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Behaviour of Corner Beam Column Joint with Rectangular Spiral Reinforcement and Longitudinal FRP Bars

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Abstract**—** *Performance of beam column connections is not satisfactory during the earthquake excitation. In order to understand the complex mechanisms and satisfactory behavior of beam column connections, lots of investigations have been done. The most critical zone in reinforced concrete moment resisting frames would be the beam column connection. The behavior of beam column connection once it is subjected to large forces during earthquakes has a great impact on the response of the structure. The shear failure has a brittle nature which is not a desirable structural performance during earthquakes. New type of shear reinforcements are introduced in this study for the purpose of reaching a higher performance and material capacity for the connection. The first specimen is made according to conventional method of design. The second specimen introduces a continued shear resistance system against discontinued conventional shear resistance system. The third model consists of spiral reinforcement and longitudinal GFRP (Glass Fiber Reinforced Polymer) bars. By investigating the model with GFRP bars and to improve the properties of GFRP reinforced beam column joint, hybridization of GFRP to be done. Two types of hybridization namely GFRP crust with steel core and steel crust with GFRP core were done. The specimen having hybridized bars checked for higher ductility and lower deformation. In this case corner beam column joint were modelled and analysed using ANSYS finite element software.*

Keywords**—** *Corner beam-column joint, rectangular spiral reinforcement, glass fiber reinforcement, hybridization*

I. INTRODUCTION

In the last decades, the prescriptions for RC structural seismic design have produced minor improvements in the steel reinforcement technology. Looking into the latest development of the seismic prescriptions, aiming to prevent severe damages of RC elements, it has been noticed that there is relatively little concern on the shape and optimal placement of steel reinforcement in these types of structural elements. Although significant achievements have been reached in structural design and building engineering, minor improvements can be identified for the steel cage reinforcement assembly in the last decades.

During horizontal earthquakes, moments and shear forces acting on the beams and columns of the frame building are resulting in internal-vertical and horizontal forces on the face of the joint core. The internal forces produce a resultant acting in the joint core, either a diagonal tensile or compressive stress. Diagonal tensile stresses and compressive forces result in cracking and crushing of the concrete core. If the shear resistance at the joint core is insufficient, there will be failures along the diagonal of the joint core. The design of the shear beam-column joint of steel reinforced concrete (SRC) contributed much to the design of joints under seismic loads.

Incorporation of continuous spiral reinforcement in circular cross section components such as beams and columns of RC structures could improve the strength, ductility, and energy dissipation capacity of such structural members. Due to the wide application of rectangular shape cross sections in RC structures, incorporation of continuous rectangular reinforcement in RC elements has recently become more popular. Application of rectangular spiral reinforcement in RC beams was first introduced by Saatcioglu and Razvi in an experimental investigation in 2005. Recently, there has been an increasing trend of studies regarding the effectiveness of rectangular spiral shear reinforcement on RC structures.

In RC rectangular elements commonly shear reinforcements are provided as stirrups. The scope of the present study is that instead of providing conventional shear reinforcement for rectangular beam column joint, spiral shear reinforcements are provided. There by investigating the frame for maximum load bearing capacity, energy absorption, ductility of the connection with single spiral rectangular shear reinforcements. The performance of joint consisting of GFRP bar along with continuous spiral reinforcement is also investigated since the use of GFRP bars as internal reinforcement in the concrete structure is widely adopted. The GFRP bars have corrosion resistant nature and it is non-magnetic. So the use of GFRP bars in the bridge construction and use in the hospital building have large significance. The lower modulus of elasticity and higher deflection are the challenges in the design of GFRP bars. Therefore the hybridization of GFRP bars with steel bars for the better performance is to be investigated in this study.

The objectives of the study is to investigate the behavior of RC beam column connections using rectangular spiral and conventional shear reinforcement system under cyclic loading using finite element formulation. Also to investigate the influence of FRP bars with spiral reinforcement on ductility at beam column joint under cyclic and reverse cyclic loading and to conduct a study on FRP bars with hybridization at beam column joint.

Mainly three types of connection namely exterior, interior and corner connection can be identified in moment resisting frames. In this study corner connection is analysed.

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II. MODELLING OF BEAM COLUMN JOINT

A. Geometrical and Material Properties

The accuracy of structural analysis using numerical methods depends on the representation of behavior of material under different state of stresses and loading conditions. Two types of reinforcing bars namely steel bars and GFRP bars were selected for this study. The properties of GFRP bars were taken from ACI 440. The details of the properties employed for finite element modelling are given in the table I. The reinforcement details of beam column specimen is given in the table II.

