COMPARING THE PERFORMANCE OF HIGH RISE BUILDINGS WITH AND WITHOUT OUTRIGGER STRUCTURAL SYSTEM UNDER LATERAL LOADING

A Dissertation Submitted
in Partial Fulfillment of the Requirement for the Award of the Degree of

MASTER OF TECHNOLOGY

in

Structural Engineering

by

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(2K22/STE/10)

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CANDIDATE'S DECLARATION

I, **Poranki Pavan Kumar Raju**, hereby declare that the work which is being presented in dissertation entitled "**Comparing The Performance of High Rise Buildings with and without outrigger structural system under lateral loading**" which is submitted by me to the partial fulfilment of the requirement for the award of the degree of **Master of Technology**, submitted in the Department of Civil Engineering, Delhi Technological University, Delhi is an authenticate record of my own work carried out during the period from 2023 to 2024 under the supervision of **Shri Gokaran Prasad Awadhiya**.

The matter presented in the dissertation has not been submitted by me for the award of any other degree or any other institute.

P. Pavan kumar

Candidate's Signature

This is to certify that the student has incorporated all the corrections suggested by the examiners in the thesis and the statement made by the candidate is correct to the best of our knowledge.

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CERTIFICATE BY THE SUPERVISOR

Certified that **Poranki Pavan Kumar Raju (2K22/STE/10)** has carried out their research work presented in this dissertation entitled **"Comparing the Performance of High-Rise Buildings with and without outrigger structural system under lateral loading"** for the award of **Master of Technology** from the Department of Civil Engineering, Delhi Technological University, Delhi, under my supervision. The dissertation embodies results of original work, and studies are carried out by the student himself and the contents of the dissertation do not form the basis for the award of any other degree to the candidate or to anybody else from this or any other University.

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ABSRACT

A comparative study of an outrigger structural system studied under the lateral loading on different buildings structural system. Obtained analysis reveals that placing outriggers at specific storeys can significantly impact the building's lateral displacement and stiffness under seismic and wind loads.

The study emphasizes the role of outriggers in enhancing the overall stability and performance of tall buildings under lateral loading conditions, providing valuable insights. Analysis of lateral displacement under seismic and wind loads indicates that the maximum lateral displacement for a building without outriggers is higher compared to buildings with outriggers at specific heights, showcasing a reduction in lateral displacement with outriggers in place.

Investigation into the percentage reduction in lateral displacement for buildings with concrete outriggers at different heights demonstrates varying levels of reduction, with outriggers positioned at optimal heights showing the highest reduction in lateral displacement under lateral loading conditions.

In this research work I prepared four different cases in ETABS software. Outrigger structural system placed as a reinforced concrete element at different locations in an entire building of G+50 stories. They serve as a fixed base for the building from that particular floor and increase the overall stiffness studied under response spectrum analysis.

Keyword: Outrigger, Belt truss, Seismic Load, response spectrum, Deflections etc.

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PORANKI PAVAN KUMAR RAJU

2K22/STE/10

LIST OF CONTENTS

CHAPTER 6:CONCLUSION AND FUTURE SCOPE

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 GENERAL

As the importance of buildings increasing day by day space availability is becoming a tough sector. So, to overcome this tall building came into existence. Having more space in the building for both commercial as well as residential will be beneficial for human beings.

High-rise structures are a suitable solution to this issue because of the limited land available in cities and the rising rates of urbanization over the past few decades (caused by the rapid population increase and migration of people from rural to urban areas).

Higher and more slender buildings are popping up in cities all over the world. This is because to advancements in material science, building technology, analysis methods, architectural and spatial restrictions, and prestige. In order to optimize usable space, it is also preferable to minimize the size of structural parts. The use of novel new structural systems and materials is pushed by these competing goals for material scientists and engineers. However, under wind excitation and earthquake excitation, the dynamic properties of buildings designed to these restrictions lead to enormous displacements and accelerations as well as massive inter-story drifts. Both the building's structural and non-structural components may sustain harm because of these significant deformations. Large forces like shears and overturning moments are also produced by windstorms and earthquakes, and they need to be resisted.

There are different types of structural system which are used for the tall buildings. those are:

1. Braced frame structural system
2. Rigid frame structural system

3. Wall-frame system (dual system)
4. Shear wall system.
5. Core and outrigger structural system
6. Infilled frame structural system
7. Flat plate and flat slab structural system
8. Tube type structural system

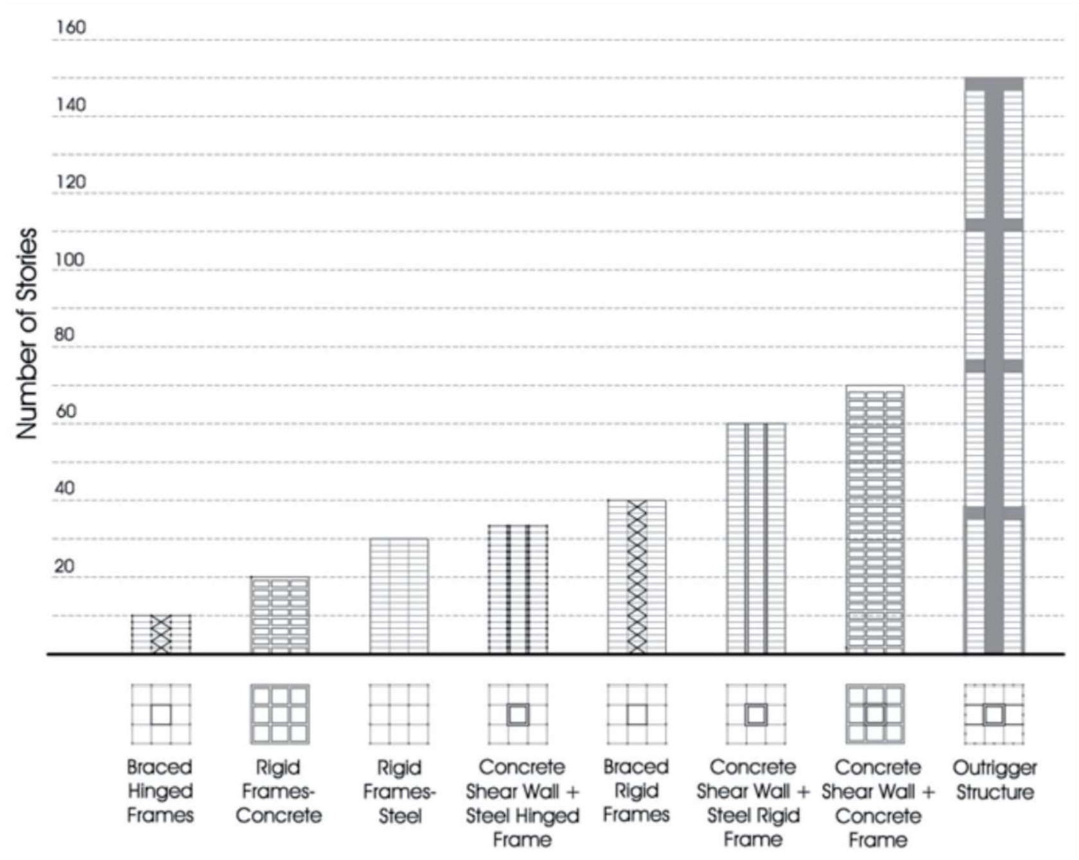


Fig 1.1: various forms of structural systems.

1.2 CORE AND OUTRIGGER STRUCTURAL SYSTEM

The outrigger structural system is a lateral load-resisting system that uses belt trusses at least three levels and extremely rigid outriggers to bind the external peripheral columns to the central core. While the outriggers engage them with the main or central shear wall, the belt trusses are fastened to the building's periphery columns. This structural system is frequently employed as one of the structural systems to effectively manage excessive drift caused by lateral load, hence minimizing the danger of structural and non-structural damage during minor or medium lateral load caused by either wind or earthquake. An outrigger system's structural reaction is determined by the tension-compression pair that is created in the outer columns. The outrigger engages the centre core and surrounding columns like a strong arm. When a lateral load is created in the central core, it is transmitted to the periphery columns by means of outriggers, thereby decreasing the overturning moment.

1.3 BACKGROUND OF OUTRIGGER SYSTEM

Outriggers are strong horizontal structures that connect a building's core to distant columns, enhancing stiffness and resistance to overturning. The concept, derived from Polynesian boats, has been applied to tall, narrow buildings for about fifty years.

- Outriggers improve resistance to overturning by creating tension-compression couples in outer columns, like how amas stabilize boats against waves.
- Outriggers reduce overall lateral drift, story drifts, and building periods, much like amas reduce a boat's rolling motion.
- Buildings can have a central core with outriggers on both sides or a side core with outriggers extending to opposite columns, similar to boat configurations.

Building outrigger behaviour act as stiff arms, generating restorative moments against core tilting. Force distribution depends on the relative stiffness of the core and outrigger system, reducing overturning moments but potentially increasing horizontal story shear forces at outrigger levels.

Belt truss plays an effective role in distributing gravity loads to mega columns which reduce shear lag effects and distribute force evenly across multiple columns, enhancing overall stiffness and torsional resistance. Belts with mega columns create an additional later load resisting system. Outrigger systems are ideal for buildings with significant overturning moments, reducing drift and wind moments, increasing stiffness, and improving occupant comfort during high winds by reducing accelerations.

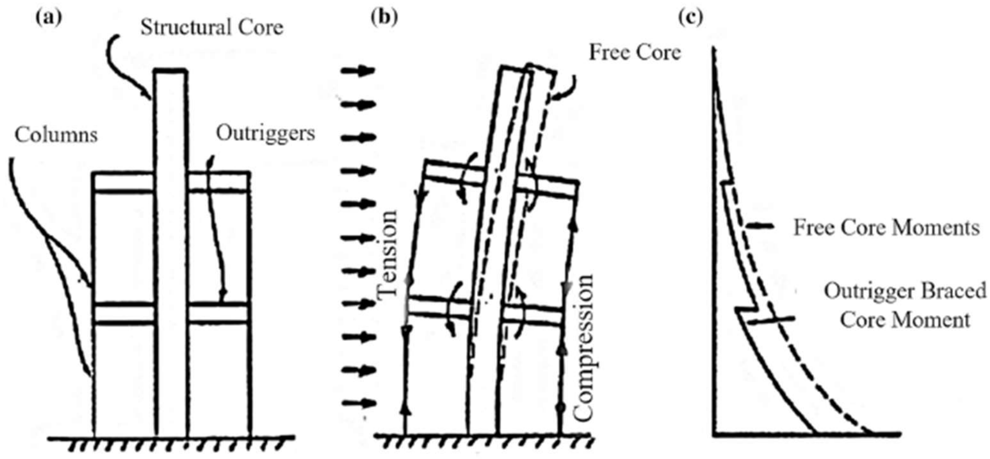


Fig 1.3: functioning of outrigger system.

1.4 ADVANTAGES OF OUTRIGGER SYSTEM

a. **Deformation reduction:** Outrigger systems effectively minimize deformations in tall buildings by engaging perimeter columns, thereby reducing core overturning moments and lateral displacements. This system can reduce core overturning moments by up to 40% in standard buildings and up to 60% in supertall towers, depending on the rigidity of the core and the outriggers. The outriggers counteract rotational forces from overturning, with forces being transmitted via perimeter columns through various truss and diaphragm configurations.

b. **Efficiency**: Belt trusses in outrigger systems can utilize perimeter columns sized for gravity loads, often requiring minimal changes for lateral load resistance. Additional flexural stiffness can be effectively added at the outrigger columns due to their greater lever arm. This optimization can reduce the material needed in the core while slightly increasing the quantities in the outrigger, belt trusses, and columns, leading to a more material-efficient design.

c. **Torsional stiffness**: Belt trusses enhance torsional stiffness by making perimeter columns act similarly to a perimeter tube, albeit not as stiff. This configuration improves the torsional performance of core-and-outrigger buildings compared to core-only structures.

d. **Disproportionate collapse resistance**: Outriggers provide alternate load paths in the event of local member or connection failures, enhancing the building's resistance to progressive collapse. This capability ensures that loads from a failed element can be redistributed to undamaged parts of the structure, though the design must ensure these alternate paths can handle the additional forces.

e. **Gravity force transfers**: Outriggers and belt trusses help mitigate differential vertical shortening between columns and the core, reducing floor slopes caused by creep, shrinkage, or thermal changes. However, this benefit is balanced by the potential for large force transfers that could be costly to manage, necessitating careful design and construction strategies.

f. **Architectural flexibility:** Core-and-outrigger systems offer architectural flexibility, allowing for variations in exterior column spacing to meet aesthetic and functional requirements. This approach enables innovative façade designs and can accommodate very tall buildings, up to 150 stories or more.

1.5 CHALLENGES OF OUTRIGGER SYSTEM

Usability of Occupied Spaces Outrigger elements can interfere with occupiable space, but strategic placement in mechanical floors or refuge areas can mitigate this issue. Proper coordination with mechanical room layouts and service routes is crucial to avoid conflicts and maintain efficiency.

Outrigger Story Locations Ideal outrigger locations are often dictated by space planning rather than structural efficiency. Acceptable performance can typically be achieved even with non-ideal placements, though creative solutions like super-diagonals can be used to minimize the impact on occupied spaces.

Diaphragm Forces, Stiffness, and Details Accurate modelling of diaphragm stiffness is vital for the proper functioning of both direct and virtual outrigger systems. Incorrect assumptions can lead to inaccurate force distribution and building deformations, necessitating careful design and possibly additional horizontal bracing.

Differential Vertical Shortening Differential shortening between core and perimeter columns due to varying stresses and material properties can cause significant force transfers. Strategies such as construction sequencing, special detailing, and avoiding direct connections can help mitigate these effects.

Differential Thermal Strains Temperature differences between the core and perimeter columns can induce significant forces in outriggers, though this is less common. Proper detailing and material selection can address this issue.

Foundation Dishing Core-centric foundation loads can cause differential settlement, leading to force transfers in outriggers. Understanding the interaction between creep, shrinkage, and dishing is essential for effective design.

Connection Forces and Details Large forces at outrigger connections require robust and often complex connection designs. Solutions vary based on material, space, and construction preferences, necessitating a tailored approach for each project.

Construction Schedule The complexity of outrigger systems can slow construction. Optimized erection schedules and clear guidelines are necessary to minimize delays, with creative solutions developed for specific regional challenges, such as high wind conditions during construction.

Seismic Design Criteria Outrigger systems lack explicit seismic design guidelines in building codes, requiring performance-based or capacity-based design approaches to ensure ductile behaviour and effective force distribution during seismic events.

Change in Story Stiffness Outriggers create stiff-story conditions that can contrast with the soft-story provisions in seismic codes. Solutions involve redefining stiffness calculations or ensuring sufficient ductility throughout the building height.

Strong Column Weak Beam Provision This seismic provision is less applicable to outrigger systems due to the presence of a strong core. Applying this philosophy to outrigger-core interactions through capacity-based or performance-based design is more appropriate.

1.6 CONDITIONS LESS SUITABLE FOR OUTRIGGER SYSTEMS

i. **Shear Deformations**

Outriggers are less beneficial in structures governed by shear deformations or with inherently stiff cores. Symmetrical distribution is ideal to maximize efficiency, while asymmetrical systems require careful design to avoid complications from differential shortening and gravity loads. For torsional control, perimeter tube systems may be more effective.

ii. **Core Flexural Stiffness**

Outrigger systems depend on the relative stiffness between the core and the outrigger columns. If the core is already very stiff, which is often the case in buildings with a low height-to-core width ratio, adding outriggers may not significantly improve the building's stiffness. In such situations, the size of the outrigger and column members required to provide additional stiffness might be impractically large. Therefore, outrigger systems tend to be more effective in buildings with taller and narrower cores, such as residential towers, compared to those with wider cores like office buildings. For residential buildings, core efficiency can be enhanced by incorporating adjacent rooms into the core structure.

iii. **Lack of Symmetry**

Outriggers perform best when they are symmetrically arranged around a central core, as this configuration maximizes the distance between outrigger columns and optimizes the force couple, thereby reducing core overturning moments without adding net axial loads to the core. In asymmetrical systems, the outrigger force couple involves axial forces in the core, complicating the design and analysis. Differential shortening in symmetrical systems results in straight downward deformation, whereas in asymmetrical systems, it can cause lateral displacements under gravity loads. Despite these challenges, successful designs of asymmetrical outrigger systems exist, addressing these concerns effectively.

iv. **Torsional Concerns**

Conventional outrigger systems are effective at reducing core overturning moments and related deformations. However, if the building's core is positioned off-center, the structure may be prone to torsional deformations and torsion-induced forces, complicating the design. For buildings where controlling torsional forces and deformations is crucial, a perimeter tube (frame) or a belt truss system may provide better performance compared to an outrigger system without belt trusses. These alternatives offer improved torsional stiffness and help manage torsional effects more effectively.

1.7 TYPES OF OUTRIGGER SYSTEMS

a. **CONVENTIONAL OUTRIGGER SYSTEM:-** A conventional outrigger system in tall buildings connects the central core to the perimeter columns through rigid horizontal structures, such as outriggers or belt trusses. This system significantly reduces lateral displacements and deformations caused by wind and seismic forces by engaging the perimeter columns to counteract core rotations and overturning moments. By distributing these forces more evenly across the building's footprint, outriggers enhance overall structural stability and reduce the demands on the core and foundation. Additionally, the system can improve torsional stiffness, mitigate differential vertical shortening, and provide alternate load paths in case of localized failures, contributing to the building's overall robustness and resilience. However, integrating outriggers can be complex due to potential interference with usable space, the need for precise coordination during construction, and the challenges of differential movements between connected elements.

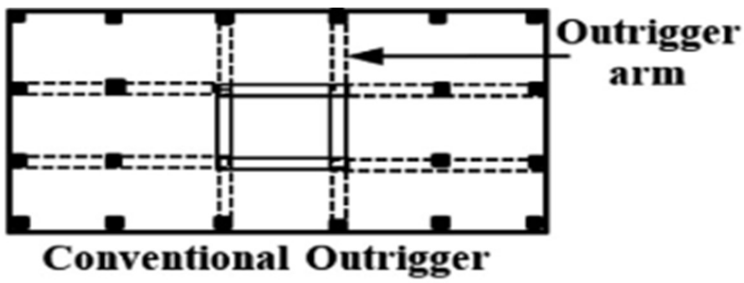


Fig 1.7.1: conventional outrigger.

b. **OFFSET OUTRIGGER SYSTEM: -**An offset outrigger system in tall buildings connects the central core to perimeter columns at specific levels, but unlike conventional systems, these connections are not symmetrical or uniformly distributed. This arrangement helps reduce lateral displacements and core overturning moments by leveraging the perimeter columns' stiffness. Offset outriggers can be beneficial in designs where architectural or functional constraints prevent symmetrical placement. They provide increased flexibility in core design and layout, potentially improving space usage and aesthetic options. However, the asymmetrical nature of offset outriggers can introduce additional complexities in load distribution and analysis, as well as potential challenges in managing differential movements and torsional effects. Despite these challenges, successful applications demonstrate their viability in enhancing structural performance and stability in high-rise buildings.

