip load-displacement hysteresis loop as shown in fig. 15. The energy dissipated by Joint S3 is lowest, which is due to early failure. The best energy dissipation potential was exhibited by Joint S4.

The arrangement of reinforcement with headed bar performed equally well and gave good results as compared to bent up bars and diagonal bars under static cyclic loading. In this study the provided diameter of the head was evaluated from the possible ultimate concrete stress immediately behind the head, where only the head area minus the bar area is effective. But if the pressure cone behind head is considered, then required area of head can be reduced considerably. The effect of confining reinforcement and the bond stress supplied by the embedded length of the ribbed bar will further reduce the required area of the head.

3.0 Conclusions

1. The failure mode for joints S1, S2 and S4 is combined joint and beam mode failure, whereas in joint S3, it is beam mode failure. It shows that head plate attached to straight bar forms compression strut in front of the plate which reduces the diagonal cracks.
2. Headed bars with orthogonally oriented plates provide best energy dissipation potential to the external beam column joint.
3. The arrangement of reinforcement with headed bar performed equally well and gave good results as compared to bent up bars and diagonal bars under static cyclic loading.

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