ASPS Conference Proceedings 1: 387-394 (2022)

Proceedings of

12th Structural Engineering Convention - An International Event (SEC 2022)

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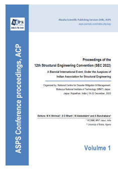

Numerical Study On Response Of Exterior Beam-Column Joint Under Cyclic Loading

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Paper ID - 040347

Abstract

In Present scenario, recent earthquakes have illustrated the severity of existing reinforced concrete (RC) beam-column joints to lateral loading. The sub-assemblage of Beam-Column are severe portion in reinforced concrete moment resisting frame as the high shear forces and larger moments getting attracted towards the joint. The Philosophy of Exterior beam-column joint are to observe its behaviour and has a significant role on the response of the reinforced concrete structure. This study includes numerical study on Exterior reinforced beam column joint with adequate shear reinforcement at joint as per IS: 13920-2016 and without shear reinforcement at joint as per IS: 456-2000. The seismic performance of G+5 RC Building of Zone III analyzed using SAP2000 and output of maximum shear force and bending moments are obtained, and one of the exterior beam-column joints at an intermediate storey is designed and satisfied for strong column and weak beam concept. The earthquake analysis of RC building of Zone III are carried out by incorporating all the modifications as per IS 1893:2002(Part-I) for Seismic loading, the loading is followed as per IS: 875 for dead & live loads and design as per code IS 13920:2016 and IS456:2000. Full scaled specimens were Numerically modelled in ANSYS 19.0 for constant axial load on column top and cyclic loading on beam end of each specimen, detailed as per IS 456:2000 and the other as per IS 13920:2016, were tested and response are obtained. This study outlined that model of IS13920:2016 performs more effective in controlling the seismic responses compared with model of IS456:2000. Further, there is significant reduction in Shear stress and observed improved ductility by providing adequate shear reinforcement in joint core of beam-column sub-assemblage.

Keywords: Beam-Column Joint, Seismic performance, responses, strong column weak beam concept, confinement, detailing.

1. Introduction

The issue of seismic hazard on Reinforced Concrete (RC) frame buildings has been investigated over the years through various strategies and is witness to devastation and destruction of structure due to joint failures. But still from the early decades, significant damages of Reinforced concrete buildings have been caused by earthquake which has been underscored the effect of beam-column joint and has not been area of research for many decades because they treated the beam column joint as rigid joint with no deformation contributed by it. In the philosophy of design, the strong column weak beam concept is recommended and the elastic behaviour of beam column joint is desirable. Sub-assemblage of beam-column has been identified as one of the weaker component of RC Moment resisting frame subjected to seismic lateral loading. In structural design a critical element, beam-column joints play a important role in resisting earthquake loading show that failure may be due to utilization of concrete not having sufficient confinement bars at joint, soft storey mechanism, BCJ failure for poor reinforcements or insufficient anchorage, column failure causing storey mechanism. The beam column joint is subjected to high shear force due to pull and push of the top and bottom bar which is caused because of the reversal nature of the seismic forces. This shear force causes the undesirable brittle failure in the joint core of the beam column joint.To eliminate the undesirable effects in structures, it is necessary to understand the response and behaviour of structural systems subjected to dynamic loads such as earthquake. So providing confinement bars at beam column connection as per IS: 13920-2016 to make our structure ductile is one of the solution which is numerically investigated using ANSYS 19.0 compared results of without confinement bars at BCJ as per IS: 456-2000.

Literature by Lowes et al [1] has discussed and evaluated the modified compression field theory to predict the shear strength of Reinforced concrete beam-column joints. Metelli et al [2] focuses on the evaluation of the joint strength and stiffness, and it points out the importance of modelling the bar bond slip within the panel zone to describe the actual frame response. [3] Experimental study on the behaviour of T-type exterior beam-column joints subjected to cyclic loading, simulating seismic loading and recommended that combination with X-cross bar plus U-bar shows lesser

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Proceedings of the 12th Structural Engineering Convention (SEC 2022), NCDMM, MNIT Jaipur, India | 19-22 December, 2022

Published online: December 19, 2022
doi:10.38208/acp.v1.526

cracks and much better control of crack capacity with improvement in seismic performance for higher seismic prone areas where moderate and severe ductility is in demand. Latest revisions for joint design [4] assure the beam failure to take place before the joint failure and Enhancements in the performance of beam-column joints detailed as per IS 13920 in the reversal of loading.To improve the [5] joint ductility with non-conventional reinforcement and by using steel fibres satisfied by experimental investigation. ShamLai et al [6] has carried out an analytical model is developed to simulate the hysteretic and stiffness degrading behaviour of reinforced concrete members and concluded that it tries to bridge the gap between the sophisticated finite element approach and the very crude discrete models with constant axial load assumptions.

