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Bursting Stresses in Beam Column Joint Analyzed and Designed as Per Indian Standards

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Abstract: ***There are many cases in which the RC building frames are subjected to failure at the beam column joint (BCJ). This is due to wrong analysis and design of joints. During the analysis of the building frame, we usually assume the BCJ of the frame as fixed joint, but in reality the BCJ are never perfectly fixed one. Due to this, the forces and moments around and the stresses within the BCJ are analysed wrongly than actually induced during the seismic loading. The various countries had updated their codal provisions for the analysis and design of BCJ based on the experiments carried on till now. In this research, it is proposed to study the bursting stresses developed in the BCJ of the proposed building subjected to the seismic loading using the finite element based software (ANSYS). The analysis and design of the building frame and its BCJ's is carried out as per the provisions in draft copy of IS:13920:2014. The BCJ so designed are modelled in finite element based software and subjected to the forces obtained from the performance based analysis of the building to study bursting stresses developed in the BCJ.***

Keywords: Beam column joint, Response spectrum analysis, Pushover analysis, Finite element analysis

1. Introduction

Reinforced concrete moment resisting frames (RCMRF) are such a structural systems that are designed to ensure proper energy dissipation and to have lateral stability when it is incur to seismic lateral loading. In this design philosophy, the strong column weak beam concept is recommended and the elastic behaviour of joints and column is desirable. BCJ have been identified as potentially one of the weaker component of RCMRF subjected to seismic lateral loading. The failure mode in which the hinges are developed in the beams rather in column or beam column joint is considered to be the most desirable in maintaining the global stability and energy dissipation of the structure without undergoing severe degradation of capacity of connection. On the other hand the reinforced concrete(RC) BCJ can exhibit less robust behaviour when severe damage is concentrated with the joint panel. So the understanding joint shear behaviour is important towards controlling the overall performance of RCC beam column joint and frames.

Beam-column-joint is that portion of the column where the beam use to join the column and that portion of column is called as the beam column joint Under the seismic effect the BCJ is believed to be the critical region due to its location in the area where the bond and the normal stresses are significantly high. The beam column joint is subjected to high shear force due to pulling and pushing of the top and bottom rebar which is caused because of the reversal nature of the earthquake forces. This shear force cause the undesirable brittle failure of the beam column joint. There are many cases of the building destruction in earthquake due to the joint failure.

2. Literature Survey

- Jung-Yoon Lee et al (2009): Under the seismic loading the moment developed across the joint acts in the opposite direction so the BCJ is subjected to the flat and upright shear force the degree of which is larger than those in the beams and column bordering the joint. In this research paper the author proposes the method to find the ductility capacity of the BCJ in RCMRF after the formation of the plastic hinges at the both the ends of the beams. After the hinge formation, longitudinal axial strain is expected to increase abruptly as the neutral axis moves towards the compressive fiber. This contributes in cross ward elongation of the cracks in BCJ. This cracks leads to the decrease in the shear strength of BCJ. The method anticipated by the author includes the effect of the longitudinal axial strain. In order to verify the method, the test results were compared.
- Guo-Lin Wang et al (2012): The BCJ are subjected to the shear force in vertical and horizontal direction. The reversed cyclic loadings are used to work out the shear strength of the BCJ when subjected to the seismic loading. When subjected to the seismic loading the innermost area of the BCJ is most critical one. So author has assumed that the shear strength of the BCJ is attended when stress of the concrete at the innermost point reach failure envelope. The reinforced concrete in the joint is taken as the homogeneous material in a plane stress. The involvement of the longitudinal reinforcement and the transverse reinforcement is considered by calculating the nominal tensile strength of the idealized material. The tensile strain outcome in transverse direction on the compressive strength of the idealized material is calculated for the tension compression failure envelope. The test was carried on the interior and exterior column joint, with and without transverse reinforcement which reveal the correctness of the model.
- **S.S.Patil et al (2013):** in this paper the author had discussed the influence of variation of the stiffness of the BCJ on maximum stress, minimum stress, displacement. The author had discussed the external BCJ mechanism, criticality of BCJ features of BCJ and equilibrium criteria.

He stated various types of loadings by which the behaviour of the building can be studied. In the research work the author had considered the G+5 office building located in zone III. The author had studied the external and corner BCJ with the parameters like maximum principle stress, minimum principle stress, displacement deformation. He also studied the end conditions and stiffness variation of BCJ. For the study the author had used the ANSYS(Finite Element Method).The finite element model was prepared based on the space frame analysis of the proposed office building.

