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Research Paper

FINITE ELEMENT MODELING OF REINFORCED CONCRETE BEAM COLUMN JOINT USING ANSYS

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The performance of beam-column joints have long been recognized as a significant factor that affects the overall behavior of Reinforced Concrete (RC) framed structures subjected to large lateral loads. The reversal of forces in beam-column joints during earthquakes may cause distress and often failure, when not designed and detailed properly. In the present study, finite element modeling of four type of exterior beam-column joint specimens is done by using ANSYS11.0. The first specimen conforms to the guide lines of IS 13920: 1993 for seismic resistant design. Second one is detailed with additional diagonal cross bracing bars at joints and beam reinforcements. Third with cross bars in beam region of 6 mm instead of cross bars in joint. Fourth specimen with cross bars of 8 mm instead of 6 mm in beam region.The specimens are subjected to similar reverse cyclic loading to simulate earthquake loading in structures. The experimental resultsfound out by Bindhu and Jaya (2010) is compared with the studies carried out by these finite element models. The comparison shows better performance of the joint when it is provided with cross bars of 8 mm in beam region.

Keywords: Beam column joint, Cyclic load, Ductility, Finite element models, Reinforced concrete, Seismic loading

INTRODUCTION

The beam column joint is the crucial zone in a reinforced concrete frame. It is subjected to large forces during severe ground shaking and its behavior has a significant influence on the response of the structure. The assumption of joint being rigid fails to consider the effects of high shear forces developed within the joint. The shear failure is always brittle in nature which is not an acceptable structural performance especially in seismic conditions.

Understanding the joint behavior is essential in exercising proper judgments in the design of joints. Therefore it is important to discuss about the seismic actions on various types of joints and to highlight the critical parameters that affect joint performance with special reference to bond and shear transfer.

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The anchorage length requirements for beam bars, the provision of transverse reinforcement and the role of stirrups in shear transfer at the joint are the main issue. A study of the usage of additional cross-inclined bars at the joint core shows that the inclined bars introduce an additional new mechanism of shear transfer and diagonal cleavage fracture at joint will be avoided. However, there were only limited experimental and analytical studies for the usage of non-conventional detailing of exterior joints. In spite of the wide accumulation of test data, the influence of cross inclined bars on shear strength of joint has not been mentioned in major international codes. In this work an attempt has been made to improve the confinement of core concrete without congestion of reinforcement in joints.

The performance of exterior joint assemblages designed for earthquake loads as per IS 1893:2002 are compared with the specimens having additional cross bracing bars provided on two faces of joint as confining reinforcements. The experimental results found out by Bindhu and Jayaare (2010) are validated with the analytical model developed using finite element software package ANSYS11.0.

DETAILS OF SPECIMENS

The beam column joints had identical beam and column sizes. The beams were 225 mm deep by 125 mm wide and columns were 225 mm deep by 125 mm wide. Figure 1 shows the cross-section and reinforcement configurations for the specimens. Ordinary Portland cement (53 grade), sand passing through 4.75 mm IS sieve and crushed granite stone of maximum size not exceeding 8 mm were used for the concrete mix. The 28-day compressive strength of the concrete cube was 44.22 N/mm^2. Steel bars of yield stress 432 N/mm^2 were used as main reinforcement and stirrup. The cover for the longitudinal bars was maintained at 15 mm for all the units. Adequate development lengths as per the code requirement were given for the beam longitudinal bars and cross bracing bars to take care of the pull out force.

ANALYTICAL MODELING

The numerical model represents only half of the beam column joint through width used in the experimental investigation. The symmetry boundary conditions are used in order to simulate the tested joint sub assemblages adequately. The beam column joint was modeled in ANSYS 11.0 (1995) with Solid 65, Solid 45 and Link 8 elements. The Solid 65 element was used to model the concrete and Solid 45 element was used to model hinge support at base. These elements have eight nodes with three degrees of freedom at each node-translations in the nodal x, y and z directions. The Link 8 element was used to model the reinforcement. This three-dimensional spar element has two nodes with three degrees of freedom at each node—translations in the nodal x, y and z directions.