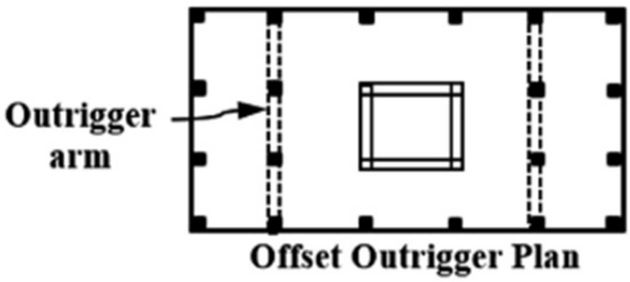


Fig 1.7.2: Offset outrigger.

c. **VIRTUAL OUTRIGGER SYSTEM : -**A virtual outrigger system improves the stability and rigidity of tall buildings by connecting the core to perimeter columns indirectly through belt trusses and floor diaphragms, rather than direct physical outriggers. This system effectively reduces lateral displacements and core overturning moments by using the floor slabs and horizontal bracing to distribute forces. The virtual approach allows for more flexibility in interior design since it avoids obstructions within the occupied spaces. However, it requires precise modelling of diaphragm stiffness and detailed attention to load paths to ensure effectiveness. Virtual outrigger systems offer significant benefits in reducing overall building drift and enhancing structural performance without compromising interior space usability.

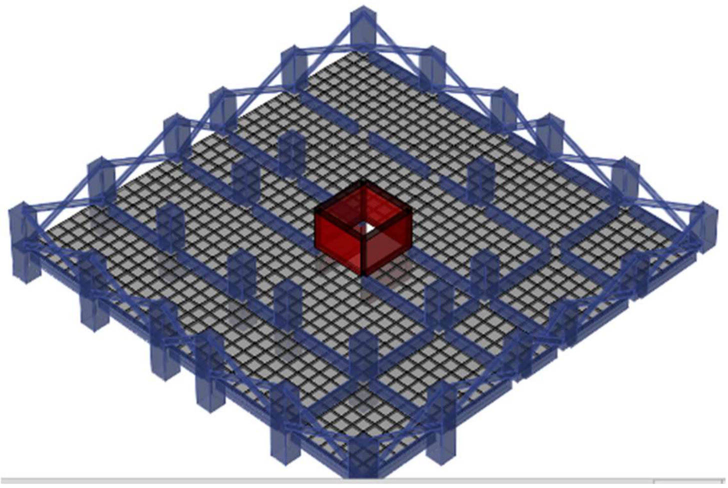


Fig 1.7.3: virtual outrigger.

d. **HYBRID OUTRIGGER SYSTEM :-** A hybrid outrigger system integrates elements from different outrigger designs, such as conventional outriggers, belt trusses, and virtual outriggers, to optimize the structural performance of tall buildings. This combination enhances resistance to lateral forces, reduces building drift, and offers improved stability. The customizable nature of hybrid systems allows for greater architectural flexibility, accommodating unique design features and functional requirements. However, this approach requires complex design and analysis, along with meticulous detailing and coordination, to ensure effective load transfer and structural integrity. By leveraging the strengths of various outrigger techniques, hybrid systems provide a highly efficient and adaptable structural solution for modern high-rise buildings.

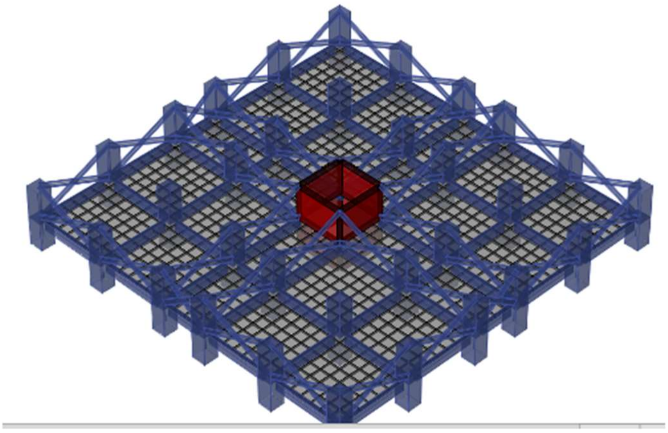


Fig 1.7.4: Hybrid outrigger system.

1.8 BRACINGS VS OUTRIGGERS

Bracings and outriggers are crucial structural elements in construction and engineering, designed to enhance the stability and support of buildings and other structures. They serve different functions and have unique characteristics:

a) Bracings:

- Bracings are structural components aimed at resisting lateral forces such as wind, seismic activity, and other horizontal loads that impact a building.
- Typically, bracings consist of diagonal or horizontal members that link various parts of a structure, like beams, columns, or trusses, to prevent swaying or deformation due to lateral forces.
- These bracings can be made from materials such as steel, concrete, or wood, selected based on the specific design and requirements of the structure.
- Various types of bracings exist, including X-bracing, V-bracing, knee bracing, and concentric bracing, each offering distinct advantages for structural stabilization.

b) Outriggers:

- Outriggers are horizontal structures extending from the core of tall buildings, connecting to perimeter columns or other structural elements, typically used to improve lateral stability in high-rise buildings.
- They function by distributing and transferring lateral loads from the core to exterior columns or shear walls, thereby reducing lateral deflection and sway, which enhances the overall structural performance.
- Outriggers are especially effective in tall buildings because they help control the structure's torsional response, decreasing the necessity for extensive internal bracing.
- Different types of outriggers include perimeter outriggers, belt trusses, and perimeter belt trusses, each designed for specific structural needs.

In summary, bracings are used to provide lateral stability and prevent deformation under horizontal loads, whereas outriggers are employed in tall buildings to improve lateral stability by redistributing loads and controlling torsional effects. Both play essential roles in maintaining the structural integrity and safety of buildings and structures.

CHAPTER 2

LITERATURE REVIEW

Wael Alhaddada et al: The research paper provides a comprehensive overview of the outrigger and belt-truss system in tall and super tall buildings, highlighting its efficiency in resisting lateral loads. It discusses various aspects of the outrigger system, including components, configurations, types, factors affecting performance, structural behaviour under different loads, and the system's pros and cons. The paper emphasizes the importance of understanding critical design issues to maximize the system's efficiency and integration into design guidelines. Significant contributions of the paper include studying outrigger systems under gravity loads, focusing on reducing the effects of phenomena like differential shortening and foundation dishing, and exploring combined systems like moment resisting frames, shear cores, and outriggers. The study also addresses methods to mitigate the effects of differential shortening, such as using adjustable outriggers and mechanically damped outriggers, to ensure the system's effectiveness.

B.G kavyasree et al: -The paper discusses the evolution of outrigger structural systems, starting from conventional outriggers to damped outrigger concepts, incorporating passive, active, semi-active, and hybrid control systems. Outrigger systems are crucial in tall buildings for mitigating story drift, base shear, and base moment of the core, with a focus on improving performance through innovative devices like negative stiffness elements.
Historically, outriggers were used in canoes and later extended to tall buildings for stability and structural response control. The introduction of damped outriggers has shown advantages in reducing building vibrations, lateral forces, structural member sizes, and construction costs. The paper highlights the need for precise semi-active and hybrid control techniques to enhance the performance and economic feasibility of outrigger structural systems. It also discusses the potential of real-time hybrid simulation and novel control systems in structural design and construction.

Optimum positioning of outriggers in tall structures is crucial for their effectiveness in resisting lateral loads.

Kiran Kamath et al: - They investigates the behaviour of different 3D models for reinforced concrete structures with central core walls, comparing those with outriggers and without outriggers. The relative flexural rigidity was varied from 0.25 to 2.0, and the position of outriggers was changed along the building's height from 0.975 to 0.4.
The research focuses on a 40-storey building with a central shear wall, considering parameters like bending moments, shear force, lateral deflection, peak acceleration of the core, and inter-storey drifts for static and dynamic analysis. The outrigger system was found to be most efficient when the relative height of the outrigger was 0.5.
Various studies on outriggers in tall buildings have been referenced, highlighting their role in reducing lateral drift and improving structural stiffness. The paper discusses the impact of outriggers on reducing lateral displacement and the rotation of walls due to outrigger-column interaction.

Hiubalt murmu et al: Introduces a new lateral force-resisting structural system for concrete high-rise buildings called the distributed belt wall system, which acts as virtual outriggers under lateral loads. It investigates the force transfer mechanism and performance of distributed belt walls, emphasizing their role in reducing lateral drift.
Alternative outrigger systems such as offset outriggers and virtual outriggers have been studied to overcome the disadvantages of conventional outrigger systems. These systems use belt structures to tie adjacent perimeter columns, transferring shear forces and reducing bending moments on the core wall.
The study suggests reinforcing belt walls with high-strength prestressing strands (PSC belt walls) to enhance shear strength based on the compression field theory. Nonlinear finite element analysis is performed to investigate the shear behaviour of PSC belt walls, including cracking and yield strengths, providing recommendations for shear design.
The research emphasizes the importance of experimentally verifying the proposed PSC belt wall system, especially for seismic design applications. It highlights the

contributions of the authors in deriving design formulas, investigating detailed behaviours through analysis, and improving the manuscript.

Jallal hasen et al: Tall buildings require lateral load resisting systems like outriggers to withstand wind or earthquake forces, with outriggers being rigid horizontal structures that enhance building stiffness and strength against drift. The study highlights the efficiency of wall outriggers over beam outriggers in high-rise buildings, emphasizing the importance of outriggers in solving structural issues in tall constructions.

Further investigations are suggested in the research, including exploring the placement of outriggers and belt trusses at various heights in buildings, studying different types of truss outriggers, and analysing the impact of outriggers on reducing lateral deflection and base moment.

The research categorizes tall building structural systems into interior and exterior structures, showcasing diagrams of each system and emphasizing the impact of wall outriggers and belt walls in enhancing building stiffness and reducing displacement and drift values.

Vaibhav et al: The study focuses on analysing the behaviour of an outrigger structure using non-dimensional parameters α and β under earthquake loads.

A 40-story 3D reinforced concrete structure with outriggers and belt truss at different levels is modelled in CSI ETABS V19.0 software. By varying the depth of outrigger beams, the lateral displacement, story drift, and base shear are analysed to understand the structural response. Increasing the depth of the outrigger beams enhances the overall lateral stiffness of the model, controlling the story drift. The research aims to understand the behaviour of outrigger systems, study the response of buildings to earthquake loads, and analyse the impact of changing outrigger beam depths on structural performance.

Parameters like lateral displacement, storey drift, and base shear are evaluated to assess the effectiveness of outrigger systems in reducing structural deformations under seismic actions.

Prateek N Biradhar et al: The study focuses on the static and dynamic behaviour of outrigger structural systems for tall buildings, aiming to enhance stiffness and stability against lateral loads like earthquakes and wind loads. A 40-storey building with a core shear wall and outrigger system is analysed for parameters like lateral displacement, storey drift, and base shear due to earthquake and wind loads. The outrigger system connects the core shear wall to exterior columns, reducing overturning moments and lateral displacement at the top floors. It significantly decreases lateral deflection and base moments compared to free core buildings.
Conclusions highlight that outrigger systems at specific stories (20th and 26th) reduce lateral displacement by 15% and storey drift by 35%. Outrigger bracing with belt truss is recommended for its weight reduction, cost-effectiveness, and aesthetic benefits.

Kyoung sun moon et al: The research paper explores the structural performance of outrigger systems in complex-shaped tall buildings like twisted, tilted, and tapered towers. Outrigger structures efficiently handle wind-induced overturning moments by connecting perimeter mega-columns to building cores through outrigger trusses.
Lateral stiffness of outrigger structures varies based on the building's design - reduced in twisted towers, increased in tapered towers, and enhanced in tilted towers due to triangulation of structural components. The study emphasizes the need for more research on structural systems and interdisciplinary collaboration for better performance in complex-shaped tall buildings. The paper discusses the evolution of tall building design from the International Style to contemporary trends focusing on various forms like twisted, tilted, and tapered structures.
Results show that as the rate of twist or taper increases in tall buildings, the lateral stiffness of outrigger structures is affected, with increased height accelerating the stiffness reduction caused by twisting the tower.

2.1 RESEARCH GAP

1. In comparison to conventional outrigger configurations, there is a dearth of research on the long-term performance and durability of alternative outrigger systems, such as offset outriggers and virtual outriggers. This underscores the need for thorough studies on the structural behaviour and maintenance needs of these cutting-edge systems.
2. There is a lack of investigation into the influence of outrigger material properties, such as steel or steel-concrete composites, on the overall structural response and efficiency of outrigger systems in tall buildings, indicating a gap in understanding the impact of material selection on system performance.

2.2 MY OBJECTIVES

1. To study the behaviour of outriggers and belt truss.
2. Direction of outriggers whether in single direction or both direction placing is required.
3. There appears to be a lack of thorough performance evaluation of outrigger systems because current studies mainly concentrate on how outriggers reduce lateral displacement and storey drift and increase the story stiffness under seismic and wind loads, ignoring the possible effects of outrigger configurations on other structural performance criteria, like dynamic response characteristics and energy dissipation capabilities.

CHAPTER 3

DESIGN METHODOLOGIES

3.1 CONVENTIONAL DESIGN PHILOSPHY

The design philosophy prioritizes structural resilience based on the severity and frequency of seismic events. It categorizes shaking into minor, moderate, and strong, with corresponding expectations for damage. After minor shaking, buildings should remain fully operational with minimal repair costs. Moderate shaking may require repair and strengthening of main members before restoration, while strong shaking could render the building temporarily dysfunctional but still standing for evacuation and recovery. This approach aims to prevent casualties resulting from structural failure during severe earthquakes. In the traditional design methodology, it is acknowledged that structures can be engineered to exhibit substantial ductility, meaning they can undergo significant displacements after yielding while retaining their structural integrity. To mitigate elastic seismic demands to inelastic levels, system-specific modification factors for ductility (Rd) and overstrength (Ro) are utilized. Typically, more stringent detailing requirements allow for higher force modification factors. Members of the Seismic Force Resisting System are dimensioned to meet the reduced seismic demands while also being detailed to ensure adequate ductility. Inter-story drifts are usually limited to a specific benchmark value, often around 0.4% for standard structures. Consequently, the initial sizing of the structural system must account for both individual member strengths and the system's displacement response.

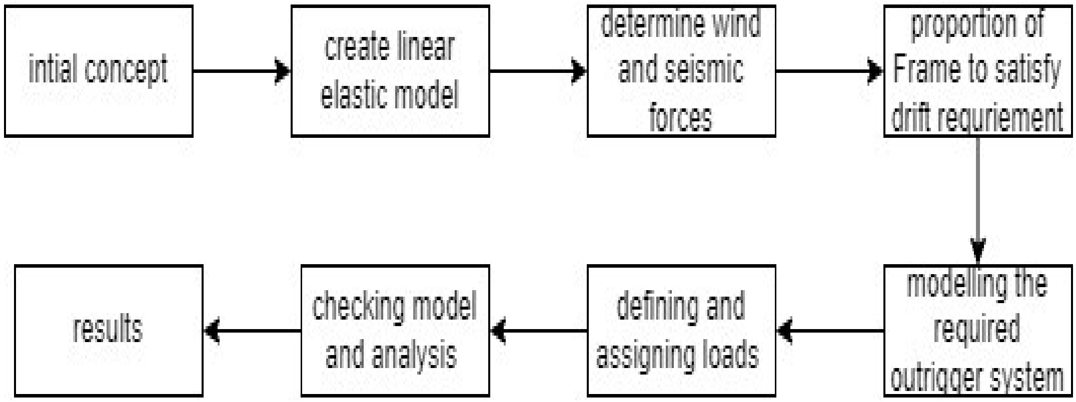


Fig 3.1: flow chart diagram of modelling and analysis of outrigger.

3.2 CASE A: CONVENTIONAL BARE FRAME

A symmetrical G+50 story building with beams, columns and slabs at floor level. Each floor of height 3M and there are 3 refused floor at a height of 45M.

Total height of the structure is 150m which comes under high rise building as per IS16700:2023.

Table 3.2: material and section properties of RC members for bare frame.

S NO	MATERIAL AND SECTION PROPERTIES	VALUES
1	Reinforcement bar	HYSD 550
2	Concrete grade	M30
3	Number of bays along X-direction	6
4	Number of bays along Y-direction	6
5	Total number of stories	G+50
6	Grid spacing along X-direction	8m
7	Grid spacing along Y-direction	8m
8	Outer Column dimensions (RCC)	1000 x 1000 mm
9	Beams dimension (RCC)	450 x 650 mm
10	Slab thickness	250 mm

.

Property modifiers/stiffness modifiers

As per IS 16700:2023, IS 1893:2016 it recommended to consider the cracked sections when we are going to perform the analysis for the structure subjected to lateral loading. At beam column joint due to lateral loading, there is more chance of development of flexural crack.

So as per IS16700:2023 Table 5, area will remain same only change will be in Moment of inertia.

Sl No.	Structural Element	Serviceability Design		Strength Design	
		Cross-Sectional Area	Moment of Inertia	Cross-Sectional Area	Moment of Inertia
(1)	(2)	(3)	(4)	(5)	(6)
i)	Slabs	$1.0A_g$	$0.35I_g$	$1.00A_g$	$0.25\ I_g$
ii)	Beams	$1.0\ A_g$	$0.7\ I_g$	$1.00\ A_g$	$0.35\ I_g$
iii)	Columns	$1.0\ A_g$	$0.9\ I_g$	$1.00\ A_g$	$0.70\ I_g$
iv)	Walls	$1.0\ A_g$	$0.9\ I_g$	$1.00\ A_g$	$0.70\ I_g$

Fig 3.2: cracked section properties of RC members as per IS 16700:2023.

3.2.1 CASE A DETAILS

Start Modelling the elements after defining the material properties initially model the outer columns after that inner columns and then beams and core walls and then slab portion.