TABLE I. Geometrical and material properties.

Column height	1200mm
Column cross section	200mm X 200mm
Beam length	600 mm
Beam cross section	200mm X 200mm
Concrete properties	
Modulus of elasticity	25000 N/mm^2
Poisons ratio	0.15
Yield strength	3.5 N/mm^2
Longitudinal reinforcement and stirrups	
Yield strength	415 N/mm^2
Poisons ratio	0.3
GFRP bars	
yield strength	600 N/mm^2
Modulus of elasticity	10 e04 N/mm^2

TABLE II. Reinforcement details.

Longitudinal bars		
Beam	Bar Diameter	12 mm
	Numbers	4 no's
Column	Bar Diameter	12 mm
	Numbers	4 no's
Transverse Bars		
Beam	Bar Diameter	6mm
	Spacing	130mm
Column	Bar Diameter	6 mm
	Spacing	130 mm

B. Non-Linear Modelling of Beam Column Joint

Modelling of reinforced beam column joint were carried out on ANSYS Workbench 16.1.The reinforcement were provided as line bodies. Circular concept were provided for main bars and stirrups. Concrete is provided as solid material and then the contact were assigned between concrete and reinforcement. Reinforcement impressions were provided by connecting all stirrups with main bars. The beam column joint to be analysed for corner joint consist of column part and two cantilever part. A corner connection is defined as a connection in which two adjacent faces of column are framed into by two beams. Both column and cantilever had an equal dimension of 200 mm x 200 mm while the overall column length was 1200 mm and cantilevered portion of length 600 mm. The design of the control specimen was done conventionally. The IS code was used for the purpose of conventional design of the specimen. 4 numbers of 12 mm diameter bars for the columns and 2 numbers of 12 mm diameter rods in top and bottom part (tension and compression zones) for the beam were used as reinforcement. 6 mm diameter bars with the spacing of 130 mm center to center were used as lateral ties in the column using a conventional design. Vertical stirrups of 6 mm diameter bar at 130mm center to center were used in the beam.

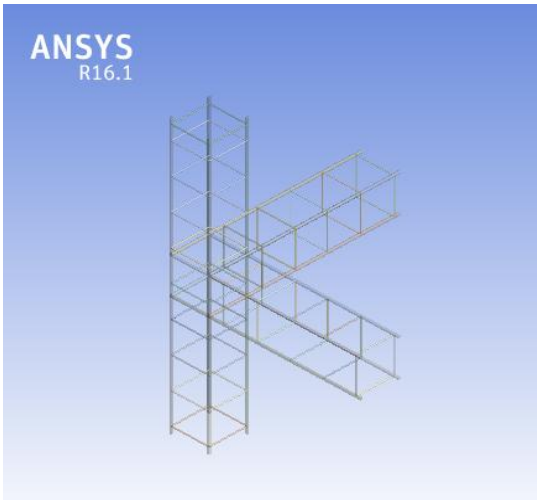

Fig. 1. Reinforcement model having conventional stirrups.

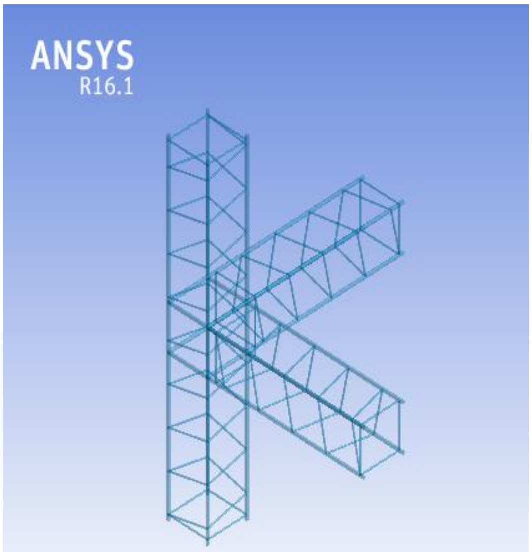

Fig. 2. Reinforcement model having rectangular spiral stirrups.