Sectional Properties (Real Constants)

The real constants considered for Solid 65 element were volume ratio and orientation angles. Since there was no smeared reinforcement, the real constants (volume ratio and orientation angle) were set to zero. No real constant sets exist for Solid 45 element. The real constants considered for Link 8 element are cross-sectional area and initial strain.

Figure 1: Reinforcement details of specimen of (a) Without Cross Bracing Bars and (b)With Cross Bracing Bars (c) Cross Bars of 6 mm in Beam Region (d) Cross Bars of 8 mm Instead of 6 mm in Beam Region

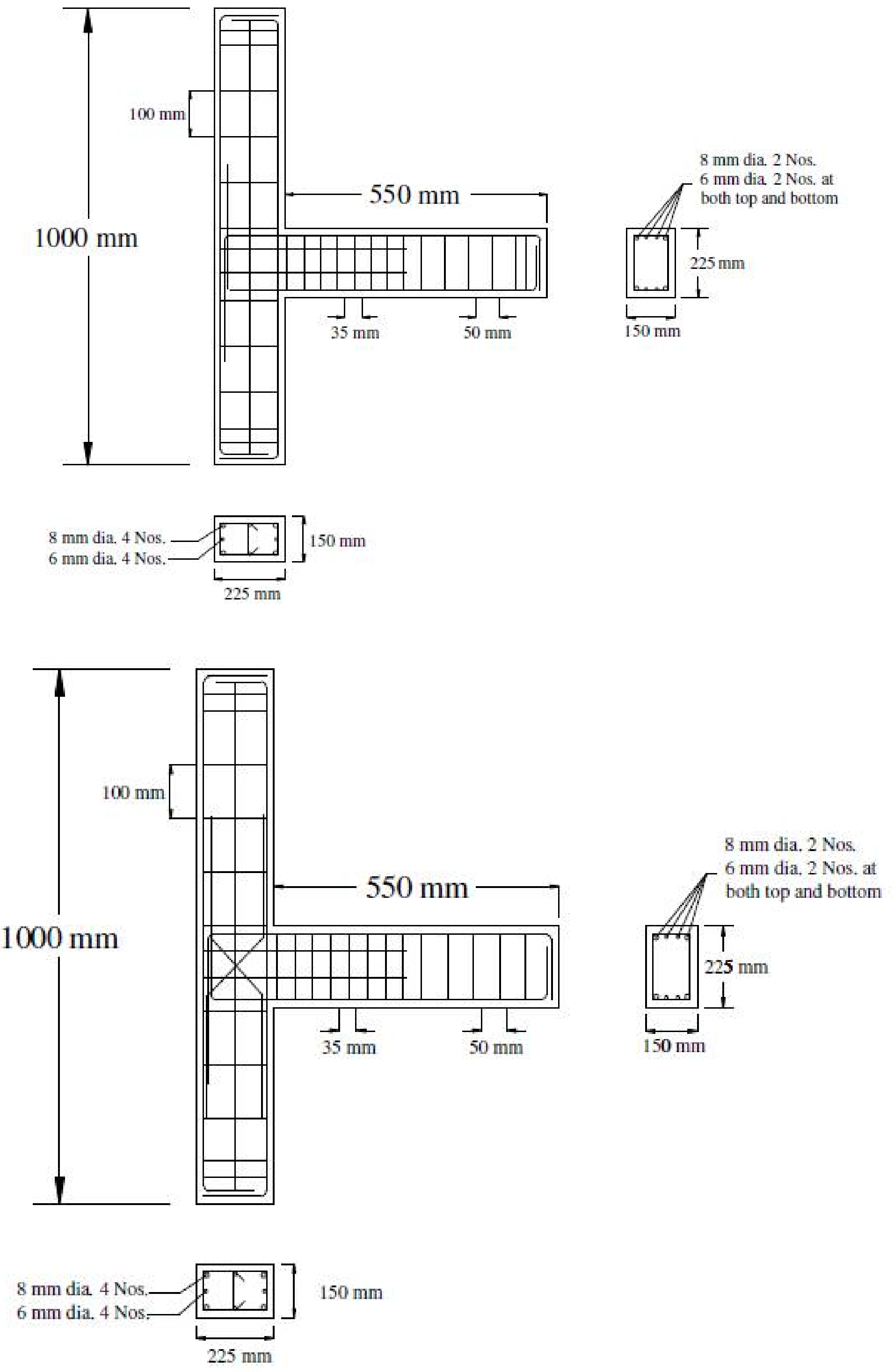
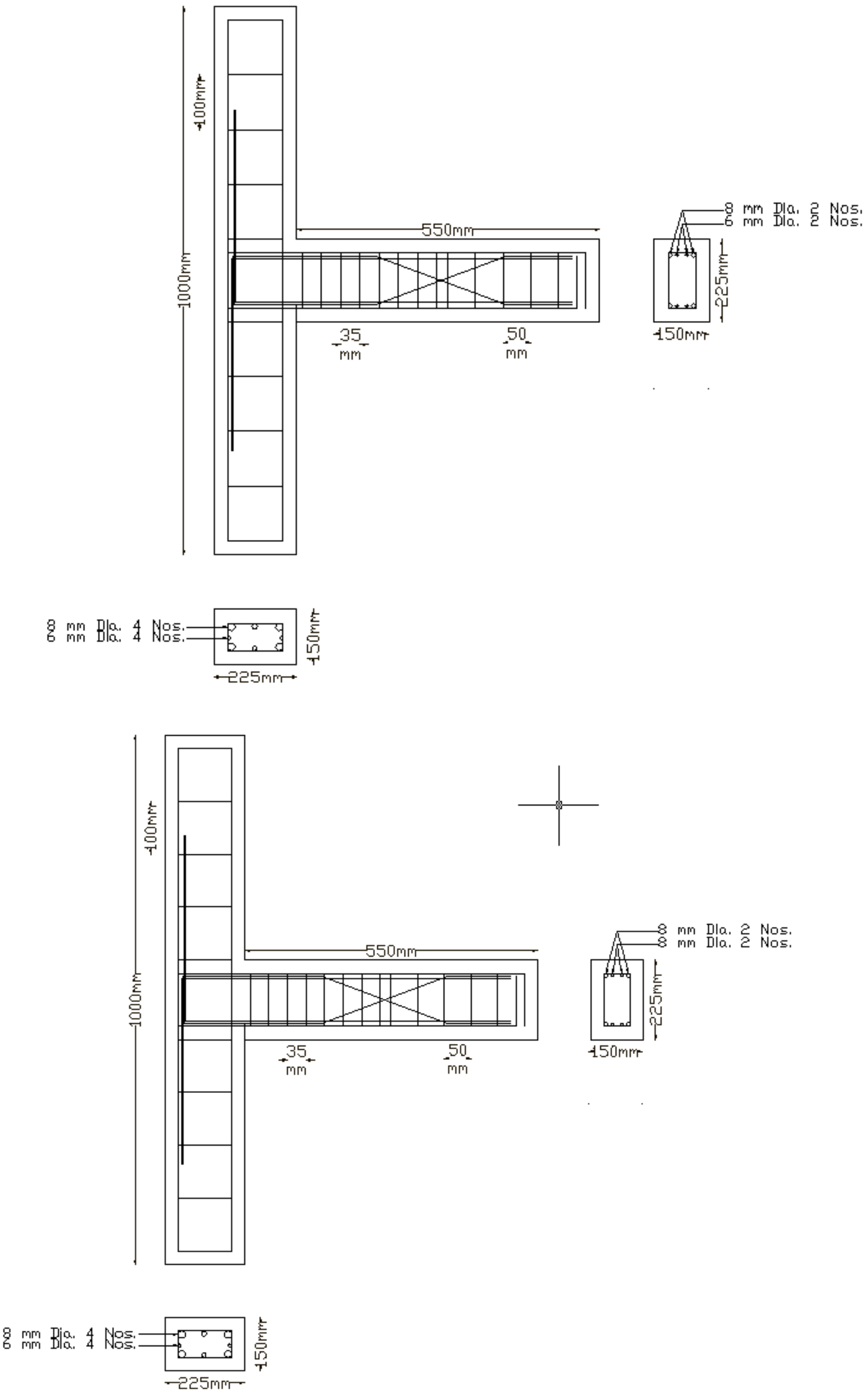


Figure 1 (Cont.)



