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Analysis Of Interior Beam Column Joint with Enhanced Reinforcement

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Abstract: Beam-column joints are taken into consideration as the vital zones of failure. In realistic condition, extending the beam reinforcement into the column under the soffit and supplying confining reinforcement at ends of beam column joint, will causes clogging of reinforcement. In order to keep away from this clogging we must lessen the improvement period of the bars and growth the spacing of confinement bars such that no failure occurs. RC frame members subjected to lateral loads has long been recognised as being influenced by the show of beam column connection. During earthquakes, the forces in beam column joints can causes stress and, in some cases, failure. In such instances overall performance beam column joints are analysed to conquer from failure in joint phase of contributors and growing the spacing of confining reinforcement without compromising the ductile capacity.

Keywords: Beam, Column, Earthquake, Ductile Capacity, Reinforcement

1. INTRODUCTION

1.1 General

In these RC systems, beam column joints were connecting regions of the building frame, and are accountable for load transfer among them. Therefore, complex forces, including compressive, tensile, and shear forces, act on beam column joints. During the earthquake, beam column joints are subjected to dynamic forces. Under dynamic loads, it faced sever stress and failure of bonding rebars with concrete. The collapse of the joint point may simply cause damage to the column loading paths and have an effect on the ductility and power dissipation ability of the body as a whole. Frequent stress may worsen the condition, ultimately in brittle fracture and the development of the bent part of the rod. Due to its apparent severe loss of bond formation and lack of strength, the longitudinal reinforcing bar is pulled out when made flat. At any level, this kind of failure is inexcusable. As a result, they must be developed to spend high amounts of power without experiencing significant loss of energy or stiffness.

Reinforced details on beam column joints are designed as per strong column - weak beam. Reinforced details on beam column joints are crucial for enhancing design stiffness within the joint in addition of X-shaped bracings in joints and will reduce the damages to concrete under fatigue failure. FEM modelling and analysis of interior beam column joints under reverse cyclic loading, using normal reinforcement steel, with x-shaped bracings at the joints, and various factors affecting the failure of joints under reverse cyclic loading conditions. The interior joints are studied with different parameters like maximum principal stress, maximum shear stress, displacement, yield load, ultimate load, displacement ductility and energy absorption capacity. The results from model are verified with experimental results by Jianxin Zhang et.al (2022)

1.2 BEAM COLUMN JOINTS

In structures, the stress resisting frames, beam column joints are segment of pillars that are common to all beam at their crossovers. In the case of a Static Load, these connections produced systems are up to fundamental parts with finite strengths and, as a result, limited tension reducing capacity. As a result, while displacements stresses were carried out at some point of earthquakes, such joints might also significantly get broken. Moreover, repairing of broken joints is difficult, and as a consequence harm should be averted with the aid of using enough layout and detailing in advance.

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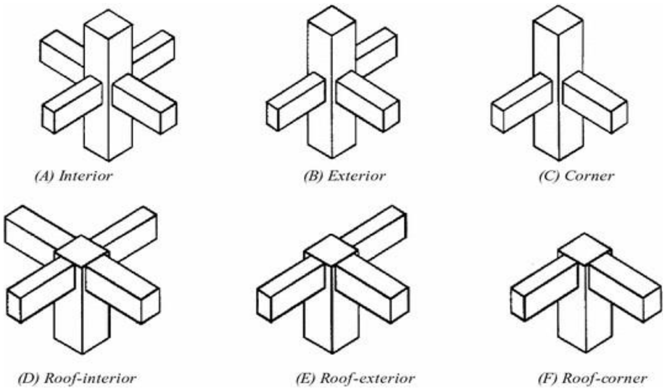
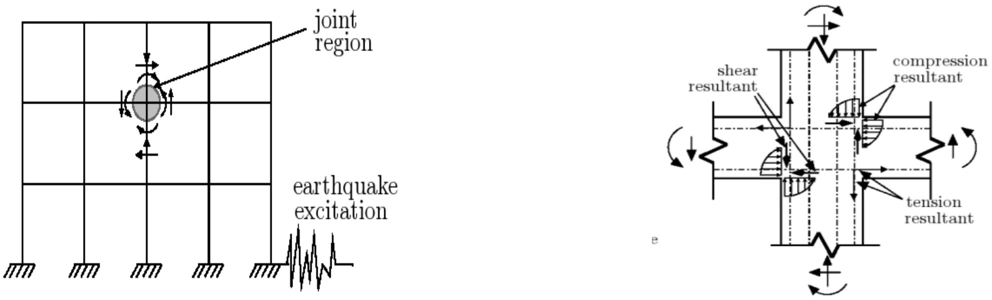


Fig. 1.2: Types of Beam Column Joints [Internet Source]

1.3 Behaviour of Beam Column joints Under Seismic Loading

Shear modulus and tension loads are experienced by beam or column in 2D frame joints subjected to earthquake loads. The expected rise in forces in a 2D solid component due to seismic and static loads. Furthermore, while the most recent seismically constructed structures are exposed to moderately severe seismic forces, it is widely predicted that the beams will develop flexural energy on the joint at the very same instant as columns will generate stresses that surpass the movements. Similarly, cracking of beams and columns or lateral buckling of columns in older frameworks could also prevent beams from attaining compromising flexural strength. Fig.1.3a illustrates the expected forces and their consequences at the joint's perimeter. As seen in Fig.1.3b the loading might cause significant loading inside the joint core. Furthermore, huge shearing stresses are developed well within joint due to the quick inversion inside the structural elements.



a) Frame with interior joint b) Detail view of joint

Figure 2: Beam Column joints Under Seismic Loading

1.4 Objectives of Study

The scope of the thesis includes a Non-linear Finite Element analysis of beam column joints with enhanced X-shaped bracing in joint region. Two interior beam column joints experimentally tested by Jianxin Zhang et al (2022) are considered in this study. The dimension of beam-column joints connections is as following

- Column of 350mmx350mm with a story height of 2.8m and
- Beam of 250mmx400mm with length of 3.4m c/c.