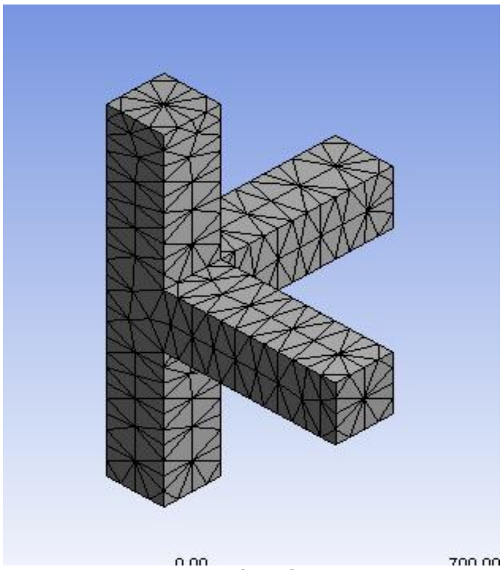

Fig. 3. Meshing diagram.

Reinforcement model for corner beam column having conventional stirrups is shown in figure 1. Reinforcement

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model for corner beam column joint having rectangular spiral stirrups is shown in figure 2. The third model for corner beam column model consist of longitudinal bars of beam as GFRP reinforced. The fourth model consist of longitudinal bars as hybridized FRP bars. In fourth model GFRP core with steel crust bars are provided. In fifth model steel core with GFRP crust were provided. Figure 3 represents the meshing diagram of beam column joint.

C. Boundary Conditions and Application of External Loads

The both face of the column were hinged and the specimen were subjected to fully cyclic deformations with increasing amplitude near the free end of one beam. Cyclic stress is the distribution of force that change over time in repetitive manner. Fully reversing type cyclic loading is applied. Once the cycle of this type of loading occurs when a tensile stress of some value is applied to an unloaded part and then released, and then a compressive stress of the same value is applied and released. The maximum displacements of beam's free end in the loading cycle were 10 mm, 20 mm, 30 mm, 40 mm and up to 70 mm for the first, second, third, fourth and last loading step, respectively. Totally seven number of steps are provided for the loading sequence. Support conditions for exterior beam column model is shown in figure 4. Cyclic loading history for the study is given in the figure 5.

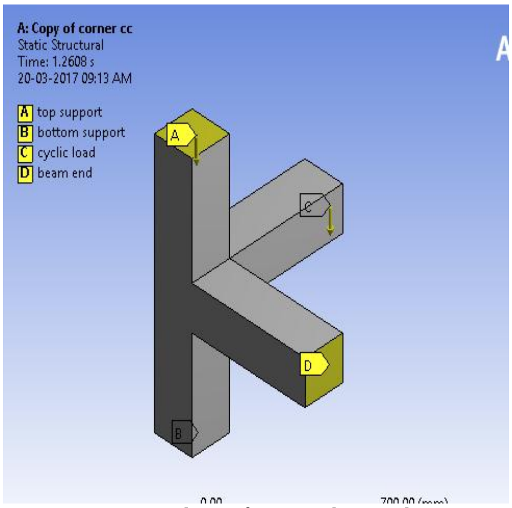

Fig. 4. Support conditions for corner beam column joint.

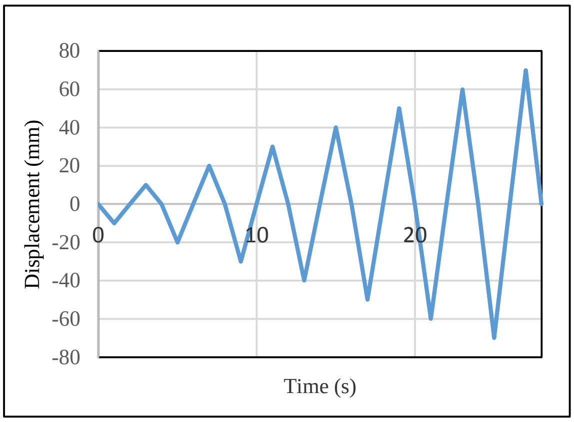

Fig. 5. Loading history.

III. Results and Discussions

First model consist of beam column joint with conventional stirrups. Second model consist of beam column joint with spiral stirrups. Third model consist of beam column joint with longitudinal bars of beam as FRP bars. In fourth and fifth models longitudinal bar consist of hybridized FRP bars. First hybridized bar consist of GFRP core with steel crust. The second type of hybridized bar consist of GFRP crust with steel core. Typical view of deflected corner beam column joint is shown in the figure 6.