Material Properties

The material properties used in the model are given in Table 1. The average 28-day cube strength (f_{cu}) of test specimens was 44.22 MPa. The relationship of cylinder strength (f'_{cu}) and cube strength (f_{cu}) as ($f'_{cu} = 0.8 f_{cu}$) and thus the ultimate compressive strength (f_c') was 35.376 MPa. The uniaxial tensile cracking stress of concrete (f_t) is determined using Equation (1)

$$f_t = 0.623\sqrt{f_c'} \quad \text{...(1)}$$

The yield stress and tangent modulus of reinforcement bars were obtained from laboratory test.

$$f = \frac{E\varepsilon}{1+\left(\dfrac{\varepsilon}{\varepsilon_0}\right)} \quad \text{...(2)}$$

where,

f = stress at any strain ε

ε_0= strain at the ultimate compressive strength f_c'

E = a constant (same as initial tangent modulus).

Modeling of Beam-Column Joint

The beam-column joint is modeled in ANSYS11 software using the above element types and the material properties. Some of the modeling details are shown in the Figure 2 and 3. The axial load is applied on the top of the column with hinged base and a roller support at 50 mm from the top. The load on the beam is applied at a distance of 50 mm from the free end. The models were analyzed with monotonic loadings in the upward and downward direction.

RESULTS

Load-displacement relationships for monotonic loading in the finite element model of specimens are shown in Figures 4 and 5. From the graph it is found that the load taking capacity of the specimen with the cross bars of 8 mm in the beam region find more confined than the other three types of the detailing arrangements. Also the defection capacity is improved in this type; moreover the cracks are reduced in fourth case. The Ansys model find stiffer than the experimental results found out by the Bindhu and Jaya (2010). This higher stiffness in finite element models may be due to the non-consideration of the micro cracks in concrete and bond slip of the reinforcement. Thus considering the ultimate load carrying capacities from experimental and analytical studies, the specimens with cross bars of 8 mm in beam region performed well as compared with the other three type of the specimen.

The displacement of the specimen at yield load and ultimate load is shown in the Tables 2 and 3. The table shows the comparison of the deflections carried out by using Ansys model for the fours specimens. A clear idea of the behavior of the specimen can also be drawn from the table.

Displacement ductility of specimen from the Ansys model is shown in the Table 4. It can be observed that the displacement ductility is enhanced for cross bars of 8 mm in beam region specimens than that of other three specimens. The displacement ductility for the specimen with cross bars of 6 mm in beam

Table 1: Material Properties Defined in Model

Material	Model No.	Element type	Material properties
1	Link-Spar8	**Linear Isotropic**	
		EX	2.1x10^{11}N/m^2
		PRXY	0.3
		Bilinear Kinematic	
		Yield stress	432x10^{6}N/m^2
		Tangent Modulus	847x10^{6}N/m^2
2	Solid	**Linear Isotropic**	3.252x10^{10}N/m^2
	- Concrete65	EX	0.15
		PRXY	
		Concrete	0.2
		Shear transfer coefficient for open crack	0.9
		Shear transfer coefficient for closed crack	3.71x10^{6}N/m^2
		Uniaxial tensile cracking stress	
3	Solid 45	Linear Isotropic	2.1 x 10^{11}N/m^2
		EX	0.3