Uma et al [7] Presented review of the postulated theories related to the behaviour of beam-column joints. Recommendation by them is that the damages in style of plastic hinges are accepted to be formed in beams instead of in columns. They reported that the factor impacting the bond transfer within the joint appears to be associated with the extent of axial load and therefore the amount of transverse reinforcements within the joints. The functional requirement of a joint, which is that the zone of intersection of beam and column, is to enable the adjoining members to develop and sustain their ultimate capacity. The demand on this finite size element is often severe especially under seismic loading. The joints should have adequate strength and stiffness to resist the interior forces induced by the framing members. The high internal forces developed at plastic hinges cause critical bond conditions within the longitudinal Reinforcing bars passing through the joint and also impose high shear demand within the joint core.

S. Patil et al [8] has Studied various parameters for monotonically loaded corner and exterior reinforce concrete beam column joint. The exterior as well as corner beam-column joint is analyzed with varying stiffness of beam column joint. The response of exterior and corner beam column joint subjected to monotonic loading is different. Various graphs like load vs. displacement (deformations), Maximum stress, Stiffness variations i.e. joint ratios of beam-column joints are plotted.

It is noted that the anchorage requirements for the beam longitudinal reinforcement and the joint Confinement with adequate shear reinforcement are the main issues related to problems of beam-column connections.

2. Research Significance

In this section, a G + 5 Storey RC building of Zone III is taken for the proposed study. The response spectrum analysis is carried out in the SAP2000 software to determine the forces generated in the members of building. By using the forces obtained by the response spectrum analysis, the structural members are designed as per the IS 13920:2016 (Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces) and IS 456:2000 (Design Of RC Structures). Finally, the Beam column joints are modeled in the ANSYS (Finite Element Method) and are to be analyzed for the Comparison of Model-IS 13920 and Model-IS 456 with shear stresses, and load deformation responses so developed in the beam column joint.

3. Methodology

The present study is based on analysis of a family of reinforced concrete Six-storey RC building frames. These buildings were first Analyzed and then designed using SAP2000. The input data required for the design of these buildings are presented in Table enlisted below.

A G+5 storey RC building in the Zone III and on the medium soil was analyzed, and the shear forces, bending moments, and axial forces around the members of building are induced seismic loading were calculated.

The joint marked "A" in Figure 1 and Figure 2 was considered for the design moment and shear force from the critical load combinations for the beam AB were 212 KN-m and 138 KN, respectively.

Table 1 Preliminary Data

1	*NUMBER OF FLOORS*	*6*
2	Typical floor height	3M
3	Plan dimension in X- direction	3 bays @ 5M = 15M
4	Plan dimension in Y- direction	3 bays @ 5M = 15M
5	Peripheral Wall thickness	250mm
	Inner Wall thickness	150mm
6	Parapet wall	150mm
7	Slab thickness	150mm
8	Size of Transverse beam	300 X 500mm
9	Size of Longitudinal beam	350 X 600mm
10	Size of column	375 X 375mm
11	Grade of concrete and Steel	M30 and FE415.

Table 2 Loading Parameters

1	*Response spectrum loading*	*X-Direction*
2	Response spectrum loading	Y-direction
3	Dead loads	
A	Floor	4.75KN/m^2
B	Walls	
	i) Peripheral Wall (Longitudinal)	12KN/m
	ii) Peripheral Wall (transverse)	12.5KN/m
	iii) Internal Wall (Longitudinal)	7.2KN/m
	iv) Internal Wall (transverse)	7.5KN/m
	v) Parapet wall	3KN/m
	Live load	
	Typical floor	3KN/m^2
	Terrace floor	1.5KN/m^2

Table 3 Earthquake Parameters

SR. NO.	*PARAMETER*	*CODE PROVISION*
1	Type of Structure	RC moment resisting structure
2	Nature of building	Residential
3	Seismic zone	III
4	Importance factor	1
5	Response reduction factor	5(SMRF)
6	Soil type	Medium
7	Damping	5%