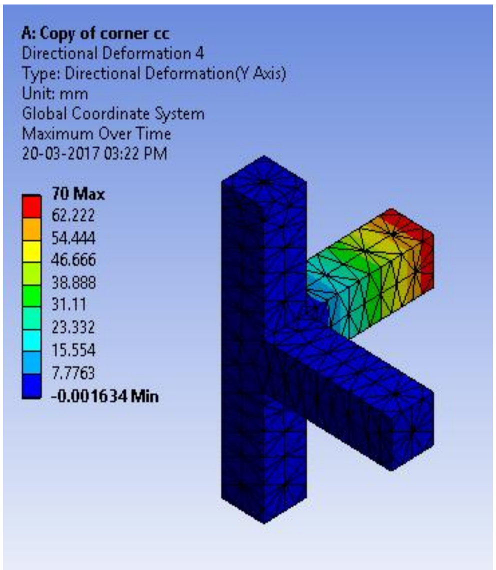

Fig. 6. Typical view of deflected corner beam column joint.

A. Comparison Between Conventional Spiral and Rectangular Spiral Reinforcement at Beam-Column Joint

1) Force –displacement hysteresis response

The force reaction for positive cycle for beam column specimen with conventional specimen is around 45.493kN. For spirally reinforced specimen force reaction increased to 48.305 kN as shown in figure 7. The percentage increment of force required is about 6.2%. This indicates that improvement in the energy dissipation capacity of the spirally reinforced specimen.

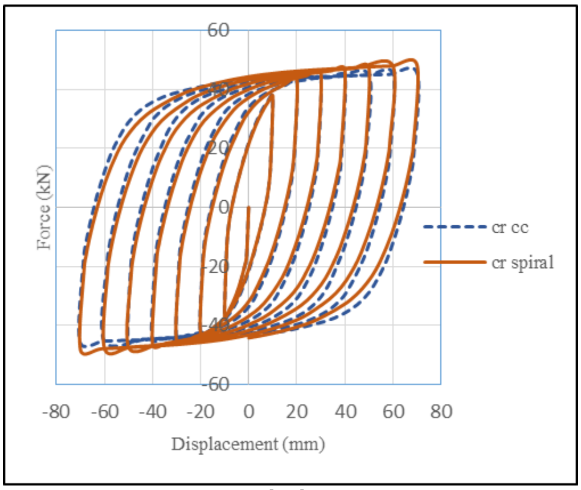

Fig. 7. Force v/s displacement response.

2) Moment reaction

Moment reaction gives the moment developed at beam column joint. For the conventionally reinforced beam column joint large moments are developed compared to the spirally reinforced specimen. For continuously reinforced beam-column joint moment developed is around 1.81×10^6 N-mm whereas in conventional the moment developed around 5.03×10^6N-mm as shown in figure 8. The rate of moment developed at beam-column joint for the conventional type is higher.

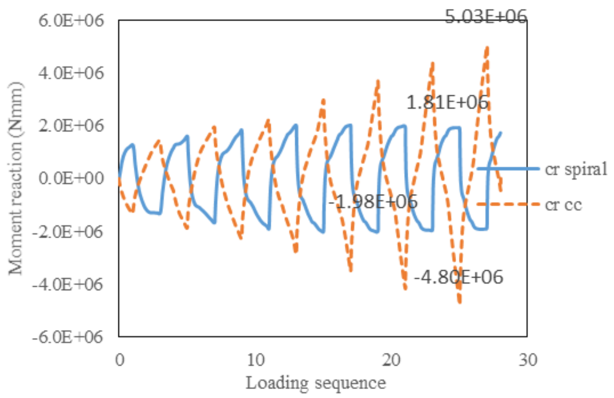

Fig. 8. Moment reaction v/s loading sequence.

B. Comparison Between Rectangular Spiral Stirrups with Longitudinal Bars as Steel and GFRP

1) Force –displacement hysteresis response

The maximum force reaction developed for the spirally reinforced beam column joint was found to be 48.305kN while replacing the longitudinal bars of beam with FRP bars force reaction reduced to 44.041kN, 6.6% of force reaction reduced for FRP bars. Area of hysteresis curve gives the energy absorption capacity. Comparison of hysteresis response of rectangular spiral stirrups with longitudinal bars as steel and FRP at corner beam-column joint is shown in figure 9.