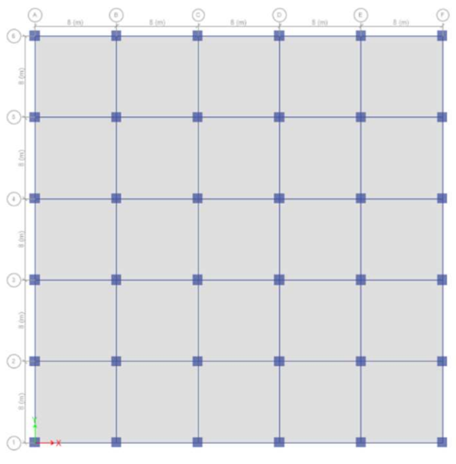


Fig 3.2.1A: Plan view of framing.

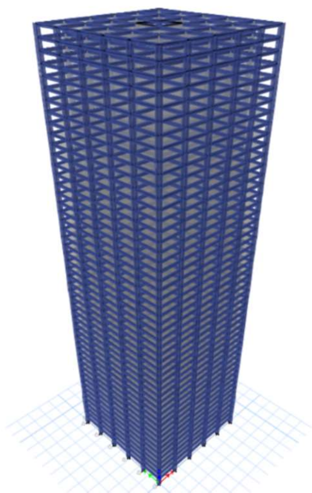


Fig 3.2.1B:3D view of framing.

After modelling, next we need to assign joint restraint to the support at the base as fixed. Next step is loading, before that we need to define all load cases in defining section.

Gravity loads and lateral loading definition

Table 3.2.1: loading pattern for the framing system.

LOAD PATTERENS	CODES
Dead load	Dead load (as per IS 875:1987 part 1)
Live load	Reduced live (as per IS 875:1987 part 2)
EQX	Seismic load (as per 1893:2016)
EQY	Seismic load (as per 1893:2016)
WLX	Wind load (as per IS 875:2015 Part 3)
EQY	Wind load (as per IS 875:2015 Part 3)

3.2.2 LOAD CALCULATIONS

DEAD LOAD

Beam load calculation:

(density of light weight brick) X (height of floor) X (thickness of wall)

=10X (3.0-0.9) X 0.2

=4.7 KN/m

Slab load calculation:

Floor finisher: density of bedding material) X (thickness of filling) + (density of flooring tile) X (thickness of the flooring) = (20X0.05) + (26.7 X 0.025)

=1.7 KN/m2

LIVE LOAD

As per IS 875:1987 PART 2 for commercial buildings rooms without separate storage= 4KN/m2.

EARTHQUAKE LOAD

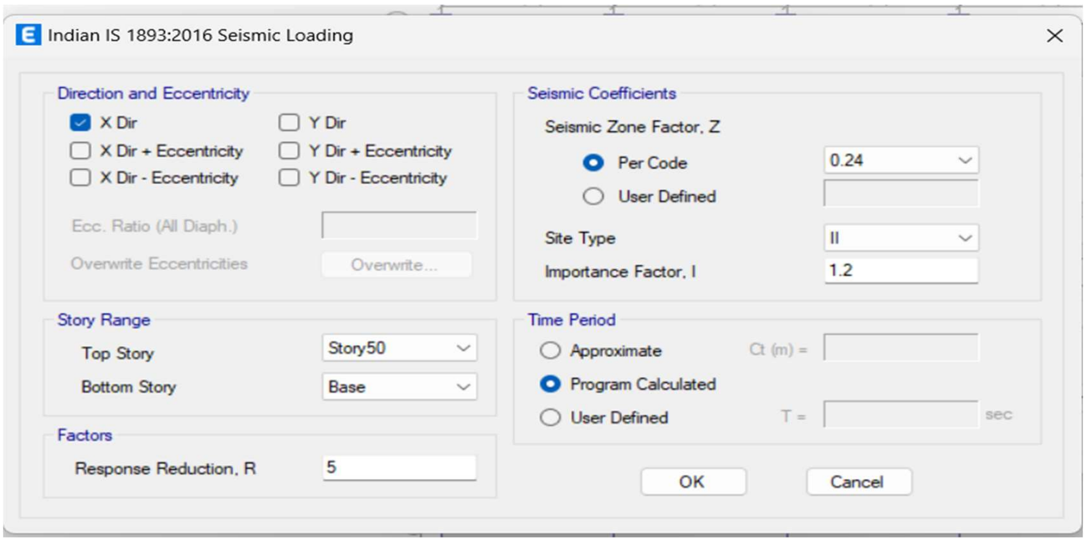


Fig 3.2.2: earthquake loading definition.

After changing the required data software, it self-calculates time period value as per IS 1893:2016.

ASSIGNING LOADS :

In CSI ETABS self-weight of the member is calculated by default no need to calculate separately. Beams are to be selected separately and assign the load as per calculation in gravity direction as distributed load. After the assigning of beam load floors are to be selected and dead weight and live load has to be assigned as distributed load.

WIND LOAD

There are four (4) methods for calculation of wind load.

1. Pressure coefficient method.
2. Force coefficient method.
3. Gust factor method.
4. Wind tunnel analysis method.

Here I have fallowed pressure coefficient method for calculating wind force.

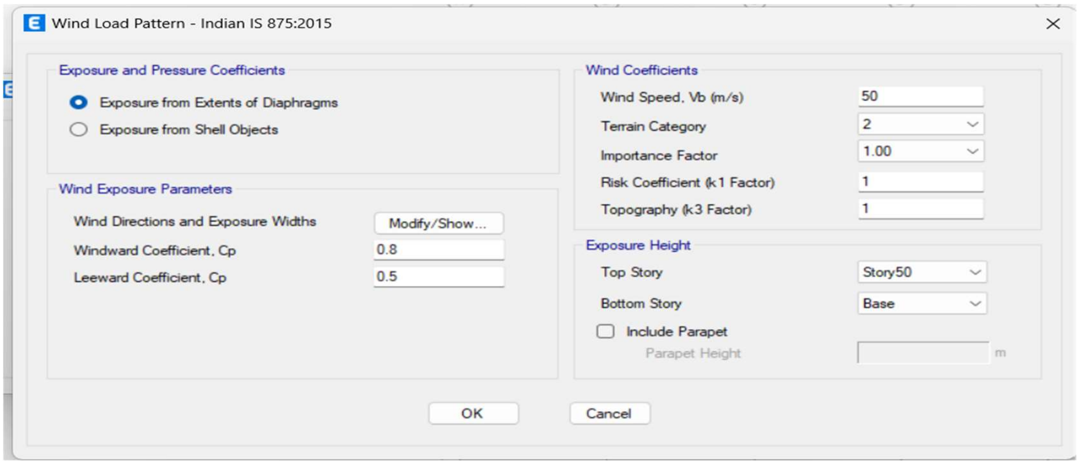


Fig 3.2.2.1: Wind load definition.

Change direction angle to 0 degree because it is in windward direction, after that in leeward direction change direction value to 90 degrees.

MASS SOURCE

In structural engineering software like ETABS, mass sources are used to define additional masses for dynamic analysis that are not part of the structural elements. These can include concentrated or distributed masses such as equipment and partitions, contributing to the building's overall mass. By accurately modelling these non-structural components, engineers can better predict the structure's response to dynamic forces like seismic or wind loads. This allows for a comprehensive analysis of the building's behaviour under various conditions, ensuring it meets safety and performance standards. In ETABS, mass sources are specified by defining the mass value, location, and direction, integrating them into the finite element model for precise dynamic analysis.

After mass source we need to define type of dynamic analysis which we are going to performed.

I have chosen "Response spectrum analysis" method for my analysis.

3.2.3 DYNAMIC ANALYSIS

To study the dynamic behaviour of the structure we need go for dynamic analysis, that for high rise buildings dynamic analysis will help to get each story responses when a structure is subject to any lateral loading event. To study the seismic effect there are 2 different types of seismic dynamic analysis

Those are 1. Response spectrum analysis

2. Time history analysis.

I have considered response spectrum analysis.

RESPONSE SPECTRUM ANALYSIS

Response spectrum analysis is a method used in structural engineering to evaluate the seismic response of a structure. It involves the conversion of ground motion data into a graphical representation known as the response spectrum, which illustrates how a structure will react to seismic forces at different frequencies. Unlike time history analysis, response spectrum analysis simplifies complex seismic inputs into a single curve, making it a powerful tool for seismic design and evaluation. By comparing the structure's response spectrum with predefined design spectra, engineers can assess its performance and make necessary adjustments to ensure structural safety against seismic events. This analysis is crucial for designing earthquake-resistant structures, especially in regions prone to seismic activity.

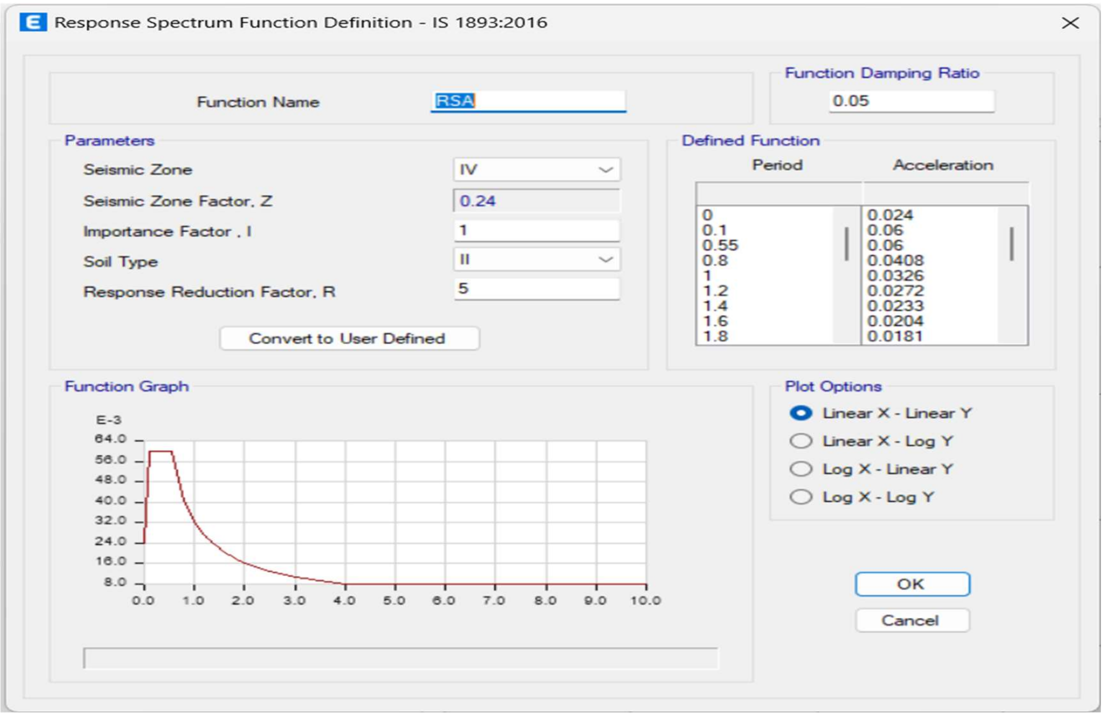


Fig 3.2.3: Response spectrum definition

3.2.4 MODEL ANALYSIS

After defying response spectrum analysis go for modifying the modal analysis. Model analysis studies the deformed shape of the structure within 60 seconds. This free vibration response is a sum of simple harmonic motions where the shape of each harmonic motion is called **mode shapes.**

Model analysis gives InSite of the structure in respect of the frequencies under deflection and from there we get torsional irregularity of the proposed structure.

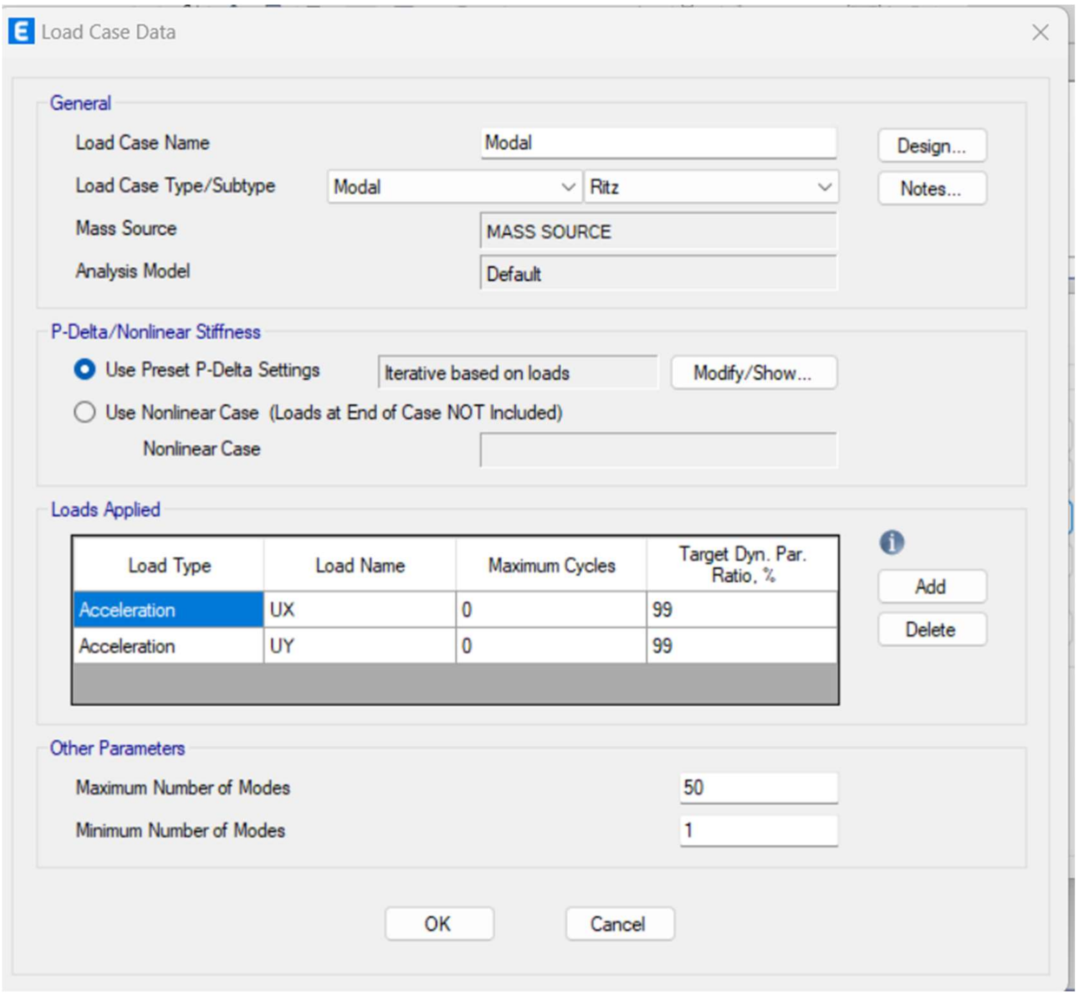


Fig 3.2.4: Model analysis definition.

3.2.5 P-DELTA EFFECT

The P-Delta effect phenomenon accounts for the interaction between the lateral deflection of a building under gravity loads and the resulting secondary effects on its internal forces. As buildings deform laterally due to gravity loads, such as the weight of the structure and applied loads, they experience additional axial forces and moments. These secondary effects, known as P-Delta effects, can significantly impact the overall stability and behaviour of the structure, particularly in tall or slender buildings. consideration the P-Delta effect in the analysis and design to ensure the structural integrity and safety of buildings, especially in seismic regions where lateral loads play a crucial role in structural performance. By incorporating P-Delta effects into calculations, the behaviour of buildings under various loading conditions will be obtained.

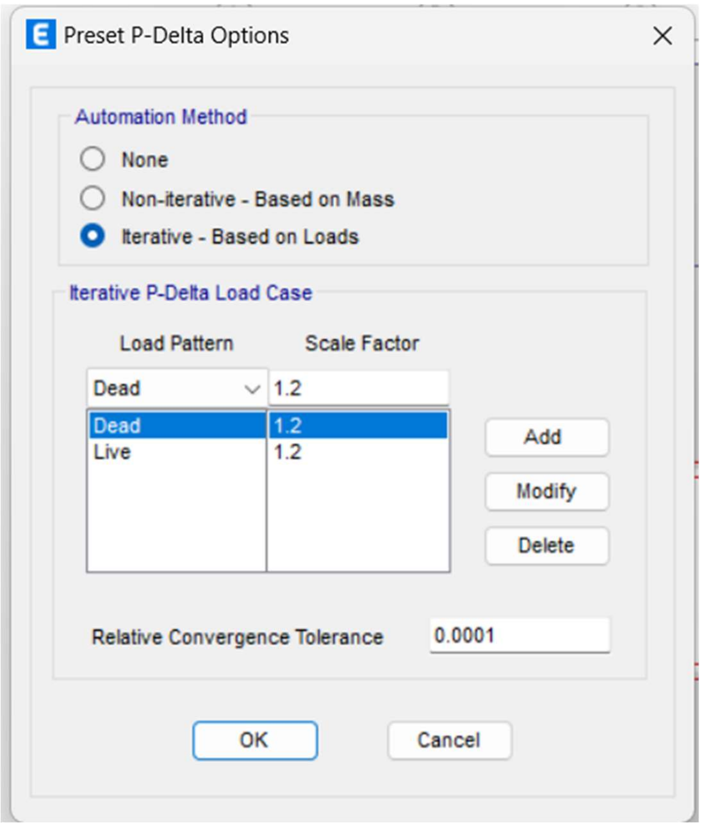


Fig 3.2.5: P-Delta definition.

After creating the P-delta effect consider all load combinations as per IS codes.

3.2.6 LOAD COMBINATIONS

Load combinations for high-rise buildings in India are governed by the Indian Standards, specifically IS 875 (Part 2) for live loads, IS 875 (Part 3) for wind loads, IS 1893 for seismic loads, and IS 456 for reinforced concrete structures. These standards prescribe various load combinations to ensure the safety and stability of high-rise buildings under different conditions. Each combination incorporates factors of safety and partial load factors to account for uncertainties. For instance, IS 456 suggests partial safety factors such as 1.5 for DL, 1.5 for LL, and 1.2 for combined DL and LL with wind or seismic loads. For seismic loads, IS 1893 outlines the Response Reduction Factor (R) and Importance Factor (I) to adjust for building ductility and significance.

Advanced high-rise building designs often employ nonlinear dynamic analysis and performance-based design to refine these combinations further. Load combinations are tailored to account for specific building characteristics, including height, shape, and material properties, ensuring comprehensive safety and serviceability under all plausible load conditions. Proper implementation of these load combinations ensures that high-rise buildings in India meet the necessary safety standards and can withstand the diverse and challenging load scenarios they may encounter throughout their lifespan.

Table 3.2.6: Load combinations.