1.To design Interior beam-column joints as per IS 456:2000 and IS 13920:2016.

Finite element analysis is performed in ANSYS workbench 2022 to find the structural performance of beam column joints

2.To study the behaviour of Beam-Column Joint connection under Reverse Cyclic loading system.

3.To study the Load vs Displacement in the interior beam column Joints.

1.5 Methodology

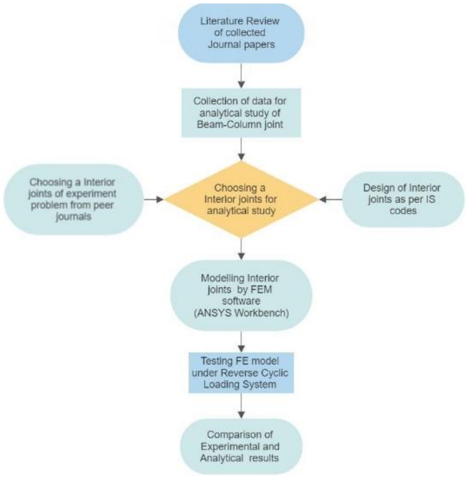


Figure 1.5 Flow of methodology for analytical study of interior joints

1.6 Organization of Thesis

The present thesis is divided into five chapters. An overview of each chapter follows.
Chapter 1 titled "Introduction" deals with introduction of beam-column joints members including types of beam-column joints and behaviour of for interior beam-column joints under seismic loading Further, objectives of the study, methodology are also presented.
Chapter 2 titled "Literature review" presents the various past research works conducted by investigators to understand the behaviour of for interior beam-column joints subjected to different loading system.
Chapter 3 titled "Design and Detailing Of Beam Column Joints" discussions including finite element modelling, nonlinearity, meshing, material properties, analysis type, failure criteria and non-linear solution techniques.
Chapter 4 titled "Modelling and Analysis" It involves procedure to create FE models for interior beam-column joints used in the present study. The contour plots for deflection and typical stress state obtained by performing FE analysis for interior beam-column joints are also presented in this chapter.
Chapter 5 titled "Results and Discussion" comprises the comparison between the results obtained from FE analysis and experimental results. The results of parametric study are also presented in this chapter.
Chapter 6 titled "Conclusions" discusses about the important conclusion drawn from the present study.

2. LITERATURE REVIEW

1.K BINDHU et.al (2009) - *"Performance of Exterior Beam-Column Joints under Seismic type loading"* -The aim of research was to determine how well the outer beam column joint performed overall. The behaviour of joints was researched by analyzing the testing of the required samples, which were all developed to satisfy the stronger column poor beam hypothesis. The development of stress fractures just on joint between columns and beams caused plenty of the samples to failure, ensuring that the stronger column poor beam circumstances were met. With the exception of a hairline splitcracks, the joint zone was devoid of defects, and the joints exhibited adequate shear resistance. Rising overall applied forces upon column enhances stress capacity and toughens the joints. Thus, unfortunately, lowers a joint's load dissipation as well as ductile. The samples using distinct confined reinforcements, as defined by IS13920, exhibited better stress dissipation but those with horizontal reinforcement detailed, as specified by IS456 and SP34. The fractures as in current investigation were centered upon this beam column joint but rather the beams portion for all samples. Like a result, a joint detailed design has been developed in order to displace the plastics hinge as in portion of beams zone [1].
2.SREEKUMAR K.J et.al (2011) - *"Seismic Resistance of Exterior Beam Column Joint with Diagonal Collar Stirrups"* -In this paper the ductile behaviour of joints determines the seismic structural performance of moment resistant structural systems. The sample with extra beam and transverse neck stirrups has approximately equal lateral load capacities to the IS -13920 sample and is virtually equivalent to a sample without extra beam reinforcing. In addition, the sample with greater tie space at joints yielded negative findings, indicating a loss in load bearing capabilities. The elasticity of the sample with lateral collared stirrups and beam reinforcing was higher than that of the sample required by IS13920 without collared stirrups and higher than that of the sample specified by IS13920 with additional beam reinforcing. The energy-

absorbing efficiency of the sample intended with lateral collared stirrups, as well as beam supports, is superior than the sample described in compliance to IS13920 [2].

3.MINAKSHI V et.al (2015) - *"Performance of RC Beam –Column Joint Connections Subjected to Cyclic Loading"* -Under dynamic loadings, ductile responses such as elasticity, stress, and flexural stresses were used to assess the effectiveness of beam column joints. In addition to shear rebars at the joint and insufficient binding of the lower rebars of beams, the controlled sample showed significant shear losses associated with sliding the lower rod beams. The main beam rods bonding requirements were damaged by the degradation in mixtures at the governing joint, resulting in a substantial drop in strength and compliance with bonding parameters. Flexural crack had found for the duration of second cycle at drift ratio of 1.2 percent with cyclic load of 15.3 kN down for altered specimen. The most load in push axis occurred with drift ratio of 5.6 percent had value of 40 kN, pull direction, the max load at a drift ratio of 5.6 perc. had a value of 31.1 kN for altered specimen [3].

4.R. SIVA C et.al (2015) - "*Seismic behavior of hybrid fiber reinforced cementitious composite beam–column joints*" - In this study, they looked at the dynamic response of externally beam column joint with HPF in the joint. By use of different HPF in assembly improves the lateral stiffness of a joint as well as its pre/post performance. HPF joint samples are compared to traditionally restricted joint samples in terms of overall looping behaviour. The ductility and post yield bending strength of HEC joint samples were about twice as high reduced joint samples. HPF joint samples with extensive scattered splitcracks show a continual reduce of strength. Within the same flexibility value, the damaging index for HPF joint samples was substantially lower than that for traditionally restricted joint samples [4].

