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A Study on Seismic Analysis of Beam –Column Joint at Seismic Zone III

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ABSTRACT

Beam-column joints are critical components in reinforced concrete structures, particularly vulnerable to seismic forces. This study investigates the seismic behavior of beam-column joints through comprehensive analysis and numerical simulations.

The research focuses on evaluating the performance of various types of joints under seismic loading conditions. Nonlinear static and dynamic analyses are employed to assess factors influencing joint response, including detailing, reinforcement configurations, and material properties.

Key parameters such as shear stress distribution, concrete confinement effects, and bond-slip behavior are examined to understand the seismic vulnerability of these joints. Performance metrics such as ductility, energy dissipation, and failure modes are analyzed to enhance structural design practices.

The findings contribute insights into improving the seismic resilience of beam-column joints, providing practical recommendations for optimizing their design and detailing to mitigate potential vulnerabilities and ensure structural safety.

INTRODUCTION

Earthquake-resistant structures rely heavily on the integrity of beam-column joints, particularly in reinforced concrete (RC) buildings. These joints experience significant forces due to ground shaking during earthquakes. This project report aims to analyze the seismic behavior of a beam-column joint and assess its performance under seismic loads. Beam-column joints are critical elements in earthquake-resistant structures, particularly those made of reinforced concrete (RC). During an earthquake, these joints experience significant forces due to the ground shaking. Understanding and analyzing their seismic behavior is crucial for designing safe and effective structures.

Here's a breakdown of key points regarding the seismic analysis of beam-column joints

1.1 Types of Beam-Column Joints:

When referring to beam-column joints in RCC (Reinforced Cement Concrete), we primarily focus on the **location** classification since achieving perfect rigidity is difficult with concrete. Here's a breakdown of the types considering RCC construction:

Interior joint: This is the most common type, where four beams meet a column at its center. These joints experience high shear forces and moments in all directions. Proper reinforcement detailing is crucial to ensure good performance

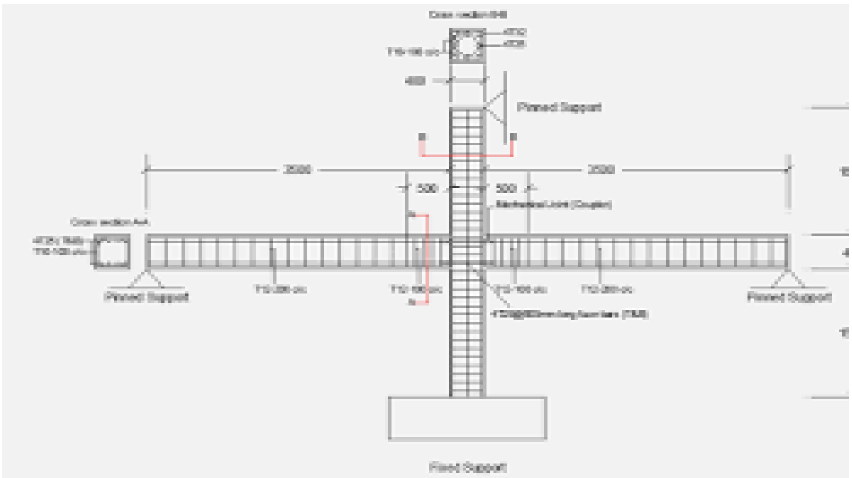


Fig.1: Interior beam column joint

Source: https://www.researchgate.net/figure/Detailing-of-sub-assemblage-of-interior-beam-column-joint-using-fuse-bars-Eight-numbers_fig4_305473769

- **Exterior joint:** Here, one beam connects to a column face, with two others framing into the perpendicular face. These joints experience high moments and shear in the direction parallel to the single beam, and require careful detailing to handle the forces.

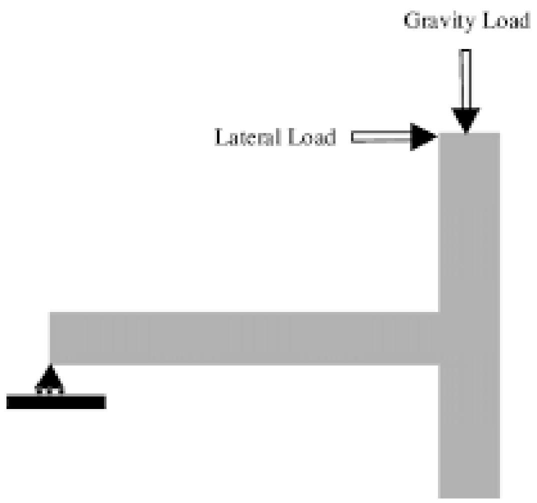


Fig.2: Exterior beam column joint

Sourcehttps://www.researchgate.net/figure/Boundary-conditions-of-exterior-beam-column-joint_fig1_331310761

.**Corner joint:** Beams connect to two adjacent faces of the column. These experience complex stress conditions with moments and shear in multiple directions. Special attention is needed during design and construction to avoid cracking and ensure proper load transfer.

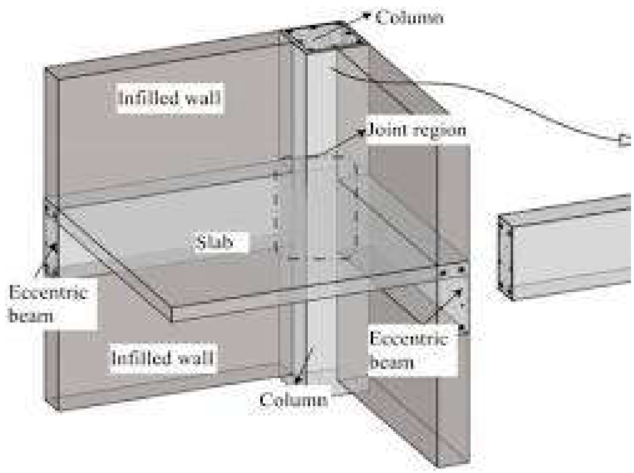


Fig.3: Corner beam column joint

Source:https://www.researchgate.net/figure/Schematic-of-eccentric-corner-beam-column-joint_fig1_34035426

LITERATURE REVIEW

Serial No.	Author Name	Year	Work Title	Research Findings
1	Park and Paulay	1992	Analyzed seismic vulnerability of beam-column joints with insufficient transverse reinforcement.	Proposed reinforcement detailing strategies to improve joint performance under seismic loading. Contributed recommendations for enhancing seismic resilience in vulnerable structures.
2	**Paulay and Priestley (1992)**:	1992	Studied retrofitting techniques to enhance seismic resistance of existing beam-column joints.	Evaluated effectiveness of different retrofit strategies in improving structural performance. Provided guidelines for upgrading existing structures to meet modern seismic design standards.
3	**Moehle and Mahin**	1994	Developed advanced analytical models to predict nonlinear behavior of beam-column joints under seismic loads	Considered material and geometric nonlinearity, enhancing accuracy in predicting joint response.
4	Eligehausen et al. (1996):	1996	Proposed analytical methods for modeling bond-slip effects and concrete crushing in seismic-loaded joints.	Validated analytical approaches with experimental results, improving understanding of joint behavior. Contributed to the development of design guidelines for seismic-resistant structures.
5	**Priestley et al.**	1996	Investigated failure modes of beam-column joints under seismic loading, emphasizing the role of shear reinforcement and joint geometry.	Highlighted the importance of detailing to mitigate shear failures and enhance joint ductility. Contributed insights into design considerations for seismic-resistant structures