- Jianping Fu et al (2000) : in this paper the author had presented the effect of the axial load ratio on the seismic behaviour of the internal BCJ. For the research work, the author had comparatively studied the five sub-assemblies of the internal joint with the varying shear level from low, moderate to high along with different axial load ratios. According to the author, the shear transfer in the joint takes place in the two stages i.e. prior to bond deterioration and after the bond deterioration. The author had stated that, under the same ductility, the joint shows the good energy dissipitation when subjected to the high load ratio. The increase of the load ratio is favourable for the BCJ when it is in the first stage of shear transfer. But, when the joint enters in the second stage, the axial load increases the compression force in the diagonal strut and leads to the crushing of the concrete in the joint.

3. Problem Statement

G + 5 storey RC building is taken for the proposed study. The response spectrum analysis is carried out in the staad pro V8i to find out the forces generated in the members. By using the forces generated by the response spectrum analysis , the structural members are designed as per the IS 13920(Ductile Detailing Of Reinforced Concrete Structures Subjected To Seismic Forces).By using the sectional properties so designed, the pushover analysis is carried out in the ETAB to get the forces acting on the joints at the hinge formation in the structure. Finally, the Beam column joints are modeled in the ANSYS (Finite Element Method) and are to be analyzed for the bursting stresses so developed in the beam column joint.

4. Methodology

In order to study the bursting stresses developed in the BCJ, the RC frame building (G+5) was taken with 4 bays at 6m centre to centre in both the directions. The building frame was modeled in the software and was subjected to the response spectrum analysis. The members were designed as per the seismic requirements. The beam column joints were analyzed based on the design of the adjacent members. The BCJ were designed as per the draft of the first revision of IS-13920. The building frame with new sections as per the BCJ consideration was subjected to the Static pushover analysis. The forces obtained at the performance point were utilized to evaluate the bursting stresses developed in the beam column joint using the Finite element based software.

5. Response Spectrum Analysis

The following are the parameters used for performing the response spectrum analysis of building frame;

Table 1: Preliminary Data

1	Number of Floors	5(Parking + Stilt Ground floor +3)
2	Parking storey height	3.5M
3	Typical floor height	3M
4	Plan dimension in X- direction	4 bays @ 6M = 24M
5	Plan dimension in Z- direction	4 bays @ 6M = 24M
6	Wall thickness	230mm
7	Slab thickness	200mm
8	Size of beam	300 X 480mm
9	Size of column	350 X 750mm
		300 X 700mm
		300 X 740mm
10	Grade of concrete and Steel	M30 and FE415.

Table 2: Loading Parameter

1	Response spectrum loading	X-direction
2	Response spectrum loading	Z-direction
3	Dead loads	
A	Floor	5KN/m^2
B	Walls	
	i) External typical floor	13KN/m
	ii) Internal Typical floor	8.5Kn/m
	iii) Terrace	4.5Kn/m
	Live load	
	Typical floor	4KN/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%

The following figure shows the building frame and the BCJ selected for the study purpose;

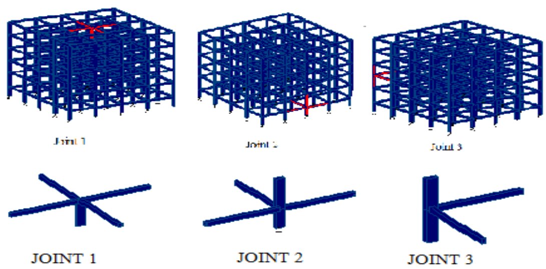

Figure 1: Building frame and BCJ seleted for study.

1) Joint 1 :- joint at terrace floor confined by beams on all four sides of joint(mid junction).

2)Joint 2:-joint at parking floor confined by beams on three sides of joint(peripheral junction)
3)Joint 3:- joint at intermediate floor confined by beams on less than three sides (corner junction).

6. Pushover Analysis

The capacity of the structure represented in the form of the graph is called as capacity curve i.e. pushover curve. The most convenient way to plot the capacity curve is by tracking the base shear and roof displacement. This is done by Pushover Analysis. It is required to study the hinge formation mechanism in the proposed building frame designed as per BCJ consideration so as to ensure the its ductile behavior. The forces generated in the members at the hinges are to be evaluated at the performance point. The performance level of the building is set by considering the provisions in ATC. The default hinge properties are used for the analysis purpose.