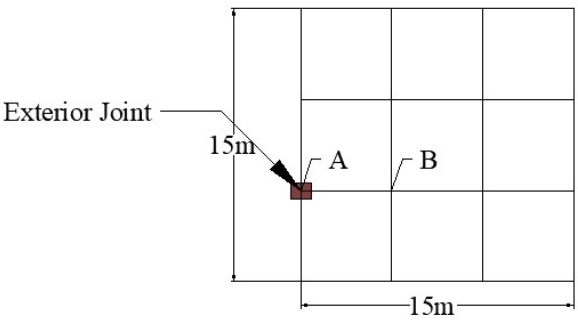

Figure 1 Plan view of RC building

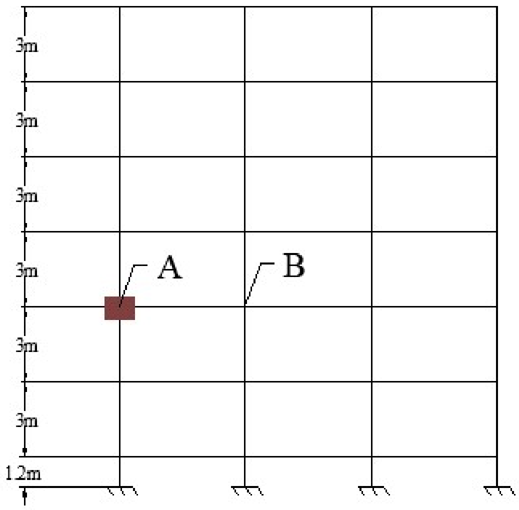

Figure 2 Elevation of RC building

Table 4 Force Results of Beam AB

S. No.	*Load combination*	*Left End (A)*		*Right End (B)*	
		Shear force (kN)	**Moments (kNm)**	**Shear force (kN)**	**Moments (kNm)**
1	1.5(DL+LL)	-114.479	-100.7813	115.2	-102.58
2	1.2(DL+0.25*LL+ELX)	-50.12	30.43	133.63	14.20
3	1.2(DL+0.25*LL-ELX)	-133.05	-191.68	50.70	-178.34
4	1.5(DL+ELX)	-33.95	66.36	**139.48**	43.20
5	1.5(DL-ELX)	**-137.61**	**-211.28**	35.82	**-197.48**
6	0.9DL+1.5ELX	-103.36	95.35	104.42	74.05
7	0.9DL-1.5ELX	-103.30	-182.29	104.74	-166.62

Similarly, for exterior column was designed for an axial load of 1525 KN and a moment of 84.3 KN-m, which were the critical values obtained from the thirteen different load combinations.

3.1. Design for Exterior joint

The joint is to be designed for the strong-column weak-beam condition, for the earthquake ground motion in the X- and Y-directions and Joint shear strength is calculated as per IS 13920:2016.

Figure 3 shown above is the SAP2000 output designed as per IS 456:2000 and checked as per IS 13920 and SP16 for design criteria, which is used for the calculation of joint shear strength of exterior beam-column joint as per IS 13920:2016.

3.2. Equation used for Joint strength and transverse reinforcement calculation as per IS13920:2016

In an exterior Joint, the column shear (V_{col}), tension force in the reinforcement (T_b) and joint shear force (V_{jh}) is calculated are follows

$$V_{col} = \frac{M_h}{l_c} \tag{1}$$

$$T_b = 1.25 f_y A_{st} \tag{2}$$

$$V_{jh} = T_b - V_{col} \tag{3}$$

Where M_h is the Hogging moment at end A of transverse beam, l_c is the storey height, f_y is yield strength of steel, A_{st} is the longitudinal reinforcement of transverse beam.

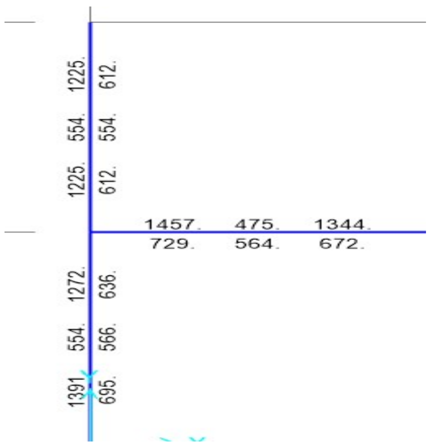

Figure 3 Reinforcement detail of Transverse beam and columns of RC building

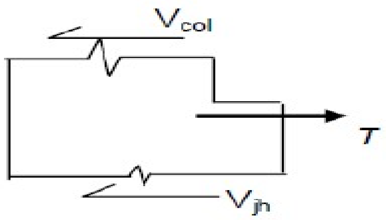

Figure 4 Force acting on Exterior beam column joint

Table 5 Effective joint width

Sl. No.	*Category*	*IS 13920:2016*
1	$b_c > b_b$	Min. of $[b_c, b_b + 0.5h_c]$
2	$b_b > b_c$	Min. of $[b_b, b_c + 0.5h_c]$

The effective width *bj* of the joint as per IS 13920:2016 is given in table 5.