6	Kunnath et al.	1997	Studied the effects of cyclic loading on joint behavior and performance under seismic conditions	Conducted experimental testing to evaluate ductility and energy dissipation mechanisms in beam-column joints. Provided data on joint response to seismic forces for validation of analytical models.
7	**Hawkins et al.**	2007	Investigated the influence of cyclic loading history and aging effects on the seismic performance.	Provided a comprehensive survey of unsupervised learning applications in networking, discussing recent advancements and identifying future directions and potential pitfalls.
8	**Kuramoto et al.**	2011	Explored the seismic performance of high-strength concrete joints, focusing on material properties and detailing effects.	Investigated strength and ductility characteristics under seismic loads. Provided data on the behavior of high-strength materials in seismic-resistant design.
9	**Kim and Park**	2015	Unsupervised learning approach for network intrusion detection system using autoencoders	Investigated hybrid steel-concrete joints to assess their performance and advantages under seismic loading. Contributed insights into the application of hybrid materials for enhanced seismic design.
10	**Li et al.**	2018	Studied the behavior of reinforced concrete joints under cyclic loading conditions.	Emphasized the importance of transverse reinforcement detailing for enhancing ductility and energy dissipation in beam-column joints. Provided recommendations for optimizing reinforcement detailing to improve seismic performance

11	**Sun et al.**	2019	Studied the effectiveness of SMAs in enhancing joint performance under seismic loading	Proposed seismic retrofitting techniques using shape memory alloys (SMAs) to improve joint ductility and energy dissipation. Contributed to innovative approaches for retrofitting existing structures for improved seismic resilience.

METHODOLOGY

4.1Joint Selection and Description: For analysis consider aSpecial Moment Resisting Frame(SMRF) (2 X 6.30 MVA ,33KV/6.6KV SUB STATION MANIKPU).located in a seismic zone III of India, as similar to Ambikapur zone . The building uses RC moment resisting frames, and we want to assess the joint's seismic capacity following Indian Standard codes.

4.2Building Information:

- Building size: 8.00 M X 35.00 M
- Safe bearing capacity of soil: 140 kn/m^2
- Concrete grade: M-20 (conforming IS 456)
- Steel grade: Fe500 (confirming IS 1786)
- Cover:
  - Footing: 50mm
  - Column: 50mm
  - Clear bottom cover:25mm & side cover:25mm For Beams
  - Clear bottom cover:15mm & side cover:20mm For Slab

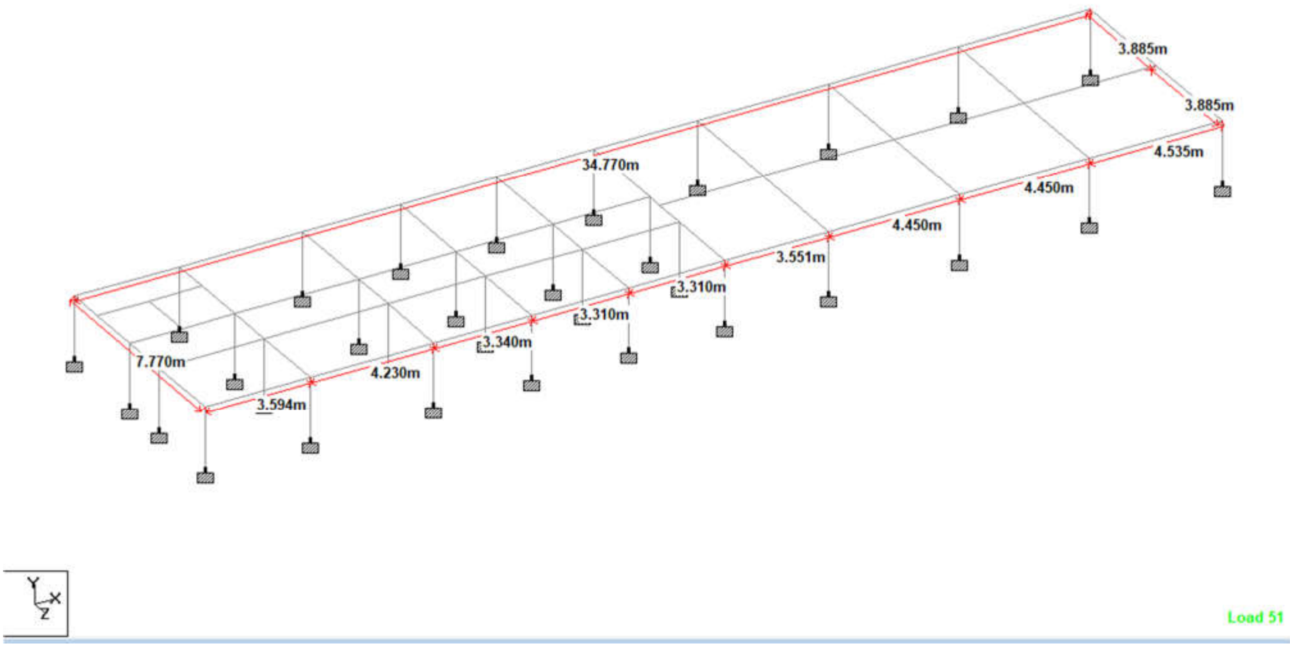


Fig.9: Building plan in Staad pro connect

4.3. Joint selection: Inthis model we select the corner joint, side joint & interior joint for seismic (ductile) design detailing & analysis of joint. analysis of this structure joint is done as per IS 13920:2016 because joint analysis is done as per mentioned code.

4.3.1). Interior beam column joint: Shown in fig.10 it consist of :-

- Column:300mm x 500mm,
- Beam : 230mm x 350 mm (At Ground level)
- Beam : 230mm x 300 mm (At Slab level)