SNO	LOAD COMBINATION	SNO	LOAD COMBINATION
1	1.5(DL+LL)	14	1.2(DL+LL+WLX)
2	1.2(DL+LL+EQX)	15	1.2(DL+LL-WLX)
3	1.2(DL+LL-EQX)	16	1.2(DL+LL+WLY)
4	1.2(DL+LL+EQY)	17	1.2(DL+LL-WLY)
5	1.2(DL+LL-EQY)	18	1.5(DL+EWLX)
6	1.5(DL+EQX)	19	1.5(DL-WLX)
7	1.5(DL-EQX)	20	1.5(DL+WLY)
8	1.5(DL+EQY)	21	1.5(DL-WLY)
9	1.5(DL-EQY)	22	0.9DL+1.5WLX

10	0.9DL+1.5EQX	**23**	0.9DL-1.5WLX
11	0.9DL-1.5EQX	**24**	0.9DL+1.5WLY
12	0.9DL+1.5EQY	**25**	0.9DL-1.5WLY
13	0.9DL-1.5EQY	**26**	DL+LL

3.3 CASE B: CONVENTIONAL FRAME WITH CORE WALL

A symmetrical G+50 story building with beams, columns, core walls and slabs at floor level. Each floor of height 3m and core walls are arranged in the centre portion of the building

3.3.1 CORE WALL

A core wall in a building serves as a structural backbone, providing crucial support and stability. Typically constructed from reinforced concrete or steel, it runs vertically through the centre of the building, connecting floors and distributing loads such as wind, seismic forces, and the building's own weight. Core walls play a pivotal role in ensuring the structural integrity and safety of tall buildings, especially in high-rise constructions. Beyond their primary function of bearing loads, they often house essential utilities like elevators, staircases, and service shafts, optimizing space efficiency. Architects and engineers carefully design core walls to meet specific structural requirements, considering factors such as building height, location, and anticipated loads. In essence, core walls are indispensable elements in modern construction, seamlessly blending functionality with structural robustness.

RECTANGULAR CORE WALL:

A rectangular core wall is a crucial structural component in high-rise buildings, primarily made of reinforced concrete, designed to resist lateral forces from wind and seismic activity. These walls typically feature high-strength vertical and horizontal reinforcement to handle tensile and shear forces, with concrete grades often M40 or higher for compressive strength. Design considerations include the height-to-width aspect ratio, wall thickness (usually 200-600mm), and the use of coupling beams for added stiffness. Construction methods like slip forming, jump forming, and the use of precast panels expedite the building process. In seismic zones, ductility is ensured through detailed reinforcement design, and advanced techniques like base isolation may be employed. Finite Element Analysis (FEA) helps in optimizing the wall's performance under various loads. Additionally, core walls often integrate essential services such as elevators and mechanical shafts, requiring careful planning to maintain structural integrity.

Defining core walls

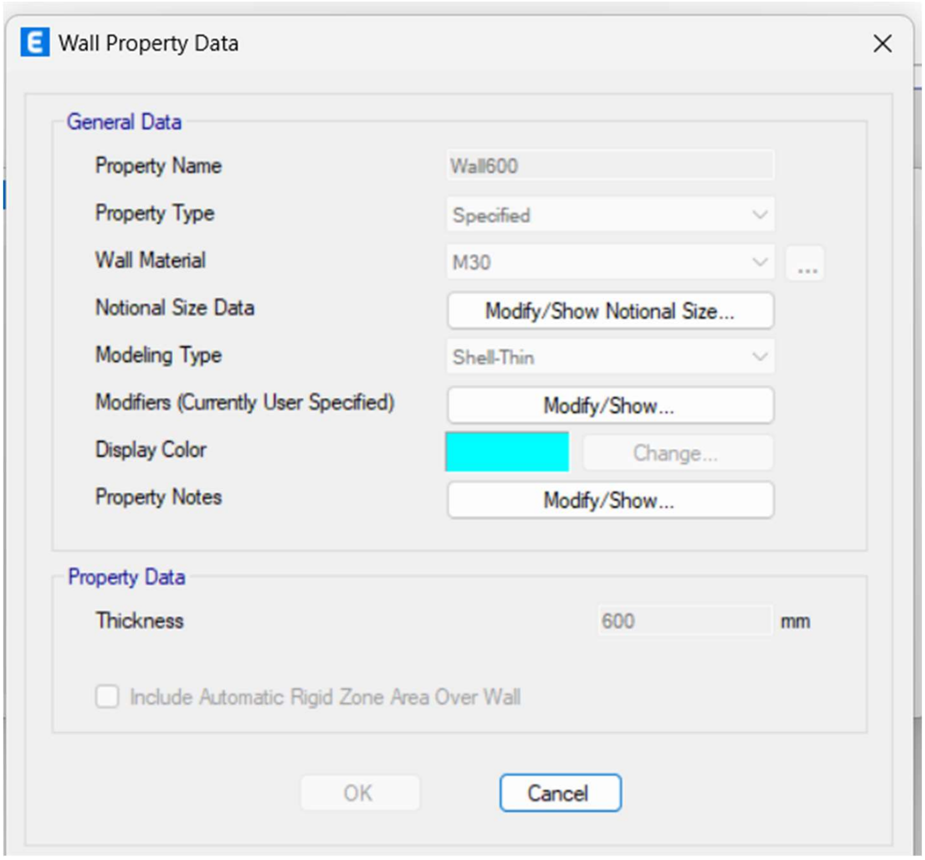


Fig 3.3.1: Core Wall property definition.

Table 3.3.1: material and section properties of RC members for bare frame with outrigger.

SL NO	MATERIAL AND SECTION PROPERTIES	VALUES
1	Reinforcement bar	HYSD 550
2	Concrete grade	M30
3	Number of bays along X-direction	6
4	Number of bays along Y-direction	6
5	Total number of stories	G+50
6	Grid spacing along X-direction	8m
7	Grid spacing along Y-direction	8m
8	Outer Column dimensions (RCC)	1000 x 1000 mm
9	Beams dimension (RCC)	450 x 650 mm
10	Core wall thickness (RCC)	600 mm
11	Slab thickness	250 mm

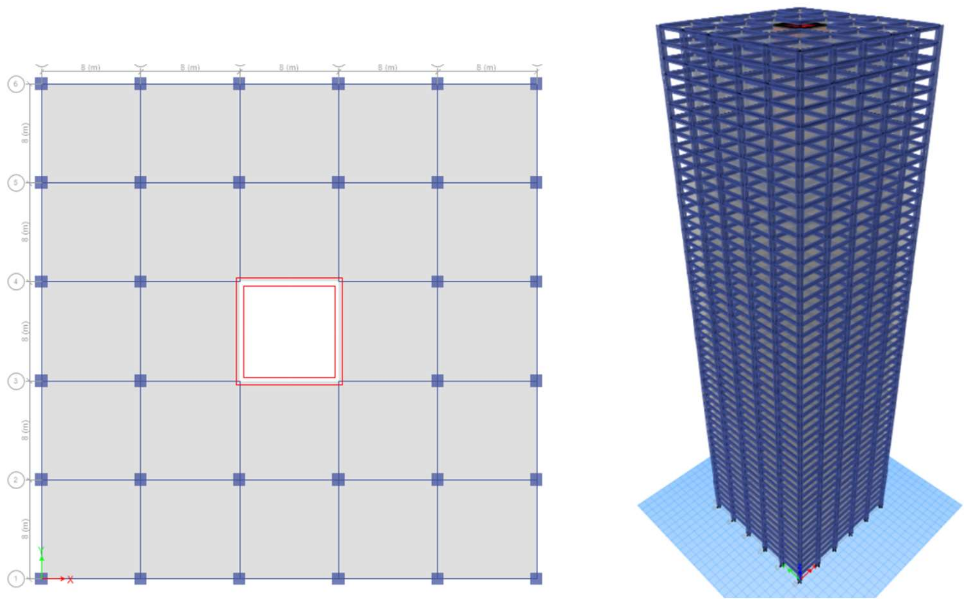


Fig 3.3.2: Plan & 3D view of frame with centre core.

3.4 CASE C: CONVENTIONAL FRAME WITH OUTRIGGER.

A symmetrical G+50 story building with beams, columns, core walls and slabs at floor level. Each floor of height 3M and there are 3 refused floor at a height of 45M.here in this case I have considered outrigger at 3 floor levels.

Table 3.4: material and section properties of RC members for bare frame with outrigger.

S NO	MATERIAL AND SECTION PROPERTIES	VALUES
1	Reinforcement bar	HYSD 550
2	Concrete grade	M30
3	Number of bays along X-direction	6
4	Number of bays along Y-direction	6
5	Total number of stories	G+50
6	Grid spacing along X-direction	8m
7	Grid spacing along Y-direction	8m
8	Outer Column dimensions (RCC)	1000 x 1000 mm
9	Beams dimension (RCC)	450 x 650 mm
10	Core wall thickness (RCC)	600 mm
11	Slab thickness	250 mm
12	Outrigger element dimension	500 x 600 mm

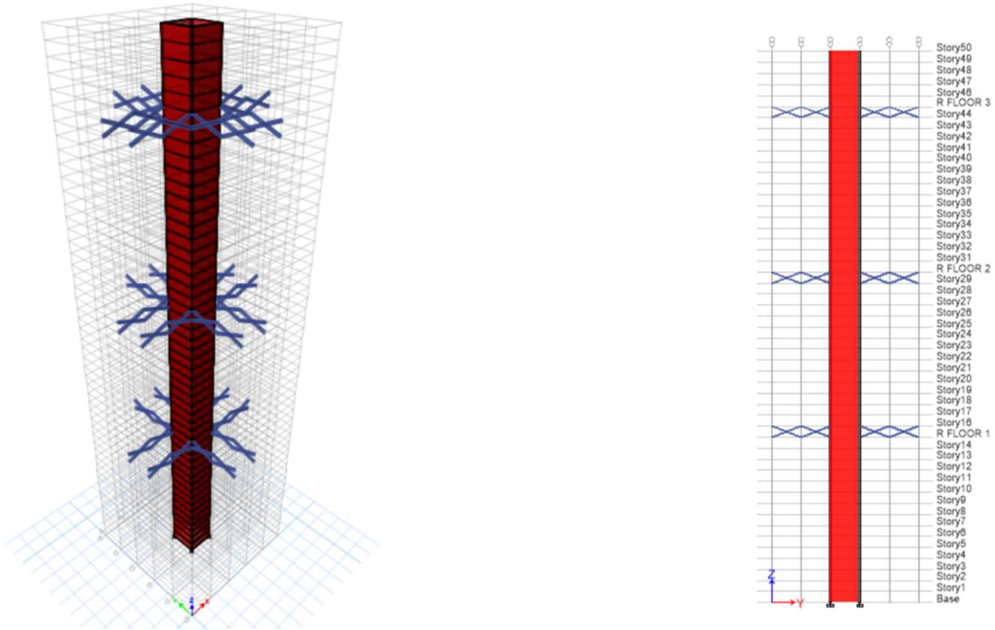


Fig 3.4: 3D view and elevation of frame with centre core and outrigger.

3.5 CASE D: CONVENTIONAL FRAME WITH OUTRIGGER AND BELT TRUSS.

A symmetrical G+50 story building with beams, columns, core walls and slabs at floor level. Each floor of height 3M and there are 3 refused floor at a height of 45M.here in this case I have considered outrigger at 3 floor levels and in the same level I have considered belt truss as a concrete member modelled as diagonally.

BELT TRUSS acts as a horizontal bracing element, connecting the core of the building to the outrigger system located at intermediate or upper levels. By distributing lateral loads more effectively, the belt truss reduces the overturning moments and displacements experienced by the structure, thereby improving its overall stability and performance. This system is particularly beneficial in tall and slender buildings where lateral stability is a significant concern. The belt truss works in conjunction with other structural elements, such as the core and perimeter columns, to create a robust and efficient lateral load-resisting system, allowing for the construction of taller and more slender skyscrapers with enhanced structural integrity.

Table 3.5: material and section properties of RC members for bare frame with outrigger.

S NO	MATERIAL AND SECTION PROPERTIES	VALUES
1	Reinforcement bar	HYSD 550
2	Concrete grade	M30
3	Number of bays along X-direction	6
4	Number of bays along Y-direction	6
5	Total number of stories	G+50
6	Grid spacing along X-direction	8m
7	Grid spacing along Y-direction	8m
8	Outer Column dimensions (RCC)	1000 x 1000 mm
9	Beams dimension (RCC)	450 x 650 mm
10	Core wall thickness (RCC)	600 mm
11	Slab thickness	250 mm
12	Outrigger element dimension	500 x 600 mm
13	Belt truss element dimension	600 x 900 mm

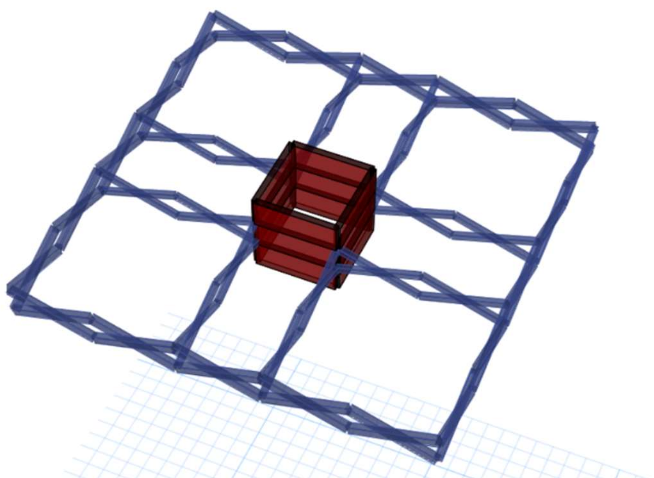


Fig 3.5.1: Plan view of frame with centre core outrigger and belt truss.

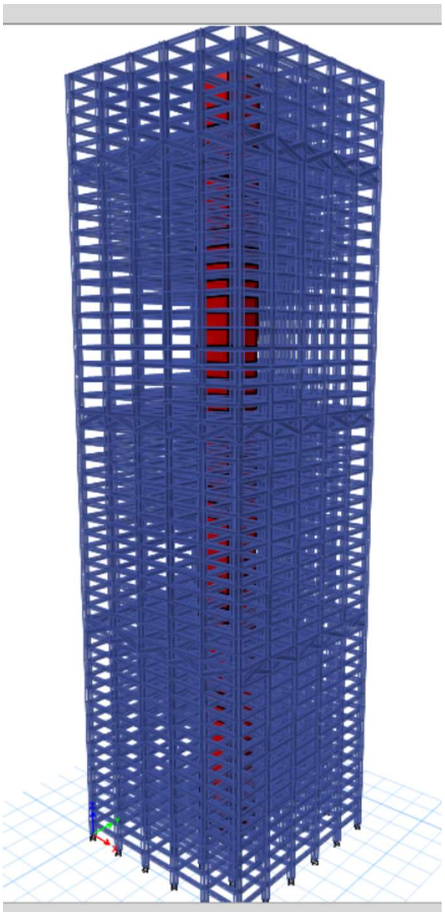


Fig 3.5.2: 3D view of frame with centre core outrigger and belt truss.

CHAPTER 4

ANALYSIS RESULTS

4.1 CASE A:

The analysis of all the cases considered are carried for both response spectrum and equivalent static method of analysis and the results obtained are for the parameters like storey displacement, storey drifts and overturning moment and check for the torsional irregularity.

Storey displacement: Storey displacement in high-rise buildings under lateral loading (wind pressure and seismic activity), lateral forces act upon the building, individual storeys experience horizontal movement, with lower storeys generally exhibiting less displacement compared to upper levels. Advanced computational tools aid in simulating and predicting storey displacements, ensuring compliance with building codes and standards that prescribe maximum allowable drift ratios or deflection limits. Ultimately, managing storey displacement is essential for maintaining structural integrity, occupant comfort, and safety in high rise building buildings subjected to lateral loading. **Maximum is 1019 mm at top story (50th floor) under the response spectrum analysis in the global-X direction.**

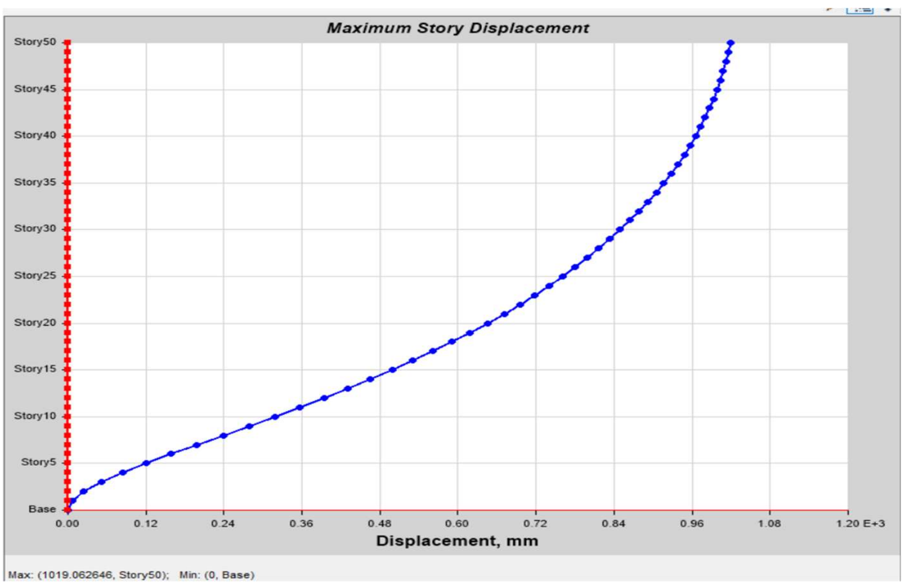


Fig 4.1.1: Maximum storey displacement of CASE A.