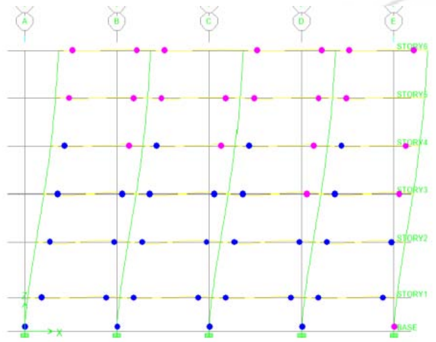

Figure 2: Hinge formation at performance point for pushX

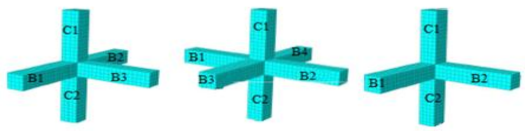

Figure 3: Detail configuration of BCJ selected for study

Table 4: Forces at performance point in Adjacent member of BCJ

Load case	M33 (KNM)			M22(KNM)			TwistKNM
	End A	Mid	End B	End A	Mid	End B	
Mid junction terrace floor							
Beam 1 & 2	0	0	0	0	0	0	2.15
Beam 3 & 4	62.3	-	-120	0	-	0	0
Corner junction intermediate floor							
Beam 1	78.5	-	-147	0	0	0	2
Beam 2	1	-	1	0	0	0	2
Outskirt junction parking floor							
Beam 1 & 2	+43	0	-85.8	0	0	0	0
Beam 3	0	0	0	0	0	0	0

7. Bursting Stresses

When the building frame is subjected to the seismic loading, the forces are generated in the members adjacent to the beam column joint. These forces induces the stresses in the beam column joint, when exceeds the minimal permissible limit leads to the bursting of the core concrete and also sometimes spalling takes place. These stresses so developed leading to the core bursting are called as the bursting stresses. The joint core are usually confined by providing the reinforcement so as to mitigate the stresses induced. The code had given the guidelines to safeguard the joint against such stresses but the past experience had proved them to be insufficient.

7.1 Analytical procedure for bursting stresses in BCJ

The codes had given the guidelines to calculate the bursting stresses developed in the beam column joint due to the seismic forces acting of the building frame. The following is the basic procedure to calculate the bursting stresses developed in the beam column Joints,

- Calculate moments in adjacent beams.
- Calculate the shear developed in column.
- Calculate the amount of steel yielded.
- Calculate the shear forces developed in the joint.
- Calculate the shear stress in the joint.
- Compare it with the shear strength of joint as per code.
- Calculate the utilization ratio.

The table below shows the results obtained for the bursting stresses using the codal provisions;

Table 5: Busrting stresses and utilization ratio for BCJ

BCJ No.	IS-13920 draft copy	Permissible Bursting stress in joint	IS-13920 draft copy
	Bursting Stresses	IS code	Utilization Ratio
1	1.98	8.21	24.1
2	1.24	6.57	18.89
3	1.77	5.47	32.31

7.2 Finite Element Analysis

The finite element method (FEM) is a numerical approach for analyzing structures. Many a time problems encountered are so complex that they cannot be solved by classical analytical methods. The method has vast applicability in fields of engineering and biomechanics. Basic principle of FEM is to make calculations at only limited (finite) number of points and then interpolate the results for entire domain .Finite Element Analysis consists of a computer model of a material or design that is stressed and analyzed for specific results. The beam column joint under consideration for the project is made up of RCC, which is ductile material so from design safety point of view, yielding criteria should be considered.

Model The beginning point of the finite element analysis is the CAD model of the beam column joints. The modeling is done in ANSYS Workbench 14.5.7. The following figure shows the cad model in ANSYS workbench;

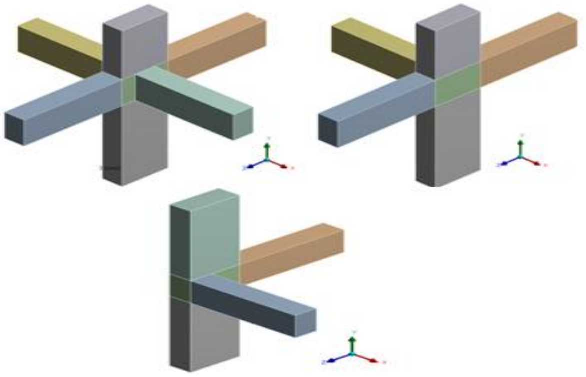

Figure 4: The CAD model of the Beam column joints

Meshing Finite element method reduces degrees of freedom from infinite to finite with the help of Discretization of entire domain. The following figure shows the meshed BCJ models in ANSYS workbench;

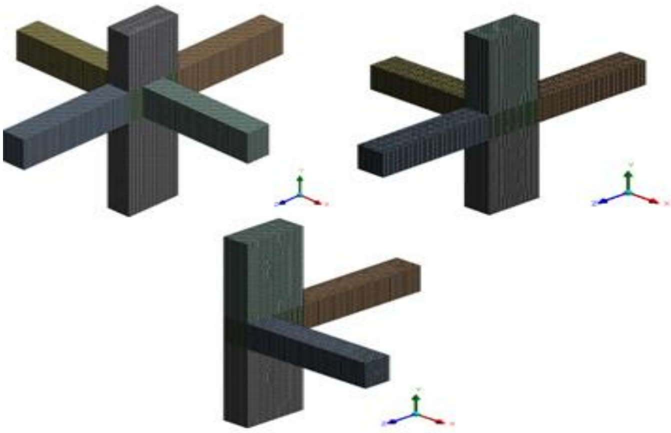

Figure 5: Meshed Beam column joint models with whole configuration

Boundary Conditions The boundary conditions applied to the model are the moments developed in the adjacent members and the support conditions. The following figure shows the boundary conditions applied to the beam column joint model;