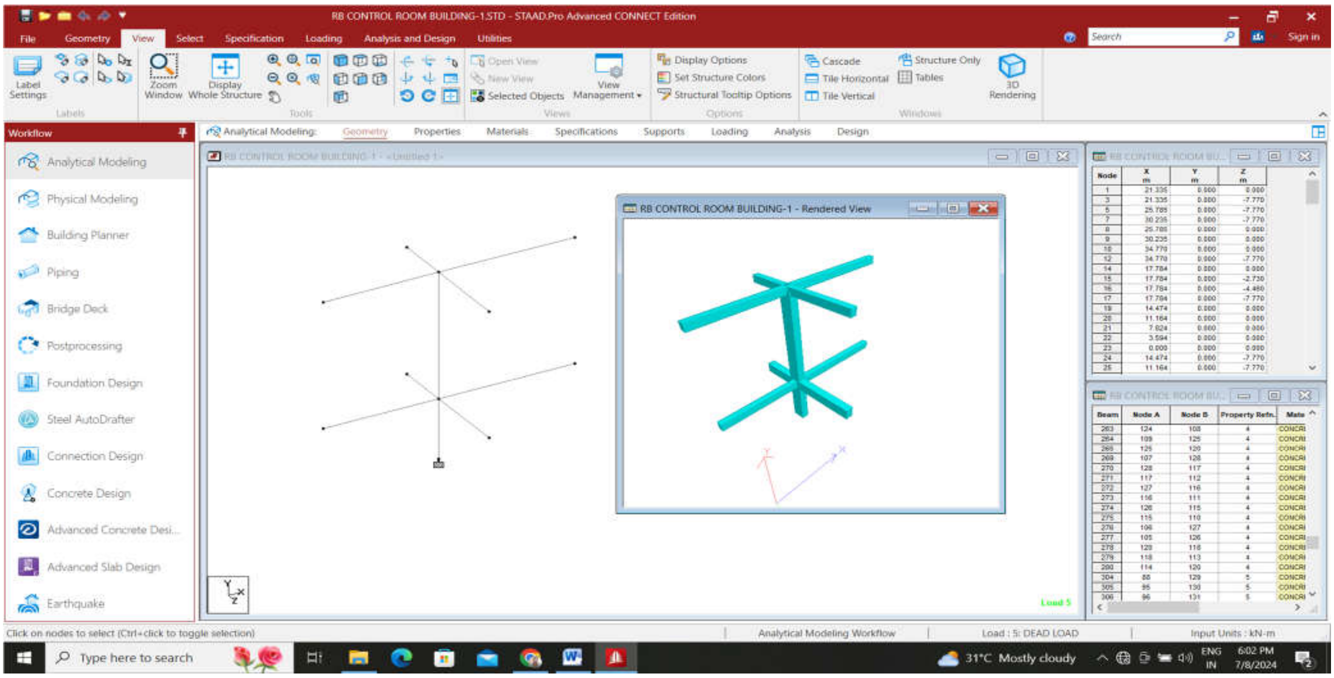


Fig.10: Interior beam column joint.

4.3.2). Corner beam column joint: Shown in fig.11(a).it consist of :-

- Column:300mm x 500mm,
- Beam : 230mm x 350 mm (At Ground level)
- Beam : 230mm x 300 mm (At Slab level)

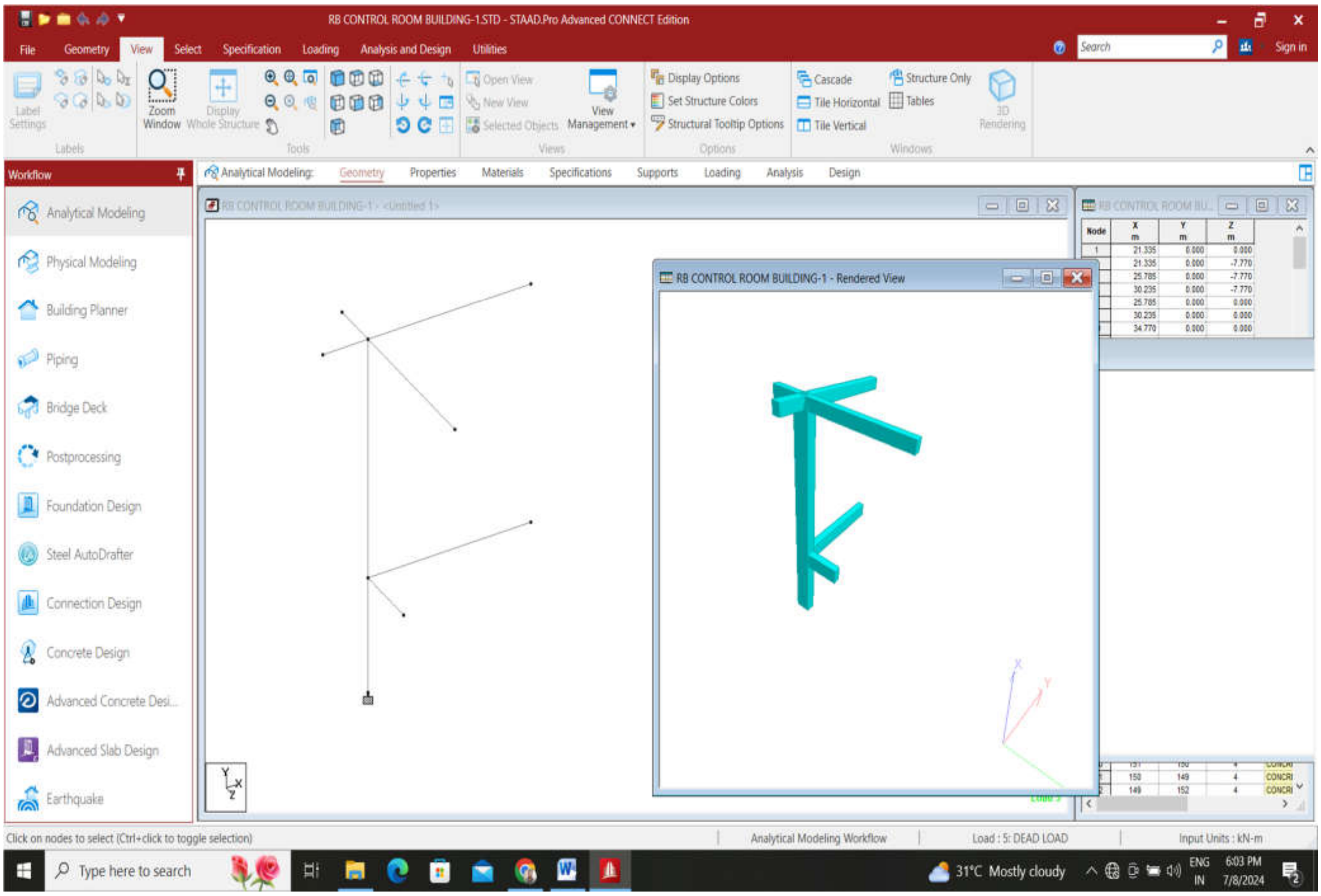


Fig.11: Corner joint(a)

4.3.3). Corner beam column joint: Shown in fig.11(b).it consist of :-

- Column: 500mm x 600mm,
- Beam : 230mm x 450 mm & 230mm x 600mm (At Ground level)
- Beam : 300mm x 600 mm (At Slab level)