Storey drift: Storey drift in high-rise buildings under lateral loading refers to the relative displacement between adjacent storeys due to horizontal forces such as wind or seismic activity. As these forces act upon the structure, each storey undergoes horizontal movement, resulting in differential displacements along the building height. Typically, lower storeys experience lesser drift compared to upper levels due to their proximity to the building's foundation. The phenomenon of storey drift is a critical consideration in structural design to ensure that displacements remain within acceptable limits to maintain occupant comfort, structural stability, and safety. Engineers employ various techniques such as selecting appropriate structural systems, optimizing building materials, and incorporating damping devices or bracing systems to mitigate excessive drift. **Maximum storey drift is 0.013465 between the storey 5 and 10, exactly at storey 8.**

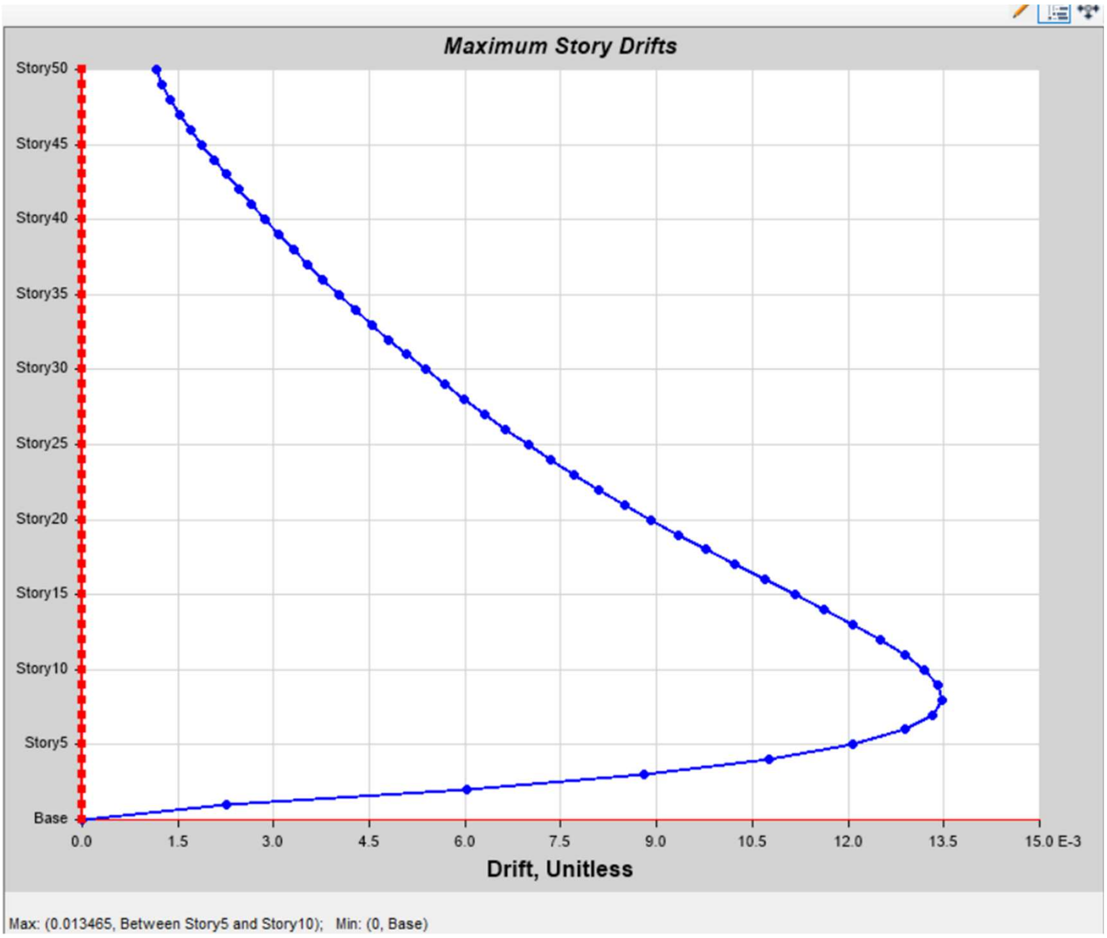
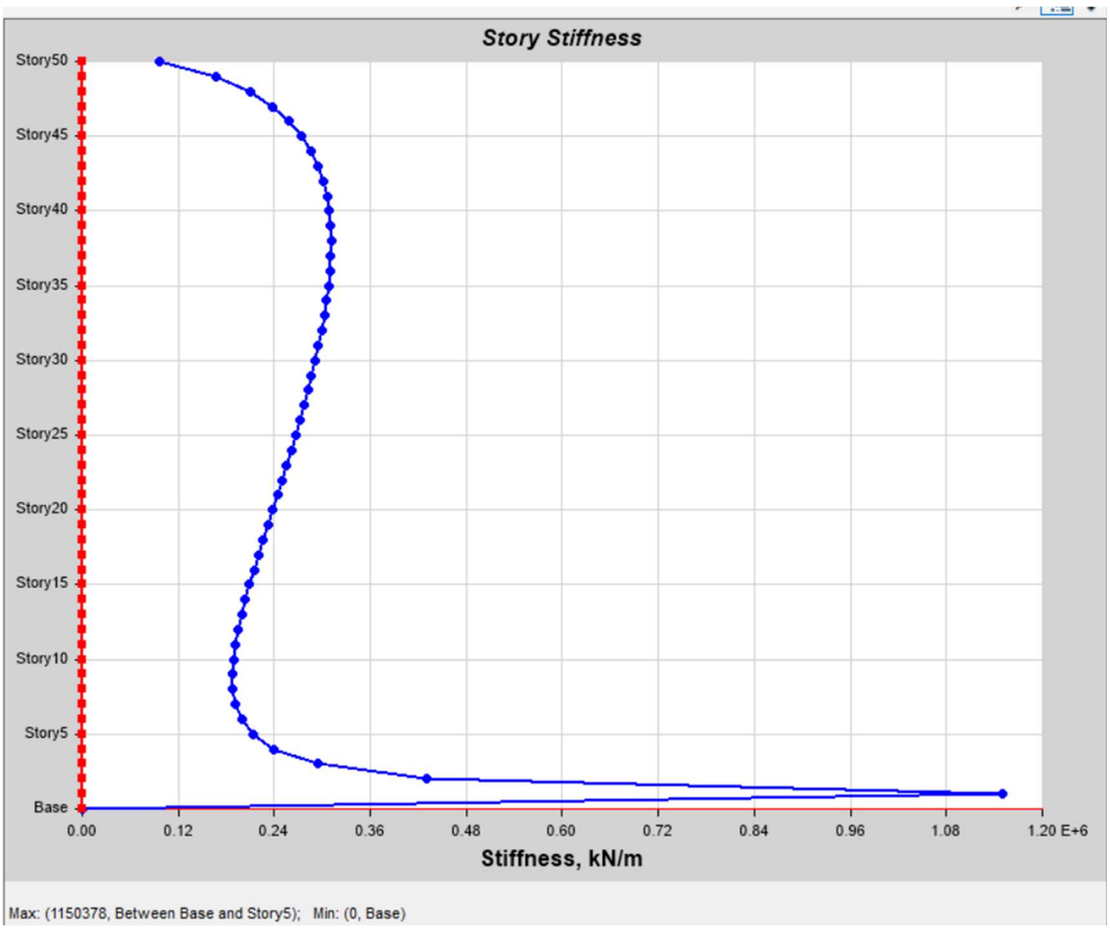


Fig 4.1.2: Maximum storey drifts of CASE A.

Story stiffness: Story stiffness It is the proportion of storey force to storey drift and is only applicable to shear buildings, or structures with infinitely stiff floor beams. In these situations, a building's lateral stiffness matrix adopts a tridiagonal shape. On the other hand, the stiffness matrix is fully populated in buildings with finite beam stiffness. Storey stiffness is almost non-existent in this situation, yet it is necessary to determine its approximate value for early seismic design. Consequently, it is necessary to redefine the storey stiffness, which was also necessary for the building's seismic design. The stiffness of a building is like the rigidity of a spine, determining its ability to resist external forces and maintain its structural integrity, core and framework engineered to withstand wind, earthquakes, and other stresses. This stiffness is achieved through a careful balance of analysis and required structural system techniques, ensuring that the building can sway and flex within safe limits without compromising its stability.



.**Fig 4.1.3: storey Stiffness of CASE A.**

Torsional irregularity: Torsional irregularity in high-rise buildings under lateral loading refers to the uneven distribution of stiffness or mass along different axes of the structure, leading to torsional or twisting effects. This irregularity can arise due to asymmetrical floor layouts, setbacks in the building's profile, or variations in structural elements such as columns and walls. When subjected to lateral forces like wind or seismic activity, torsional irregularities can cause the building to rotate or twist about its vertical axis, potentially leading to structural instability and increased drift. Structural engineers carefully analyze and mitigate torsional irregularities during the design phase by implementing strategies such as redistributing mass or stiffness, incorporating torsional bracing systems, or optimizing the building's geometry. Advanced computational techniques enable engineers to simulate and assess the torsional behavior of high-rise structures, ensuring compliance with regulatory requirements and enhancing overall structural performance and safety under lateral loading conditions.

Modal	1	20.093	0.2649	0.5506	0	0.2649	0.5506	0	0.1078	0.0519	0
Modal	2	20.091	0.5506	0.2649	0	0.8155	0.8155	0	0.0519	0.1078	0
Modal	3	14.048	0	0	0	0.8155	0.8155	0	0	0	0.8174
Modal	4	5.605	0.0251	0.0515	0	0.8407	0.867	0	0.3529	0.1723	0
Modal	5	5.604	0.0515	0.0251	0	0.8921	0.8921	0	0.1723	0.3529	0
Modal	6	4.193	0	0	0	0.8921	0.8921	0	0	0	0.0745
Modal	7	3.088	0.0094	0.0178	0	0.9015	0.9099	0	0.0171	0.009	0
Modal	8	3.088	0.0178	0.0094	0	0.9193	0.9193	0	0.009	0.0171	0
Modal	9	2.406	0	0	0	0.9193	0.9193	0	0	0	0.0285
Modal	10	2.075	0.0055	0.0103	0	0.9248	0.9296	0	0.0369	0.0198	0
Modal	11	2.075	0.0103	0.0055	0	0.9351	0.9351	0	0.0198	0.0369	0
Modal	12	1.64	0	0	0	0.9351	0.9351	0	0	0	0.016
Modal	13	1.511	0.0037	0.0068	0	0.9388	0.9419	0	0.0114	0.0062	0
Modal	14	1.511	0.0068	0.0037	0	0.9456	0.9456	0	0.0062	0.0114	0
Modal	15	1.209	0	0	0	0.9456	0.9456	0	0	0	0.0107
Modal	16	1.157	0.0027	0.0051	0	0.9484	0.9507	0	0.0157	0.0084	0
Modal	17	1.157	0.0051	0.0027	0	0.9535	0.9535	0	0.0084	0.0157	0
Modal	18	0.915	0.002	0.004	0	0.9555	0.9575	0	0.0082	0.0041	0
Modal	19	0.915	0.004	0.002	0	0.9595	0.9595	0	0.0041	0.0082	0
Modal	20	0.743	0.0011	0.0038	0	0.9606	0.9633	0	0.0105	0.003	0

Fig 4.1.4: Mass participation ratio with modes in case A.

4.2 CASE B:

A symmetrical G+50 story building with beams, columns, core walls and slabs at floor level. Each floor of height 3M and there are 3 refused floors at a height of 45M.here in this case I have considered outrigger at 3 floor levels.

Storey displacement: Storey displacement in high-rise buildings under lateral loading (wind pressure and seismic activity), lateral forces act upon the building, individual storeys experience horizontal movement, with lower storeys generally exhibiting less displacement compared to upper levels. Advanced computational tools aid in simulating and predicting storey displacements, ensuring compliance with building codes and standards that prescribe maximum allowable drift ratios or deflection limits. Ultimately, managing storey displacement is essential for maintaining structural integrity, occupant comfort, and safety in high rise building buildings subjected to lateral loading.

Maximum is 375 mm at top story (50th floor) under the response spectrum analysis in the global-X direction.

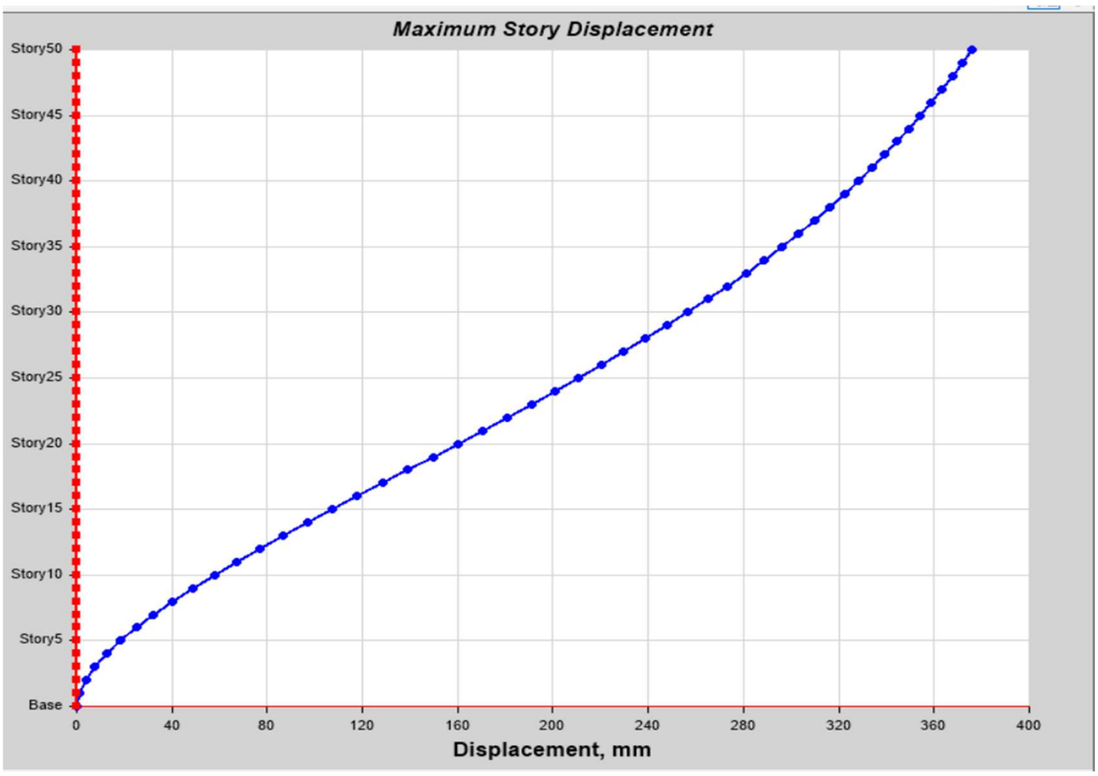


Fig 4.2.1: Maximum storey displacement of CASE B.

Storey drift: Storey drift in high-rise buildings under lateral loading refers to the relative displacement between adjacent storeys due to horizontal forces such as wind or seismic activity. As these forces act upon the structure, each storey undergoes horizontal movement, resulting in differential displacements along the building height. Typically, lower storeys experience lesser drift compared to upper levels due to their proximity to the building's foundation. The phenomenon of storey drift is a critical consideration in structural design to ensure that displacements remain within acceptable limits to maintain occupant comfort, structural stability, and safety. Engineers employ various techniques such as selecting appropriate structural systems, optimizing building materials, and incorporating damping devices or bracing systems to mitigate excessive drift. Accurate analysis and simulation using computational tools aid in predicting and controlling storey drift, enabling designers to meet regulatory requirements and optimize the performance of high-rise buildings under lateral loading. **Maximum storey drift is 0.003536 between the storey 15 and 20, exactly at storey 18. There is a decrease in story drift because of placement of outriggers.**

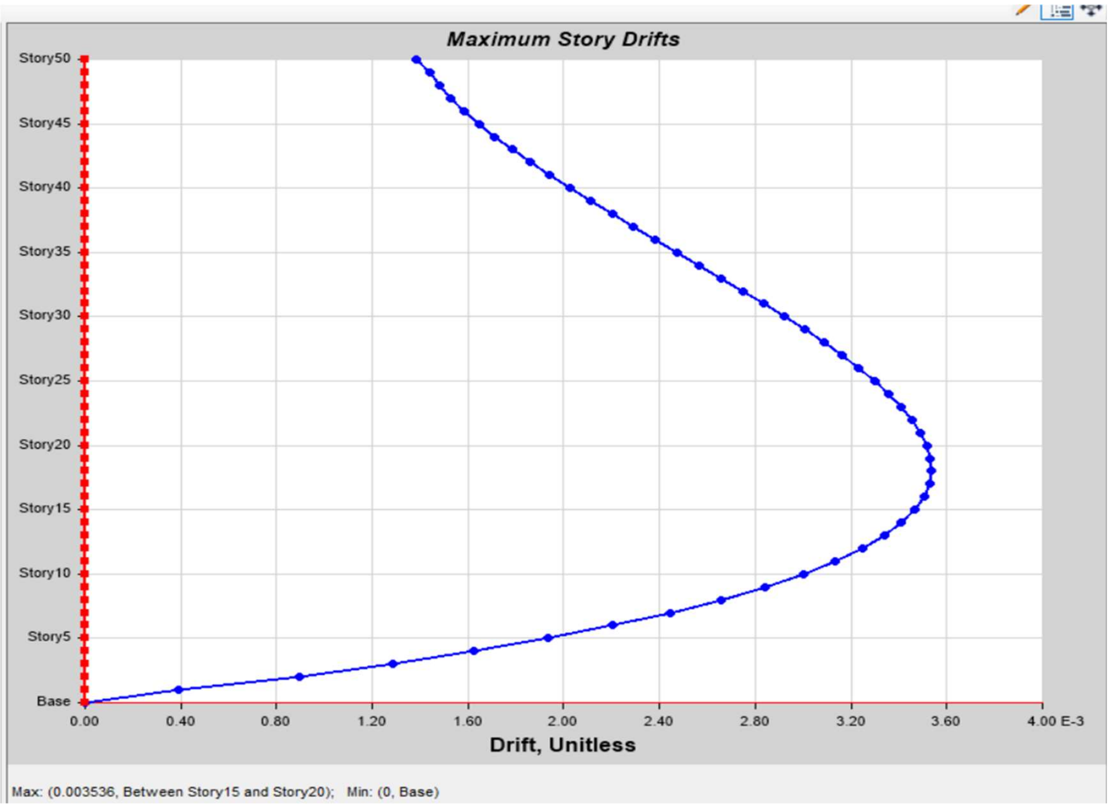


Fig 4.2.2: Maximum storey drift of CASE B.

Story stiffness: Story stiffness It is the proportion of storey force to storey drift and is only applicable to shear buildings, or structures with infinitely stiff floor beams. In these situations, a building's lateral stiffness matrix adopts a tridiagonal shape. On the other hand, the stiffness matrix is fully populated in buildings with finite beam stiffness. Storey stiffness is almost non-existent in this situation, yet it is necessary to determine its approximate value for early seismic design. Consequently, it is necessary to redefine the storey stiffness, which was also necessary for the building's seismic design. The stiffness of a building is like the rigidity of a spine, determining its ability to resist external forces and maintain its structural integrity, core and framework engineered to withstand wind, earthquakes, and other stresses. This stiffness is achieved through a careful balance of analysis and required structural system techniques, ensuring that the building can sway and flex within safe limits without compromising its stability.