Figure 2: Modeling details in ANSYS using cross bars in joint

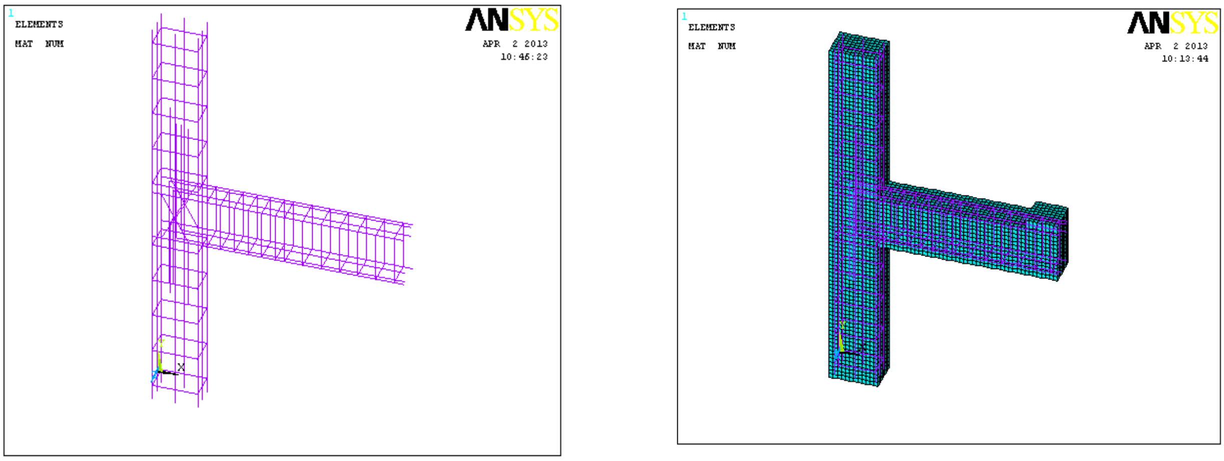


Figure 3: Modeling Details in ANSYS Using Cross Bars in Beam Region

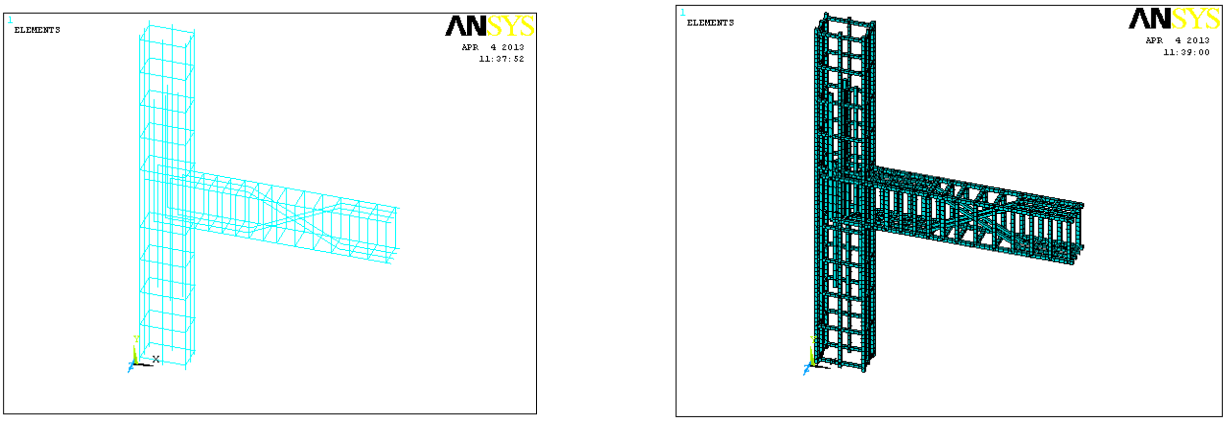


Figure 4: Comparison of Load-displacement Relations of Specimens

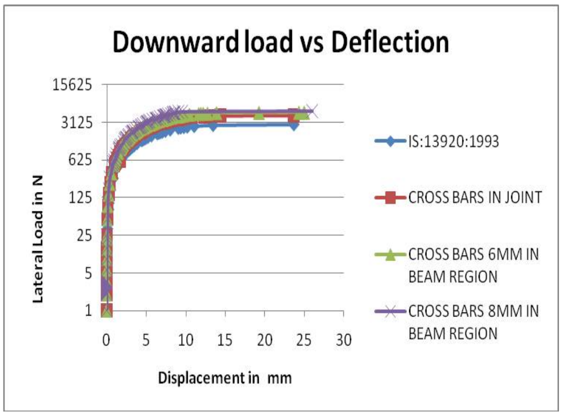


Figure 5: Comparison of Load-displacement Relations of Specimens

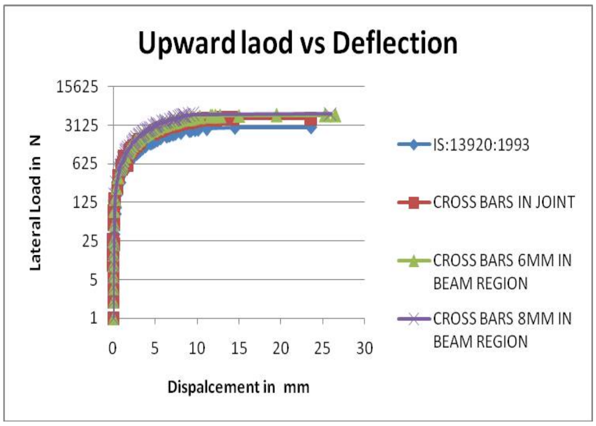


Table 2: Displacement of the Specimen at Yield Load.

