COMPARATIVE SEISMIC PERFORMANCE ASSESSMENT OF MULTI-STOREY RC BUILDINGS WITH FLOATING COLUMNS,INCLINED COLUMNS AND COREWALL SYSTEM .

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ABSTRACT

Earthquakes are among the most destructive natural hazards affecting the safety and stability of multi-storey reinforced concrete (RC) buildings. Modern architectural requirements often necessitate the use of floating and inclined columns to provide column-free spaces and improve the aesthetic appearance of buildings. However, these structural configurations introduce vertical irregularities that significantly influence the seismic behaviour of the structure. Hence, it is essential to evaluate their performance under earthquake loading to ensure structural safety and serviceability. The present study investigates the comparative seismic performance of multi-storey RC buildings incorporating floating columns, inclined columns, and core wall systems using ETABS . A total of 36 analytical models comprising G+10, G+15, and G+20 buildings were analysed in Seismic Zones II, III, and IV . Four structural configurations, namely Basic Model (BM), Four-Column Core (FCC), Nine-Column Core (NCC), and Core Wall (CW), were evaluated using the Response Spectrum Method. The seismic response of each model was assessed based on base shear, roof displacement, storey drift, storey stiffness, overturning moment, and fundamental time period. The analytical results indicate that seismic response becomes more severe with increasing building height and seismic zone. Buildings with floating columns exhibited higher roof displacement, storey drift, and overturning moments due to discontinuity in the load transfer mechanism. Inclined column configurations demonstrated improved lateral stiffness and reduced displacement compared with floating column models. Among all the structural systems analysed, the Core Wall (CW) models consistently exhibited the best seismic performance by providing minimum roof displacement and storey drift, maximum storey stiffness, and superior overall structural stability. The study concludes that floating column configurations should be used with caution in moderate and high seismic zones unless supported by efficient lateral load-resisting systems, while core wall systems provide the most effective solution for enhancing the seismic performance of multi-storey RC buildings.

Keywords: Reinforced Concrete Buildings, Floating Columns, Inclined Columns, Core Wall Systems, Response Spectrum Analysis, ETABS , Seismic Performance.

1. INTRODUCTION

The increasing demand for high-rise reinforced concrete (RC) buildings has led to the adoption of innovative structural configurations that satisfy both functional and architectural requirements. Rapid urbanization, limited land availability, and the need for efficient space utilization have encouraged the construction of multi-storey buildings incorporating advanced structural systems. However, these structures are frequently subjected to lateral loads caused by earthquakes and wind, making seismic performance one of the most important considerations in structural design.

Earthquakes are among the most destructive natural hazards, capable of causing severe damage to buildings and infrastructure due to the sudden release of energy within the Earth's crust. The resulting ground motion induces dynamic forces that significantly affect the behaviour of structures. Therefore, buildings located in seismic-prone regions must be designed to withstand these forces without experiencing excessive deformation or structural failure. The seismic performance of a building depends on several factors, including structural configuration, mass distribution, stiffness, ductility, building height, and the efficiency of the lateral load-resisting system.

Modern architectural trends often require large column-free spaces for parking areas, commercial facilities, auditoriums, and open-plan interiors. To satisfy these requirements, structural elements such as floating columns and inclined columns are increasingly adopted. Floating columns provide flexibility in architectural planning by discontinuing the vertical load path at intermediate storeys, whereas inclined columns improve the architectural appearance while influencing the stiffness and load transfer mechanism of the structure. Although these systems offer functional and aesthetic advantages, they also introduce vertical irregularities that may adversely affect the seismic behaviour of buildings.

To improve the seismic resistance of such irregular structures, lateral load-resisting systems such as reinforced concrete core walls are commonly incorporated. Core walls enhance structural stiffness, reduce lateral displacement and inter-storey drift, and improve the overall stability of buildings subjected to earthquake loading. Evaluating the effectiveness of floating columns, inclined columns, and core wall systems is therefore essential for ensuring structural safety and achieving an optimum balance between architectural requirements and seismic performance.

The present study focuses on the comparative seismic performance of multi-storey RC buildings with different structural configurations using **Response Spectrum Analysis** in **ETABS** . The investigation considers G+10, G+15, and G+20 buildings located in Seismic Zones II, III, and IV as per **IS 1893 (Part 1): 2016**, and evaluates critical response parameters such as base shear, storey displacement, storey drift, stiffness, overturning moment, and fundamental time period to identify the most efficient structural system.

1.2 Principles of Seismic Structural Design

The seismic performance of a building depends on the proper application of structural design principles that ensure safety, stability, and serviceability during earthquake excitation. A well-designed structure should efficiently resist lateral forces while maintaining adequate strength, stiffness, and ductility. The behaviour of reinforced concrete buildings under seismic loading is greatly influenced by the arrangement of structural members, continuity of load paths, distribution of mass and stiffness, and the effectiveness of the lateral load-resisting system. Adopting appropriate seismic design principles minimizes structural damage and enhances the overall performance of buildings during earthquakes.

1.2.1 Structural Regularity

Structural regularity is one of the most important requirements for achieving good seismic performance. Buildings with regular geometry, uniform mass distribution, and consistent stiffness along their height experience a more predictable response under earthquake loading. Irregularities in plan or elevation may lead to stress concentration, torsional effects, and excessive lateral deformation. Therefore, maintaining structural regularity helps in achieving efficient load transfer and reduces the possibility of localized structural damage.

1.2.2 Lateral Load Resistance

A building should possess adequate lateral load resistance to withstand earthquake-induced forces without significant structural damage. Structural elements such as moment-resisting frames, shear walls, core walls, and bracing systems contribute to resisting horizontal loads and controlling lateral displacement. An efficient lateral load-resisting system improves stability and enhances the seismic performance of multi-storey buildings.

1.2.3 Load Transfer Mechanism

The structural components of a building should provide a continuous and direct load path from the roof to the foundation. Earthquake-induced forces generated at each floor must be transferred safely through slabs, beams, columns, and foundations without interruption. Discontinuities in the load path, such as floating columns, increase force concentration in supporting members and may adversely affect the seismic behaviour of the structure.

1.2.4 Structural Continuity

Structural continuity ensures that beams, columns, slabs, and lateral load-resisting elements remain effectively connected throughout the building. Continuous structural members improve force distribution and reduce the likelihood of local failures during seismic excitation. Proper continuity also enhances structural integrity and enables the building to act as a single stable system under dynamic loading.

1.2.5 Stiffness Distribution

Uniform distribution of stiffness throughout the building height plays a significant role in controlling storey drift and lateral displacement. Sudden variations in stiffness create soft-storey effects and increase seismic demand on specific levels. The incorporation of core walls and other lateral load-resisting elements helps improve stiffness and minimizes excessive deformation during earthquake loading.

1.2.6 Ductility and Energy Dissipation

Ductility is the ability of a structure to undergo large inelastic deformations without sudden failure. During an earthquake, ductile structural members absorb and dissipate seismic energy through controlled deformation, thereby reducing the risk of collapse. Adequate reinforcement detailing, proper member proportions, and compliance with seismic design codes significantly enhance the ductile behaviour of reinforced concrete buildings.

1.3 Factors Affecting Seismic Behaviour of Buildings

The seismic behaviour of a reinforced concrete building is governed by several structural and geometric parameters that influence its response during earthquake excitation. The distribution of mass, stiffness, strength, and structural configuration determines the magnitude of seismic forces developed in the building and the manner in which these forces are transferred to the foundation. Buildings with proper structural planning, adequate lateral load-resisting systems, and uniform load distribution generally exhibit better seismic performance than irregular structures. Therefore, understanding the factors affecting seismic behaviour is essential for designing safe, stable, and earthquake-resistant multi-storey buildings.

1.3.1 Structural Configuration

The structural configuration of a building significantly influences its behaviour under earthquake loading. Buildings having regular geometry, symmetrical layouts, and continuous load paths generally exhibit better seismic performance than irregular structures. A well-planned structural configuration ensures uniform distribution of seismic forces and minimizes stress concentration. On the other hand, irregular structural arrangements such as floating columns and inclined columns modify the load transfer mechanism and increase the complexity of structural response. Hence, proper structural configuration plays a vital role in improving the overall stability and safety of buildings subjected to seismic forces.

1.3.2 Building Height

Building height is one of the most important factors affecting seismic response. As the height of a structure increases, its natural time period also increases, resulting in greater lateral displacement and inter-storey drift during earthquake excitation. High-rise buildings experience larger dynamic effects compared to low-rise structures and therefore require efficient lateral load-resisting systems to control deformation. Proper consideration of building height is essential for achieving satisfactory seismic performance and preventing excessive structural damage.

