Effect of Column And Beam Geometry on The Seismic Behavior of Multi-Storey Reinforced Concrete Frames

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Abstract- *This research paper investigates the seismic performance of multi-storey building frames with varying column and beam geometries under seismic loads. A G+10 storey reinforced concrete (RC) building frame was analyzed using STAAD Pro V8i software in seismic zone III with medium soil conditions. Three models (Plan A, Plan B, and Plan C) were considered, each with different cross-sectional dimensions for columns and beams (230×230 mm, 300×300 mm, and 380×380 mm, respectively). The study evaluated key structural responses, including support reactions, bending moments, shear forces, axial forces, and displacements. Results indicate that increasing member dimensions reduces displacement and axial forces but increases bending moments and shear forces. Plan C (380×380 mm) exhibited the least displacement, while Plan A (230×230 mm) showed the highest. The findings highlight the importance of optimizing member geometry for seismic resilience in multi-storey buildings*

I. INTRODUCTION

Earthquakes are a devastating natural phenomenon that can cause widespread destruction and loss of life. The sudden release of energy in the Earth's crust generates seismic waves that can travel long distances, affecting structures and the ground surface. The impact of earthquakes on structures is a critical consideration in seismic design and analysis.

Seismic Effect

The seismic effect on structures is influenced by various factors, including:

1. Seismic Zone: India is divided into different seismic zones (II-V) based on the expected intensity of earthquakes.
2. Soil Type: Soil properties play a crucial role in seismic analysis, as they can amplify or reduce seismic forces.
3. Structural Design: The design of structures, including the type of foundation, superstructure, and materials used, can significantly impact their seismic performance.

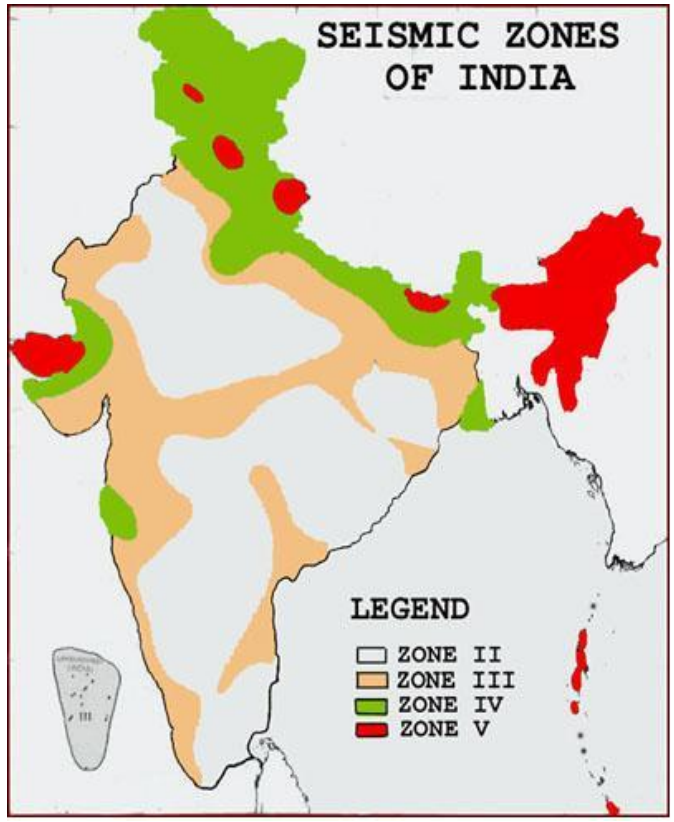


Fig.1.1 Seismic Zones in India

As per Seismic code IS 1893:2002, the intensity and vibration due to seismic waves are calculated by the following expression-

$$A_h = \frac{Z I S_a}{2 R g}$$

Where A_h = design seismic horizontal coefficient,
Z = Zone factor (IS 1893:2002, in table 2)

Table-1.1 Seismic Zones & Intensity

Seismic Zone	II	III	IV	V
Intensity	Low	Moderate	Severe	Very Severe
Z	0.10	0.16	0.24	0.36

The design seismic horizontal coefficient (Ah) is calculated using the zone factor (Z), importance factor (I), response reduction factor (R), and average response acceleration coefficient (Sa/g).