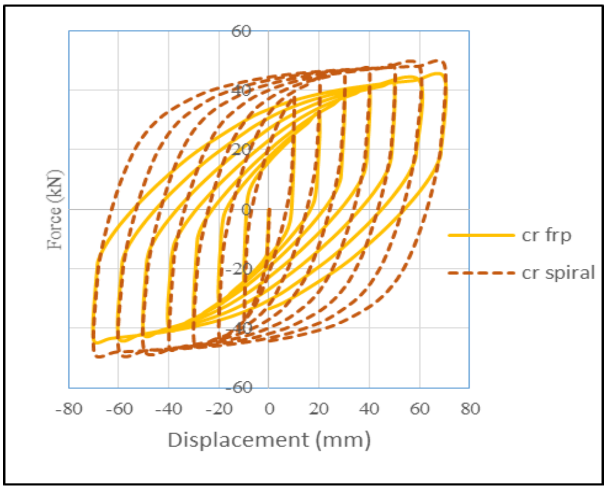

Fig. 9. Force v/s displacement response.

2) Moment reaction

Moment reaction gives the moment developed at beam column joint. Initially lesser amount of moment developed at beam-column joint with FRP bars since FRP having higher tensile strength than that of steel bars. But as the cyclic loading acts the moment transferred to the joint increases at higher rate due to the lower modulus of elasticity of FRP bars as shown in figure 10.

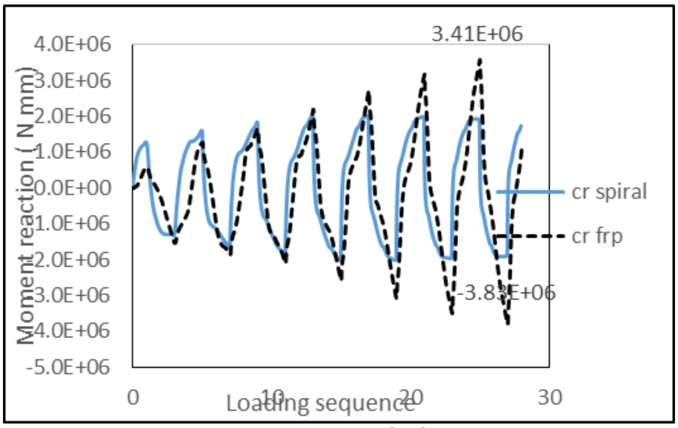

Fig. 10. Moment reaction v/s loading sequence.

C. Comparison of Rectangular Spiral Stirrups with Longitudinal Bars as FRP and Hybridized FRP Bars

1) Force –displacement hysteresis response

FRP bars as longitudinal bars in the beam shows lesser energy absorption. This is due to the fact that FRP bars have lesser modulus of elasticity. So to incorporate the advantages of steel bars, FRP bars need to be hybridized. Combination of FRP bars with steel bars gives the improved properties resultant bar. For studying the hybridized bars two types of hybridization are adopted. First hybridization consist of FRP core with outer steel and second hybridization consist of steel core with FRP crust.

The wider hysteresis curves are obtained for hybridized specimen. Hybridized bars having steel core gives higher resistance to the applied load. The maximum value for force reaction for FRP was 44.041kN and for hybridized FRP bars force reaction increased to 47.374 kN. Hybridized reinforcement using steel core with FRP crust appeared a better behavior in terms of energy absorption capacity. For the FRP reinforced and hybridized FRP reinforced corner beam column joint the force v/s displacement response are shown in figure 11.

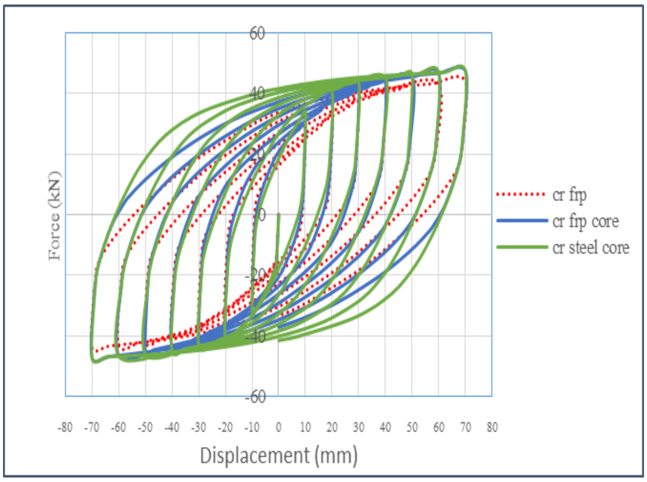

Fig. 11. Force v/s displacement response.