1.3.3 Mass Distribution

The distribution of mass within a building directly influences the magnitude of inertia forces generated during an earthquake. Uniform mass distribution along the height of the building results in a more predictable seismic response, whereas sudden variations in mass may lead to dynamic irregularities and increased seismic demand. Proper distribution of mass reduces torsional effects, improves load transfer, and enhances the overall stability of the structure during earthquake loading.

1.3.4 Stiffness Distribution

Structural stiffness determines the ability of a building to resist lateral deformation caused by seismic forces. Buildings with uniform stiffness throughout their height generally experience lower storey drift and improved seismic performance. Sudden variations in stiffness may create soft-storey effects, resulting in excessive deformation and stress concentration. The incorporation of lateral load-resisting elements such as reinforced concrete core walls significantly enhances structural stiffness and reduces lateral displacement under earthquake loading.

1.3.5 Vertical Irregularity

Vertical irregularity refers to the sudden variation in stiffness, strength, mass, or geometry along the height of a building. Such irregularities interrupt the smooth transfer of seismic forces and increase the likelihood of localized structural damage. Floating columns represent one of the most common forms of vertical irregularity because they discontinue the direct load path from the upper floors to the foundation. Buildings with vertical irregularities generally experience higher storey drift, roof displacement, and overturning moments compared to regular structures. Therefore, careful analysis and appropriate structural measures are necessary when designing irregular buildings in seismic regions.

1.3.6 Floating Columns

A floating column is a vertical load-bearing member that terminates at an intermediate floor instead of extending continuously to the foundation. The loads carried by the floating column are transferred to supporting beams or transfer girders, which subsequently transmit them to the columns below. Floating columns are widely adopted in modern buildings to provide large column-free spaces for parking, commercial areas, and architectural flexibility. However, the discontinuity in the load transfer path increases seismic vulnerability by producing higher lateral displacement, inter-storey drift, and force concentration in supporting structural members. Consequently, floating column buildings require careful seismic evaluation to ensure structural safety.

1.3.7 Inclined Columns

Inclined columns are structural members placed at an angle with respect to the vertical axis of a building. These columns are commonly used in modern structures to achieve innovative architectural forms while also influencing the structural behaviour of the building. Due to their inclination, they are subjected to combined axial compression, bending moments, and shear forces. Properly designed inclined columns can improve lateral stiffness and reduce displacement under seismic loading. However, they require detailed structural analysis because the inclination introduces additional horizontal force components that influence the overall load transfer mechanism.

1.3.8 Core Wall Systems

Core wall systems consist of reinforced concrete shear walls generally provided around lift shafts and staircase enclosures to resist lateral loads generated by earthquakes and wind. These walls significantly increase the lateral stiffness of the building, reduce roof displacement and inter-storey drift, and improve overall structural stability. Core walls also minimize torsional effects by providing a continuous and efficient load path for seismic forces. Owing to their superior performance, core wall systems are widely adopted in medium- and high-rise buildings located in earthquake-prone regions and are considered one of the most effective lateral load-resisting systems in modern structural engineering.

Scope of The Work

This research looks at RC-framed buildings in seismic zones II, III, and IV with a response reduction factor of 3, an importance factor of 1.2, and 5% damping. In order to assess the impact of inclined and floating columns, 21 m x 21 m symmetrical building layouts were created. A bay width of 3.5 m, floor height of 3.3 m, and bottom floor height of 6 m are the common parameters considered in the 10, 15, and 20 storeys structures. ETABS 2021, a computer program based on finite element techniques, was chosen to analyze the structure under seismic and wind loads. The analysis was performed based on the guidelines issued either under IS 1893:2016 (Part 1) or IS 875 (Part 3):2015. At the building perimeter, inclined columns were incorporated to investigate the effect of different critical parameters, such as overturning moments, base shear, inter-story drift, storey displacement, and lateral deflections in seismic excitation.

2.Aims and Objectives

The objectives of the present study are:

- To evaluate and compare the seismic performance of reinforced concrete (RC) buildings of varying heights (G+10, G+15, and G+20) with different structural configurations, including the Basic Model (BM), Core Wall Model (CW), Four-Column Core Floating Column Model (FCC), and Nine-Column Core Floating Column Model (NCC), under earthquake loading in Seismic Zones II, III, and IV.
- To investigate the influence of structural configuration, seismic zone, and building height on key seismic response parameters such as base shear, roof displacement, storey drift, overturning moment, lateral stiffness, and natural time period, including a comparison between buildings with floating columns, inclined columns, and conventional vertical columns.
- To assess the effectiveness of reinforced concrete core wall systems in enhancing seismic performance by improving lateral stability, reducing displacement and storey drift, increasing stiffness, and maintaining overall structural serviceability.

To validate the ETABS numerical analysis through comparison with manual calculations for selected seismic parameters and identify the most effective structural configuration for achieving improved earthquake resistance and structural stability

3.LITERATURE REVIEW

Agarwal et al. (2006) [1]

P. Agarwal and M. Shrikhande, in their book *Earthquake Resistant Design of Structures*, presented the fundamental concepts of seismic analysis and design of reinforced concrete structures. The authors explained the behaviour of buildings under earthquake loading, emphasizing the importance of ductility, stiffness, strength, and proper load transfer mechanisms. Various analytical procedures including Equivalent Static Analysis, Response Spectrum Analysis, and Dynamic Analysis were discussed in accordance with Indian Standard codes. The study concluded that regular structural configuration and adequate lateral load-resisting systems significantly improve seismic performance and reduce structural damage during earthquakes.

S. K. Duggal (2007)[2]

S. K. Duggal presented the principles of earthquake-resistant design in his book *Earthquake Resistant Design of Structures*. The study discussed seismic zoning, structural irregularities, dynamic behaviour of buildings, and codal provisions related to earthquake-resistant construction. The author emphasized that vertical irregularities such as floating columns and soft storeys increase structural vulnerability during earthquake loading. Proper structural configuration and the adoption of suitable lateral load-resisting systems were recommended to enhance the overall stability of reinforced concrete buildings.

Jagadish et al. (2014)[3]

The authors investigated the influence of structural irregularities on reinforced concrete buildings subjected to seismic loading. The study highlighted that discontinuities in load paths significantly affect the behaviour of buildings during earthquakes. Parameters such as stiffness distribution, storey drift, and lateral displacement were analysed. The results indicated that irregular buildings experience greater deformation compared with regular structural configurations. The authors recommended adopting efficient lateral load-resisting systems and maintaining structural continuity to improve seismic performance.

Akella Naga Sai Baba et al. (2022)[4]

Akella Naga Sai Baba and co-authors carried out a study entitled *Evaluation of Response Spectrum and Equivalent Static Analysis for Recognizing the Safest Position of Floating Columns by ETABS in Zone V*. The research investigated a G+10 reinforced concrete building with floating columns placed at different locations. The analytical models were developed using ETABS and analysed by both Equivalent Static Analysis and Response Spectrum Analysis in accordance with IS 1893 provisions. Structural parameters including base shear, storey displacement, and storey drift were compared for different floating column arrangements. The study concluded that floating columns located near the building corners produced larger lateral displacement and drift, whereas centrally positioned floating columns exhibited comparatively better seismic behaviour. The authors emphasized that floating columns should be carefully located in buildings situated in higher seismic zones.

Krishna Chaitanya et al. (2022) [12]

Krishna Chaitanya and co-authors conducted a study titled *Seismic Analysis and Positioning of Floating Columns in a Multistorey Building using ETABS*. The objective of the research was to evaluate the influence of floating column location on the seismic response of a G+10 reinforced concrete building. ETABS 2018 software was used to perform Response Spectrum Analysis in accordance with IS 1893. Parameters such as storey displacement, storey drift, and base shear were compared for various structural configurations. The results indicated that the presence of floating columns interrupted the direct load transfer mechanism and significantly increased displacement and inter-storey drift. The authors concluded that the positioning of floating columns plays a vital role in determining the seismic performance of multi-storey buildings.

Aleti et al. (2023)[13]

Aleti Ganesh and co-authors presented a comparative study entitled *Comparison of Response Spectrum and Equivalent Static Analysis for Identifying the Safest Location of Floating Columns Using ETABS in Zone IV*. The research analysed several floating column configurations in a reinforced concrete building to determine the safest location under earthquake loading. ETABS software was employed to perform both Equivalent Static Analysis and Response Spectrum Analysis. The seismic performance of each model was evaluated based on storey displacement, base shear, and storey drift. The study observed that Response Spectrum Analysis provided a more realistic representation of structural behaviour compared with Equivalent Static Analysis. The authors concluded that floating column location significantly influences the seismic response and should be carefully considered during structural planning and design.