5.REKHA S PATEL et.al (2015) - *"An Experimental Study on Effect of Diameter of Rebar on Exterior Beam Column Joint"*-In this paper, the maximum load bearing capacity enhanced when the dimension of steel rods was reduced, and the maximum bending also reduced. In comparison to sample 2or3, the load bearing capacity of sample1 enhanced and the bending reduced by 10 perc. In comparison to specimens with wide stirrup design, beam column joints with narrower spacing have improved load bearing ability and eventual bending. In comparison to some other samples, the bending moment of sample4 lowered by 15 perc. The link between concrete and steel been improved by using different diameters rods, resulting together in substantially reduced fracture thickness. It is capable to achieve increased elasticity by raising the no. of rods and lowering the dimension of rods. The ductility ratio for sample1 was 25 percent greater than for sample3 & 12 times better than for sample2. Several and densely packed crack were generated via supplying narrower stirrups, halting crack formation [5].

6.SUDIP CHAPAGAI et.al (2017) - *"Experimental study on size effect of RC beam-column joint with and without hybrid fibres under cyclic loading"*-This study report looked at three differrent types of samples: Traditional beam-column joints were compared to SF/HF reinforced concrete beam-column joints in terms of shear strength. SF and HF increase a variety of qualities, such as flexibility ratio and energy release, with regard to time of significant, as per research. With comparison to similar Standard samples, the advantage in ductility due to HF/SF increased. When compared to regular samples, HF/SF exhibit a huge increase in shear strength. All fibres used in Hybrid form provide a superior matrix. This possessed the ability to collect fractures as a function of recombination, significantly enhancing qualities. The maximum stress per unit volume of the joint matches the standard sample. HF concrete joints gives a better improvement for max load bearing than SF and traditional samples [6].

7.HONG YANG et.al (2018) - "*Seismic behavior comparison of reinforced concrete interior beam-column joints based on different loading methods*"-The aim of the experiment was always to determine the seismic behaviour of inner beam column connections when loading was applied to the beam outer edge and column upper edge. After applied load, the loss to the 4 Column edge samples was concentrated with in joint core, having few but bigger longitudinal fractures dispersed throughout the joint, whereas the loss towards the 4 beam edge samples appeared throughout the joint, with compact and tiny crack. The modification in loading approach had a significant impact on horizontal beam rod slip response. The deviated angle of the post component loading to a Column edge was more natural, however the Beam edge worked well in test [7].

8.JACK P. MOEHLE et.al (2018) - "*Shear Strength of Exterior and Corner Beam-Column Joints without Transverse Reinforcement*"-A study looked at the stiffness of edge beam column joints without transverse reinforcing rods exposed to reversed compressive load to simulate seismic effects. Typical hooks were used to secure horizontal beam reinforcing inside the joint. Reducing overall column lateral load, raising the proportion of beam thickness to pillar depths, plus yielding inside the adjacent horizontal frame all represents a portion shear capacity. Several models were created for different sorts of joints, such as stronger joints and joints with a wider range of imperfections. ACI318 frame simulation parameters are used to create a beam column joint model. joint element size, column's axial force, plus compressive stress was all included in this edition [8].

9.ROMANBABU M. OINAM et.al (2019) - *"Cyclic performance of steel fiber-reinforced concrete exterior beam-column joints"*-The results of research on beam column joint samples exposed to transverse dynamic loading are presented. The purpose was to evaluate how effective SF reinforced concrete would be decreasing shear stirrups in Flexural members having solid column/poor beam at beam column joints. The slightly bent arrangement for beam rebars

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with inside beam column joints led into shear failure in core even deformation of beam with original rebars forms, according to test results. Even without transverse rods in the beam column joints, all SF model had equilateral stiffness, energy dissipation, or mechanism of breakdown. Moreover, under applied loads, the ultimate stress of SF beam column joints showed better tolerance [9].

10.MARGHERITA P et.al (2020) - *"Semi-empirical model for shear strength of RC interior beam-column joints subjected to cyclic loads"*-Analysis of outgrowth to RC inner beam column joints of such prototype for strength properties is presented in this paper. The suggested design formula was proven by the 25 samples of beam column joints that have been developed for the shear according to Euro/ACI standard. As the central compression stress of the column rises, the lateral joint reinforcing ratio to longitudinal shear strength reduced, while the concrete shear capacity is better. The shear stirrups have the highest effective stress proportion, that is equivalent about 23 percent. Lateral rods were more efficient that to longitudinal stirrups in adding shear capacity to internal beam column joints [10].

11.BISWAJIT ROY et.al (2020) - *"Construction joints in substandard beam-column connections subjected to cyclic loading*"-The influence of a structural member connections in multi-story inferior beam column joints were explored in this research. Were 3 test samples containing control and jointed specimens were tested, delivering varying amounts of beam column reinforcement, subjecting it to fatigue tests. As transverse & longitudinal reinforcing, low carbon steel rods were adopted. Damages were mostly seen in beam column joint, the external surface of column, or the beam first at column surface in each of the samples. The maximum movement tolerance of the standard & joint samples are almost similar, with the exception of the sample, who had a 20% fall in breakdown movement relative with sample2. The max ductile and final dampening ratio drop was observed to be 17percent. It was discovered that the maximal variance in energy absorption potential was 12percent [11].

12.MOHAMMD S. A et.al (2021) - *"Seismic performance of R.C buildings with Beam-Column joints upgraded using FRP laminates"* -The effects and outcomes of CFRP on the dynamic loads on weak building are studied in this research using Non-linear analyses below the base displacement intensity of a chosen earthquake. Due to seismic forces, the vital beam column joints in the original research construction were overloaded well over collapse limit. Even though suggested CFRP technique elevated column shear, it enhanced the research construction project seismic response to the appropriate safety criterion. Improved the stress tolerance of the experimental building beam by 14percent and column by 25persent. Overall inelastic twists were lowered nearly about 20percent for beam & 26percent for column. CFRP technique may greatly enhance the dynamic capability of seismic vulnerable structures and are usually best [12].