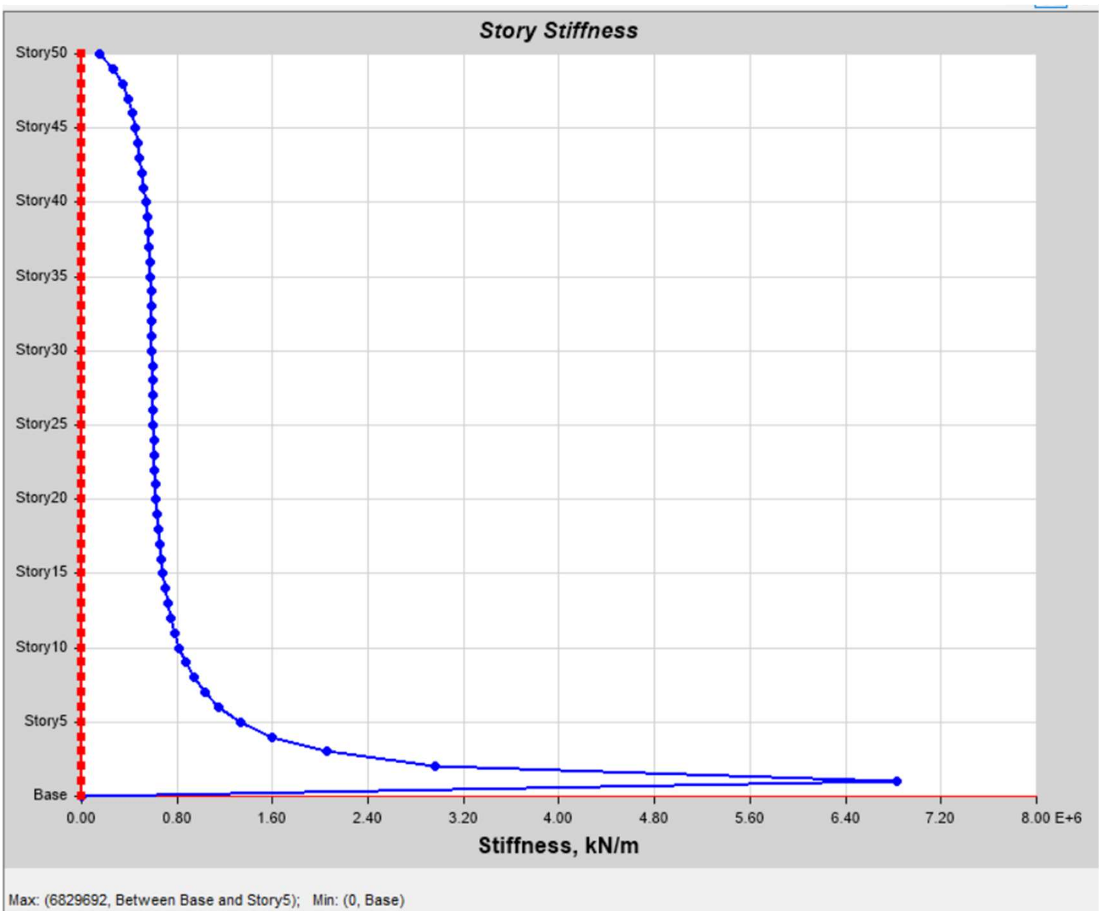


Fig 4.2.3: storey stiffness of CASE B.

4.3 CASE C:

A symmetrical G+50 story building with beams, columns, core walls and slabs at floor level. Each floor of height 3M and there are 3 refused floor at a height of 45M.here in this case I have considered outrigger at 3 floor levels.

Storey displacement: Storey displacement in high-rise buildings under lateral loading (wind pressure and seismic activity), lateral forces act upon the building, individual storeys experience horizontal movement, with lower storeys generally exhibiting less displacement compared to upper levels. This variance in displacement creates "storey drift," necessitating careful consideration during design and analysis phases. Structural engineers employ various strategies to mitigate excessive displacement, including selecting appropriate materials, optimizing structural systems, and integrating damping devices or bracing systems Ultimately, managing storey displacement is essential for maintaining structural integrity, occupant comfort, and safety in high rise building buildings subjected to lateral loading. **Maximum is 212 mm at top story (50th floor) under the response spectrum analysis in the global-X direction.**

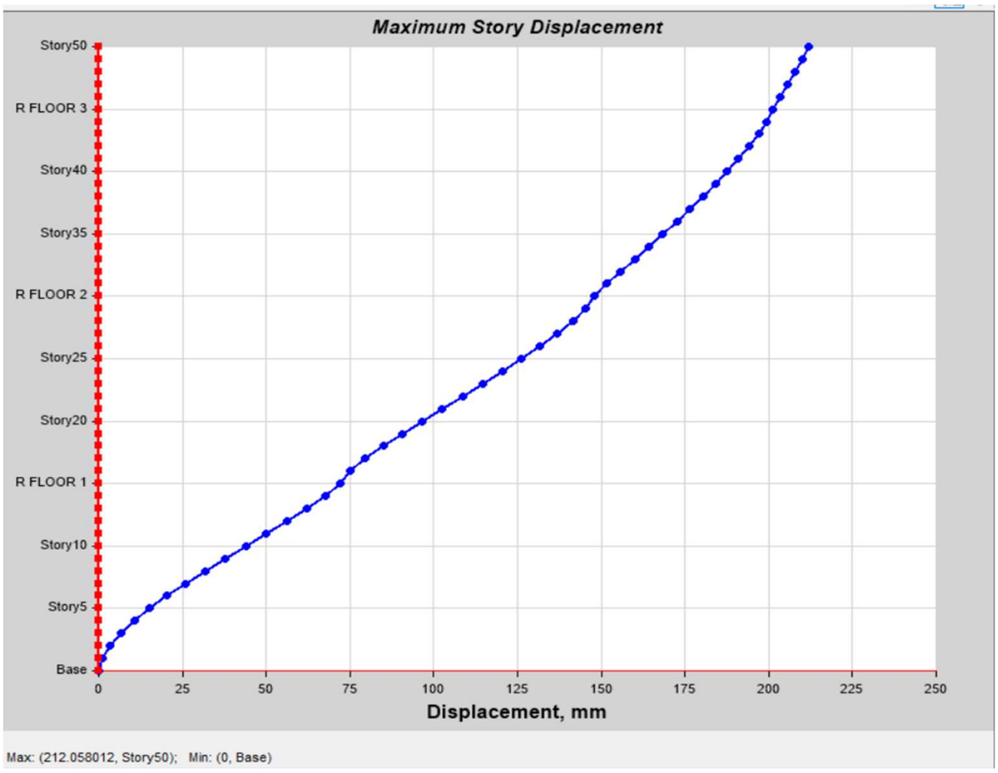


Fig 4.3.1: Maximum storey displacement of CASE C.

Storey drift: Storey drift in high-rise buildings under lateral loading refers to the relative displacement between adjacent storeys due to horizontal forces such as wind or seismic activity. As these forces act upon the structure, each storey undergoes horizontal movement, resulting in differential displacements along the building height. Typically, lower storeys experience lesser drift compared to upper levels due to their proximity to the building's foundation. The phenomenon of storey drift is a critical consideration in structural design to ensure that displacements remain within acceptable limits to maintain occupant comfort, structural stability, and safety. structural systems, optimizing building materials, and incorporating damping devices or bracing systems to mitigate excessive drift. Accurate analysis and simulation using computational tools aid in predicting and controlling storey drift, enabling designers to meet regulatory requirements and optimize the performance of high-rise buildings under lateral loading. **Maximum storey drift is 0.002058 between the storey 11 and 15, exactly at storey 11. There is a decrease in story drift because of placement of outriggers.**

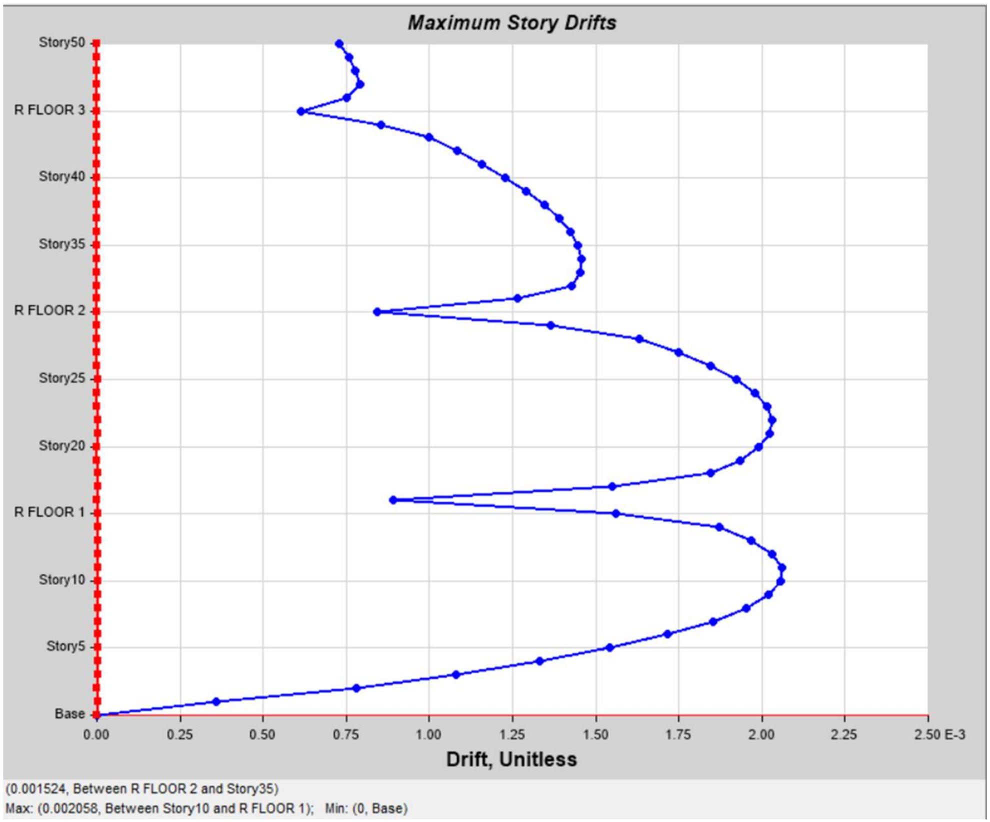


Fig 4.3.2: Maximum storey drift of CASE C.

Story stiffness: It is the proportion of storey force to storey drift and is only applicable to shear buildings, or structures with infinitely stiff floor beams. In these situations, a building's lateral stiffness matrix adopts a tridiagonal shape. On the other hand, the stiffness matrix is fully populated in buildings with finite beam stiffness. Storey stiffness is almost non-existent in this situation, yet it is necessary to determine its approximate value for early seismic design. Consequently, it is necessary to redefine the storey stiffness, which was also necessary for the building's seismic design. The stiffness of a building is like the rigidity of a spine, determining its ability to resist external forces and maintain its structural integrity, core and framework engineered to withstand wind, earthquakes, and other stresses. This stiffness is achieved through a careful balance of analysis and required structural system techniques, ensuring that the building can sway and flex within safe limits without compromising its stability.

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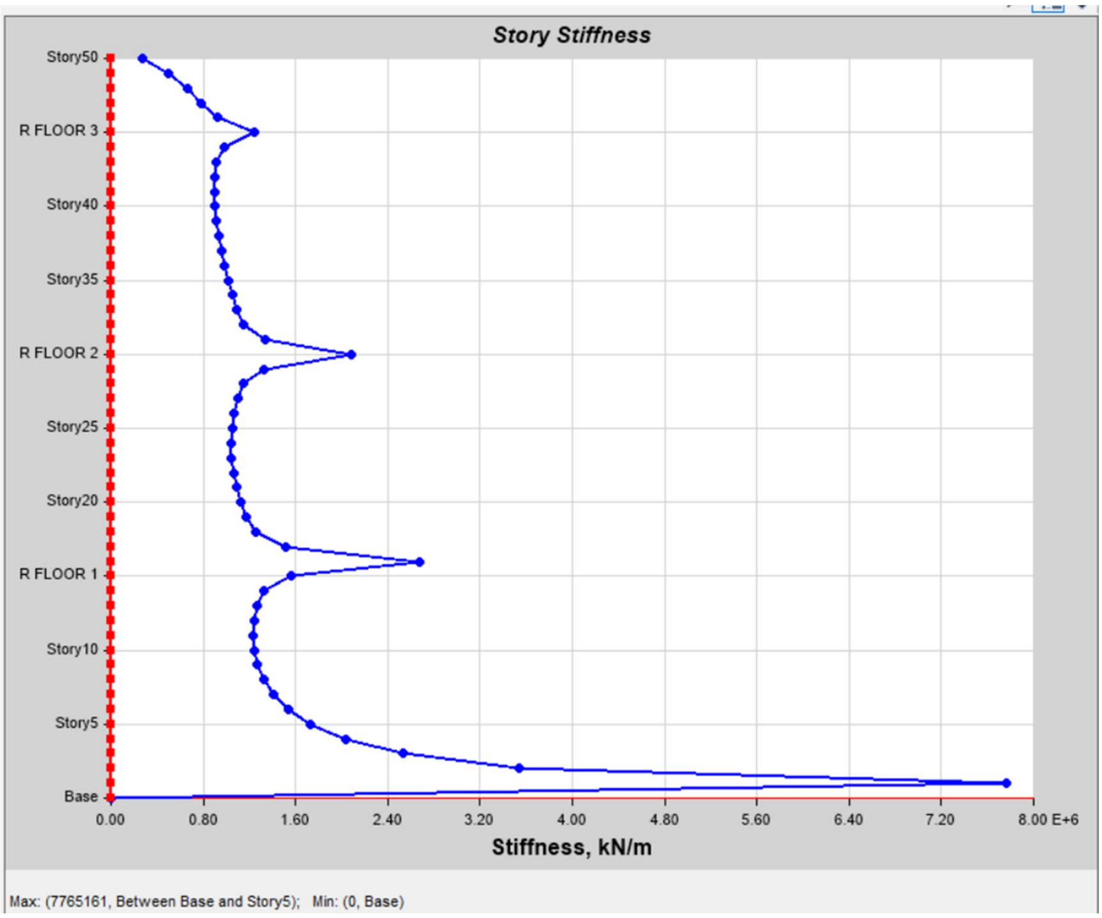

Fig 4.3.3: storey stiffness of CASE C.

Torsional irregularity: Torsional irregularity in high-rise buildings under lateral loading refers to the uneven distribution of stiffness or mass along different axes of the structure, leading to torsional or twisting effects. This irregularity can arise due to asymmetrical floor layouts, setbacks in the building's profile, or variations in structural elements such as columns and walls. When subjected to lateral forces like wind or seismic activity, torsional irregularities can cause the building to rotate or twist about its vertical axis, potentially leading to structural instability and increased drift. Structural engineers carefully analyze and mitigate torsional irregularities during the design phase by implementing strategies such as redistributing mass or stiffness, incorporating torsional bracing systems, or optimizing the building's geometry. Advanced computational techniques enable engineers to simulate and assess the torsional behavior of high-rise structures, ensuring compliance with regulatory requirements and enhancing overall structural performance and safety under lateral loading conditions.

Case	Mode	Period sec	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ
Modal	1	8.779	0.0072	0.7497	0	0.0072	0.7497	0	0.2272	0.0022	0
Modal	2	8.779	0.7497	0.0072	0	0.7569	0.7569	0	0.0022	0.2272	0
Modal	3	8.349	0	0	0	0.7569	0.7569	0	0	0	0.8191
Modal	4	2.58	0.0012	0.1133	0	0.7582	0.8702	0	0.4149	0.0045	0
Modal	5	2.58	0.1133	0.0012	0	0.8714	0.8714	0	0.0045	0.4149	0
Modal	6	2.569	0	0	0	0.8714	0.8714	0	0	0	0.0797
Modal	7	1.505	0	0	0	0.8714	0.8714	0	0	0	0.0281
Modal	8	1.307	0.0004	0.0355	0	0.8718	0.907	0	0.0559	0.0006	0
Modal	9	1.307	0.0355	0.0004	0	0.9074	0.9074	0	0.0006	0.0559	0
Modal	10	1.03	0	0	0	0.9074	0.9074	0	0	0	0.017
Modal	11	0.8	0	0	0	0.9074	0.9074	0	0	0	0.0103
Modal	12	0.727	0.0003	0.0188	0	0.9077	0.9262	0	0.0657	0.0011	0
Modal	13	0.727	0.0188	0.0003	0	0.9265	0.9265	0	0.0011	0.0657	0
Modal	14	0.638	0	0	0	0.9265	0.9265	0	0	0	0.0064
Modal	15	0.582	0	0	0.7896	0.9265	0.9265	0.7896	0	0	0
Modal	16	0.562	0.0005	0.02	0	0.927	0.9465	0.7896	0.0303	0.0007	0
Modal	17	0.562	0.02	0.0005	0	0.947	0.947	0.7896	0.0007	0.0303	0
Modal	18	0.482	0.0002	0.0016	0	0.9472	0.9486	0.7896	0.0516	0.0068	0
Modal	19	0.482	0.0016	0.0002	0	0.9488	0.9488	0.7896	0.0068	0.0516	0
Modal	20	0.418	0.0001	0.0073	0	0.9488	0.956	0.7896	0.0077	0.0001	0

Fig 4.3.4: Mass participation ratio with modes in CASE C.

4.4 CASE D: A symmetrical G+50 story building with beams, columns, core walls and slabs at floor level. Each floor of height 3M and there are 3 refused floors at a height of 45M.here in this case I have considered outrigger at 3 floor levels and in the same level with belt truss as a concrete member modelled diagonally.

Storey displacement: Storey displacement in high-rise buildings under lateral loading (wind pressure and seismic activity), lateral forces act upon the building, individual storeys experience horizontal movement, with lower storeys generally exhibiting less displacement compared to upper levels. This variance in displacement creates "storey drift," necessitating careful consideration during design and analysis phases. Optimizing structural systems, and integrating damping devices or bracing systems. Ultimately, managing storey displacement is essential for maintaining structural integrity, occupant comfort, and safety in high rise building buildings subjected to lateral loading. Maximum is 190 mm at top story (50^{th} floor) under the response spectrum analysis in the global-X direction.