Rajeev Kumar et al. (2022)[14]

Rajeev Kumar and Neeraj Kumar Jain carried out a comparative study entitled *Comparative Analysis on Inclined Column by Using STAAD Pro under Lateral Loads at Different Positions*. The objective of the study was to investigate the influence of inclined columns placed at various locations in a G+9 reinforced concrete building subjected to earthquake and wind loads. Different inclined column configurations were analysed and compared with a conventional vertical column building. Structural parameters such as storey displacement, storey drift, axial force, bending moment, and shear force were evaluated. The results indicated that properly positioned inclined columns improved lateral stiffness and reduced displacement when compared with conventional buildings. The authors concluded that inclined columns can enhance structural performance when designed and detailed appropriately.

Aishnavi Patil et al. (2025)[5]

The study compared reinforced concrete buildings with and without floating columns using ETABS. Parameters such as base shear, storey displacement, and storey drift were evaluated. The results showed that floating columns significantly increased lateral displacement and inter-storey drift, indicating reduced seismic performance compared with conventional framed buildings.

Mohammed Zameer Ahamed (2022)[6]
Mohammed Zameer Ahamed investigated the seismic behaviour of reinforced concrete buildings with floating columns using Response Spectrum Analysis and Nonlinear Time History Analysis in ETABS. The study compared buildings with and without floating columns in Seismic Zone V. Critical parameters such as base shear, storey displacement, inter-storey drift, and time period were analysed. The results indicated that buildings with floating columns experienced greater displacement and drift because of discontinuity in the load transfer path. The study concluded that floating columns should be avoided in severe seismic zones unless additional lateral load-resisting systems are incorporated to improve structural safety.

Uplenchwar et al. (2022)[7]
Ankita R. Uplenchwar and Shilpa Samrutwar presented a review titled *Seismic Analysis of a Structure with Soft Storey and Floating Column*. The study examined the combined influence of floating columns and soft storeys on the seismic behaviour of reinforced concrete buildings using ETABS. Both Equivalent Static Analysis and Response Spectrum Analysis were considered. Parameters such as storey drift, storey shear, torsion, and storey moment were evaluated. The authors observed that the combination of floating columns and soft storeys significantly increased lateral deformation and torsional effects. The study recommended providing suitable lateral load-resisting systems in such buildings to improve seismic safety.

C. Vivek Kumar et al. (2023)[8]
Aleti Ganesh and co-authors investigated the safest location of floating columns in reinforced concrete buildings using ETABS through Equivalent Static Analysis and Response Spectrum Analysis. Various floating column configurations were analysed to compare base shear, storey drift, and displacement. The study demonstrated that buildings with floating columns located near the corners exhibited larger displacement and drift than centrally located configurations. Response Spectrum Analysis was found to provide more realistic estimates of structural behaviour under seismic loading. The authors concluded that floating column location significantly affects seismic performance and should be considered carefully during structural planning.

Purvesh and Pujari (2023)[15]
Purvesh and Pujari presented a comprehensive review on the structural behaviour of buildings incorporating inclined columns. The study discussed the influence of inclined columns on lateral stiffness, overturning moment, storey drift, and seismic resistance. Different structural systems, including diagrid systems, core-braced systems, and outrigger systems, were reviewed to understand their compatibility with inclined columns. The study concluded that inclined columns improve the overall stiffness of buildings and reduce lateral displacement when properly integrated with suitable lateral load-resisting systems. The authors recommended further research on high-rise reinforced concrete buildings with inclined columns under dynamic loading.

Lingeshwaran et al. (2021)[16]
N. Lingeshwaran, K. Venkatesh and M. Suresh investigated the seismic performance of reinforced concrete buildings with floating columns and shear walls using ETABS. Three structural configurations consisting of a conventional frame, a floating column building, and a floating column building with shear walls were analysed using Response Spectrum Analysis and Time History Analysis. Structural parameters such as base shear, storey displacement, and inter-storey drift were evaluated. The study concluded that buildings incorporating floating columns experienced larger displacement and drift, whereas the inclusion of shear walls significantly improved lateral stiffness and reduced seismic response. The authors recommended the use of shear walls in buildings containing floating columns to enhance structural safety.

Palani Jagan et al. (2024)[17]
Palani Jagan and Joseph Antony investigated the influence of soil–structure interaction on the seismic behaviour of reinforced concrete buildings with floating columns. Advanced numerical modelling techniques were adopted to simulate nonlinear soil behaviour along with structural response during earthquake loading. Parameters such as storey displacement, base reactions, and inter-storey drift were compared for different soil conditions. The results demonstrated that flexible soil conditions considerably increased lateral displacement and seismic demand in floating column buildings. The study concluded that soil–structure interaction should be considered during the seismic design of buildings with vertical irregularities to achieve realistic structural performance.

Akula et al. (2024)[9]
Akula Prakash and co-authors carried out a detailed seismic analysis of an unsymmetrical reinforced concrete building incorporating floating columns using ETABS 2022. Both Equivalent Static Analysis and Response Spectrum Analysis were performed in accordance with Indian Standard code provisions. Parameters including bending moment, shear force, storey displacement, and lateral deflection were evaluated. The results revealed that floating columns considerably increased bending moments and lateral displacement, particularly at the transfer levels. The authors concluded that appropriate structural planning and strengthening measures are essential when adopting floating columns in earthquake-prone regions.

Shailendra Singh Yadav et al. (2025)[10]
Shailendra Singh Yadav and Ankit Soni analysed the seismic behaviour of a G+20 steel building with floating columns using ETABS. Various structural configurations incorporating floating columns at different storey levels and bracing systems were investigated under seismic loading. The study compared base shear, storey displacement, and inter-storey drift for all models. The results indicated that floating columns significantly increased lateral displacement and drift, while the introduction of bracing systems improved structural stability by reducing lateral deformation. The authors concluded that floating columns should always be supported by

suitable lateral load-resisting systems to improve seismic performance.

Parmar et al. (2025)[11]

Parmar D., Ponnappan N. and Prasanth S. investigated the seismic behaviour of reinforced concrete buildings constructed on sloping ground by considering soil–foundation–structure interaction. Different structural systems incorporating shear walls and hybrid lateral load-resisting systems were analysed using advanced numerical modelling techniques. Parameters such as roof displacement, inter-storey drift, and structural stability were evaluated under earthquake loading. The study demonstrated that buildings incorporating reinforced concrete shear walls exhibited significantly lower displacement and improved structural performance compared with conventional framed buildings. The authors emphasized the importance of efficient lateral load-resisting systems for enhancing seismic safety in high-rise structures. (frontiersin.org)

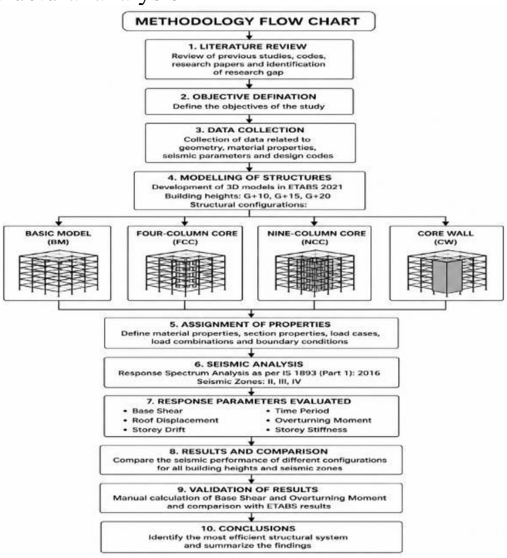
Tijare et al. (2025)[18]

Shravasti Tijare, A. R. Gupta and A. H. Deshmukh carried out a comparative seismic performance study of reinforced concrete frames incorporating exterior floating columns and inclined floating columns using Response Spectrum Analysis. ETABS software was employed to analyse different structural configurations developed in accordance with IS 1893 (Part 1): 2016. Base shear, roof displacement, storey drift, stiffness, and overturning moment were evaluated for each model. The results indicated that inclined floating column configurations exhibited improved lateral stiffness and reduced displacement compared with conventional floating column systems. The study concluded that the combination of inclined columns with efficient lateral load-resisting systems can considerably improve the seismic behaviour of reinforced concrete buildings while maintaining architectural flexibility.