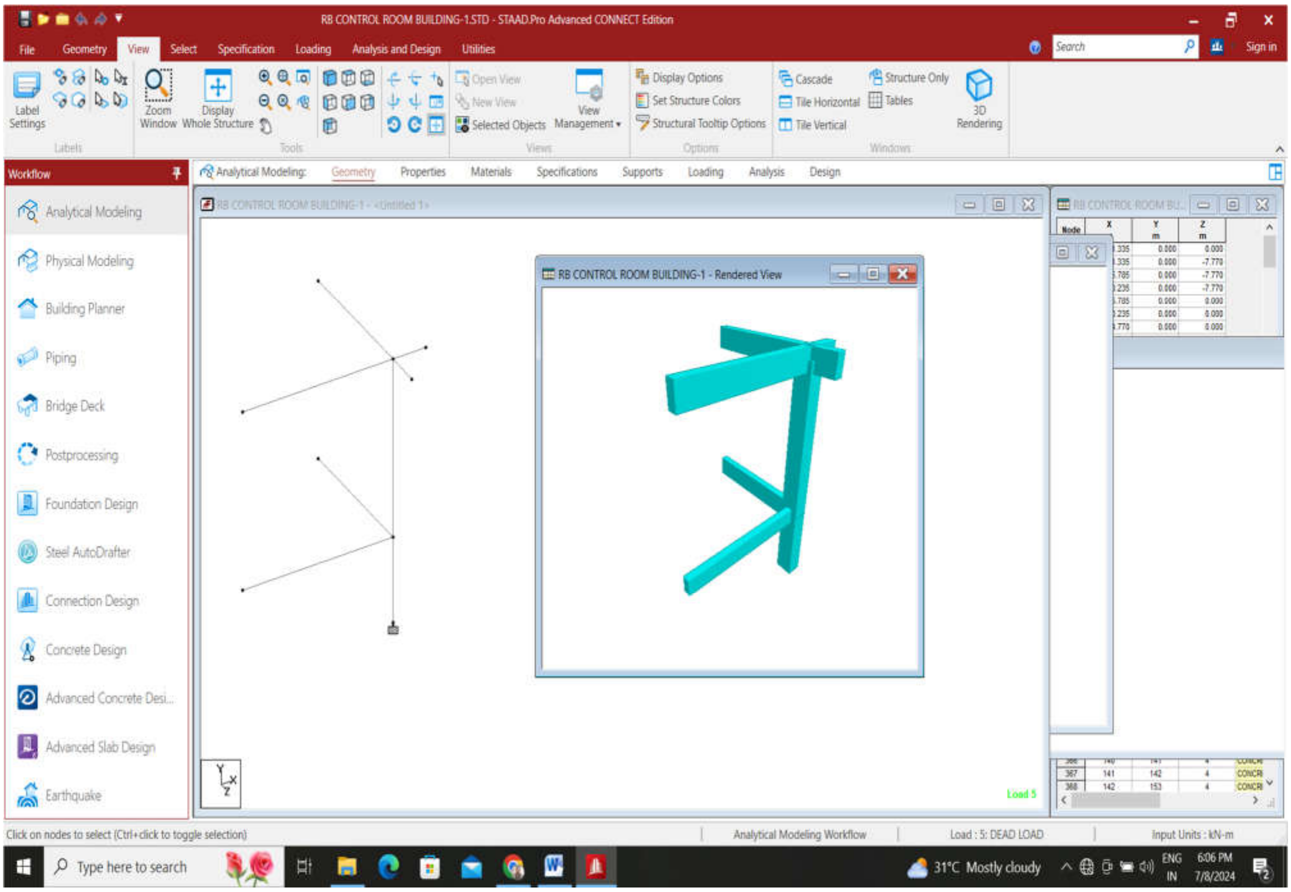


Fig.11: Corner joint(b)

4.3.4). Exterior beam column joint: Shown in fig.12.it consist of :-

- Column: 500mm x 600mm,
- Beam : 230mm x 450 mm & 230mm x 500mm (At Ground level)
- Beam : 300mm x 600 mm (At Slab level)

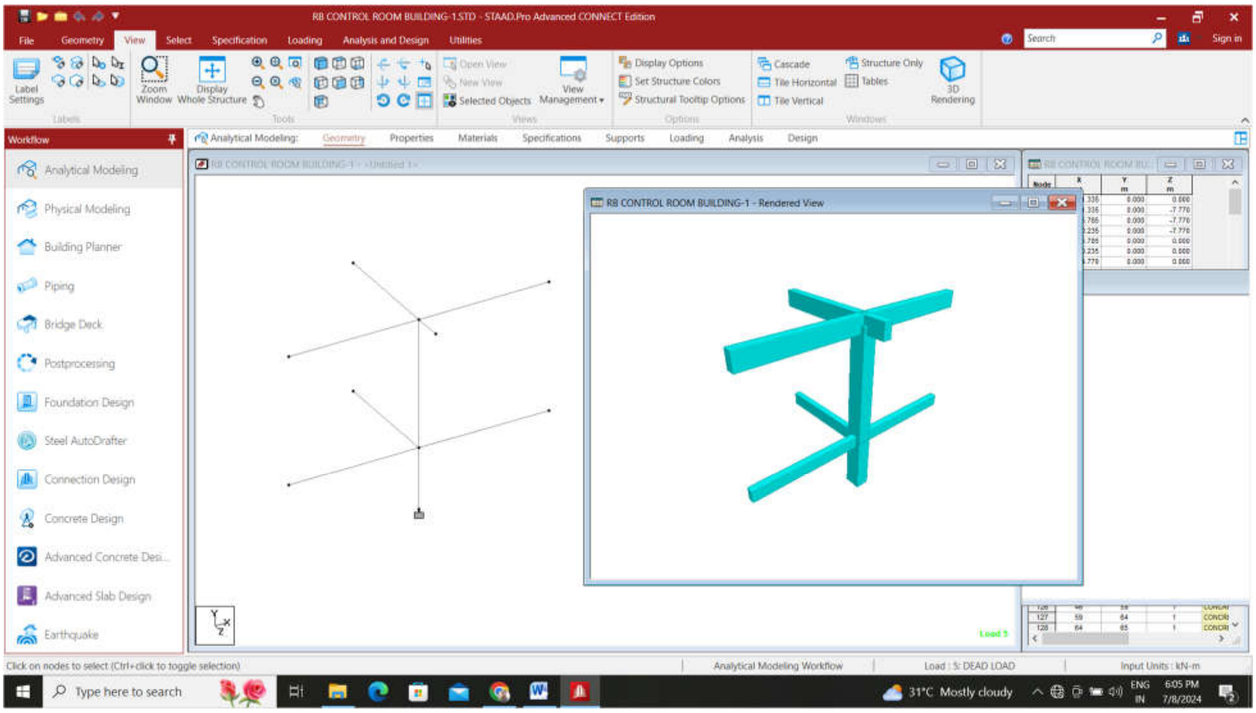


Fig.12: Exterior joint

Loading in building :

This analysis consists Dead load (confirming(IS 875 part I), Live load(confirming IS 875 part II), wind load (IS 875 part III)&earthquacke load (conforming IS 1893 part I)

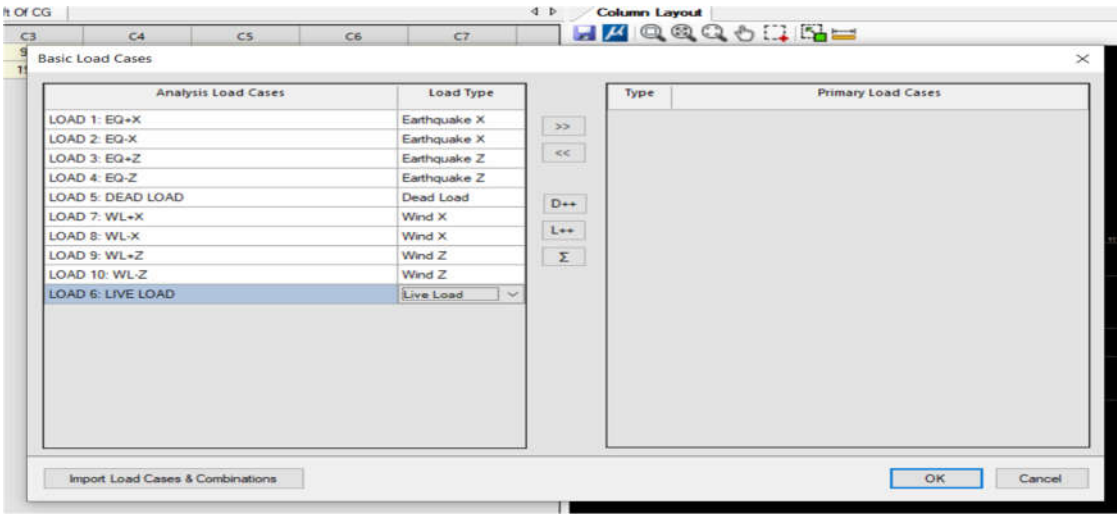


Fig.12: Avilable load cases.

From analysis in staad pro software creates total 125 no of load combinations for analysis.