Where, b_b denotes the width of the beam, h_c *is* the depth of the column in the considered direction of shear.

The effective shear area A_{ej}, of the joint is equal to bj*hj where hj is the depth of the joint which can be taken as the depth of the column.

3.3. Nominal shear strength of joint is calculated as

$$V_{nj} = \gamma\sqrt{f_{ck}}A_{ej} \quad (4)$$

Where, ϒ=1.2 for confined on three face.

- F_{ck} = characteristic strength
- A_{ej} = bj*hj (joint area)
- *ϒ* is the strength coefficient

3.4. Transverse Reinforcement

As per clause 8.1 of IS 13920:2016, the area of rectangular hoop

$$A_{sh} = 0.18 * S * h * \left(\frac{f_{ck}}{f_y}\right) * \left[\frac{A_g}{A_k} - 1\right] \quad (5)$$

Flexural strength ratio

As per IS13920:2016 it should be

$$\left(\frac{\sum M_c}{\sum M_b} \geq 1.4\right) \quad (6)$$

Thus, all the joint sub-assemblages considered for the Numerical study were checked for shear strength and the strong-column weak-beam theory. The only difference was in the arrangements of transverse reinforcement. Special confining reinforcement was provided in the joint region with detailing as per IS 13920. In the Indian concrete code of practice, IS 456 joints are not provided with stirrups.

4. Finite Element Modeling

The finite element method (FEM) is a numerical approach for analyzing structures. Basic principle of FEM is to make calculations at finite number of points and interpolating the results.

4.1. Concrete modeling

SOLID65 is preferred for 3-D modeling of solids with or without reinforcing bar. The solid is capable of cracking in tension and crushing in compression. Since we know Concrete betray large number of micro cracks, especially, at the interface between closer aggregate and mortar, even before subjected to any load. The presence of these micro cracks has a great effect on the mechanical behavior of concrete. Hence SOLID65 is selected for element which is defined by eight nodes having three degree of freedom at each node: translations in the nodal x, y, z directions.

4.2. Steel reinforcement

To model rebar, discrete modeling is preferred by assuming that bond between steel and concrete is 100 percent. Column beam has six degree of freedom at each node. These include rotation about x, y, z directions and Translation in the x, y, z directions. This element is well-suited for linear, large rotation, and large strain nonlinear applications. Hence link180 element is used.

4.3. Material Properties

Table 6 Material Properties

Materials	**Density (Kg/m^3)**	**Elastic modulus (MPa)**	**Poisons ratio**	**Fck (MPa)**	**Fy (MPa)**	**Element used**
Concrete	25000	29250	0.2	30		SOLID65
Reinforcing steel	7850	2e5	0.3		415	Link180

4.4. Numerical program

The model of the exterior beam-column joint is full scaled and modelled in ANSYS 19.0. The dimensions and reinforcement details of the models are shown in Figures 5 and 6. The models are classified into two groups, The Model-IS 13920 is designed with reinforcement detailed as per IS 13920 (BIS, 2016) and The Model-IS 456 is detailed as per IS 456 (BIS, 2000). Both models are tested under constant axial load with cyclic load at the end of the beam.

A constant column axial load of 17380 N (1.13% of axial load) applied on column top and for cyclic loading at the beam end, a vertical displacement at the beam end was applied in a slowly increasing as Push and Pull, with result recorded for every 5 mm vertical displacement. Graph shown in Figure 7 is vertical displacement graph.