4. METHODOLOGY

The analysis procedure adopted in the study consists of the following major steps:

- Structural modelling
- Definition of material and section properties
- Assignment of loads
- Structural analysis



Structural Geometry

A symmetrical building plan measuring 21 m × 21 m was considered for the analysis. A constant bay width of 3.5 m was adopted. The typical storey height was considered as 3.3 m, while a ground-storey height of 6 m was adopted for the structural models.

Material and Section Properties

The material properties, including the concrete and steel grades, were defined according to the requirements of the structural analysis. The sectional properties of the beams, columns, and slabs were assigned in the ETABS model. Fixed-base supports were provided at the foundation level.

Loading and Analysis Setup

The structural models were subjected to dead load, live load, floor finish load, wall load, earthquake load, and wind load. The loads were defined through appropriate load patterns and subsequently assigned to the structural elements.

Mass Source

The seismic mass of the structure was defined considering 100% of the dead load and 25% of the live load.

Response Spectrum Configuration

Response Spectrum Analysis was performed in accordance with IS 1893:2016. A Type II response spectrum corresponding to medium soil conditions was considered. The seismic excitation was applied in both the X and Y directions. A damping ratio of 5% was adopted in accordance with the code recommendations. The analysis was configured to achieve more than 90% modal mass participation.

Modal Analysis

Eigenvalue analysis was performed for the extraction of vibration modes. Twelve modes were considered for the analysis, ensuring more than 90% mass participation. The Complete Quadratic Combination (CQC) method was adopted for modal combination.

DETAILS OF MODEL

Table 1

Parameter	**Details**
Type of Structure	**Intermediate Moment Resisting Frames**
Number of Stories	**G+10, G+15 & G+20**
No. of Bays in X-Direction	**6**
No. of Bays in Y-Direction	**6**
Bay Width	**3.5 m**
Floor Height	**Bottom: 6 m; Typical: 3.3 m**
Beam Size (b × d)	**300 × 500 mm; 600 × 2000 mm**
Column Size	**400 × 400 mm; 800 × 800 mm; 1000 × 1000 mm;**

Parameter	Details
	1200 × 1200 mm; 500Ø; 600Ø
Thickness of Core Wall	250 mm
Concrete Grade	M50 for beams and columns; M30 for slab
Steel	Fe500
Infill Material	AAC Block
Density of Concrete	25 kN/m³
Type of Soil	Medium
Damping	5%
Seismic Zone	II, III & IV
Zone Factor	0.10, 0.16, 0.24
Response Reduction Factor	3
Loads	Floor finish = 1.25 kN/m²; Imposed load = 3 kN/m²; Wall load = 2.5 kN/m
Load Combinations	As specified for DL, IL, EQX/EQY, REQX/REQY and WINX/WINY combinations

Sl. No.	Model Name	Model Description
1	BM10	G+10 model with all columns resting on the ground.
2	FCC10	G+10 model with 4 columns at the core and 16 inclined columns at the perimeter resting on the ground.
3	NCC10	G+10 model with 9 columns at the core and 16 inclined columns at the perimeter resting on the ground.
4	CW10	G+10 model with walls at the core and 16 inclined columns at the perimeter resting on the ground.
5	BM15	G+15 model with all columns resting on the ground.
6	FCC15	G+15 model with 4 columns at the core and 16 inclined columns at the perimeter resting on the ground.
7	NCC15	G+15 model with 9 columns at the core and 16 inclined columns at the perimeter resting on the ground.
8	CW15	G+15 model with walls at the core and 16 inclined columns at the perimeter resting on the ground.
9	BM20	G+20 model with all columns resting on the ground.
10	FCC20	G+20 model with 4 columns at the core and 16 inclined columns at the perimeter resting on the ground.
11	NCC20	G+20 model with 9 columns at the core and 16 inclined columns at the perimeter resting on the ground.
12	CW20	G+20 model with walls at the core and 16

Parameter		Details
		inclined columns at the perimeter resting on the ground.

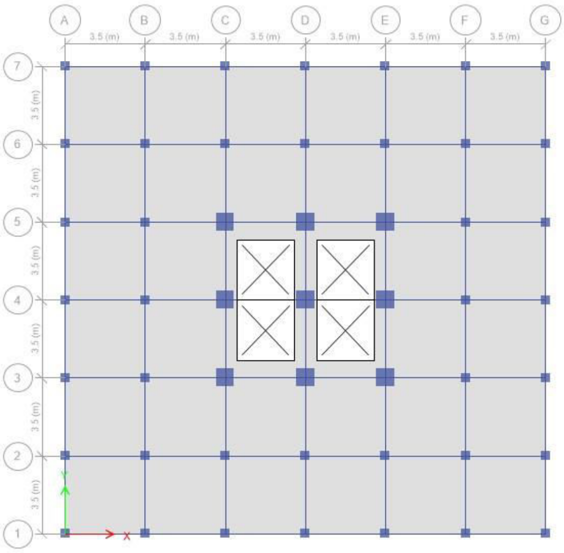
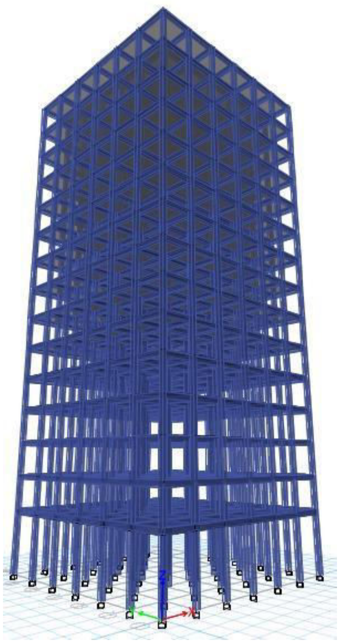