Table-1.2 Importance Factor

S.N.	Structure	Importance Factor
1.	Importance service and district structures, such as hospital, school, and monumental, emergency structures like television station building; large community halls like cinema, assembly halls and subway station, Power stations.	1.5
2.	Other structures.	1

and R= Response Reduction Factor

Table 7 Response Reduction Factor [1], *R*, for Building Systems
(*Clause* 6.4.2)

Sl No.	Lateral Load Resisting System	*R*
(1)	(2)	(3)
	Building Frame Systems	
i)	Ordinary RC moment-resisting frame (OMRF)[2]	3.0
ii)	Special RC moment-resisting frame (SMRF)[3]	5.0
iii)	Steel frame with	
	a) Concentric braces	4.0
	b) Eccentric braces	5.0
iv)	Steel moment resisting frame designed as per SP 6 (6)	5.0
	Building with Shear Walls[4]	
v)	Load bearing masonry wall buildings[5]	
	a) Unreinforced	1.5
	b) Reinforced with horizontal RC bands	2.5
	c) Reinforced with horizontal RC bands and vertical bars at corners of rooms and jambs of openings	3.0
vi)	Ordinary reinforced concrete shear walls[6]	3.0
vii)	Ductile shear walls[7]	4.0
	Buildings with Dual Systems[8]	
viii)	Ordinary shear wall with OMRF	3.0
ix)	Ordinary shear wall with SMRF	4.0
x)	Ductile shear wall with OMRF	4.5
xi)	Ductile shear wall with SMRF	5.0

Soil Properties

Soil-structure interaction is a complex phenomenon that involves the interaction between the soil and the structure. Understanding soil properties, such as:

1. Soil Type: Different soil types, such as clay, sand, or rock, can affect seismic forces.
2. Soil Stiffness: The stiffness of the soil can impact the response of the structure.
3. Soil Damping: The damping characteristics of the soil can influence the seismic response.

STAAD Pro V8i

STAAD Pro V8i is a powerful structural analysis and design software that can perform seismic analysis and design according to various international codes, including IS 1893:2002. The software offers advanced features, such as:
1. Seismic Load Generation: STAAD Pro can generate seismic loads based on the seismic zone and soil type.

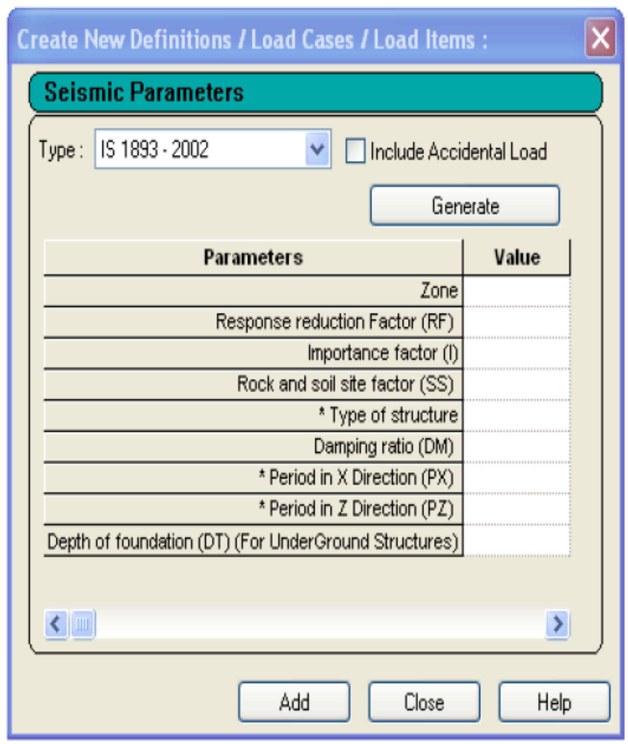


Fig.1.4 Generating of Seismic loads

2. Dynamic Analysis: The software can perform dynamic analysis, including response spectrum analysis and time history analysis.

Zone f1 = Seismic zone coefficient Refer Table 2 of IS:1893(Part 1)-2002.

RF f_2 = Response reduction factor. Refer Table 7 of IS: 1893 (Part 1) -2002.

I f_3 = Importance factor depending upon the functional use of the structures, characterized by hazardous consequences of its failure, post-earthquake functional needs, historical value, or economic importance. Refer Table 6 of IS: 1893(Part 1)-2002.