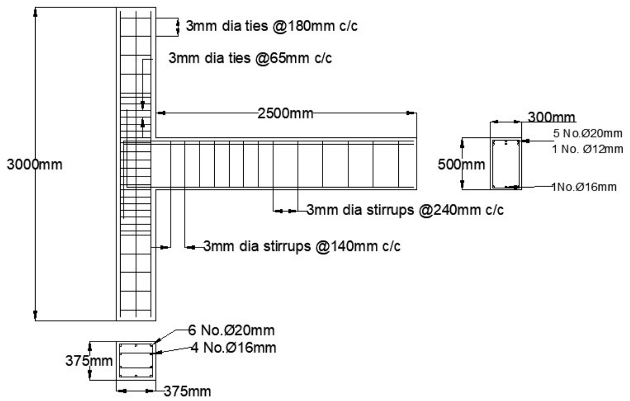

Figure 5 Reinforcement details of Model-IS 13920

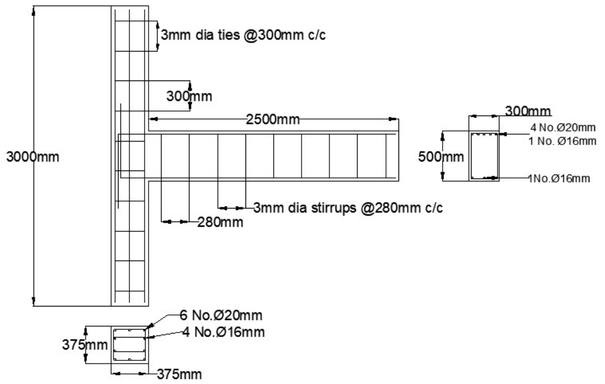

Figure 6 Reinforcement details of Model-IS 456

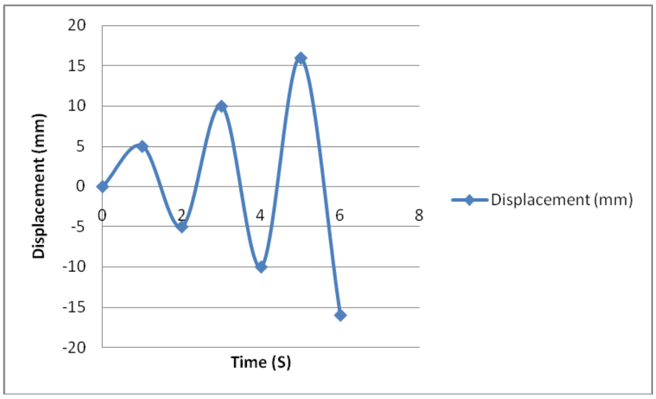

Figure 7 Vertical Displacement curve

5. Results and Discussion

The test results are obtained after performing the finite element analysis of the beam column joint using ANSYS workbench which are presented in the form of Joint shear strength Vs Joint force in exterior beam column joint for Zone III G+5 building and checked for strong column weak beam theory, load-deformation hysteretic curves for both Models are obtained using ANSYS 19.0, Maximum shear stress, Maximum Principal stress are represented below.

Table 7 Force Results of Exterior beam column joint

Earthquake	*Vcol (KN)*		*Tb(KN)*		*Joint Capacity Requirement (KN)*		*Joint strength provided (KN)*
	Sway to right	**Sway to left**	**Top**	**Bottom**	**Sway to right**	**Sway to left**	
X-direction	98.9	44.8	756	378	656.8	333.3	924
Y-direction	120.4	123.2	977	965	857	842	924