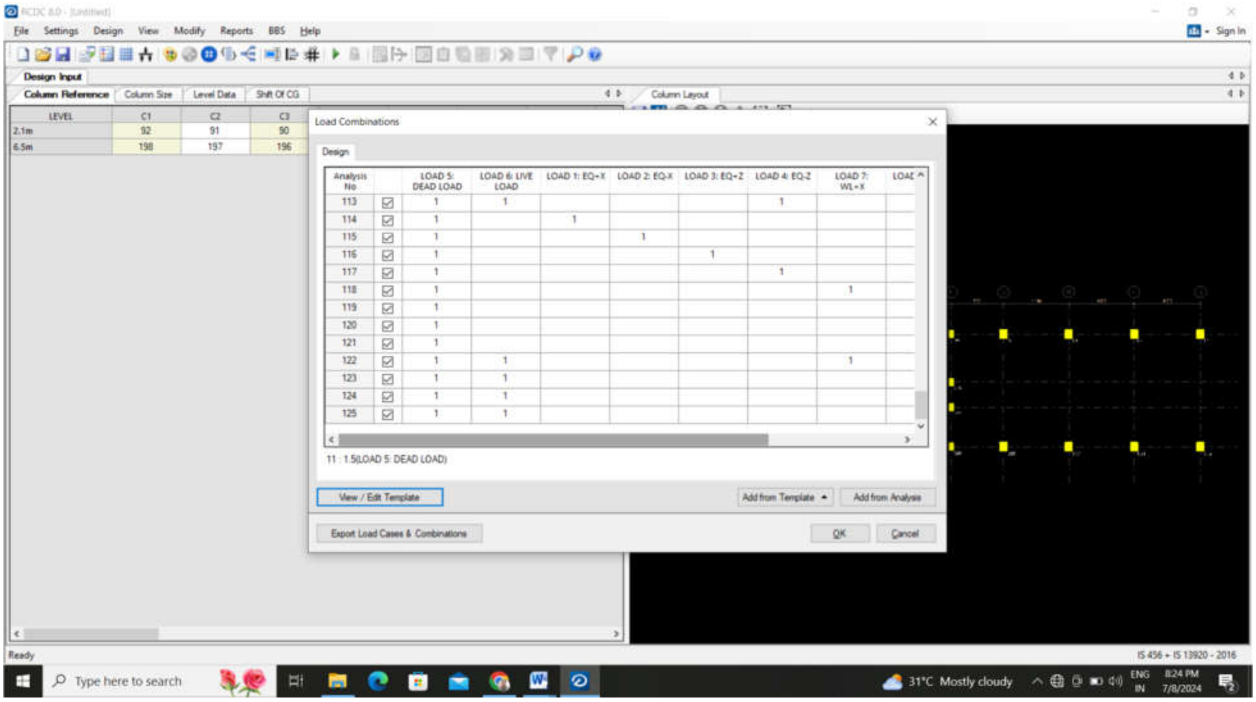


Fig.13: Avilable load cases.

ANALYSIS AND DESIGN

Analysis

After modeling in stand pro analysis is done by software without any kind of warning .Some modeling images are shown below to represent analysis:

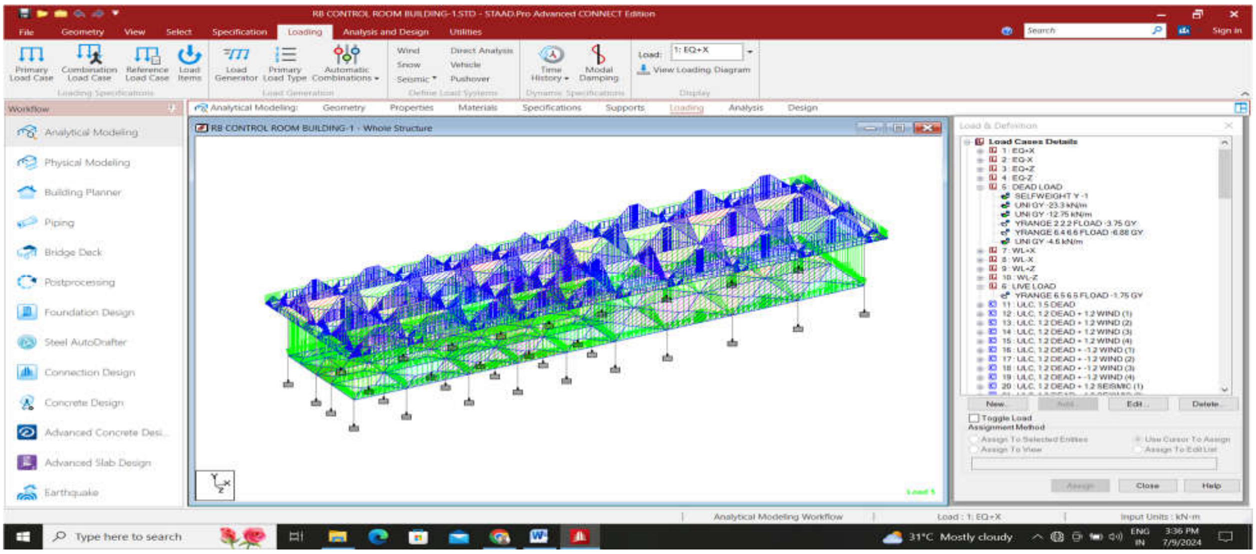


Fig.14: loading in structure(DL)

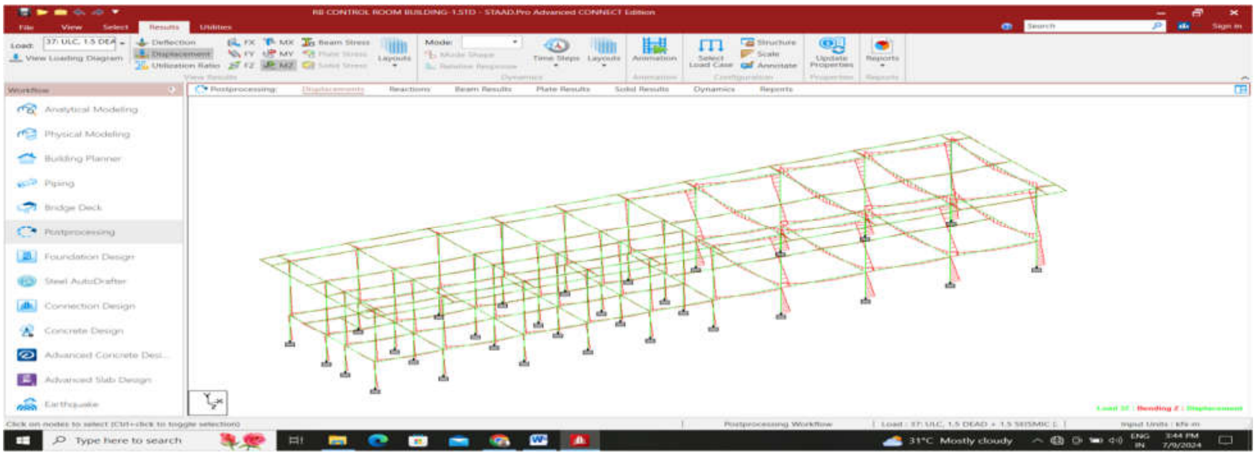


Fig.15: bending in letral direction due to critical load combination 37.

