The integration of exoskeletal structures into mid-rise buildings represents a significant advancement in architectural and structural engineering,

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

The integration of exoskeletal structures into mid-rise buildings represents a significant advancement in architectural and structural engineering, offering a departure from conventional construction methods. This innovative approach involves the creation of a secondary, external structural framework—the exoskeleton—that envelops and supports the primary building structure. This exoskeleton, typically constructed from steel or reinforced concrete, acts as the primary load-bearing system, freeing the interior structure from this responsibility. This separation of structure and space allows for numbers of compelling advantages. A lot of attention has been paid to exoskeleton systems as a way to overcome the shortcomings of other alternatives. Their non-invasive and effective method, which is based on biomimicry, increases the building's stiffness and resistance to lateral forces, greatly relieving the structure of seismic loads.

Firstly, exoskeletons offer enhanced structural performance, particularly crucial in regions susceptible to seismic activity or high winds. The external frame can be designed to resist lateral forces more effectively, increasing the building's resilience and safety. Secondly, and perhaps more significantly from an architectural standpoint, the exoskeleton allows for the creation of open, column-free interior spaces. This flexibility in layout offers greater freedom in design and allows for easier adaptation to changing needs over the building's lifespan. Large, uninterrupted floor plates become possible, facilitating diverse uses, from open-plan offices to flexible retail spaces. Beyond structural and spatial benefits, exoskeletons offer exciting possibilities for architectural expression. The external framework can become a prominent design feature, contributing to the building's aesthetic identity and creating a distinctive visual presence. Furthermore, the exoskeleton provides an ideal platform for integrating sustainable design elements. It can support solar shading devices, vertical green walls, rainwater harvesting systems, and other features that contribute to energy efficiency and environmental performance. While the concept of exoskeletal structures in mid-rise construction presents a unique set of challenges and opportunities, balancing cost-effectiveness with the potential for significant architectural and functional improvements. This exploration of integrating exoskeletons into mid-rise buildings is driven by the desire for more resilient, adaptable, and sustainable built environments.

There are different types of exoskeletons system which are used for the buildings those are:

1) 2D Exoskeleton
    a.) Orthogonal
    b.) Parallel
2) 3D Exoskeleton
    a) Flat
    b) Curved

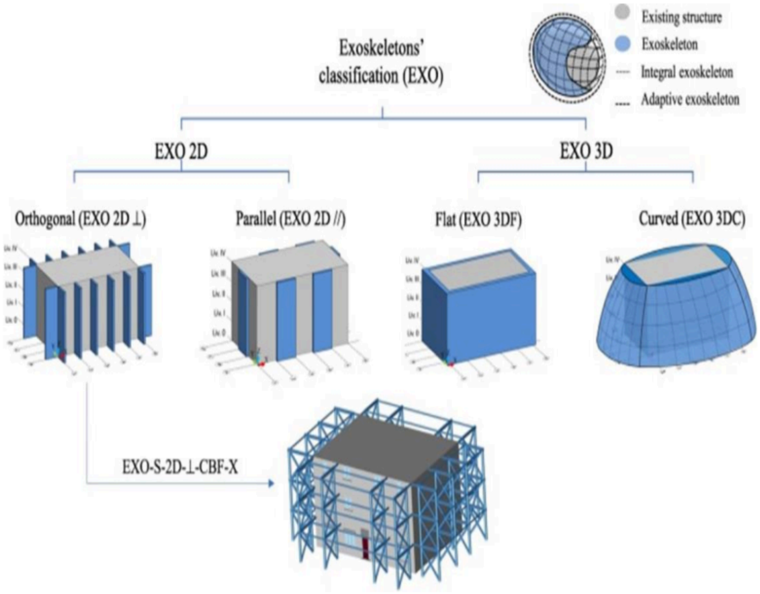


Fig 1.1: Classification of Exoskeletons.

1.2 STEEL EXOSKELETON STRUCTURAL SYSTEM

The Exoskeleton Structure is a lateral load-resisting system that transmitted to the building's foundation. The building's mass resists this motion, generating inertial forces that act throughout the structure. These forces cause stresses and strains in the building's structural elements. The connections between the existing building and the exoskeleton allow these seismic forces to be transferred to the stronger and stiffer external frame. The exoskeleton, with its robust steel members and bracing, resists these lateral forces more effectively than the original, potentially weaker structure. Think of it like adding a strong, supportive cage around a weaker box. When you shake the ground, the cage (exoskeleton) takes most of the stress and prevents the weaker box (original building) from collapsing or being severely damaged.

In essence, the exoskeleton works by providing an alternative, stronger load path for seismic forces, reducing the demand on the original building's structural capacity and enhancing its overall resilience to earthquakes. The key is a well-designed and properly connected external frame that can effectively interact with the existing structure during a seismic event.

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.

1.3 BACKGROUND OF STEEL EXOSKELETON SYSTEM

The steel exoskeleton system in buildings emerged from the late 19th-century innovation of steel-framed construction, pioneered by structures like the Home Insurance Building. This "skeleton frame" allowed for taller buildings with larger openings, liberating design from thick masonry walls. Throughout the 20th century, steel frames became standard for skyscrapers due to steel's strength and efficiency.