Fig: Plan view of Basic Model



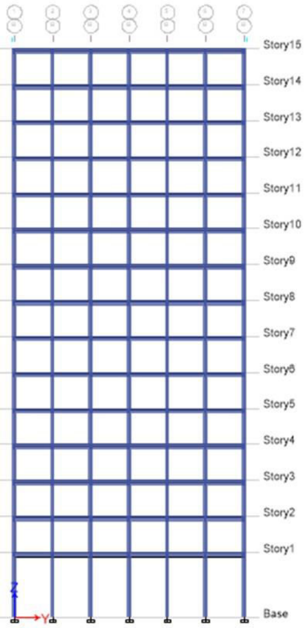


Fig:3D viewof Basic Model Elevation viewof Basic Model

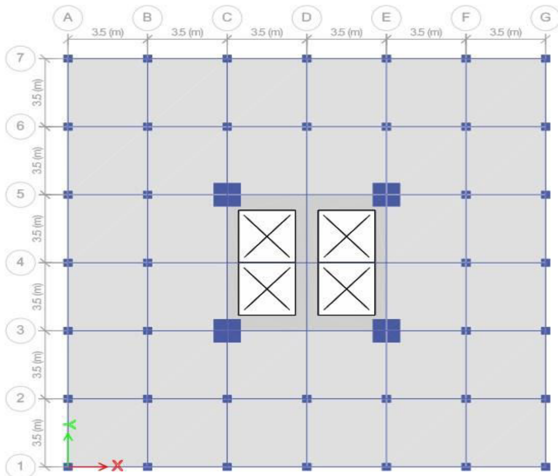


Fig: ModelFCC– Plan of Model with four columns at core

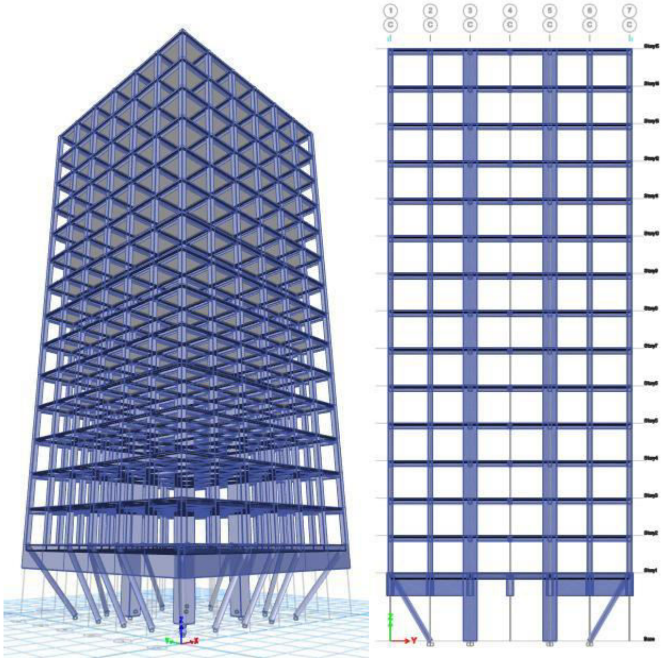


Fig: Model FCC – 3D View of Model Elevation View

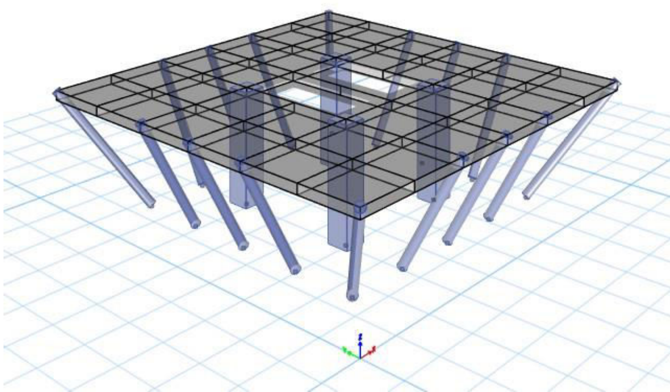


Fig: Model FCC -3D view of inclined columns in model with four column at core

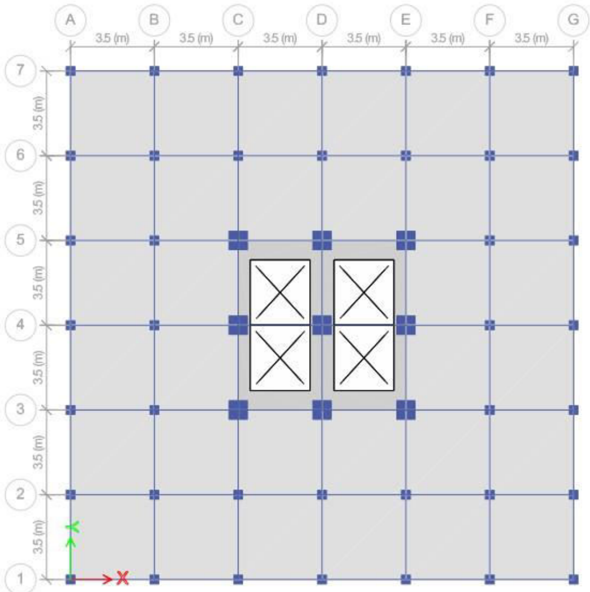


Fig: Model NCC– Plan of Model with nine columns at core

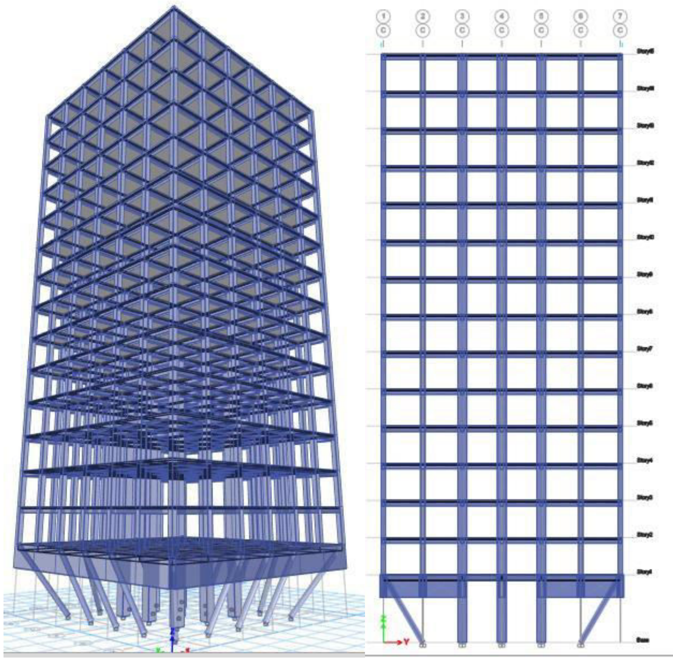


Fig: Model NCC 3D View of & Elevation View of Model with nine columns at core with nine columns at core

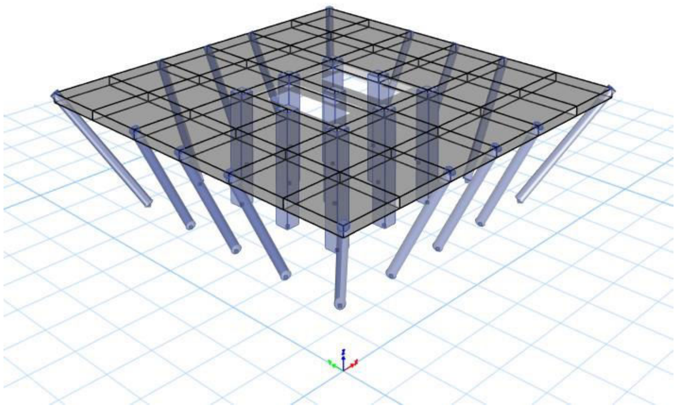


Fig: Model NCC -3D view of inclined columns in model with nine columns at core

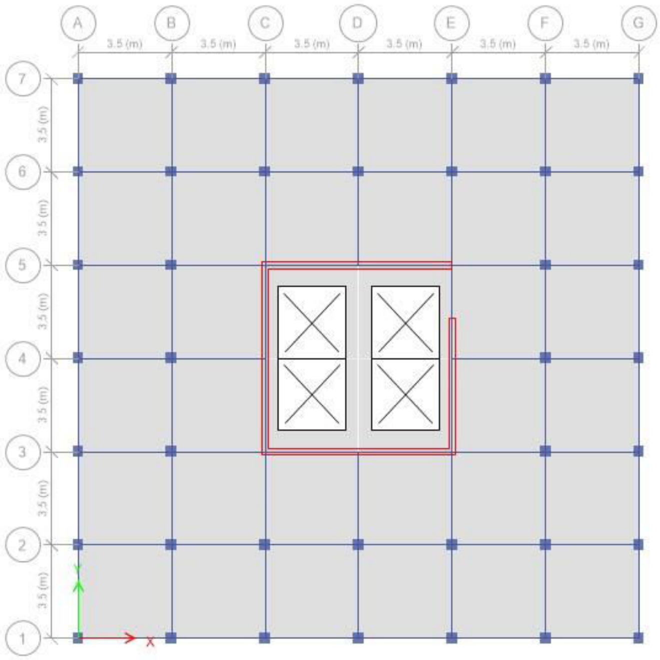


Fig: Model CW -Plan view of model with wall at core

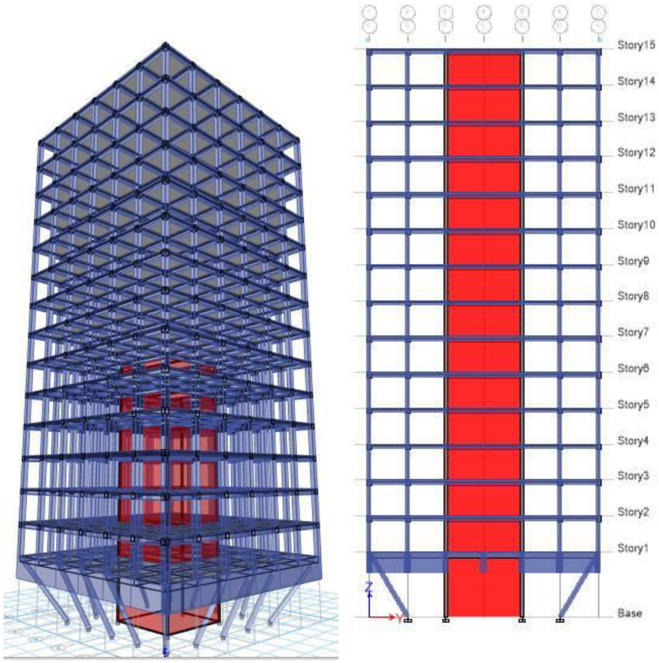


Fig: Model CW – 3D View of Model &Elevation View of Model with wall at core Model with wall at core

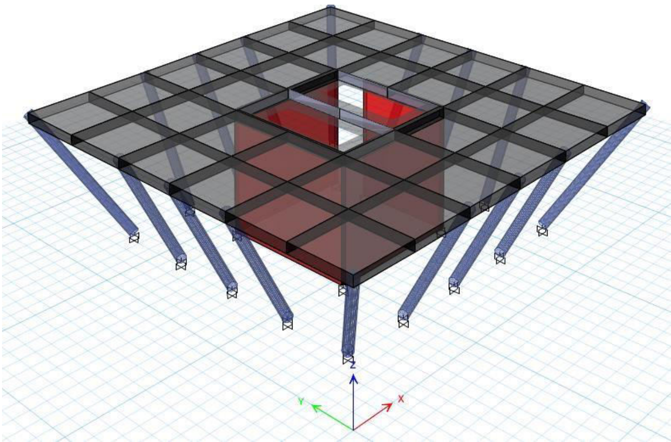


Fig: Model 4 -3D view of inclined columns in model with wall core

- The remaining models of G+10 & G+20 storey also have same plan &elevations with different number of storeys.