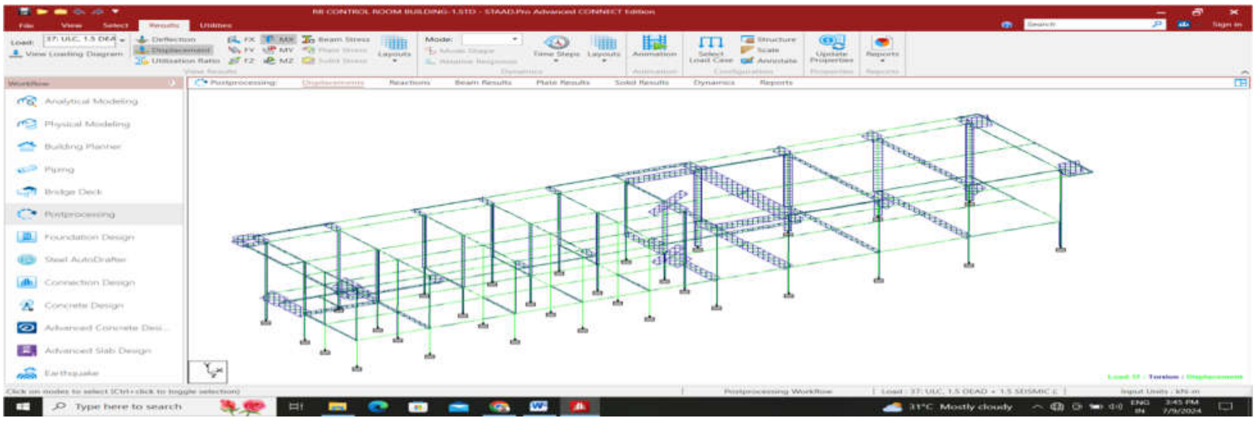


Fig.16 torsion due to critical load combination 37.

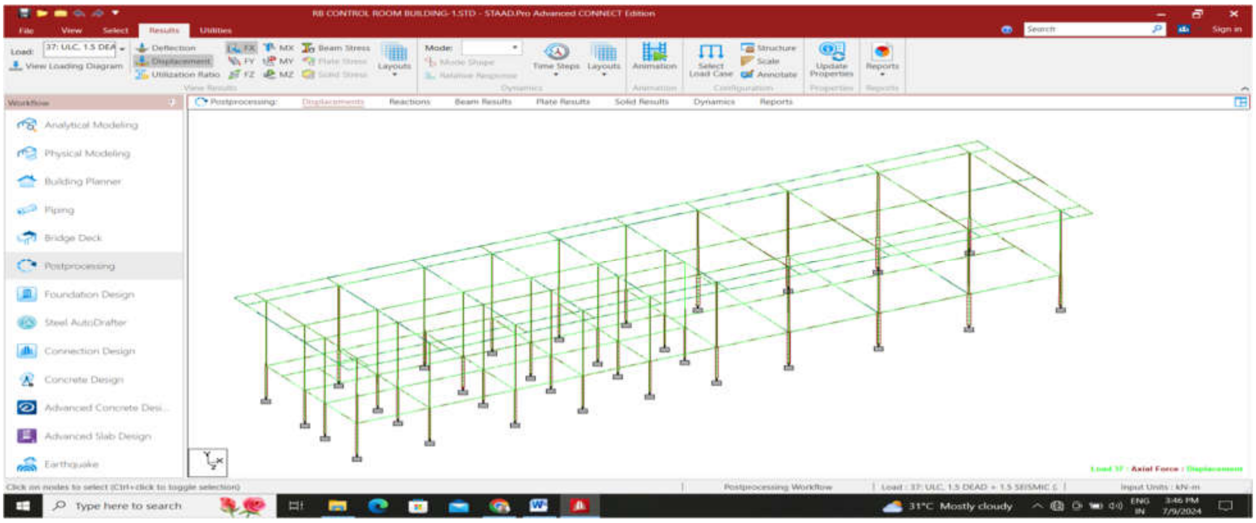


Fig.17: axial load displacement due to critical load combination 37.

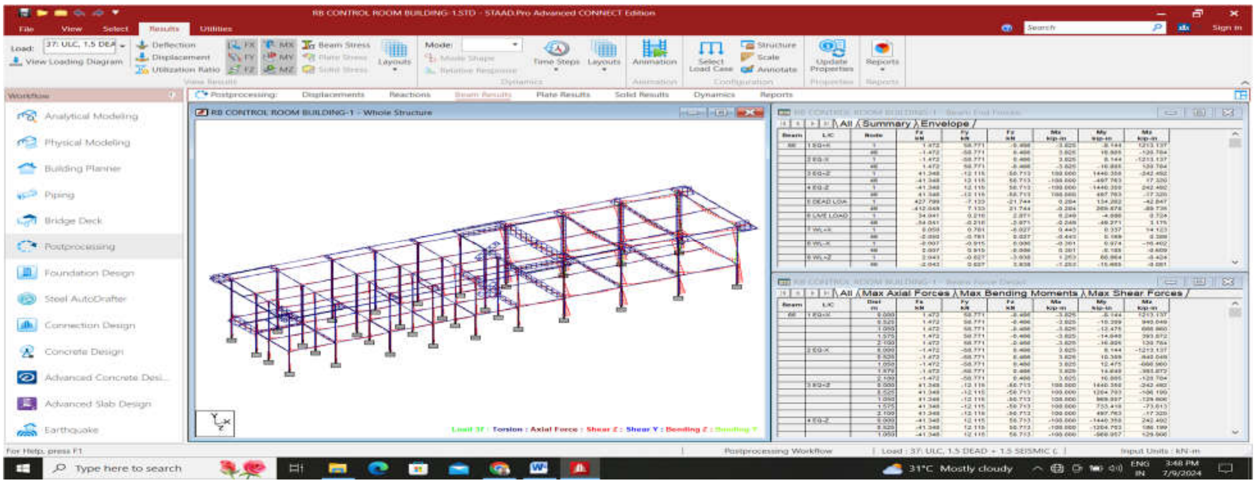
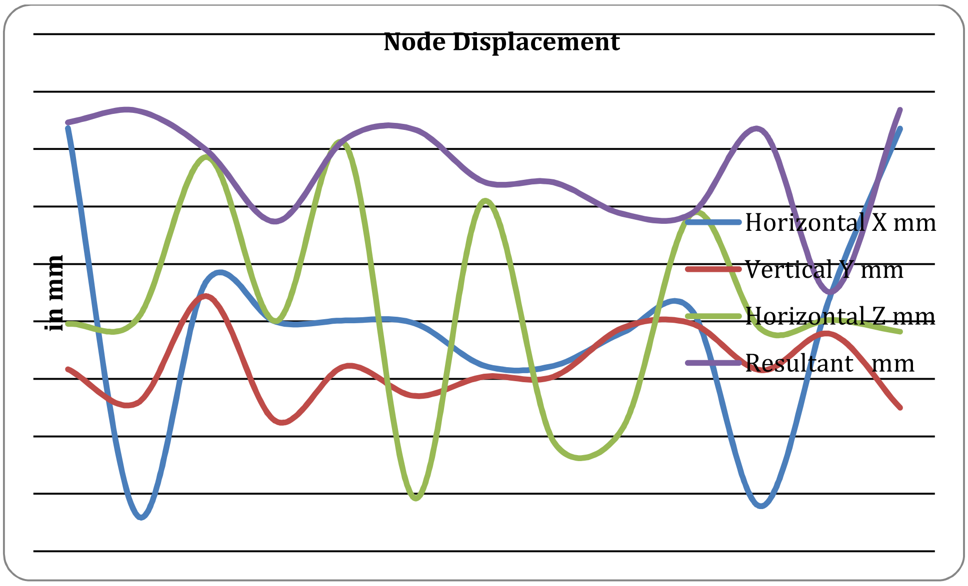


Fig.18: combined effect of torsion, axial force, bending due to critical load combination 37.