5.1. Joint strength Vs Joint Capacity Required

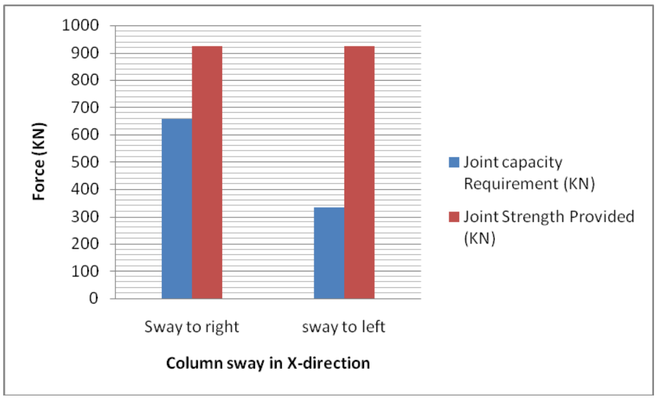

Figure 8 Joint Force Results of Earthquake in X-direction

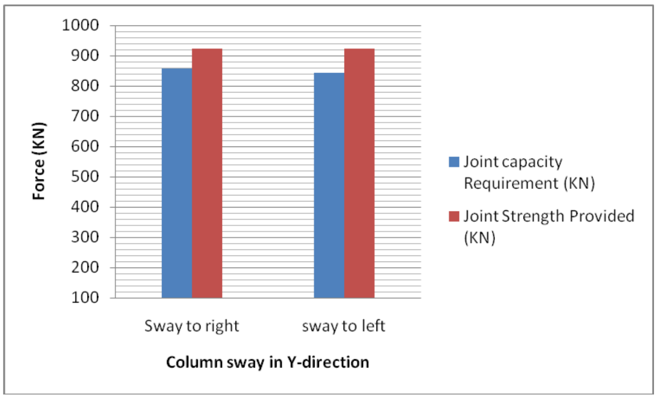

Figure 9 Force Results of Earthquake in Y-direction

From above Figure it is clear that Joint strength is more that Joint Capacity requirement. Hence exterior beam column is safe designed.

5.2. Check for strong column weak beam theory

Table 8 Flexural Strength Ratio

Earthquake forces	*As per code IS 13920(2016)*	*Obtained value of Flexural strength Ratio*
X-direction	$\left(\frac{\sum M_c}{\sum M_b} \geq 1.4\right)$	1.641
Y-direction	$\left(\frac{\sum M_c}{\sum M_b} \geq 1.4\right)$	1.506

Hence, it is checked for strong column and weak beam theory and it satisfy the required Flexural strength ratio as per IS 13920:2016.

5.3. Load-deformation hysteretic curves for both Models are obtained using ANSYS 19.0, Maximum shear stress, Maximum Principal stress