13.JIANXIN ZHANG et.al (2022) - "*Seismic performance of HSS reinforced interior beam-column joints with high-strength steel fiber concrete and enhanced reinforcements*"-To improve the performances of HSS rods, research study assessed the use of high strength steel rods as horizontal reinforcing and high-strength steel fibre concrete in the joints. The elastic behaviour of internal beam column joints with HSS rods was examined using a mixed algorithm that included HSSFC plus X form rods improved bracing. The total effectiveness of HSS in interior joints was investigated using seismic loading to assess the impacts of higher reinforcement. Furthermore, superior binding ability between HSS rods and HSSFC reduced slip of horizontal rebars in beam and bending tensions, resulting in significantly reduced bond slip at beam edges [13].

14.S. S. PATIL et.al (2013) – *"A Study of R.C.C. Beam-Column Connection Subjected to Monotonic Loading"* -This study examined the behaviour of corner and outside beam-column junctions as well as the support circumstances while applying quasi-static loads. i.e., monotonic loading on the beam's cantilever end. Minimum stress and maximum stress both rise as load increases displacement. When compared to an external beam column junction, the corner beam column joint behaves differently. Minimum stress and maximum stress alter non-linearly as the structure's stiffness varies [14].

15.JERIN S SEBASTIAN et.al (2016) – *"An Analytical Investigation on Improving Ductile Reinforcement of Exterior Beam Column Joints"* -This research examines the possible use of steel plates as anchorages and the usage of steel fibres in confined areas. They noticed that employing plates as anchorages can increase the ductility of the junction. It was discovered that inserting plates in the centre of the beam-column junction's column width increased ductility. The IS specimen's maximum load carrying capacity and limit state capacity have both drastically decreased. The maximum allowed load is increased by using steel fibres and mechanical anchorages with stirrup spacing of 100mm [15].

16.GIUSEPPE SANTARSIERO et.al (2018) - "*FE Modelling of the Seismic Behaviour of Wide Beam Column Joints Strengthened with CFRP Systems*"-In order to boost seismic capacity when a wide beam is present, this study proposes a feasible configuration of strengthening methods using Fibre Reinforced Polymers (FRP) systems. Large beam-column junctions without a strengthening mechanism were used to calibrate in-depth nonlinear finite element models. Then, a FRP strengthening intervention based on a new arrangement was modelled in order to run further simulations under seismic activity. It was shown that significant strength and ductility gains may be achieved utilising a very simple and affordable training setup. This approach was used to assess the effectiveness of the strengthening intervention [16].

17.MOHAMED I.S. ELMASRY et.al (2018) – *"An Analytical Study of Improving Beam-Column Joints Behaviour Under Earthquakes"* -In this research, we offer a finite element model of an external beam-column junction that may be used to mimic the behaviour of such joints in traditional RC frame structures built for gravity loads. Multiple samples are analysed, including one for the control (unstrengthened) condition and others for the stronger conditions (using a variety

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of methods). Banded joints utilising CFRP sheets are one method of study for reinforcement. Each scenario is modelled, and then the analysis of incremental loading to failure is performed. Each case's stress and deformation data is analysed and compared to the others. The beam-column joint's structural stiffness, strength, and energy dissipation capacity may all be improved by CFRP, as shown by numerical data [17].
18.PRANALI WASNIK et.al (2021) – *"Cyclic load Analysis of beam column joint using ANSYS"* -In this case study, six samples with varying characteristics are selected and designed using ANSYS using ductile detailing IS 139202016 and nonductile detailing's IS 4562000. The results suggest that adding lateral reinforcement increases shear strength. The shear strength of all samples is strong, which enhances the load bearing capacity and displacement, particularly with the inclusion of stirrups at L/3andL/4 scales [18].

3. DESIGN AND DETAILING OF BEAM COLUMN JOINTS:

3.1 General

Beams and columns in moment resistant frames are joined at a single location known as the beam-column junction, where the slab may or may not be present. Because the joints are believed to be stiff in RC constructions, beam column joints are crucial zones for properly transmitting loads between connected parts. Because of the poor design practise of beam column joints, there is a strong need for mobilising their inelastic powers to disperse seismic energy in real buildings and how it interacts structurally with the parts framing into a junction. Interior beam column joints are studied in this work, and test data is drawn from experiments done by Jianxin Zhang et al (2022). Section 3.2 discusses the experimental work.

3.2 Experimental Details of Jianxin Zhang et.al (2022)

Jianxin Zhang et.al (2022) studied and conducted an experimental work to resist the seismic force in the interior beam column joint with enhanced X-shaped bracing reinforcement at the joint core to investigate load vs deformation, reduced fatigue failure in the joints. The dimension of beam columnjoints connections is as following.

- Column of 350mmx350mm with a story height of 2.8m and
- Beam of 250mmx400mm with length of 3.4m c/c.

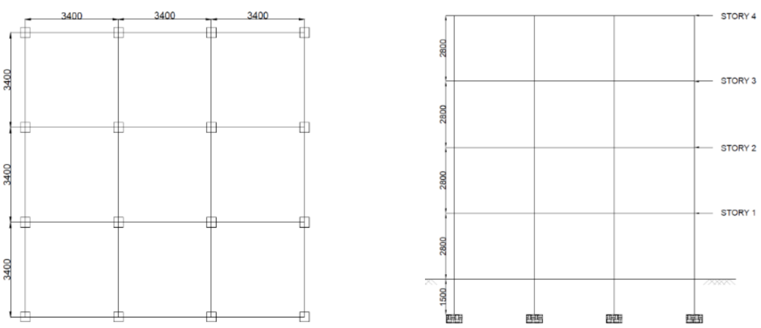
Table 3.2 Details of tested interior joints

Interior joints	Designed as per	Concrete strength (MPa)	Steel strength (MPa)		Loading system
			longitudinal	stirrups	
IN2	GB 50011-2010	35	HRB600	HRB400	Reverse cyclic
IN2-X	GB 50011-2010	35	HRB600	HRB400	Reverse cyclic

3.3 Analysis of Four Storey Building

A four-story reinforced concrete structure in the Chennai neighbourhood was chosen for the examination of joints' behaviour using Etabs. The Chennai region is located in seismic zone III, which is vulnerable to powerful earthquakes, according to IS: 1893–2016. For this research, an examination of buildings with earthquake resistance is taken into account. The bay's length was 3.4 metres in both directions, and each floor's height was 2.8 metres. Figure 3.3 illustrates elevation and plan drawings, respectively.