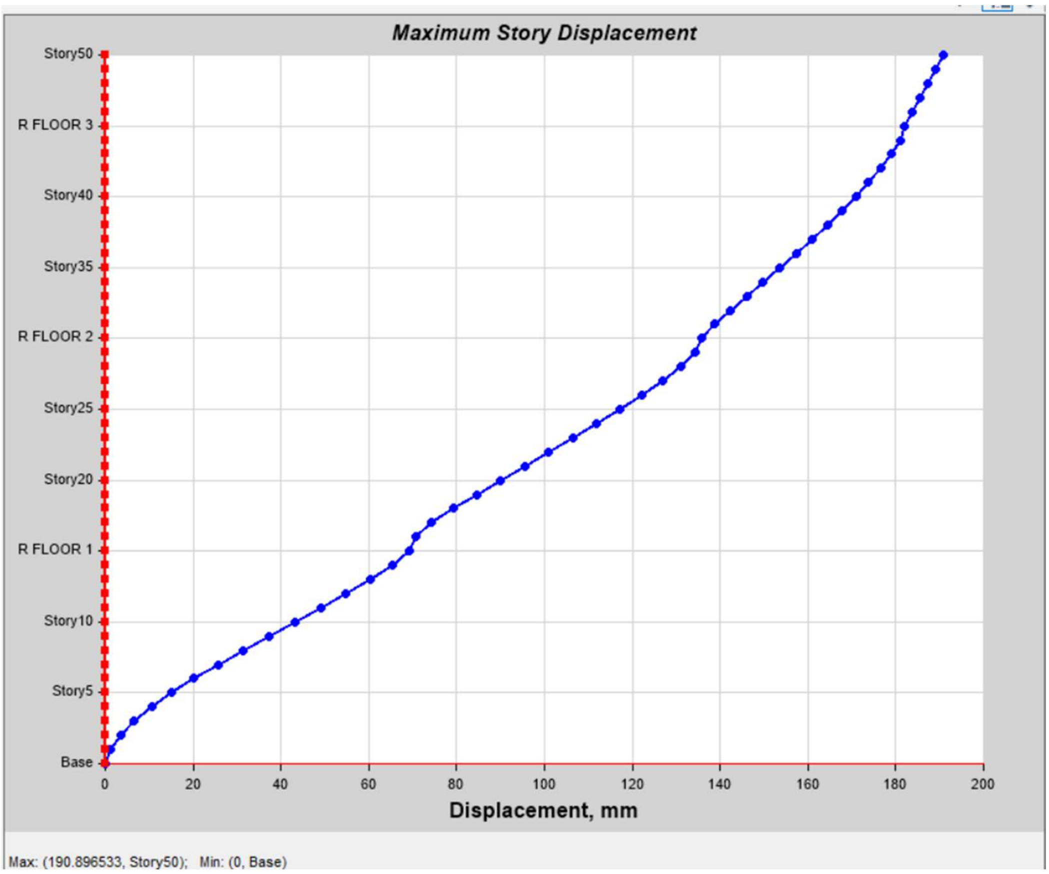

Fig 4.4.1: Maximum storey displacement of CASE D.

Storey drift: Storey drift in high-rise buildings under lateral loading refers to the relative displacement between adjacent storeys due to horizontal forces such as wind or seismic activity. As these forces act upon the structure, each storey undergoes horizontal movement, resulting in differential displacements along the building height. Typically, lower storeys experience lesser drift compared to upper levels due to their proximity to the building's foundation. The phenomenon of storey drift is a critical consideration in structural design to ensure that displacements remain within acceptable limits to maintain occupant comfort, structural stability, and safety, optimizing and incorporating bracing systems to mitigate excessive drift. Accurate analysis and simulation using computational tools aid in predicting and controlling storey drift, enabling designers to meet regulatory requirements and optimize the performance of high-rise buildings under lateral loading. **Maximum storey drift is 0.001981 between the storey 10. There is a decrease in story drift because of placement of outriggers and belt truss.**

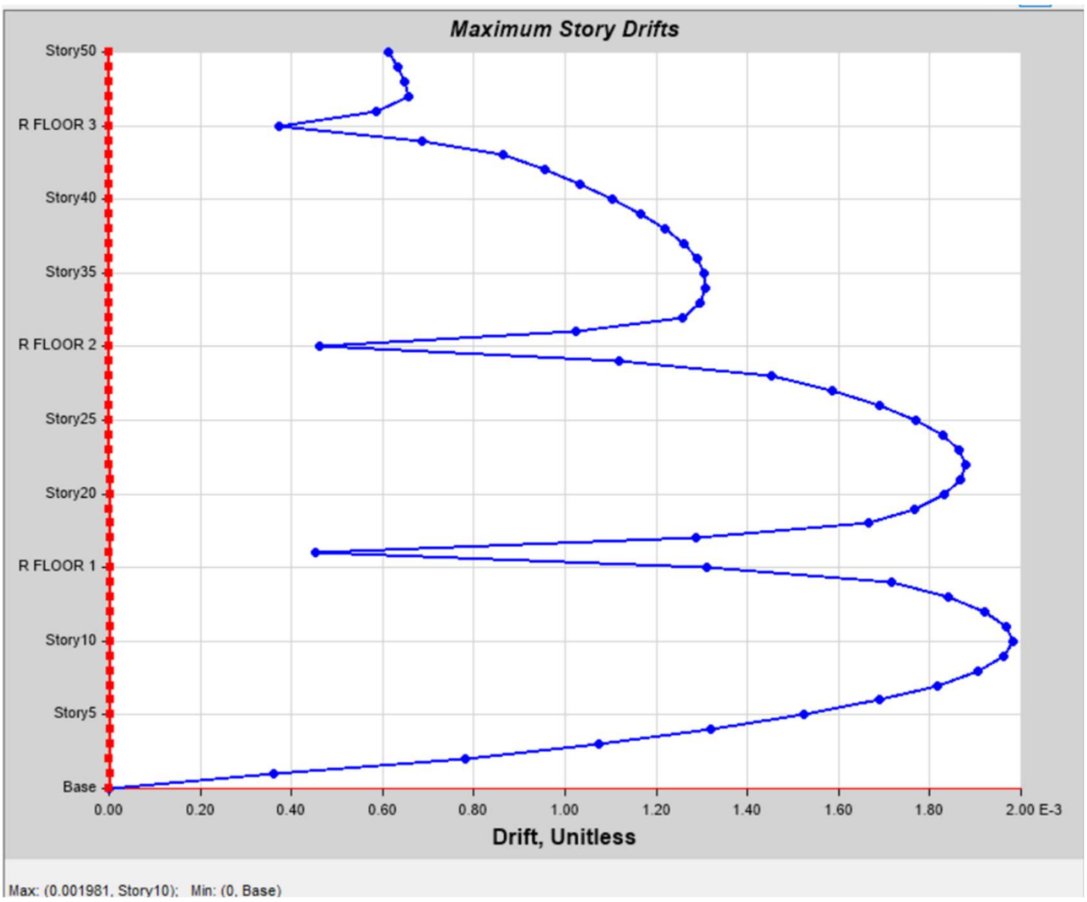

Fig 4.4.2: Maximum storey drift of CASE D.

Story stiffness: Story stiffness It is the proportion of storey force to storey drift and is only applicable to shear buildings, or structures with infinitely stiff floor beams. In these situations, a building's lateral stiffness matrix adopts a tridiagonal shape. On the other hand, the stiffness matrix is fully populated in buildings with finite beam stiffness. Storey stiffness is almost non-existent in this situation, yet it is necessary to determine its approximate value for early seismic design. Consequently, it is necessary to redefine the storey stiffness, which was also necessary for the building's seismic design. The stiffness of a building is like the rigidity of a spine, determining its ability to resist external forces and maintain its structural integrity, core and framework engineered to withstand wind, earthquakes, and other stresses. This stiffness is achieved through a careful balance of analysis and required structural system techniques, ensuring that the building can sway and flex within safe limits without compromising its stability.

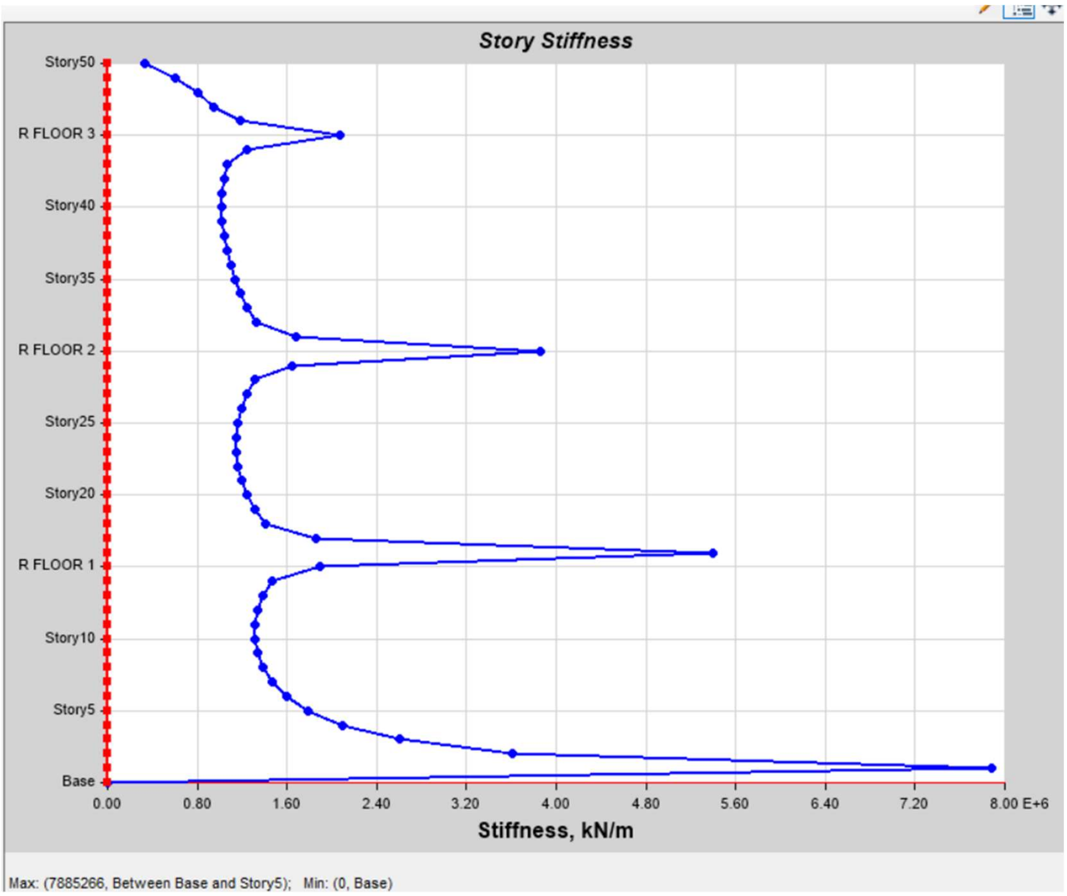

Fig 4.2.3: storey stiffness of CASE D.

Torsional irregularity: Torsional irregularity in high-rise buildings under lateral loading refers to the uneven distribution of stiffness or mass along different axes of the structure, leading to torsional or twisting effects. This irregularity can arise due to asymmetrical floor layouts, setbacks in the building's profile, or variations in structural elements such as columns and walls. When subjected to lateral forces like wind or seismic activity, torsional irregularities can cause the building to rotate or twist about its vertical axis, potentially leading to structural instability and increased drift. Structural engineers carefully analyze and mitigate torsional irregularities during the design phase by implementing strategies such as redistributing mass or stiffness, incorporating torsional bracing systems, or optimizing the building's geometry. Advanced computational techniques enable engineers to simulate and assess the torsional behavior of high-rise structures, ensuring compliance with regulatory requirements and enhancing overall structural performance and safety under lateral loading conditions.

Case	Mode	Period sec	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ
Modal	1	8.366	0.0087	0.7594	0	0.0087	0.7594	0	0.2158	0.0025	0
Modal	2	8.366	0.7594	0.0087	0	0.7681	0.7681	0	0.0025	0.2158	0
Modal	3	8.036	0	0	0	0.7681	0.7681	0	0	0	0.8403
Modal	4	2.503	0.0014	0.1077	0	0.7695	0.8758	0	0.4328	0.0056	0
Modal	5	2.503	0.1077	0.0014	0	0.8772	0.8772	0	0.0056	0.4328	0
Modal	6	2.454	0	0	0	0.8772	0.8772	0	0	0	0.0694
Modal	7	1.448	0	0	0	0.8772	0.8772	0	0	0	0.0191
Modal	8	1.287	0.0005	0.0319	0	0.8777	0.9091	0	0.0509	0.0008	0
Modal	9	1.287	0.0319	0.0005	0	0.9096	0.9096	0	0.0008	0.0509	0
Modal	10	0.908	0	0	0	0.9096	0.9096	0	0	0	0.0247
Modal	11	0.738	0	0	0	0.9096	0.9096	0	0	0	0.006
Modal	12	0.691	0.0007	0.0183	0	0.9103	0.9279	0	0.0695	0.0025	0
Modal	13	0.691	0.0183	0.0007	0	0.9286	0.9286	0	0.0025	0.0695	0
Modal	14	0.588	0	0	0	0.9286	0.9286	0	0	0	0.0035
Modal	15	0.576	0	0	0.81	0.9286	0.9286	0.81	0	0	0
Modal	16	0.553	0.0008	0.0198	0	0.9294	0.9483	0.81	0.0272	0.0012	0
Modal	17	0.553	0.0198	0.0008	0	0.9492	0.9492	0.81	0.0012	0.0272	0
Modal	18	0.477	0.0003	0.0018	0	0.9495	0.951	0.81	0.0511	0.0083	0
Modal	19	0.477	0.0018	0.0003	0	0.9512	0.9512	0.81	0.0083	0.0511	0
Modal	20	0.403	0.0004	0.0075	0	0.9516	0.9588	0.81	0.0079	0.0004	0

Fig 4.2.4: Mass participation ratio with modes IN CASE D.

CHAPTER 5

COMPARISION OF RESULTS

5.1 Comparing storey displacement of all the cases considered under response spectrum analysis.

CASE A: Maximum is 1019 mm at top story (50th floor).

CASE B: Maximum is 375 mm at top story.

CASE C: Maximum is 212 mm at top story.

CASE D: Maximum is 190 mm at top story.

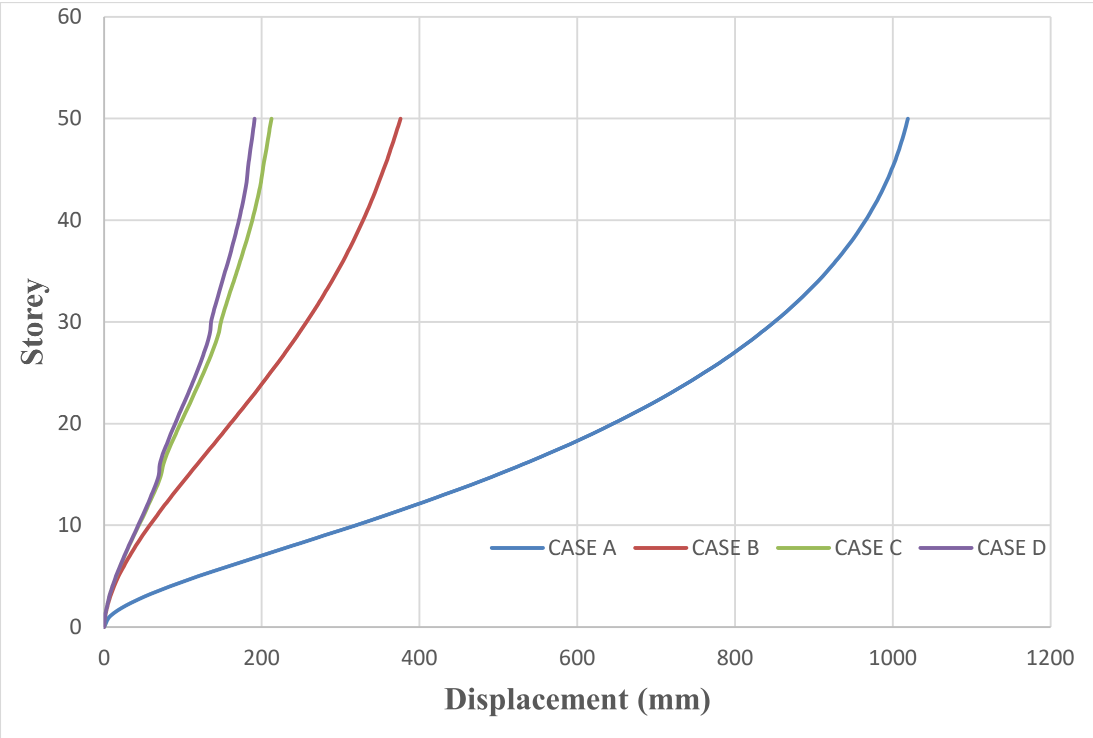

Fig 5.1: Comparative results of story displacement under R S A.

From the results obtained for all four cases after the placement of the outrigger structural system in the building framing there is nearly **82.9%** decrease in storey displacement. Which shows that after the placement of the outrigger structural system there is increase in the stability of the structure.

5.2 Comparing storey drift of all the cases considered under response spectrum analysis.

CASE A: maximum storey drift is 0.013465 at storey 8.

CASE B: maximum storey drift is 0.003536 at storey 18

CASE C: maximum storey drift is 0.002058 at storey 11.

CASE D: maximum storey drift is 0.001981 at storey 10.