SS f_4 = Rock or soil sites factor (=1 for hard soil, 2 for medium soil, 3 for soft soil). Depending on type of soil, average response acceleration coefficient S_a/g is calculated corresponding to 5% damping. Refer Clause 6.4.5 of IS: 1893 (Part 1) -2002.

ST f_5 = Optional value for type of structure (=1 for RC frame building, 2 for Steel frame building, 3 for all other buildings). If this parameter is mentioned the program will calculate natural period as per Clause 7.6 of IS:1893(Part 1)-2002.

DM f_6 = Damping ratio to obtain multiplying factor for calculating S_a/g for different damping. If no damping is specified 5% damping (default value 0.05) will be considered corresponding to which multiplying factor is 1.0. Refer Table 3 of IS:1893(Part 1)-2002.

PX f_7 = Optional period of structure (in sec) in X direction. If this is defined this value will be used to calculate S_a/g for generation of seismic load along X direction.

PZ f_8 = Optional period of structure (in sec) in Z direction. If this is defined this value will be used to calculate S_a/g for generation of seismic load along Z direction.

DT f_9 = Depth of foundation below ground level. It should be defined in current unit. If the depth of foundation is 30 m or below, the value of A_h is taken as half the value obtained. If the foundation is placed between the ground level and 30 m depth, this value is linearly interpolated between A_h and $0.5A_h$.

Fig.1.5 Parameter used in Staad Pro

3. Structural Design: STAAD Pro can design structures according to various international codes, ensuring compliance with seismic design requirements.

Objective of the Study

The objective of this research is to investigate the seismic behavior of building frame structures in seismic zone III with medium-type soil and varying member geometry properties. The study aims to:

1. Evaluate Seismic Performance: Assess the seismic performance of the building frame structure.
2. Study Structural Behavior: Investigate the behavior of the structure under seismic loads.
3. Compare Seismic Effects: Compare the seismic effects on different structures with varying member properties.

This study will contribute to the development of more earthquake-resistant designs and provide valuable insights into the seismic behavior of building structures.

II. LITERAURE REVIEW

Seismic analysis is a critical aspect of structural engineering that helps understand how buildings respond to seismic forces. Various researchers have studied the seismic behavior of structures, and their findings are summarized below:

Seismic Analysis of Multi-Story Buildings

1. D.R. Deshmukh and A.K. Yadav: Analyzed and designed a G+19 storied RC building frame using Staad Pro software, considering seismic zone III and IS code provisions.
2. Narla Mohan et al.: Compared seismic and wind analysis of G+20 RC multistory commercial building frames with different seismic zones and basic wind speeds using Etabs software.

Seismic Behavior of Irregular Buildings

1. Rajesh Chaturvedi and Piyush Mandloi: Studied seismic analysis of vertical irregular buildings using Etabs software with Time History method.
2. Laxmikant Vairagade and Vikrant Nair: Compared seismic analysis of G+15 storied buildings stiffened with bracing shear walls in different seismic zones.

Seismic Response of Structures with Different Plan Configurations

1. Veena S Ravi and Sreedevi Lekshmi: Compared the effect of shape and plan configuration on seismic response of structures in seismic zones II and V.
2. Nonika N and Mrs. Gargi Danda: Compared seismic analysis of regular and irregular multistoried buildings with sixteen stories.

Seismic Analysis Using Different Software

1. Chhavi Gupta and Ibrahim B.: Compared seismic behavior of multi-storey building composite steel and reinforced concrete framed structures.
2. Kasliwal N. and Rajguru R.: Studied the effect of numbers and position of shear walls on seismic behavior of multistory structures using Etabs software.

Key Findings

- Seismic analysis is crucial for understanding the behavior of structures under seismic forces.
- Different seismic zones and soil types significantly impact the seismic response of structures.
- Various software, such as Staad Pro, Etabs, and SAP2000, can be used for seismic analysis and design.
- The choice of analysis method, such as response spectrum or time history analysis, depends on the structure's complexity and seismic zone.

III. METHODOLOGY

Step-I Modeling of Building Frame 24.38m x 24.38 along to X & Z direction of G+ 10 stories of 3D frame with different geometry of columns with medium soil and Seismic zone III.