It is generally accepted that the unit weight of concrete infill is 25 kN/m3, whereas the unit weight of masonry infill is 20 kN/m3. The selfweight of the beams, the wt. of slab, and the weight of the masonry infill made up the dead load on the beams. It has been expected that the live loads on the floorsandroof will be 3.0 kN/m2 and 1.5 kN/m2, respectively. Considering that the earthquakeloads are greater than the windloads and that there is a height restriction on the structure.



(a) Plan (b) Elevation

Figure 3.3: RC frame considered in present study (a) Plan (b) Elevation

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3.4 Design and Detailing's of Interior beam column Joints

The design and detailing's described the dimensions of the specimens, load calculations, reinforcement details are solved by Etabs and the choosing the critical interior beam-column joint of story2 for the analysis. The design specifications are considered based on code IS 456:2000, IS 13920:1993 and SP 34.

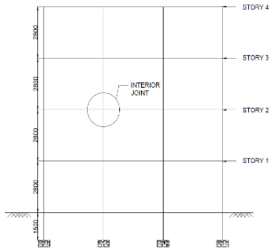
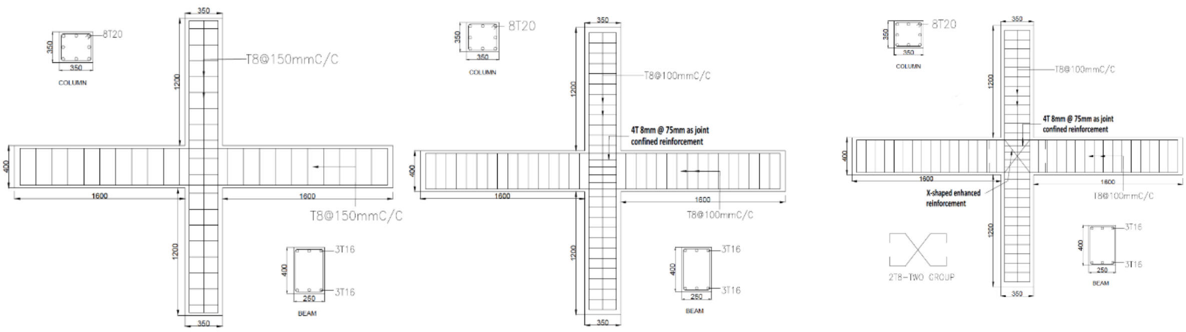


Fig 3.4.1 Critical interior beam column joints of story2

Table 3.4: details of interior beam column

Columns		Beams	
Dimension	350mmX350mm	Dimension	250mmX400mm
Longitudinal reinforcement	#8-20mm dia. bars	Longitudinal reinforcement	#6-16mm dia. bars
Stirrups (2L – 8mm dia. Bars)	@150mm C/C (BCJ 456)	Stirrups (2L – 8mm dia. Bars)	@150mm C/C (BCJ 456)
	@100mm C/C (BCJ 13920)		@100mm C/C (BCJ 13920)
	@100mm C/C (BCJ 13920-X)		@100mm C/C (BCJ 13920-X)
#2- 8mm group of X-shaped bracing at joint region with Ld of 0.1 of width of beam			

The following models are considered for the study:



a) BCJ-456 b) BCJ-13920 c) BCJ 13920-X

Fig 3.4.2 Detailing's of beam column Joints

4. FE MODELLING OF INTERIOR BEAM COLUMN JOINTS

4.1 Finite Element Modeling of RC beam column Joints

Interior beam column modelling and analysis using ANSYS Joints subjected to reverse cycle stresses, using standard reinforcing steel, diagonal crossbars placed at the joints, and other factors affecting joint failure. Maximum core stress, tensile stress, displacement, yield load, ultimate load, displacement ductility, and energy absorption capacity are studied for interior connections. The answer to the structure is obtained by formulating and combining constituent properties. In FEA, modelling takes up 40% to 60% of the whole solution time. Unreliable structural modelling leads to incorrect solutions. Runtime for solutions is decreased by good geometry idealisation. It is possible to correctly analyse three-dimensional structures as two-dimensional structures. Time and memory are saved by using creative thinking while idealising and meshing the structure. There are three stages in ANSYS joint modelling.

- Choosing of element type
- Assigning material characteristics
- Modelling and meshing of a geometry model.

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Table 4.1 ANSYS elements

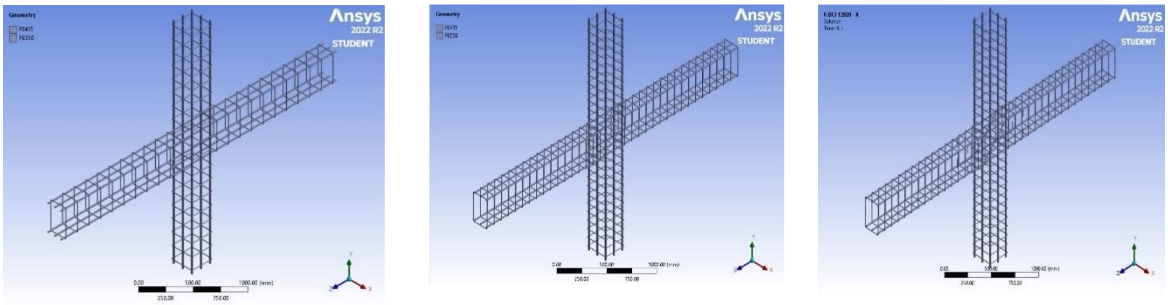
Material's	Ansys Element
Concrete	Solid 65
Steel	Link180

4.2 Modeling of Interior beam column joint models

The following interior beam column Joint models are taken into consideration for the study and are listed in Table 4.2 below. The typical views of the reinforcements detailed as per code IS 456:2000 and IS 13920:1993 produced by the Ansys programme are displayed in Figures 4.2.1 and Figure 4.4.2 illustrates typical views of the Ansys-generated control beam column joints.