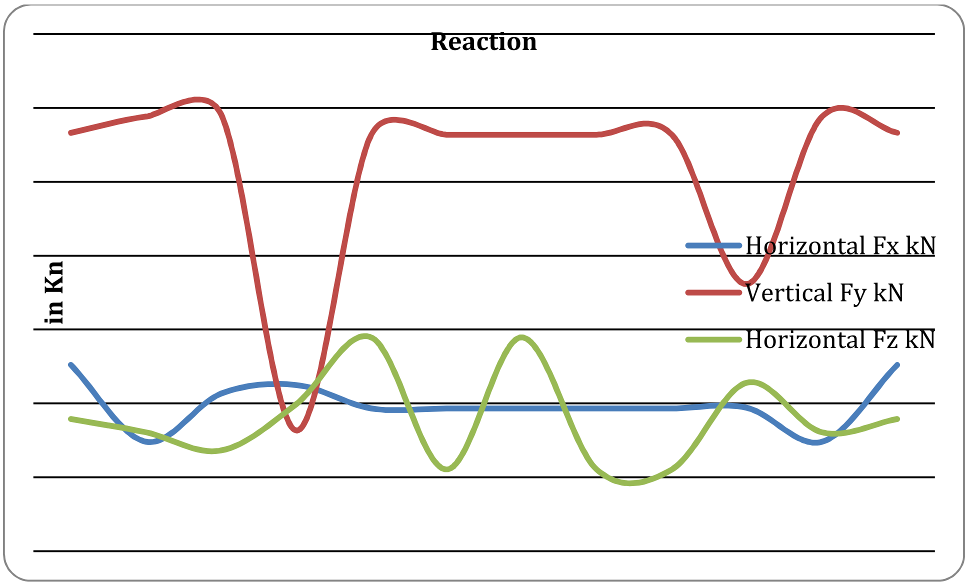
5.1.Node displacement:



Graph.1:Node dispalcement summary.

From above graph is maximum positive displacement is 16.817mm & maximum negative displacement is -16.905 & corresponding resultant displacement is 18.411 mm.

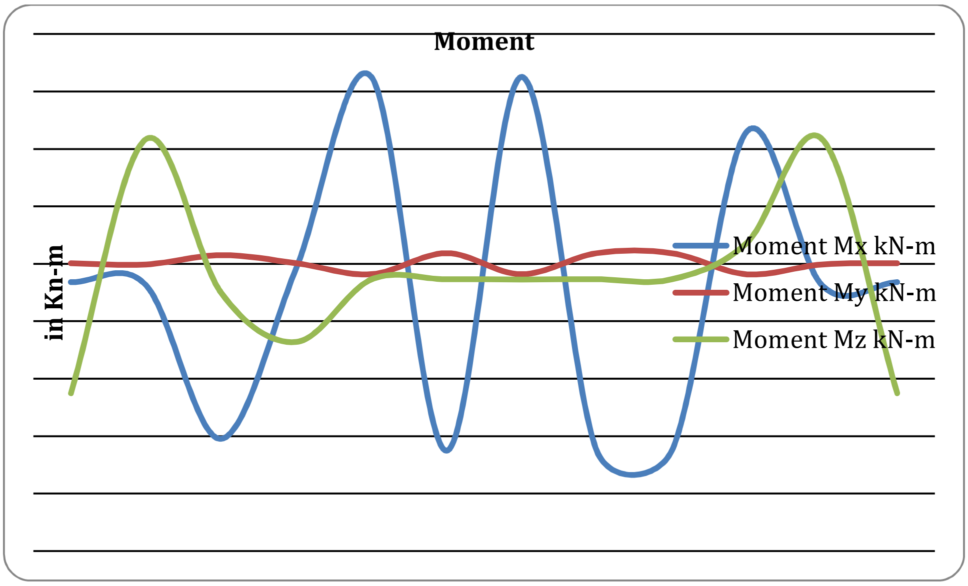
5.2.Reaction Summary:



Graph.2 Reaction summary.

From above graph Maximum Horizontal Reaction F_x= 104.433 kn,Maximum Verticall Reaction F_Y= 782.043kn, Maximum Horizontal Reaction F_z= 178.653 kn,

5.3.Moment Summary:



Graph.3: Moment summary.

From above graph Maximum Horizontal MomentM_x= 325.390kn-m,Maximum VerticallMomentM_Y= 18.498 kn-m, Maximum Horizontal Moment M_z= -225.384 kn-m,

5.4.Maximum column and beam end forces:

	FxkN	FykN	FzkN	MxkN-m	My kN-m	MzkN-m
Beam	16.803	-224.68	-1.542	-4.096	-3.285	378.191
Column	186.355	104.109	-32.92	0.535	-91.422	-261.973

5.4.Joint analysis and interaction curve of selected beam column joint:

I. Interior beam column joint:

Sway Calculation (Stability Index)

For Global-X Direction

Level	Load Name	Story Height (m)	Gravity Load P (kN)	Relative Displacements (mm)	Story Shear (kN)	Stability Index	Sway condition IS 456:2000
		A	B	C	D	B x C / (A x D)	
0m to 2.1m	LOAD 1: EQ+X	2.1	10371.583	1.552	1002.002	0.008	Non Sway
2.1m to 6.5m	LOAD 1: EQ+X	4.4	4947.383	7.894	878.306	0.01	Non Sway

For Global-Y Direction

Level	Load Name	Story Height (m)	Gravity Load P (kN)	Relative Displacements (mm)	Story Shear (kN)	Stability Index	Sway condition IS 456:2000
		A	B	C	D	B x C / (A x D)	
0m to 2.1m	LOAD 3: EQ+Z	2.1	10371.583	1.101	1002.002	0.005	Non Sway
2.1m to 6.5m	LOAD 3: EQ+Z	4.4	4947.383	6.151	878.306	0.008	Non Sway

- **Effective Length Calculation**

Calculation Along Major Axis Of Column

Joint	Column Stiffness	Beam Sizes		Beam Stiffness		Beta
		Beam 1 (Length x Width x Depth)	Beam 2 (Length x Width x Depth)	Beam 1	Beam 2	
	N/m	mm	mm	N/m	N/m	
Bottom	148.81	No Beam	No Beam	-	-	1
Top	148.81	1730 x 230 x 350	2730 x 230 x 350	47.501	30.101	0.739

Sway Condition (as per Stability Index)	=	Non Sway
Effective Length Factor along Major Axis	=	0.9

Calculation Along Minor Axis Of Column

Joint	Column Stiffness	Beam Sizes		Beam Stiffness		Beta
		Beam 1 (Length x Width x Depth)	Beam 2 (Length x Width x Depth)	Beam 1	Beam 2	
	N/m	mm	mm	N/m	N/m	
Bottom	53.571	No Beam	No Beam	-	-	1
Top	53.571	3340 x 230 x 350	4230 x 230 x 350	24.604	19.427	0.643

Sway Condition (as per Stability Index)	=	Non Sway
Effective Length Factor along Minor axis	=	0.87

- **Calculation of Design Moment**

Direction	Manalysis	Mmin (Abs)	Mdesign	Mslndx (Abs)	Mdesign-final
	A	B	C	E	F
Major Axis - Mux	-6.16	7.43	-7.43	0	-7.43
Minor Axis - Muy	55.1	---	55.1	0	55.1