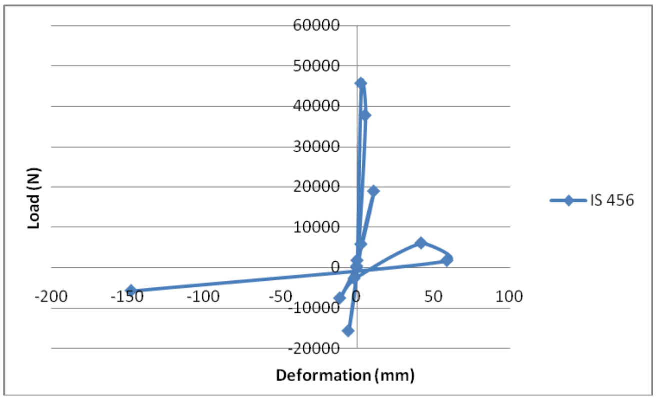

Figure 10 Hysteresis curve for Model-IS 456 of exterior beam column joint

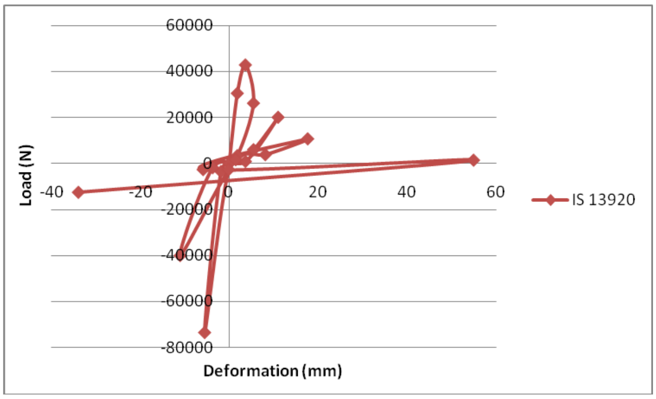

Figure 11 Hysteresis Curve for Model-IS 13920 of exterior beam column joint

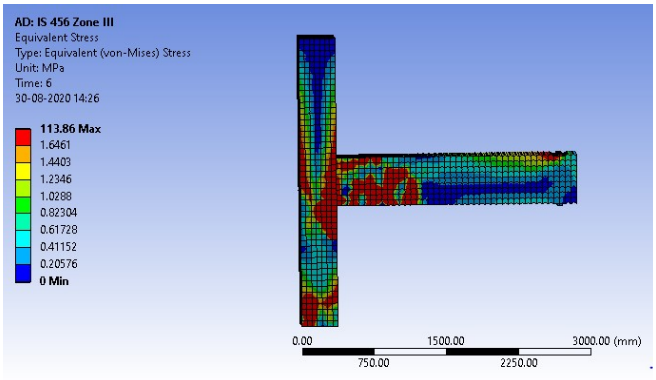

Figure 12 Equivalent stress of Model-IS 456

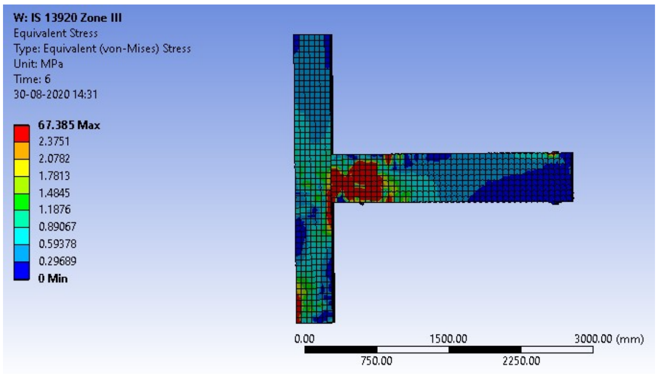

Figure 13 Equivalent stress of Model-IS 13920

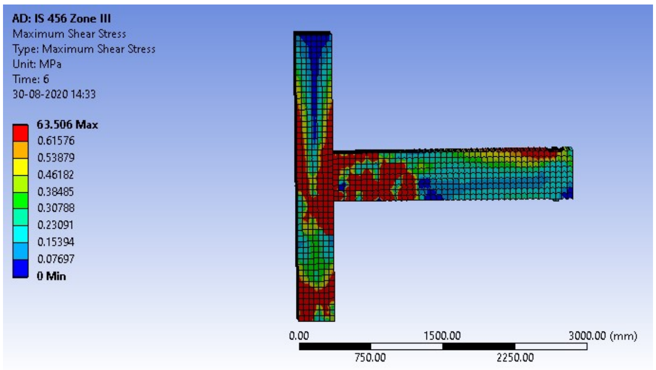

Figure 14 Maximum shear stress of Model-IS 456

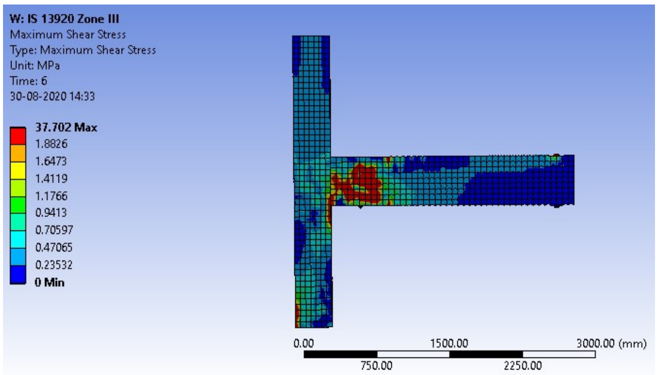

Figure 15 Maximum shear stress of Model-IS 13920

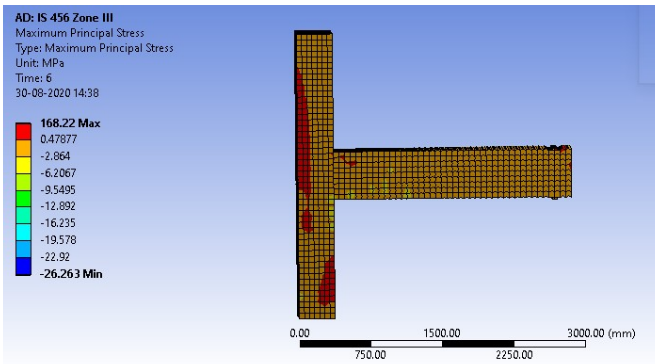

Figure 16 Maximum Principal Stress of Model-IS 456

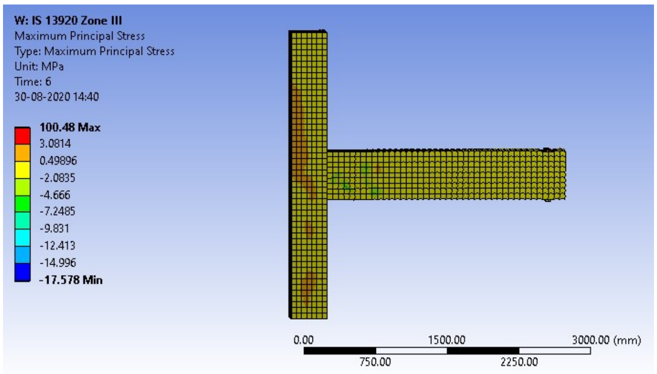

Figure 17 Maximum Principal Stress of Model-IS 13920

5.4. Crack pattern of Exterior beam column joint

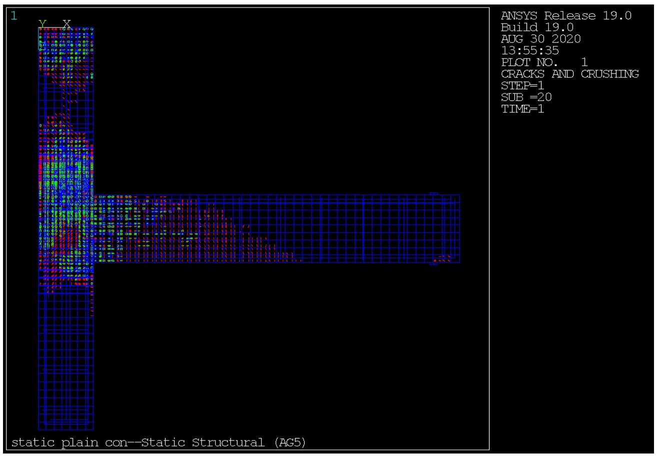

Figure 18 Crack Pattern of Model-IS 456

In this section the numerical results of both with transverse reinforcement and without transverse reinforcement in the joint section are interpreted. Their behaviour throughout the analysis is studied from the recorded data obtained from the Load and deformation behaviour, crack pattern, maximum shear stress, maximum Principal stress using ANSYS.

- From hysteresis curve, provided transverse reinforcement in joint section increases the ductility of beam column joint as well as load carrying capacity.

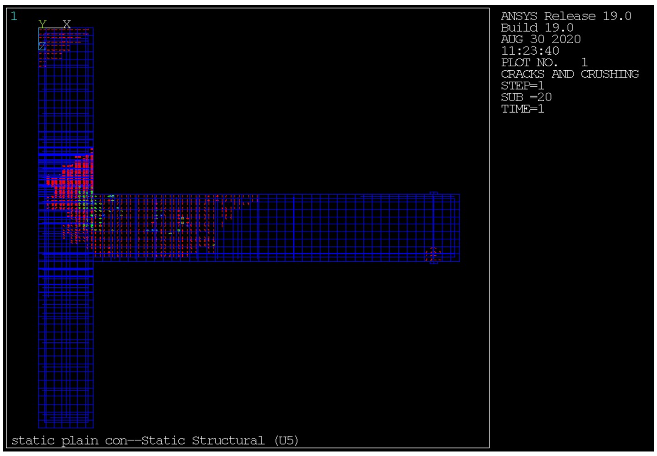

Figure 19 Crack Pattern of Model-IS 13920

- Shear stress value for IS 456 specimen is 63.50MPa where as IS 13920 has 37.702MPa. Hence shear stress is reduced up to 40.6% by providing adequate shear reinforcement at the joint core.