Table 4.2 Details of the Specimen

Interior joints	Design and Detailing's	Concrete grade	Steel reinforcement		Loading system
			longitudinal	stirrups	
BCJ-456	IS456:2000	M30	FE550	FE415	Reverse cyclic
BCJ-13920	IS 13920:2016	M30	FE550	FE415	Reverse cyclic
BCJ-13920(X)	IS 13920:2016	M30	FE550	FE415	Reverse cyclic



a) BCJ-456 b) BCJ-13920 c) BCJ 13920-X

Figure 4.4.1 Reinforcement Detail's as per IS codes

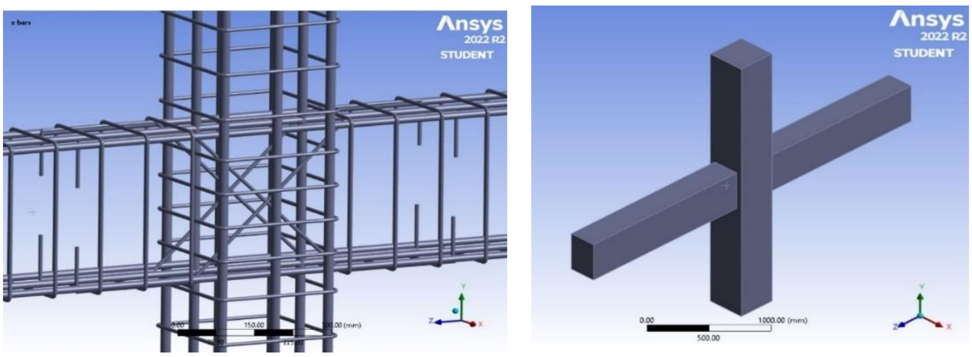


Fig 4.4.2 Typical View of X- shaped bracing reinforcement in joint and Concrete model of a Control Beam column Joints

4.3 Finite Element Discretization

After the model has been created, meshing is the first stage in finite element analysis. The model is therefore split into a number of finite parts. The choosing of the mesh density is an essential stage in finite element modelling. When a model has an acceptable number of elements, the results converge. The number of items selected has a direct relationship to how accurate the findings are. It is advised to use rectangular-shaped mesh with a meshing size of 50mm for the internal joint model.

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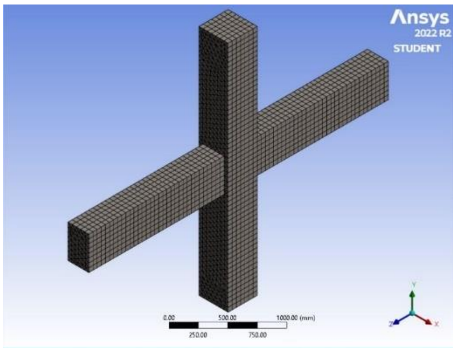

Figure 4.3 Typical View of Mesh of Interior Beam-Column Joint

4.4 Application of Loads and Boundary Condition

In order to limit the model and get a singular solution, displacement boundary conditions are required. Boundary conditions must be added at places of symmetry, where the supports and loadings are present, and at other locations to guarantee that the model behaves in the same manner as the experimental beams. With hinged boundary criteria, each column end was given. A steady load was given to one of the column ends. The free end of the beam received a transverse load. In order to achieve a regulated deflection, an experimental research was used to determine the load applied for the model defined in accordance with code IS 456:2000. Figure 4.4 depicts the model described in code 13920:1993 with the same load applied.

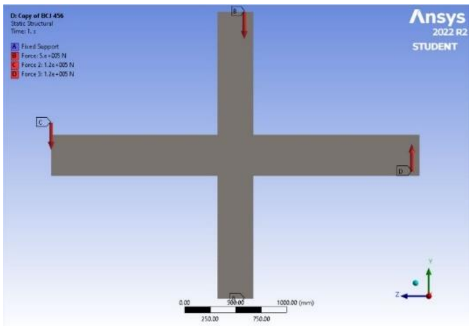

Figure 4.4 loading condition on interior beam-column joint

5. RESULTS AND DISCUSSIONS

The main aim of this thesis is to compare the finite clement model and the interior beam column joints of Jianxin Zhang et.al (2022) and ensure that the elements in interior joints, properties, real constant and convergence criteria suitable to model in ANSYS Workbench 2022 R2 and behave similar to experimental beams.

5.1 Model verification

In this section, the finite element analysis results of the 3 categories of interior joints were reported and correlated with the test results (Jianxin Zhang et.al 2022). For the interior joints, load verses deflection behavior was considered as a main parameter to verify the finite element model. In experimentally tested interior joints, LVDTs used to record the deflection of beams. FEM performance was validated with experimental results. The following subsection describes the correlation of the finite element models.

5.2 Load and Deflection Interior Beam Column Joints

The FEA for modeled beams obtained from ANSYS Workbench 2022 R2 showed good response over experimental results. The ultimate deflection values for interior beam column joints from FEA, experimental values are shown in table 5.2. Reverse Cyclic load with 30kN increment is applied at the beam end and the deflections were observed. From the figure it is seen that the joint got stressed more at joints than the ends. Since the beams are symmetrical the deflections were similar in the end's beams.