Work done	Bindhu and Jaya[1]				Current Work			
Type of Loading	**Experiment (IS: 13920)**	**Ansys (IS: 13920)**	**Experiment (Cross bars in joint)**	**Ansys (Cross bars in joint)**	**IS: 13920**	**Cross bars in joint**	**6mm bars in Beam**	**8mm bars in Beam**
DownwardLoading	4.30	4.95	3.75	4.565	4.562	3.116	2.639	2.417
Upward Loading	4.15	5.445	2.8	4.59	5.415	3.116	2.639	2.425
AverageDisplacement	4.225	5.1975	3.275	4.5775	4.9885	3.116	2.639	2.421

Table 3: Displacement of the Specimen at Ultimate Load

Work done	**Bindhu and Jaya[1]**				**Current Work**			
Type of Loading	**Experiment (IS: 13920)**	**Ansys (IS: 13920)**	**Experiment (Cross bars in joint)**	**Ansys (Cross bars in joint)**	**IS: 13920**	**Cross bars in joint**	**6mm bars in Beam**	**8mm bars in Beam**
Downward Loading	22.55	17.165	35.35	22.97	23.639	23.667	24.332	25.465
Upward Loading	18.05	22.485	21.90	29.545	23.639	23.667	24.332	25.465
Average Displacement	20.30	19.82	28.62	26.25	23.639	23.667	24.332	25.465

Table 4: Displacement Ductility of Specimens from ANSYS Model

		Displacement				**Displacement Ductility**		**Average Dis-placement ductility**
		Yield		**Ultimate**				
Work Done	**Specimen**	**Downward Direction**	**Upward direction**	**Downward direction**	**Upward direction**	**Downward direction**	**Upward direction**	
Bindhu and Jaya	Experiment IS:13920	4.3	4.15	22.55	18.05	5.2441	4.349	4.79655
	Ansys IS:13920	4.95	5.445	17.165	22.485	3.4676	4.1294	3.7985
	Experiment Cross joint	3.75	2.8	35.35	21.9	9.426	7.821	8.6235
	Ansys Cross joint	4.565	4.59	22.97	29.545	5.031	6.4368	5.7339
Current Work done	IS:13920	4.562	5.415	23.639	23.639	5.181	4.365	4.773
	Cross joint	3.116	3.116	23.667	23.667	7.595	7.5953	7.595
	6 mm bars in Beam	2.639	2.639	24.332	24.332	9.2201	9.2201	9.2201
	8 mm bars in Beam	2.417	2.425	25.465	25.465	10.5357	10.501	10.5183

region is increased by 17.62% as compared with the cross bracing bars in the joint region. Also the displacement ductility is further increased in case of cross bars of 8 mm in beam region by 27.79% as that of the cross bars in joint region.

CONCLUSION

The following conclusions can be stated based on the evaluation of the analyses of reinforced concrete beams column joint.

1. The failure mechanism of a reinforced concrete beam column joint is modeled

quite well using FEA, and the failure load predicted is very close to the failure load measured during experimental testing.

2. The test specimens with diagonal confining bars of 8 mm in the beam region have shown better performance, exhibiting higher strength with minimum cracks in the joint. All the specimens failed by developing tensile cracks at interface between beam and column. The joint region of specimens of cross bars is free from cracks except some hair line cracks which show the joints had adequate shear resisting capacity.
3. From the analytical study it is observed that the provision of cross diagonal reinforcement in beam region increased the ultimate load carrying capacity and ductility of joints in the both upward and downward loading conditions.
4. The increase in reinforcing bar cross section has a significant effect on the flexural strength.
5. The entire load-deformation response of the model produced compares well with the response from experimental result. This gave confidence in the use of ANSYS 11.0 and the model developed.

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