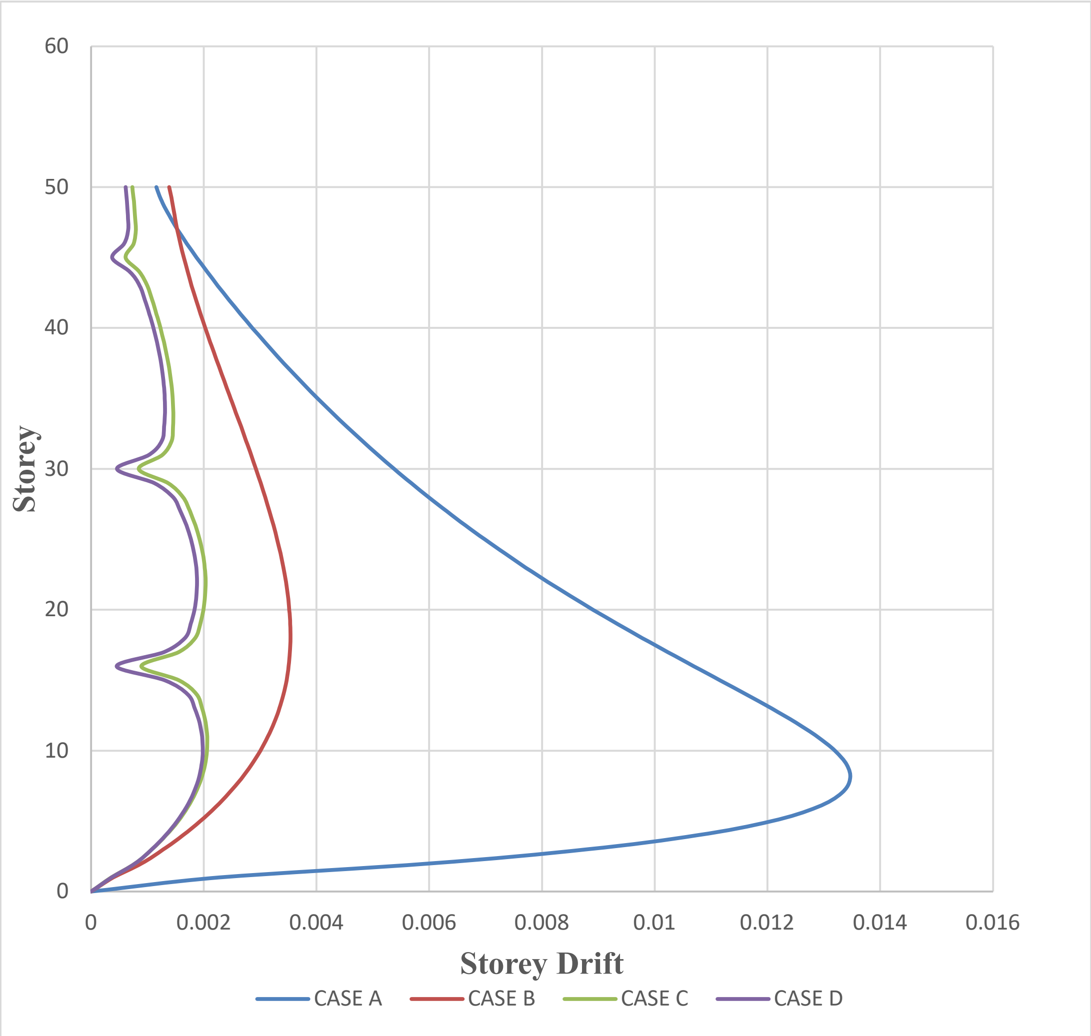

Fig 5.2: Comparative results of story drift under R S A .

From the results obtained for all four cases after the placement of the outrigger structural system in the building framing there is nearly **84.9%** decrease in storey drift.

5.3 Comparing storey stiffness of all the cases considered under response spectrum analysis.

When the stiffness of a building increases, it signals a significant improvement in its structural integrity and resistance to deformation under load. This enhancement translates to greater stability, reduced deformation, and improved performance in terms of occupant safety and comfort. Buildings with increased stiffness are better equipped to withstand external forces like wind and seismic activity, minimizing the risk of structural failure or damage. However, this improvement may come with potential cost implications due to the need for stronger materials or additional reinforcement. Architects and engineers must carefully consider stiffness requirements during the design phase to strike a balance between structural integrity, cost-effectiveness, and functional and aesthetic goals, ensuring an optimal outcome for the building's performance and longevity.

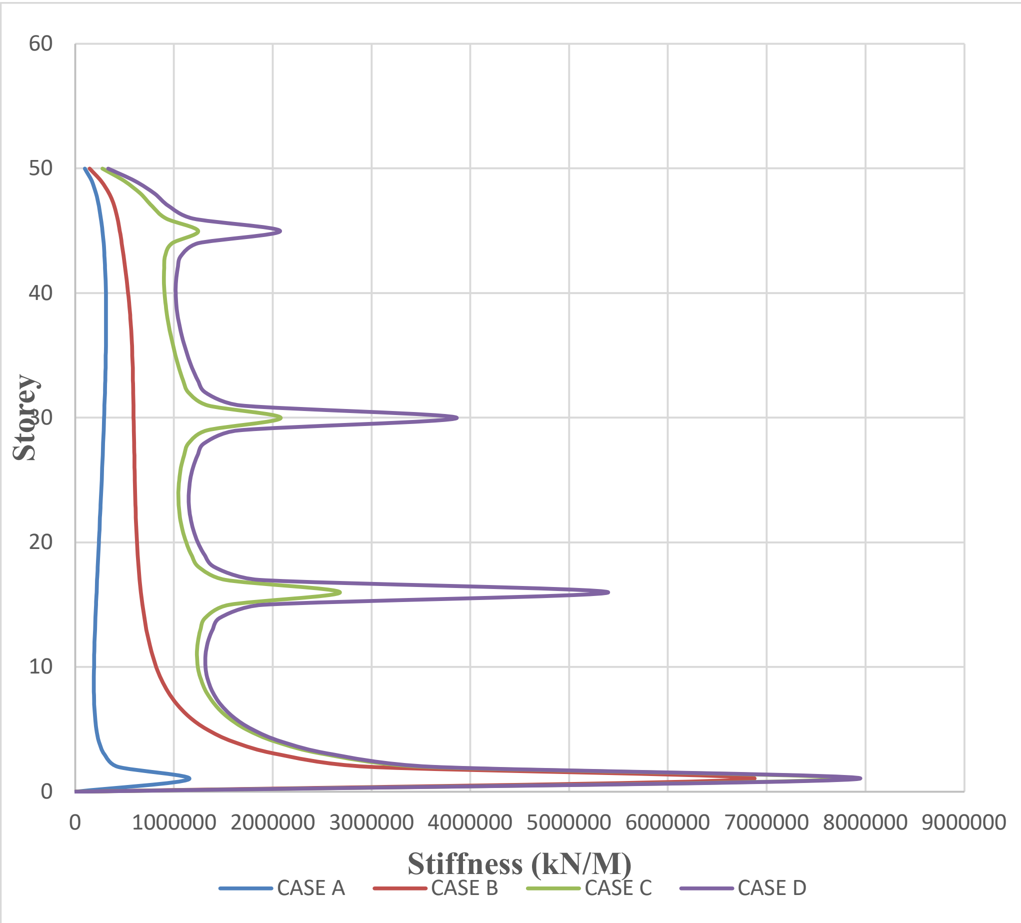

Fig 5.3: Comparative results of story stiffness under R S A.

5.4 Comparing storey displacement of all the cases considered under Wind analysis along global X-direction.

CASE A: Maximum is 1835 mm at top story (50th floor).

CASE B: Maximum is 650 mm at top story.

CASE C: Maximum is 356 mm at top story.

CASE D: Maximum is 310 mm at top story.

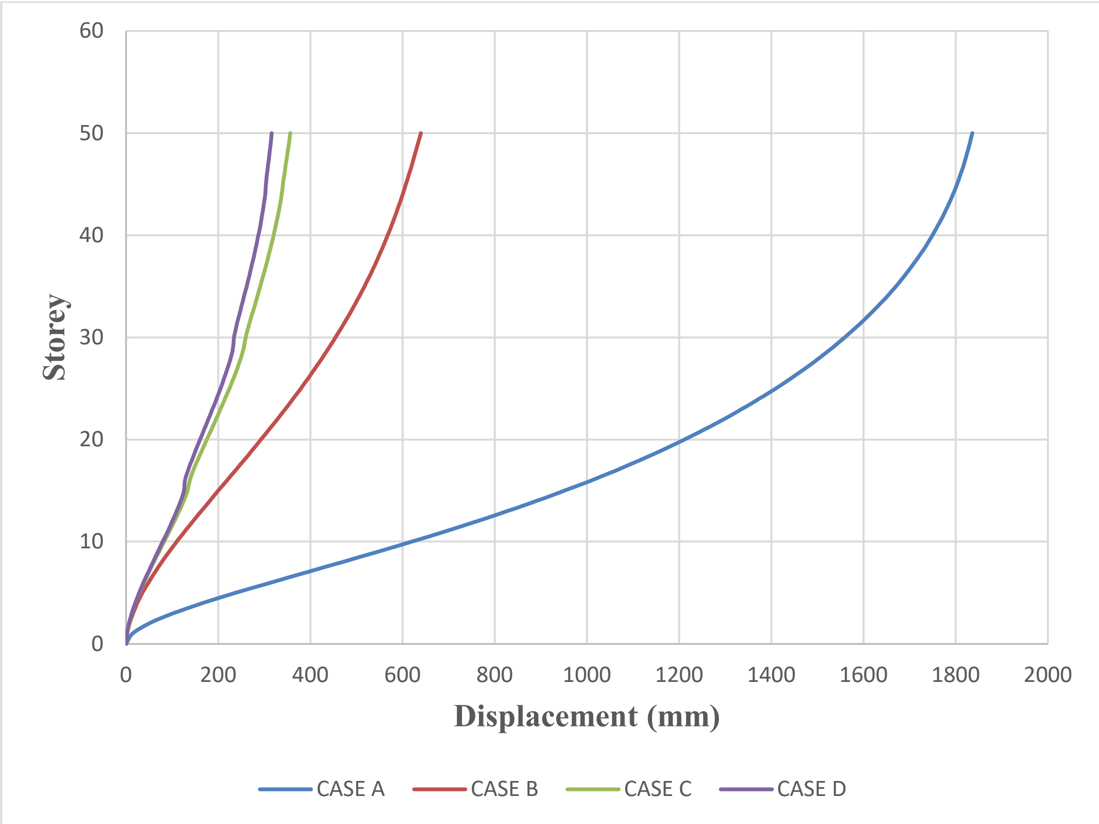

Fig 5.4: Comparative results of story displacement under wind load.

5.5 Comparing storey drift of all the cases considered under Wind analysis along global X-direction.

CASE A: Maximum is 0.02586 at story 08.

CASE B: Maximum is 0.006221 at story 18.

CASE C: Maximum is 0.00376 at story 10.

CASE D: Maximum is 0.00356 at story 10.

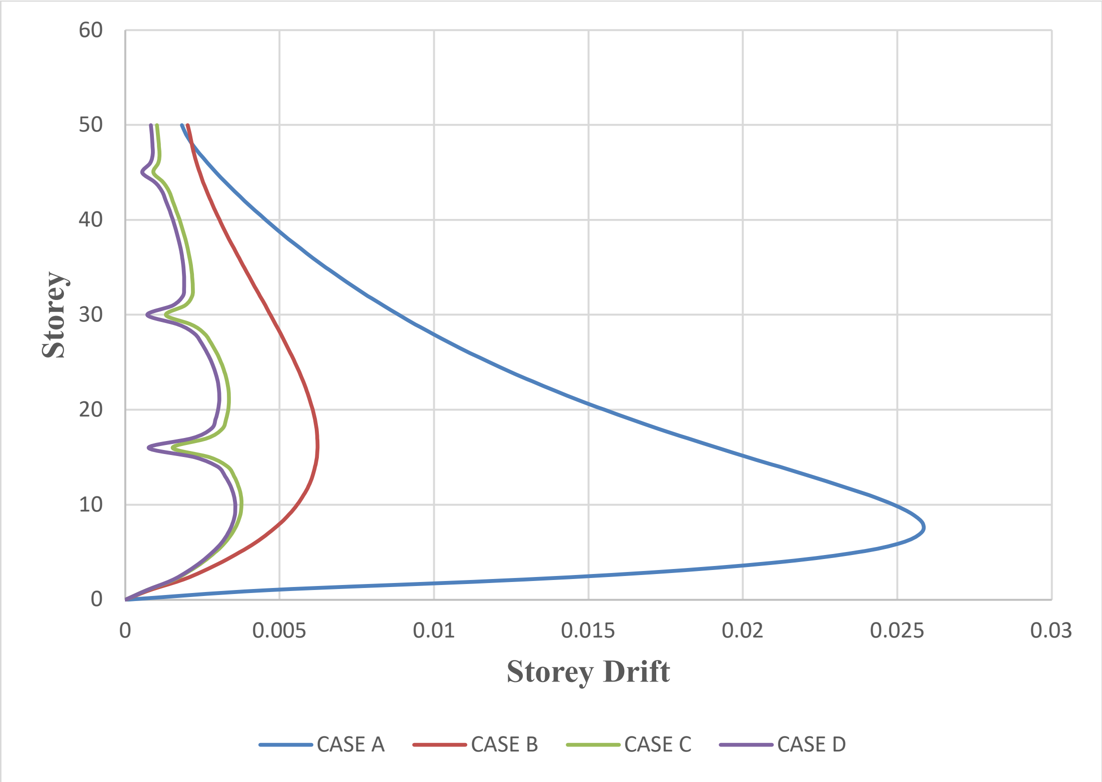

Fig 5.5: Comparative results of story drift under wind load.

5.6 Comparing storey stiffness of all the cases considered under Wind analysis along global X-direction.

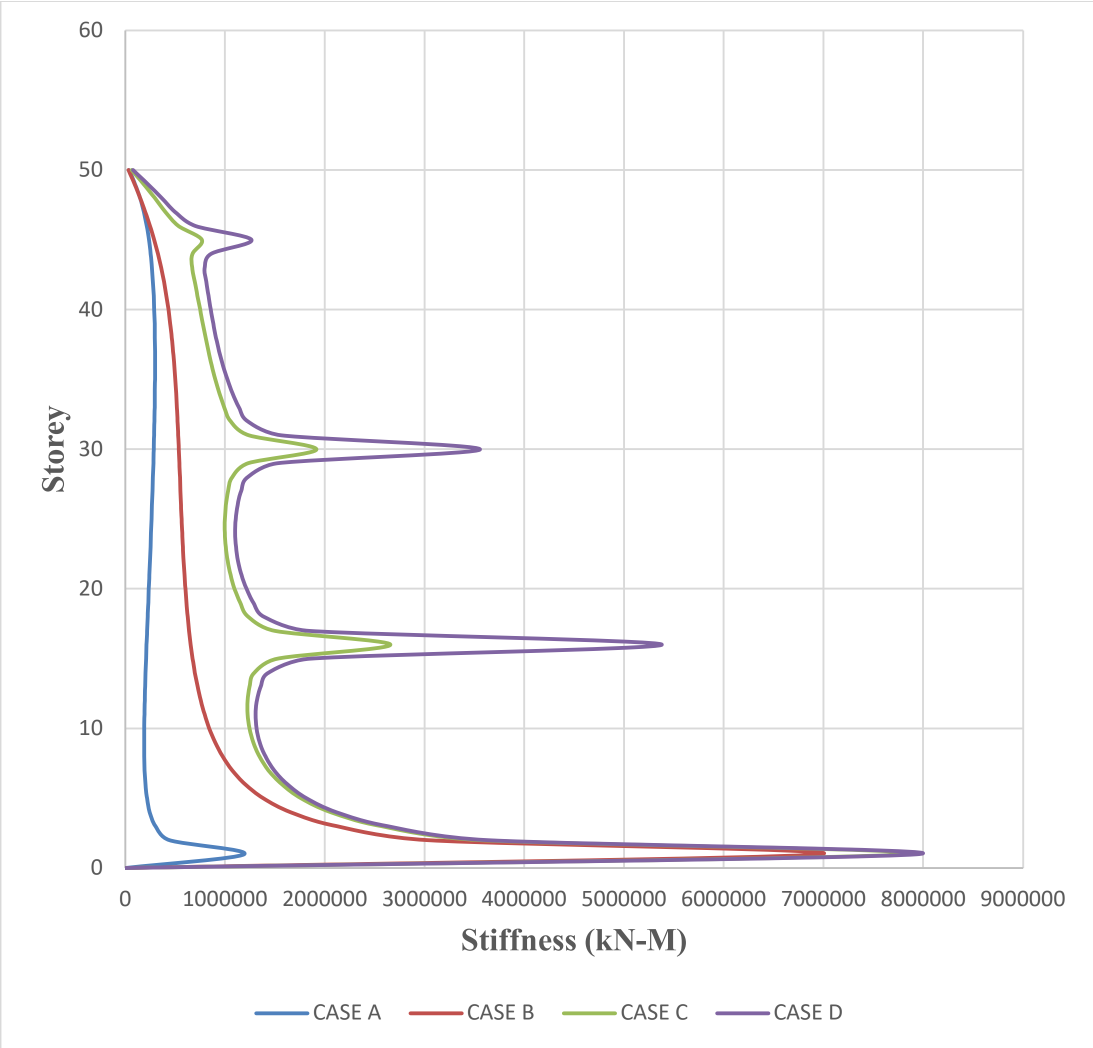

Fig 5.6: Comparative results of story stiffness.

Wherever there is placement of outrigger structural system there is increase in the story stiffness which leads to overall increase in the stiffness of the structure.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

Outrigger systems are an effective structural scheme that is used in high-rise construction to add lateral stiffness and distribute the moment demand within the core to the exterior columns. At the time of writing, very little research has been conducted on the seismic design and performance of outrigger system. Additionally, current prescriptive building codes in India and the United States do not provide a straightforward design procedure that considers multiple performance objectives. This work shows that a building can be analysed by considering the outrigger element as a concrete beam and belt truss element as a concrete rectangular material made up of RCC generally used for common construction purpose. So, by the analysis conducted on four different cases of the building shows that there is much more difference in the performance of a buildings under lateral loading and analytically proved by the response spectrum analysis that story displacement, storey drift is automatically reduced in the diaphragm after the placement of outrigger structural system without placing of any damping system. So, this work can be considered as a reference for the design and execution of the of any high-rise structure which is going to be constructed in India by considering outrigger structural system which increase the performance of the storey stiffness. And this work can be used to effectively design outrigger systems for multiple performance objectives at different hazard levels, two structures were shown to behave as predicted at the three hazard levels. considered. The analysis also has sufficient margin of safety against collapse at the hazard level to satisfy the intent of Indian building codes. The outrigger system is therefore shown to be a safe choice of High-rise structures that can successfully be designed.

6.2 FUTURE SCOPE

There are multiple issues that were identified during this course of study which require additional investigation but were outside of the scope of this thesis. Further research into these areas would help further develop the outrigger-structural system as an efficient choice of Seismic Frame Resisting System for tall buildings. These issues are briefly summarized here**.**

a) a) A thorough examination of various connections for the outrigger-to-wall interface would be beneficial to the development of outrigger systems. Various connection designs have been implemented in outrigger buildings that are currently in operation. These consist of embedding truss members into the wall, utilizing a continuous truss cast into the wall, and attaching to previously cast embed plates. It is advisable to do an investigation of the advantages and disadvantages of various connections with regards to their simplicity of construction, cost, efficacy, and performance under seismic and wind loads.

b) Strong column weak beam concept-based design for the outrigger system focusing on mega columns.

c) Comparing the performance of outrigger systems with friction based and fluid viscus damper and implementation of damping system into the outriggers.

d) Capacity based design or performance-based design for the outriggers and belt truss at the specified location.

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