Table 5.2 Ultimate displacement at ends of beams for interior joints

Specimen ID	Deflections for Experimental model in mm (Δ_{exp})	Deflections for Ansys model in mm (Δ_{any})	% Errors in results
BCJ's 456	-	75.81	-
BCJ's 13920	94.5	102.9	8.90%
BCJ's 13209-X	100.6	113.2	11.13%

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5.2.1 Load and Deflection Interior Joints BCJ 456

The interior joint BCJ-456 is designed as per IS 456-2000, when it is subjected to reverse cyclic loading on joints it shown maximum deflection of 75.81mm at 100kN as shown Figures 5.2.1.1. Load and deflection of values of each loading cycle are tabulated in Table 5.2.1. Load vs deflection curves for Interior joints BCJ-456 specimen is shown in figure 5.2.1.2. which showed non-linear behaviour in beam column joints in both the direction of applied load.

Table 5.2.1 Load and Deflection values for BCJ-456

Applied load (Py) in kN		BCJ-456	
		Load(kN)	Displacement(mm)
0.25 Py	upward direction	25	12.3
0.5 Py		50	26.25
0.75 Py		75	44.9
1.0 Py		100	75.81
-0.25 Py	downward direction	-25	-12.3
-0.50 Py		-50	-26.25
-0.75 Py		-75	-44.9
-1 Py		-100	-75.81

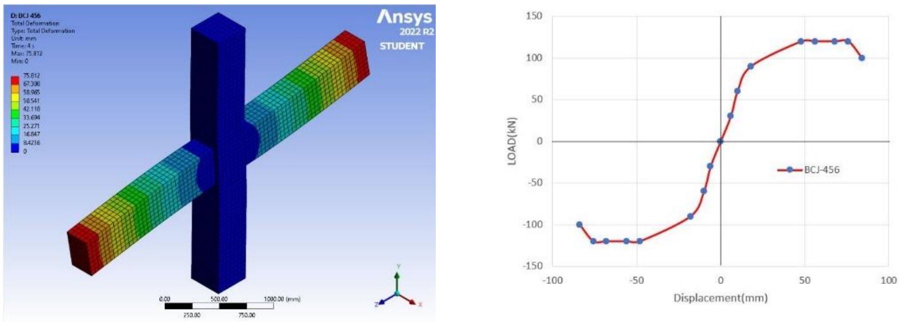

Figure 5.2.1 Load vs Displacement of model and curves for Interior joints model (BCJ 456)

5.2.2 Load and Deflection Interior Joints BCJ 13920

The interior joint BCJ-13920 is designed as per IS 13920-2016, when it is subjected to reverse cyclic loading on joints it shown maximum deflection of 102.9mm at 120kN as shown Figures 5.2.2.1 when Load and deflection of values of each loading cycle are tabulated in Table 5.2.2. Load vs deflection curves for Interior joints BCJ-13920 specimen for finite element model and experimental model is shown in figure 5.2.2.2. which showed non-linear behaviour in beam column joints in both the direction of applied load at the beam ends.

Table 5.2.2 Load and Deflection values for BCJ-13920

Applied load (Py) in kN		BCJ-13920	
		Load(kN)	Displacement(mm)
0.25Py	upward direction	30	16.8
0.5 Py		60	40.9
0.75 Py		90	72.9
1.0 Py		120	102.9
-0.25 Py	downward direction	-30	16.8
-0.50 Py		-60	40.9
-0.75 Py		-90	72.9
-1 Py		-120	102.9

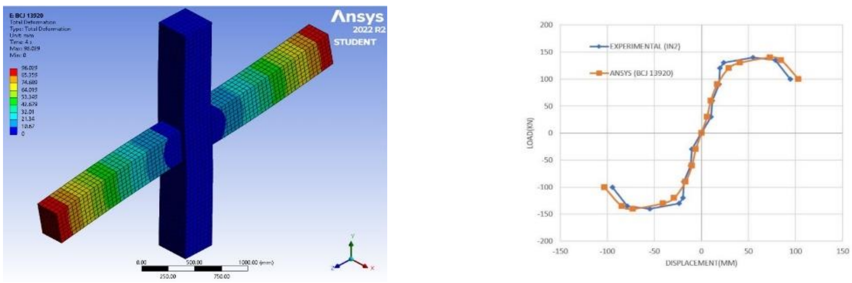

Figure 5.2.2. Load vs Deflection of model and curve of FEA model BCJ 13920

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5.2.3 Load and Deflection Interior Joints BCJ 13920

The interior joint BCJ-13920 is designed as per IS 13920-2016, when it is subjected to reverse cyclic loading on joints it shown maximum deflection of 113.2mm at 120kN as shown Figures 5.2.3.1 when Load and deflection of values of each loading cycle are tabulated in Table 5.2.3. Load vs deflection curves for Interior joints BCJ-13920 specimen for finite element model and experimental model is shown in figure 5.2.3.2. which showed non-linear behaviour in beam column joints in both the direction of applied load at the beam ends.