- Equivalent stress and Maximum Principal Stress in IS 456 is 113.86MPa and 168.22MPa and for IS 13920 is 67.385MPaand 100.48MPa.

6. Conclusion

The objective of investigation was to evaluate the response of the exterior beam-column joints designed and detailed as per codes IS 1893 (BIS, 2002) and IS 13920 (BIS, 2016) for the earthquake-resistant design. Both models were designed for adequate shear strength in the joint and to satisfy the strong-column weak-beam theory. One model was made with the special confining reinforcement as per the provisions of IS 13920. The effect of special confining reinforcement on the behaviour of joint has been studied by comparing the test results of another model which is detailed without the special confining reinforcement. Following conclusions have been drawn from this study

1. Comparing the numerical investigation we can say that the deflection in the confined model is comparatively lesser than that of the unconfined model.
2. It is observed that the stress in the specimen is better in the transverse reinforced in joint core when compared with the normal specimen without transverse reinforcement.
3. Ductility on structure is improved and load carrying capacity is increased.
4. Crack pattern in confined specimen is less as compared with unconfined specimen.
5. Hysteresis curve of both specimen is compared and found IS 456 model gives more deformation compared with IS 13920 model it means IS 13920 model has increased its load carrying capacity.
6. Adequate reinforcement in joint core of the beam column joint reduce the failure of the joint from column portion to the beam portion of joint which will prevent progressive collapse.

Disclosures

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