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2) Moment reaction

Lesser moments are developed on the beam column joint with hybridized FRP bars as shown in figure 12. Hybridized FRP having steel core produces lesser moment.

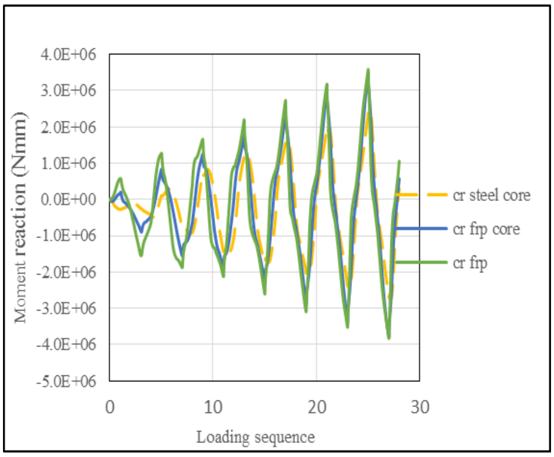

Fig. 12. Moment reaction v/s loading sequence.

D. Summary of Results

1) Force reaction

Table III shows the value of force reaction for corner beam column joint. For corner joint having conventional stirrups force reaction is 45.493kN but value is found to be increased to 48.305 kN for spirally reinforced specimen. For corner joint having FRP longitudinal bars the force reaction is found to be 44.041 kN. The corner joint with hybridized bars the force reaction is found to be 47.374 kN and 47.218 kN for FRP core and steel core respectively.

TABLE III. Value of force reaction for corner beam column joint.

Specimen	Maximum value of force reaction (kN)	
	Positive cycle	Negative cycle
cr cc	45.493	45.404
cr spiral	48.305	48.181
cr FRP	44.041	43.868
cr FRP core	47.374	47.159
cr steel core	47.218	47.071

2) Moment reaction

Table VI shows the value of moment reaction for exterior beam column joint. For corner joint having conventional stirrups the moment developed is around 5.03×10^{6} N mm and for spiral stirrups the moment developed is around 1.81×10^{6} N mm. Corner joint having FRP longitudinal bars the moment developed is found to be 3.59×10^{6} N mm. For corner joint having FRP core and steel core the moment developed is 3.47×10^{6} N mm and 2.36×10^{6} N mm respectively.

TABLE IV. Value of moment reaction for exterior beam column joint.

Specimen	Maximum value of moment reaction (N mm)	
	Positive cycle	Negative cycle
cr cc	5.03×10^{6}	4.80×10^{6}
cr spiral	1.81×10^{6}	1.98×10^{6}
cr FRP	3.59×10^{6}	3.61×10^{6}
cr FRP core	3.47×10^{6}	3.59×10^{6}
cr steel core	2.39×10^{6}	2.71×10^{6}

3) Deformation

Table V shows the final deformation values for exterior beam column models. The deformation of 0.7918 mm is found for conventional spiral specimen and the deformation is decreased to 0.2427 mm for spirally reinforced specimen. For the specimen consist of longitudinal bars as FRP the deformation is found to be 1.4338 mm. For specimen consist of longitudinal bars as hybridized FRP the deformation is found to be 1.035 mm for FRP core and 0.8245 mm for steel core.

TABLE V. Value of deformation for exterior beam column joint.

Specimen	Deformation (mm)
cr cc	0.7918
cr spiral	0.2427
cr FRP	1.4338
cr FRP core	1.0352
cr Steel core	0.8245

IV. CONCLUSION

The beam-column joints for corner connection were analysed using ANSYS software and results were compared for hysteresis response, moment reaction and deformation. Following are the main findings from the study.

- When comparing the exterior beam column joint having conventional stirrups to that of continuously spiral specimen, deformation reduces to 69%, stiffness increased around 6.2 % and lesser moment transfer at the joint region.
- Energy absorption capacity of spiral reinforced specimen is found to be higher than conventional beam-column specimen.
- It can be concluded that seismic performance of spirally reinforced rectangular beam column joint is higher than conventional stirrups for corner connection.
- When comparing the spiral reinforced beam column joint with FRP bars as longitudinal reinforcement in beams to that of spiral reinforced specimen with steel bars gives lesser amount of energy absorption and higher deformation.
- FRP bars needs to be hybridized for the better seismic performance.
- Specimen having hybridized bar shows the improved ductility and lesser deformation.
- Hybridized bars having steel core shows better performance than FRP core.

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