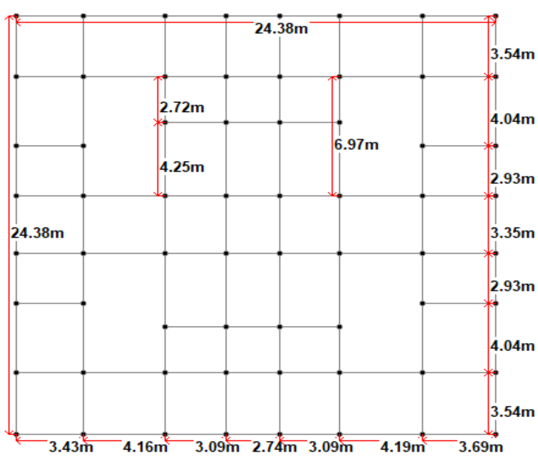


Fig. 3.1 Building Plan

Step-2 In this work, Selection of the seismic zone III as per IS- 1893 (part-I) -2002

Table-3.1 Seismic zone

Seismic zone	II	III	IV	V
Intensity	Low	Moderate	Severe	Very Severe
Z	0.10	0.16	0.24	0.36

Step-3Load Combinations:

Table-3.2 Number of Load Case details

Load Case Number	Load Case
1	DL
2	LL
2	EQ X
4	EQ Z
5	1.5(DL+LL)
6	1.5(DL+EQ X)
7	1.5(DL-EQ X)
8	1.5(DL+EQ Z)
9	1.5(DL-EQ Z)
10	1.2(DL+LL+EQ X)
11	1.2(DL+LL-EQ X)
12	1.2(DL+LL+EQ Z)
13	1.2(DL+LL-EQ Z)

Step-4 The building frame designing in 3D frame using Staad Pro v8i software.

Step-5 Analysis of the structure on seismic zone III, providing different geometry of columns. Fig shows Seismic load in X and Z direction.

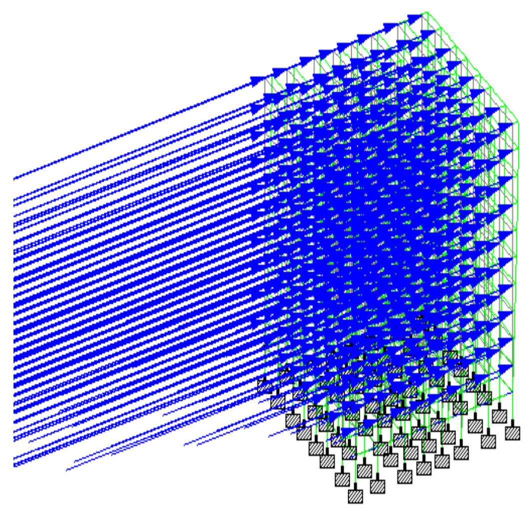


Fig.3.2 Seismic Force in X direction

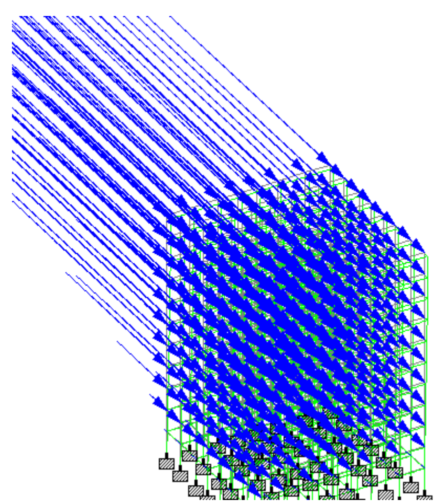


Fig.3.3 Seismic Force in X direction

Step-6 A comparative Study of forces as : Max BM, Max Displacement, Story Displacement, Max SF, Axial Forces.