Table 5.2.3 Load and Deflection values for BCJ 13920-X

Applied load (Py) in kN		BCJ-13920(X)	
		Load(kN)	Displacement(mm)
0.25Py	upward direction	30	17.3
0.5 Py		60	41.4
0.75 Py		90	75.8
1.0 Py		120	108.2
-0.25 Py	downward direction	-30	17.3
-0.50 Py		-60	41.4
-0.75 Py		-90	75.8
-1 Py		-120	113.2

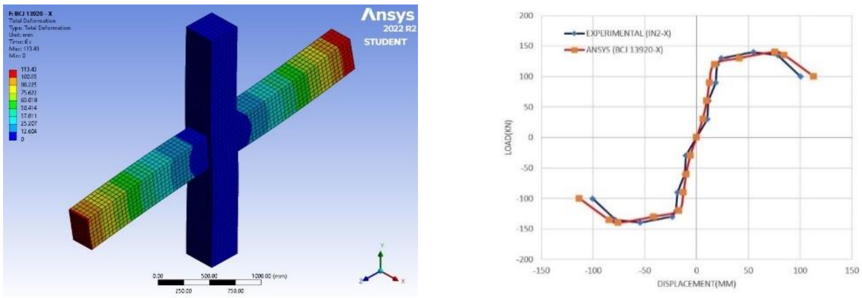

Figure 5.2.3 Load vs Deflection of model and curve of FEA model BCJ 13920-X

5.3 Shear behaviour of interior joints

Joint shear behaviour is described for the simulation outcomes in a FE study of the internal beam column connection. The internal beam column connection specimen is shown in Figures 5.3.1 to 5.3.3, demonstrating beam tensile stress at the beam strain sides and diagonal concrete tensile damage at the joints. Therefore, the top and bottom of the left and right-side beams, as well as the column bars on the tension side of the longitudinal columns, were under tension. Internal joints for numerical output have now shown both beam bar yielding along the joint's longitudinal axis and core compressive damage.

5.3.1 Shear behaviour of model BCJ 456

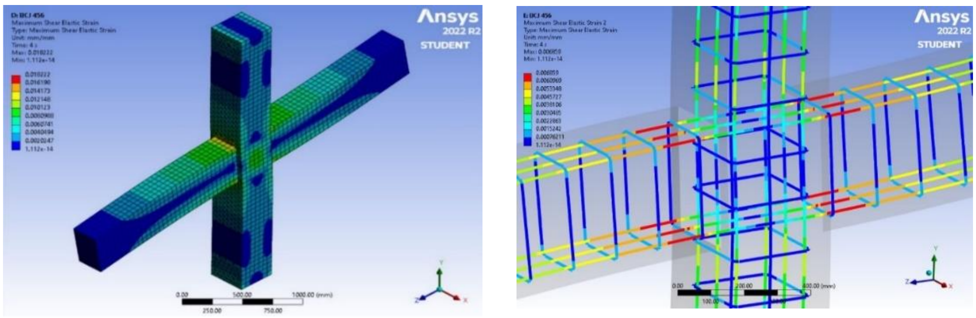

Figure 5.3.1 Joint shear behaviour of the interior beam column joint model BCJ-456

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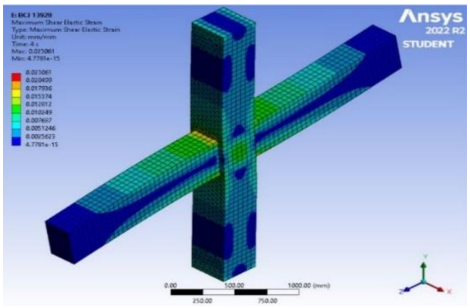
5.3.2 Shear behaviour of model BCJ 13920



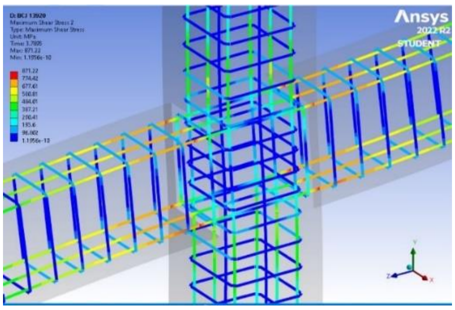
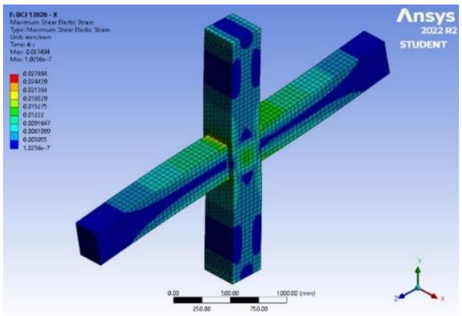


Figure 5.3.2 Joint shear behaviour of the interior beam column joint model BCJ-13920

5.3.3 Shear behaviour of model BCJ 13920-X



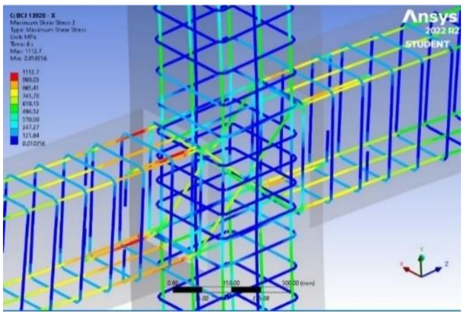


Figure 5.3.3 Joint shear behaviour of the interior beam column joint model BCJ 13920-X

6. CONCLUSION AND FUTURE SCOPES

6.1 Conclusions of interior beam column joints

The following conclusions of interior joints are on the analysis of the FE models.

1. The designing and detailing of interior beam columnjoints as per IS codes.
2. The ANSYS Workbench 2022 FEA model are able to analyzed interior beam column joints with enhanced X-shaped bracing in the joint region.
3. The results obtained from FEA are very close to results observed in the experiments.
4. The difference between FEA model results and experimental results are within 12% range of accuracy in terms of ultimate displacement prediction.
5. The displacement of BCJ 13920-X model showed maximum displacement of 113.2mm compare to BCJ 456 and BCJ 13920 models.
6. The shear behaviour of FEA models of interior beam column joint among the models BCJ 13920-X reduced stress in the longitudinal reinforcement of beams at the plastic hinge region of joint.

6.2 Further Scope of Study

- In this work, analysis was conducted only for lateral loads. This can be extended for seismic loading.
- Diagonal x-shaped bracing reinforcement bars can be provided at the joint and extended in the column direction.
- The behaviour of beam column joint in RC frame shall be analysed by replacing HYSD bars with FRP bars fully and partially

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