Where

A	=	Moments directly from analysis
B	=	Moments due to minimum eccentricity
C	=	Maximum of analysis moment and min. eccentricity = Max (A,B)
E	=	Moment due to slenderness effect
F	=	Final design Moment = Max(C- Top Bottom , D- Top Bottom) + E

Design Of Shear

Shear Calculation from Beam Capacity

Along D:

Height of column above level considered (hst1)	=	2050	mm
Height of column below level considered (hst2)	=	875	mm
Height (hst)	=	3275	mm

Along B:

Height of column above level considered (hst1)	=	2050	mm
Height of column below level considered (hst2)	=	875	mm
Height (hst)	=	3275	mm

Beam Size	**Beam angle w.r.t. column Ly**	**Torsion moment**	**Moment Capacity Beam @ Top**				**Moment Capacity Beam @ Bottom**				**Resultant Moment**			
(mm)	(deg)	(kNm)	Mu (kNm)	Astreq (sqmm)	Astpro (sqmm)	Mucap (kNm)	Mu (kNm)	Astreq (sqmm)	Astpro (sqmm)	Mucap (kNm)	Top Ly (kNm)	Top Lx (kNm)	Bot Ly (kNm)	Bot Lx (kNm)
230x350	270	-0.08	89.57	971.52	981.74	90.57	10.87	209.49	235.62	25.34	0	90.57	0	25.34
230x350	0	-0.91	60.14	628.26	628.32	61.12	49.76	481.18	603.18	59.07	61.12	0	59.07	0
230x350	90	-1.05	102.47	1098.84	1608.5	153.93	0	209.49	235.62	25.34	0	153.93	0	25.34
230x350	180	-0.03	66.7	698.69	981.74	90.57	27.82	265.19	339.3	35.57	90.57	0	35.57	0

Effective moment for Column

	Mu Major (Along D) (kNm)		Mu Minor (Along B) (kNm)	
	Left	Right	Left	Right
Top	90.57	61.12	90.57	153.93
Bottom	35.57	59.07	25.34	25.34

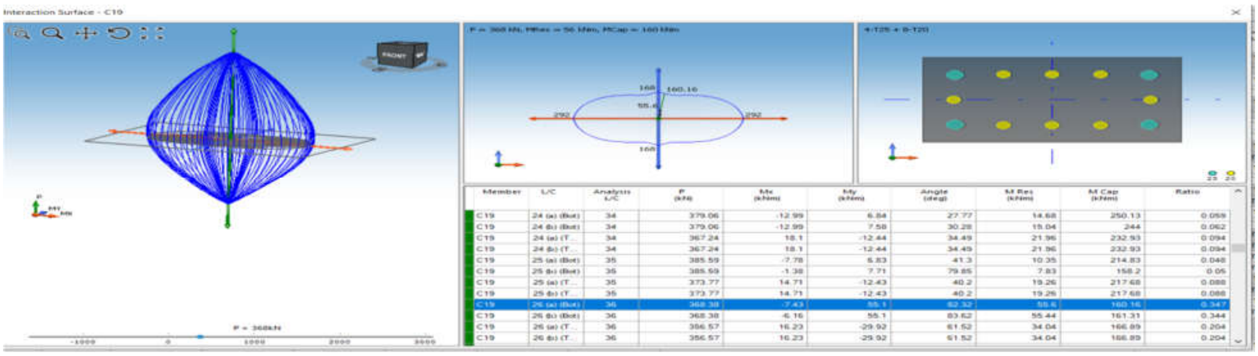


Fig.19: Coresponding Interior Beam Column Intraction Curve.

1. Result & Discussion

5.1. Result

Joint check for all four selected joints are described below on the basis of analytical calculation:

I. **Interior beam column joint:** Shown in fig.10

1.Check At Beam-Column Interior Joints:

1. Flexure Strength Of Joint:

Moment Capacity Calculations for Beam

Beam Size	**Beam angle w.r.t. column Ly**	**Torsion moment**	**Moment Capacity Beam at Top**				**Moment Capacity Beam at Bottom**				**Resultant Moment**			
(mm)	(deg)	(kNm)	Mu (kNm)	AstReq (sqmm)	Ast Pro (sq mm)	Mu Cap (kNm)	Mu (kNm)	Ast Req (sqmm)	Ast Pro (sqmm)	Mu Cap (kNm)	Top @ D (kNm)	Top @ B (kNm)	Bot @ D (kNm)	Bot @ B (kNm)
230 x 350	270	-0.08	89.57	971.52	981.74	90.57	10.87	209.49	235.62	25.34	0	90.57	0	25.34
230 x 350	0	-0.91	60.14	628.26	628.32	61.12	49.76	481.18	603.18	59.07	61.12	0	59.07	0
230 x 350	90	-1.05	102.47	1098.84	1608.5	153.93	0	209.49	235.62	25.34	0	153.93	0	25.34
230 x 350	180	-0.03	66.7	698.69	981.74	90.57	27.82	265.19	339.3	35.57	90.57	0	35.57	0

2. **Shear Strength of Joint:**

Beams Along D

Angle w.r.t Column Ly (deg)	**Reference Location**	**Width (mm)**	**Depth (mm)**	**Ast Pro Top (sqmm)**	**Ast Pro Bot (sqmm)**
0	Right	230	350	628.32	603.18
180	Left	230	350	981.74	339.3

Shear Checks

Conditions	AST-Total (sqmm)	V-Reinf (kN)	Max (Vuy1, Vuy2) (kN)	V (Shear Demand) (kN)	B' (mm)	D' (mm)	Aje (sqmm)	τjd (N/sqmm)	τjc (N/sqmm)	τjd<τjc
Right Top + Left Bottom	967.62	501.95	63.97	437.99	300	500	150000	2.92	7.5	OK
Left Top + Right Bottom	1584.92	822.18	63.97	758.21	300	500	150000	5.05	7.5	OK

Beams Along B

Angle w.r.t Column Ly (deg)	Reference Location	Width (mm)	Depth (mm)	Ast Pro Top (sqmm)	Ast Pro Bot (sqmm)
270	Left	230	350	981.74	235.62
90	Right	230	350	1608.5	235.62

Shear Checks

Conditions	AST-Total (sqmm)	V-Reinf (kN)	Max (Vux1, Vux2) (kN)	V (Shear Demand) (kN)	B' (mm)	D' (mm)	Aje (sqmm)	τ_{jd} (N/sqmm)	τ_{jc} (N/sqmm)	$\tau_{jd} < \tau_{jc}$
Right Top + Left Bottom	1844.12	956.64	76.64	880	500	300	150000	5.87	7.5	OK
Left Top + Right Bottom	1217.36	631.51	76.64	554.87	500	300	150000	3.7	7.5	OK

CONCLUSION

1. **Performance in Seismic Zone III (Ambikapur):**
    - The structural analysis and design of the building's beam-column joints have been carefully evaluated under seismic considerations.
    - The joints have been assessed for both flexural and shear capacities, which are critical for seismic resistance.
    - Adequate reinforcement and detailing have been provided to ensure the joints can withstand the seismic forces anticipated in Zone III.
2. **Key Findings:**
    - **Interior Joints:** Found to meet both flexural and shear strength requirements, indicating robust performance under seismic loading.
    - **Corner Joints (a and b):** Similarly designed to withstand seismic forces, with adequate reinforcement and moment capacities verified.
    - **Exterior Joints:** Noted as experiencing higher demands of both shear and flexure due to longer spans and load distribution, but adequately designed to meet these demand

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