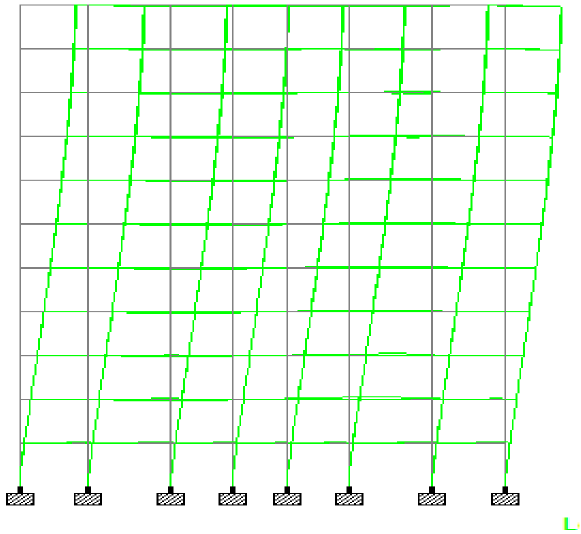
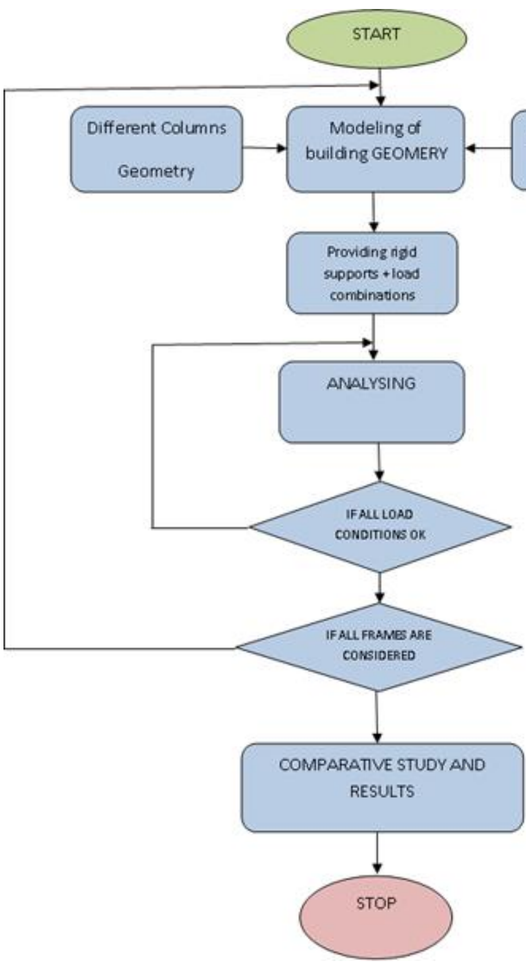


Fig.3.4 Deflection

Flow Chart Diagram: the proposed method of analysis of the structure in the form of Flow Chart Diagram as shown in fig.3



.3.5 Flow Chart Diagram

IV. MATERIAL PROPOERTIES

The following materials and geometrical properties were considered in this study:

Material Properties
- Density of R.C.C.: 25 kN/m³
- Density of Masonry: 20 kN/m³

Geometrical Properties
Three different plan categories with varying column geometries were considered:

Plan A
- Column size: 230mm x 230mm
- Beam size: 230mm x 230mm

Plan B
- Column size: 300mm x 300mm
- Beam size: 300mm x 300mm

Plan C
- Column size: 380mm x 380mm
- Beam size: 380mm x 380mm

The structural plan dimensions were 24.38m x 24.38m, with a story height of 3.2 meters.

Loading Conditions
Dead Loads
- Brick masonry wall loads:
  - Plan A: 14.85 kN/m
  - Plan B: 14.50 kN/m
  - Plan C: 14.10 kN/m
- Parapet wall load: 5.0 kN/m
- Floor load:
  - Slab load: 3.75 kN/m² (assuming 150mm thick slab)
  - Floor finish: 1 kN/m²

Total load: 4.75 kN/m²

Live Loads
- Live load on typical floors: 3 kN/m² (as per IS: 875, Part II, 1987)
- Live load on seismic calculation: 0.75 kN/m²

Earthquake Loads
- Seismic zone: III
- Seismic load calculation: as per IS: 1893 (2002)

Seismic Force Parameters
- Zone factor: 0.16 (Table 2, IS: 1893)
- Damping ratio: 0.05 (Table 3, IS: 1893)

- Importance factor (I): 1.5 (Table 6, IS: 1893)
- Response reduction factor (R): 5 (Table 7, IS: 1893)
- Soil site factor (S): Medium soil

Fundamental Natural Period of Vibration
The fundamental natural period of vibration (T) was calculated using the following formulas:

- $T_x = 0.09h/\sqrt{dx}$ (Clause 7.6.2, IS: 1893)
- $T_z = 0.09h/\sqrt{dz}$ (Clause 7.6.2, IS: 1893)

where h is the height of the building frame, dx is the total length of the building frame along the X direction, and dz is the total length of the building frame along the Z direction. The acceleration coefficient (Sa/g) was calculated as per IS code.