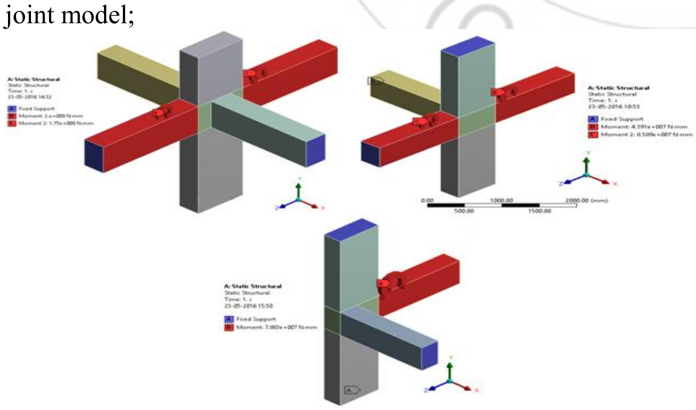

Figure 6: Boundary conditions applied to the Beam column joint models

8. Results and Discussion

The following are the results obtained after performing the finite element analysis of the beam column joint using ANSYS workbench.

Table 5: Bursting stresses in BCJ

BCJ	Bursting Stress		Permissible Stress	Utilization Ratio	
No.	Manual	Ansys		Manual	Ansys
1	1.98	1.93	8.82158	24.09	23.49
2	1.24	1.434	6.57	18.87	21.81
3	1.77	1.86	5.47	32.31	33.95

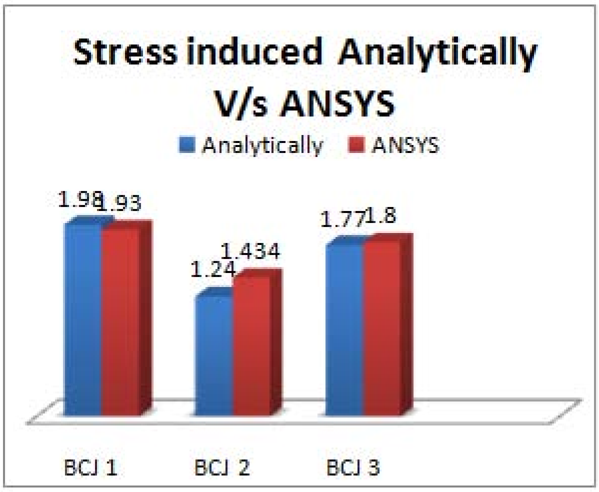

Figure 7: Stress induced in BCJ

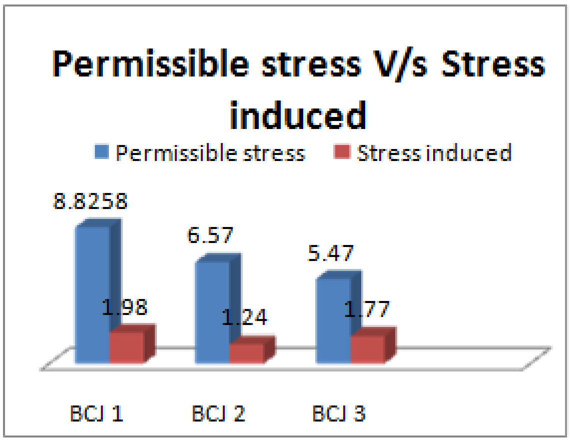

Figure 8: Permissible Stress and induced stress

9. Conclusion

The beam column joint of the building frame so considered are evaluated for the seismic loading. It can be observed from the results and graph that, there is variation in the behavior of the BCJ based on its location and configuration. Through the pushover analysis, the hinge formation mechanism reveals the ductile behaviour of the building frame. The critical hinges are formed from the bottom to top and in the beams to columns. This shows the strong column weak beam behaviour of the building frame so designed with due consideration to the BCJ. The analytical results and finite element analysis performed revealed that the BCJ designed as per the draft of the first revision of IS-13920 are safe in bursting stresses developed at the performance point of the building. The corner junction at the intermediate floor is found to be comparatively more critical than the other joints. This is particularly due to the less confinement provided by the adjacent member to the BCJ. The amount of horizontal shear reinforcement provided in the joints as per the codal provisions and the are sufficient to resists the stresses developed in the joint during the seismic loading.

10. Future Scope

- Study the behaviour of the beam column joint of the building structure for different time history data.
- Study the behaviour of the beam column joint at different levels with different configurations.
- Study the effect of shear wall on the behaviour of the beam column joint.

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