5.RESULTS AND DISCUSSION

Table 5.1 (a) Comparison of various parameters for Inclined Column and Vertical Column in Zone 4

	G+10		
	Zone 4		
Parameters	Core Wall with Inclined Column	Core Wall with Vertical Column	% Change
Base Shear (kN)	7937	5992	-24.5
Roof Displacement (mm)	36.5	53.14	45.6
Time Period (sec)	1.92	2.22	15.6
Overturning Moment (kN-m)	778695	969475	24.5
Stiffness (kN/m)	2945709	2704161	-8.2

	G+15		
	Zone 4		
Parameters	Core Wall with Inclined Column	Core Wall with Vertical Column	% Change
Base Shear (kN)	9213	6956	-24.5
Roof Displacement (mm)	58.2	82.41	41.6
Time Period (sec)	1.92	2.22	15.86
Overturning Moment (kN-m)	1061789	1258220	18.5
Stiffness (kN/m)	2500856	2245769	-10.2

	G+20		
	Zone 4		
Parameters	Core Wall with Inclined Column	Core Wall with Vertical Column	% Change
Base Shear (kN)	9611	6833	-28.9
Roof Displacement (mm)	53.7	81.19	51.2
Time Period (sec)	1.92	2.28	18.6
Overturning Moment (kN-m)	1373020	1576913	14.85
Stiffness (kN/m)	2216205	1923666	-13.2

Table 5.1(a) shows that the inclined-column configuration provides better seismic performance in Zone IV

Table 5.1(b) Comparison of various parameters for Inclined Column and Vertical Column in Zone 3

	G+10		
	Zone 3		
Parameters	Core Wall with Inclined Column	Core Wall with Vertical Column	% Change
Base Shear (kN)	5291	4397	-16.9
Roof Displacement (mm)	24.7	40.09	62.3
Time Period (sec)	1.33	1.36	2.3
Overturning Moment (kN-m)	742745	932145	25.5
Stiffness (kN/m)	3203955	2841908	-11.3

	G+15		
	Zone 3		
Parameters	Core Wall with Inclined Column	Core Wall with Vertical Column	% Change
Base Shear (kN)	7013	6178	-11.9
Roof Displacement (mm)	41.4	60.24	45.5
Time Period (sec)	1.33	1.36	2.63
Overturning Moment (kN-m)	1038497	1251389	20.5
Stiffness (kN/m)	2750237	2384455	-13.3

Parameters	G+20		
	Zone 3		
	Core Wall with Inclined Column	Core Wall with Vertical Column	% Change
Base Shear (kN)	7418	6121	-17.49
Roof Displacement (mm)	59.8	91.02	52.2
Time Period (sec)	1.33	1.36	2.63
Overturning Moment (kN-m)	1373020	1672338	21.8
Stiffness (kN/m)	2216205	1822829	-17.75

Table 5.1 (c) Comparison of various parameters for Inclined Column and Vertical Column in Zone 2

Parameters	G+10		
	Zone2		
	Core Wall With Inclined Column	Core Wall With Vertical Column	% Change
Base Shear (kN)	2456	2078	-15.4
Roof Displacement (mm)	16.9	25.8	52.4
Time Period (sec)	0.804	0.848	5.5
Overturning Moment (kN-m)	725255	1104056	52.23
Stiffness (kN/m)	3203955	2957250	-7.7

Parameters	G+15		
	Zone2		
	Core Wall With Inclined Column	Core Wall With Vertical Column	% Change
Base Shear (kN)	3848	3178	-17.4
Roof Displacement (mm)	28.85	41.1	42.4
Time Period (sec)	0.804	0.848	5.5
Overturning Moment (kN-m)	1038497	1435514	38.23
Stiffness (kN/m)	2500856	2283282	-8.7

Parameters	G+20		
	zone 2		
	Core Wall With Inclined Column	Core Wall With Vertical Column	% Change
Base Shear (kN)	5310	4312	-18.8
Roof Displacement (mm)	59.75	85.1	42.4
Time Period (sec)	0.804	0.848	5.5
Overturning Moment (kN-m)	1373020	1897926	38.23
Stiffness (kN/m)	2216205	1979071	-10.7

5.1 BASE SHEAR FOR DIFFERENT MODELS

Fig. 5.11 Variation of Base Shear with Building Height for Different Structural Configurations in Seismic Zone II,III,IV

- As we get from Zone 2 to Zone 4, base shear becomes much more pronounced. This is expected since higher seismic zones are associated with more intense seismic activity, requiring structures to withstand greater lateral forces.

- The core wall model has the greatest base shear values continuously across all zones and building heights. The base shear is increased due to the core wall's substantial stiffness and resistance to lateral stresses.
- Base shear values are often lower in basic models and designs with four or nine columns at the core as compared to the core wall arrangement. **5.2 Drift**

STOREY DRIFT

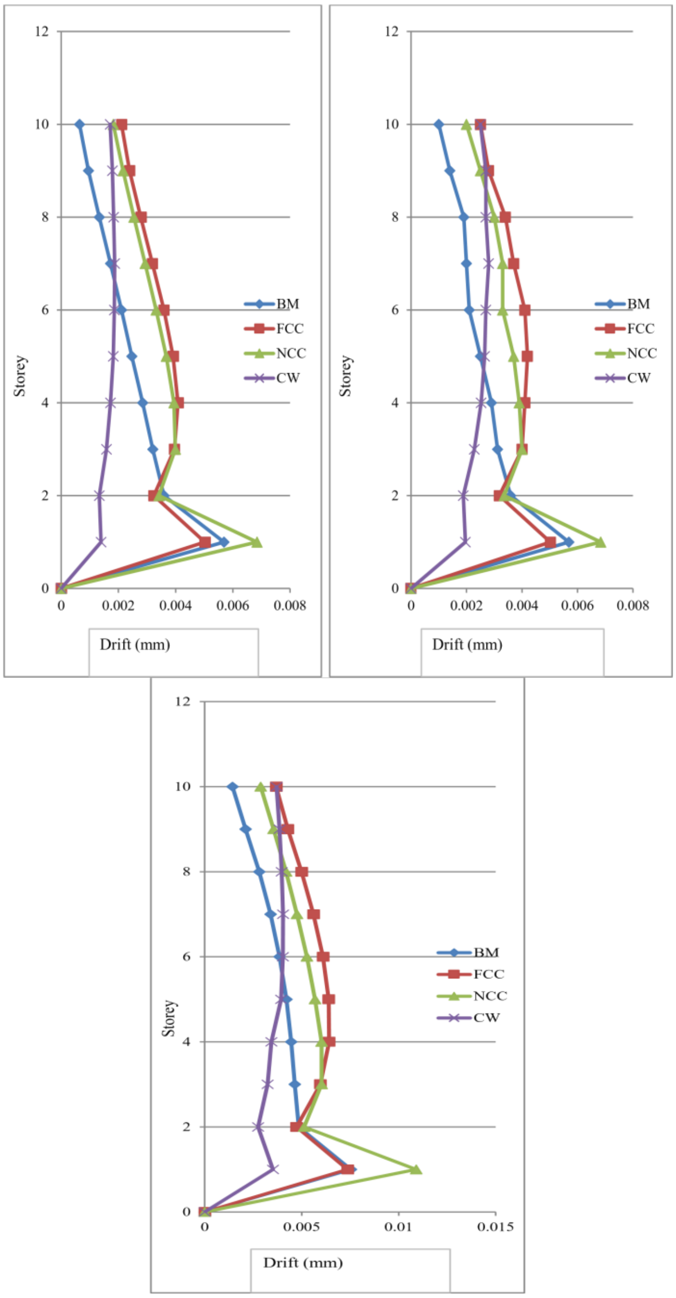


Fig: Comparison of Story Drift of all the G+10 model in Zone 2,Zone 3 ,Zone 4

Substantial increase in drift is seen at first floor due to floating columns. Maximum drift is observed in FCC model in zone 2.