V. ANALYSIS AND RESULT

Table 5.1 Support Reaction

PLAN CATEGORY	SUPPORT REACTION IN KN
PLAN A	**5518.382**
PLAN B	**5238.529**
PLAN C	**5054.373**

Table 5.2 Support Reaction Moment in X Direction

PLAN CATEGORY	SUPPORT REACTION MOMENT IN X DIRECTION (KN-m)
PLAN A	**311.976**
PLAN B	**323.942**
PLAN C	**343.894**

Table 5.3 Support Reaction Moment in Z Direction

PLAN CATEGORY	SUPPORT REACTION MOMENT IN Z DIRECTION (KN-m)
PLAN A	**321.35**
PLAN B	**335.094**
PLAN C	**357.481**

Table 5.4 Maximum Axial force

PLAN CATEGORY	AXIAL FORCE IN KN
PLAN A	**5512.399**
PLAN B	**5228.35**
PLAN C	**5038.042**

Table 5.5 Maximum Shear force

PLAN CATEGORY	SHEAR FORCE IN KN
PLAN A	**304.995**
PLAN B	**304.316**
PLAN C	**308.075**

Table 5.6 Maximum Bending Moment

PLAN CATEGORY	MAX. BENDING MOMENT IN KN-m
PLAN A	**776.013**
PLAN B	**799.284**
PLAN C	**836.324**

Table 5.7 Maximum Displacement

PLAN CATEGORY	MAX. DISPLACEMENT IN mm
PLAN A	**1642.686**
PLAN B	**586.313**
PLAN C	**239.134**

Table 5.9.1 Compare three plans with Storey wise Displacement in X Direction

STOREY	DISPLACEMENT IN mm (PLAN A)	DISPLACEMENT IN mm (PLAN B)	DISPLACEMENT IN mm (PLAN C)
10	1671.697	620.134	265.936
9	1618.1	599.046	256.289
8	1527.626	564.672	241.169
7	1405.413	518.695	221.156
6	1258.177	463.646	197.35

5	1091.854	401.725	170.693
4	911.692	334.883	142.022
3	722.204	264.807	112.07
2	527.182	192.925	81.459
1	330.039	120.524	50.756
G.F.	137.121	49.94	20.958
BASE	0	0	0

Table 5.9.2 Compare three plans with Storey wise Displacement in Z Direction

STOREY	DISPLACEMENT IN mm (PLAN A)	DISPLACEMENT IN mm (PLAN B)	DISPLACEMENT IN mm (PLAN C)
10	1599.102	590.124	251.802
9	1548.19	570.372	242.865
8	1462.05	538.002	228.767
7	1345.466	494.524	209.991
6	1204.885	442.341	187.575
5	1045.995	383.549	162.411
4	873.802	319.998	108.231
3	692.583	253.278	85.517
2	505.906	184.724	77.815
1	316.949	115.526	48.556
G.F.	131.711	47.887	20.06
BASE	0	0	0

VI. CONCLUSION

The following conclusions were drawn from this study:

1. Support Reactions: Maximum support reaction was found in Plan A, while minimum in Plan C. Support reaction moment in X direction increased with increased geometry of columns and beams.
2. Axial Forces: Axial forces decreased with increased cross-section parameters of columns and beams. Maximum axial force was found in Plan A, while minimum in Plan C.
3. Shear Forces: Maximum shear force was carried at Plan C, and minimum at Plan A, with minor variation between Plan A and Plan B.
4. Bending Moments: Bending moments increased with increased geometry parameters of columns and beams. Maximum bending moment was carried at Plan C, and minimum at Plan A.
5. Node Displacement: Maximum displacement was observed at Plan A, while minimum displacement at Plan C, indicating that increased geometry parameters lead to a more stable structure.
6. Storey Wise Displacement: Storey displacement increased with increased storey height. Maximum storey displacement was observed at Plan A, and minimum at Plan C.

Final Conclusions

The study concluded that:

- Support reactions, axial forces, node displacement, and storey wise displacement were maximum at Plan A and minimum at Plan C.
- Support reaction moment, shear forces, and bending moment were maximum at Plan C and minimum at Plan A.

Future Scope of the Study

The study can be further extended to:

1. Variation in Member Properties: More variations in member properties can be considered.
2. Tall Structures: The study can be extended to taller structures.
3. Dynamic Analysis: Dynamic analysis or Etabs analysis can be included in future studies.