STOREY DRIFT

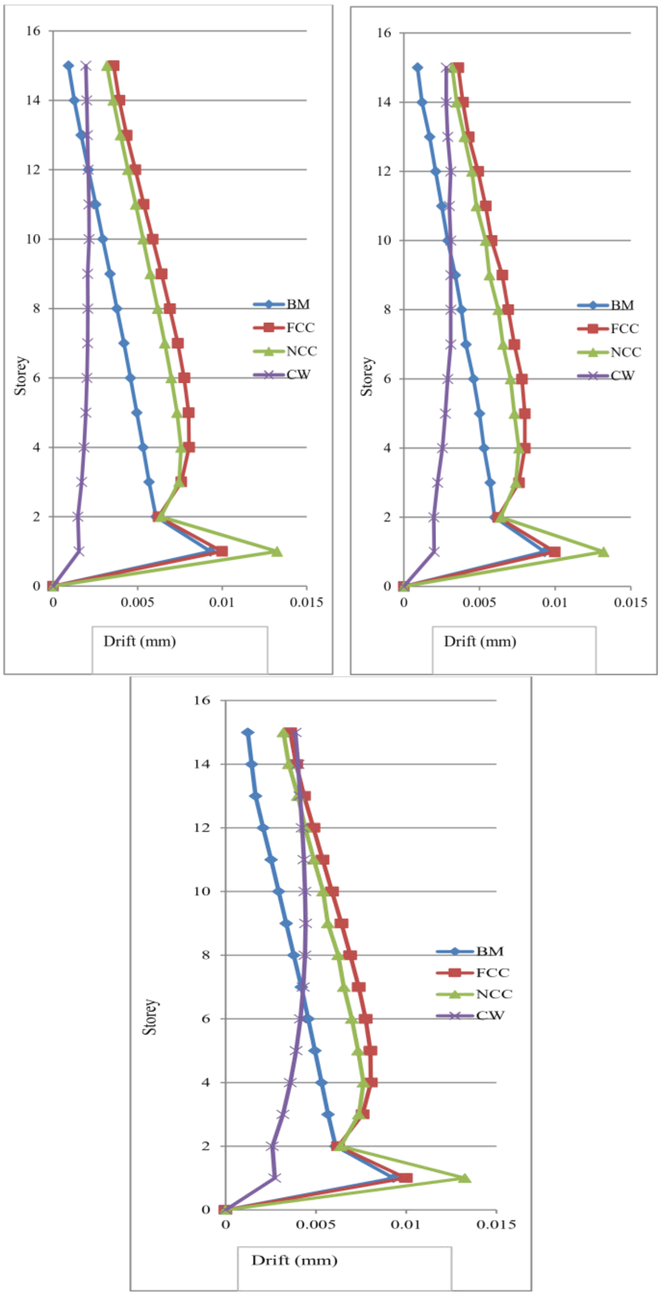


Fig: Comparison of Story Drift of all the G+15 model in Zone 2,Zone 3 ,Zone 4

Core wall model being stiffer has less drift. The FCC & NCC model shows similar drift profile.

For an increased in number of floors the minimum drift is observed in basic model.

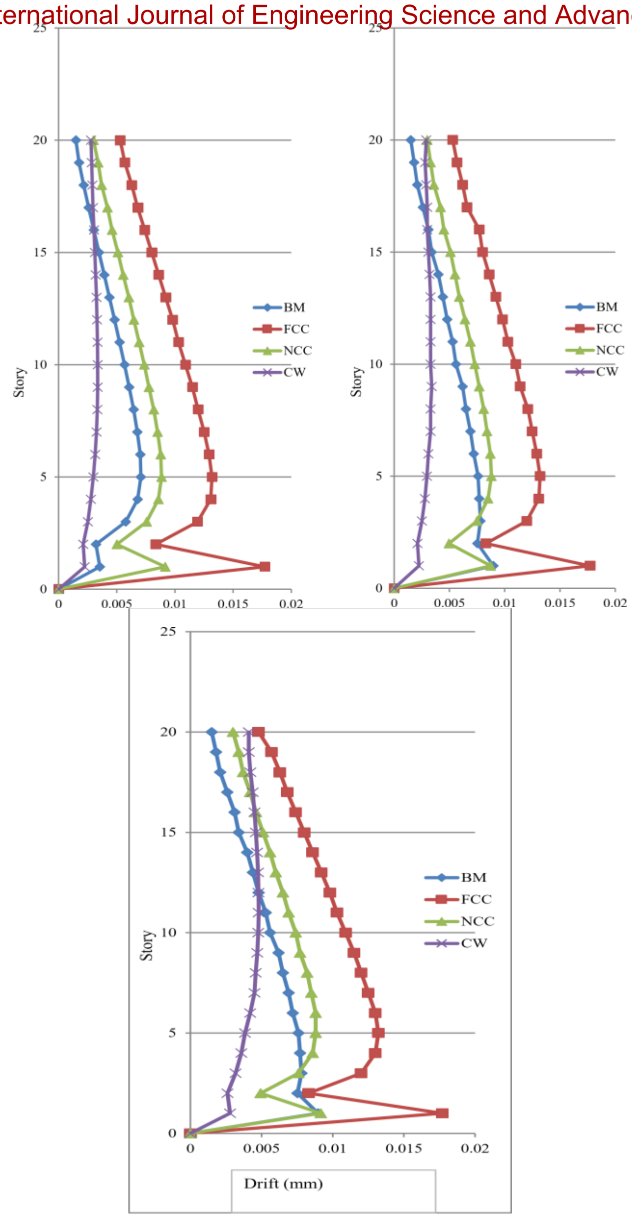
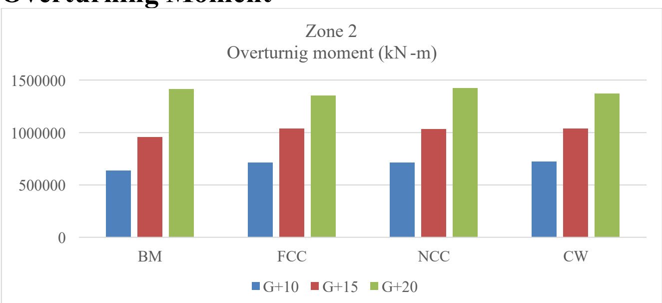
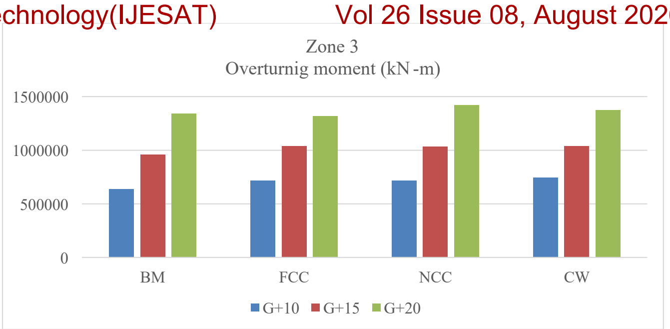


Fig: Comparison of Story Drift of all the G+20 model in Zone 2,Zone 3 ,Zone 4

1. In Zone 2, the base shear and lateral forces are relatively low, resulting in minimal story drift across all building heights.
2. As the seismic intensity increases in Zone 3, the drift values also rise. The increase is more pronounced in taller buildings (G+15 and G+20) due to their greater flexibility.
3. In Zone 4, where the design seismic forces are significantly higher, story drift reaches its peak values.

Overturning Moment





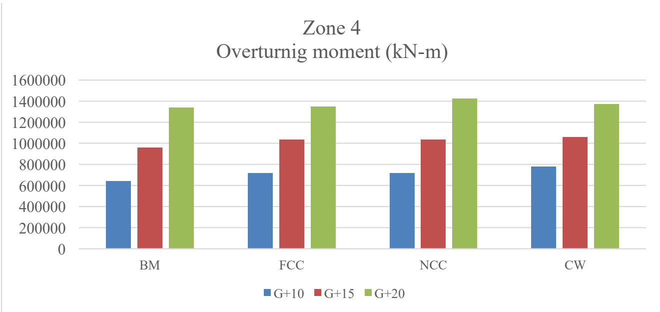
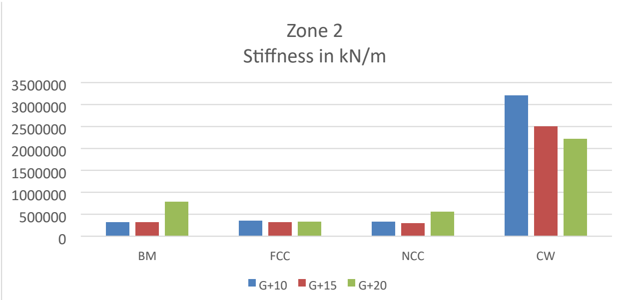


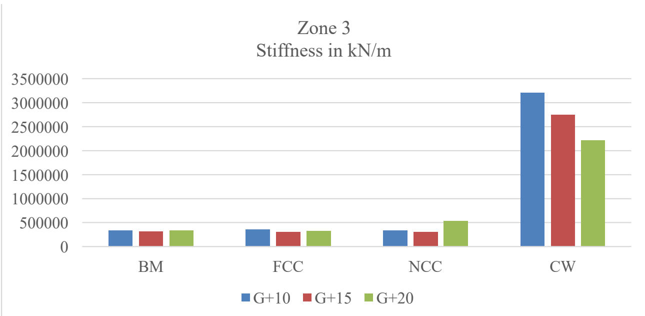
Fig: Comparison of overturning moment of all the models in Zone 2,3,4

In G+10 building the overturning is found to be decreased by 12.1% in FCC, 11.9 % in NCC & 21.14% in CW model. Similarly in G+15 building the overturning was increased by 8.15% in FCC, 8.04% in NCC and 10.7% in CW model. Similarly in G+20 building the overturning was increased by 0.9% in FCC, increased by 6.24% in NCC and 2.54% in CW model.

1. The **CW** model consistently shows the highest overturning moments, particularly for G+10 and G+20, due to its inherent stiffness and mass distribution.
2. The **BM** model exhibits the lowest overturning moments, confirming its flexibility and suitability for high-seismic zones where energy dissipation is critic.
3. The **FCC** and **NCC** models show intermediate values, with NCC slightly higher, indicating that increase in columns may increase stiffness and overturning tendencies.

Stiffness :





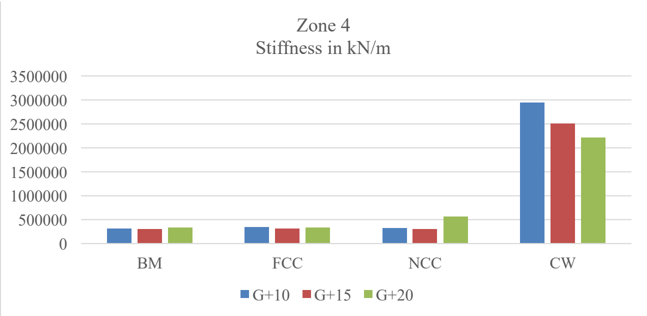
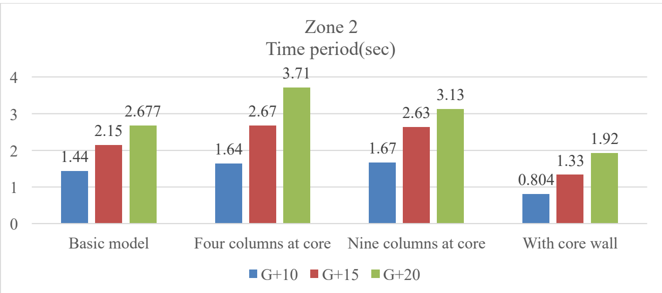
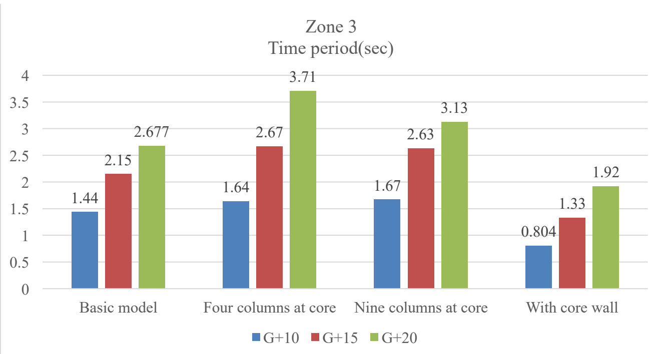


Fig: Comparison of stiffness of all the models in Zone 2,3,4.

- The CW model consistently exhibits the highest stiffness values across all zones and heights. This is due to its rigid concrete wall system, which provides excellent resistance to lateral deformation.
- The BM model shows moderate stiffness, with values increasing significantly at G+20 in Zones 2 and 4. This can be reduced by structural adjustments or additional bracing at higher heights.
- The FCC model maintains relatively consistent stiffness across heights. This indicates stable performance across different seismic zones.
- The NCC model exhibits variability, particularly at G+20, where stiffness increases sharply (e.g., from 296,888 at G+15 to 557,107 at G+20 in Zone 2). This suggests structural changes or bracing adjustments at higher heights.

TIME PERIOD





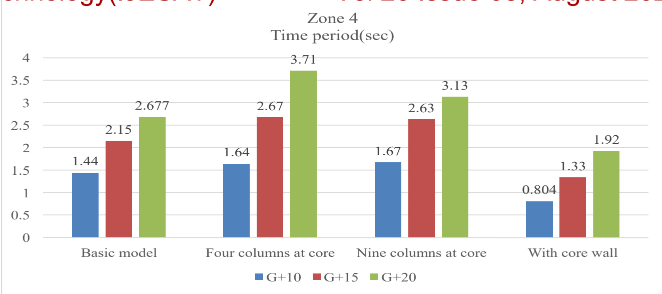


Fig: Comparison of time period of all the models in Zone 2,3,4.

6.Conclusions

- The seismic performance of RC buildings is significantly influenced by building height, structural configuration, and seismic zone. Base shear and roof displacement increased with increasing building height and earthquake intensity. The maximum base shear of 9611 kN was observed in the G+20 Core Wall (CW) model in Seismic Zone IV, while the minimum value of 2456 kN was recorded for the G+10 model in Zone II. Similarly, the highest roof displacement of 201 mm occurred in the G+20 Four-Column Core Floating Column (FCC) model, whereas the lowest displacement of 59.75 mm was recorded in the Core Wall (CW) model in Zone II. As the seismic zone increased from Zone II to Zone IV, all seismic response parameters, including base shear, roof displacement, storey drift, and overturning moment, increased significantly due to higher earthquake intensity.
- Structural configuration has a considerable effect on seismic behaviour, with floating column systems exhibiting inferior performance compared to conventional configurations. The FCC model recorded the highest storey drift, with a maximum drift ratio of approximately 0.59% in the G+20 building, and also exhibited the highest natural time period of 3.71 s, indicating greater structural flexibility. Buildings with floating columns (FCC and NCC) experienced 41%–121% greater roof displacement and higher storey drift than the Basic Model, demonstrating that floating columns reduce lateral stiffness and adversely affect seismic performance.
- The incorporation of a reinforced concrete core wall and the use of inclined columns significantly improve the seismic performance of RC buildings. The Core Wall (CW) model reduced roof displacement by approximately 31%–50% across different building heights and seismic zones and exhibited the lowest natural time period in the range of 0.804–1.92 s, indicating greater stiffness and improved seismic stability. Although overturning moment increased with building height, the CW model maintained better structural stability due to improved lateral resistance. In addition, buildings with vertical columns showed 12%–29% lower base shear than

inclined column systems; however, inclined columns demonstrated superior overall seismic performance by reducing roof displacement by 40%–62% and overturning moment by 14%–52% through improved force redistribution.

- The ETABS numerical analysis was successfully validated through manual calculations, confirming the reliability of the analytical results. The comparison showed only a 0.36% difference in base shear and a 1.28% difference in overturning moment, demonstrating excellent agreement between manual calculations and ETABS outputs. Overall, the Core Wall (CW) configuration proved to be the most effective structural system for enhancing earthquake resistance while maintaining structural stability and serviceability across different building heights and seismic zones.The objectives of the present study were successfully achieved through the comparative seismic evaluation of G+10, G+15, and G+20 reinforced concrete buildings with Basic Model (BM), Four-Column Core (FCC), Nine-Column Core (NCC), and Core Wall (CW) configurations. The study demonstrated that the Core Wall (CW) system provides the most effective lateral load-resisting mechanism under seismic loading and is therefore recommended for improving the earthquake resistance of multi-storey reinforced concrete buildings.

Future scope

1. Extend the study to include base isolation techniques or energy dissipation devices to enhance seismic resilience.
2. Investigate hybrid systems combining inclined columns with diagrid or outrigger frameworks for tall buildings.
3. Explore the use of high-performance materials (e.g., FRP, UHPC) to reduce weight and improve ductility in irregular structures.

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