The "exoskeleton" concept, prominent from the late 20th century onwards, externalizes the primary steel structure. This offers superior lateral stiffness for tall buildings, allows for striking architectural expression (making the structure a design feature), and creates more flexible internal spaces. Beyond new construction, it's increasingly used for retrofitting, enhancing seismic safety and sustainability. Architects like Norman Foster and Richard Rogers (e.g., Pompidou Centre) are associated with exposing building structures, and modern examples like the Burj Al Arab and "The W"rapper showcase the versatility and impact of steel exoskeletons.

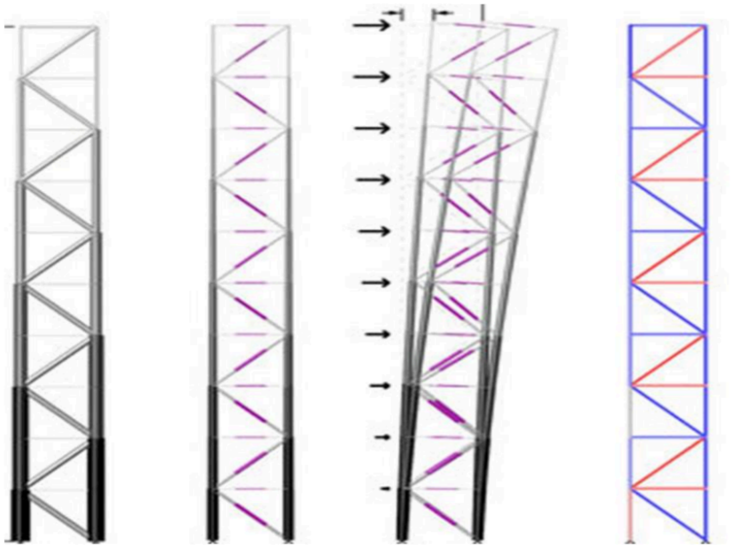


Fig 1.3: functioning of exoskeleton system.

1.4 ADVANTAGES OF EXOSKELETON SYSTEM

a. Increased Lateral Strength: The primary advantage is a significant boost in the building's ability to withstand horizontal forces generated during earthquakes. The robust external frame of the exoskeleton acts as an additional load-resisting system.

b. Increased Stiffness: The exoskeleton stiffens the overall structural system. This leads to reduced lateral displacement (overall drift) and relative movement between floors (story drift), minimizing both structural and non-structural damage.

c. Improved Stability: By providing an external bracing system, the exoskeleton enhances the building's overall stability, reducing the risk of collapse during strong seismic events.
d. Modified Dynamic Response: The added stiffness from the exoskeleton can shorten the building's natural period of vibration. Depending on the earthquake's frequency content and the site's soil conditions, this shift can sometimes lead to a more favourable seismic response.
e. External Intervention: A major advantage over traditional internal retrofitting methods is that the exoskeleton is primarily constructed on the exterior of the building. This significantly minimizes disruption to the occupants and the building's interior activities. Residents or operations can often continue within the building during the retrofit process.
f. Architectural Enhancement: The external exoskeleton can offer opportunities to redefine the building's aesthetics, providing a modern look or adapting it to changing urban contexts. Architects can use the exoskeleton as a design element to create a visually appealing and structurally sound building.
g. Sustainability: Retrofitting existing buildings is generally more sustainable than demolishing and constructing new ones, as it conserves embodied energy and reduces construction waste. The integration of energy-efficient elements further enhances the sustainability aspect.

1.5 CHALLENGES OF EXOSKELETON SYSTEM

Load Transfer Mechanism: The biggest challenge is how to effectively transfer loads between the exoskeleton and the existing RCC members (columns, beams, slabs, shear walls). This requires robust and reliable connections that can withstand significant forces without causing damage to either the exoskeleton or the RCC structure.

Anchorage and Fixation: Designing secure and durable anchorage systems to attach the exoskeleton to the concrete is crucial. This needs to consider the existing concrete strength, potential for cracking, and the long-term performance of the anchors under cyclic loading and environmental conditions.

Compatibility of Materials: Ensuring compatibility between the materials of the exoskeleton (likely steel or composites) and the concrete is important to prevent corrosion or other detrimental interactions over time.

Stiffness Mismatch: The exoskeleton will likely have a different stiffness than the existing RCC structure. Achieving a harmonious load-sharing mechanism where both components work together effectively to resist displacement and drift is complex. A significant stiffness mismatch could lead to one component being overloaded while the other is underutilized.

Kinematic Compatibility (Building Movement): RCC structures undergo slight movements due to temperature changes, settlement, and applied loads. The exoskeleton needs to accommodate these movements without inducing stress concentrations or restricting the building's natural behaviour.

Predicting Structural Response: Accurately predicting how the combined system (RCC structure + exoskeleton) will behave under various loading conditions (wind, seismic, gravity) requires sophisticated structural analysis and modelling techniques.

Customization and Retrofitting: Existing RCC structures have varying geometries and structural configurations. The exoskeleton system would likely need to be highly customizable and adaptable to each specific building, making design and manufacturing complex and potentially expensive.

Architectural and Functional Integration: The exoskeleton needs to be integrated with the building's existing architecture and functionality without causing significant obstructions or hindering access. This can be a major aesthetic and practical challenge.

Constructability and Installation: Installing a large-scale exoskeleton system around an existing building can be logistically challenging, requiring specialized equipment and construction techniques, especially for occupied buildings.

Applying an exoskeleton system to enhance the stiffness and reduce displacement of an existing RCC structure presents significant engineering challenges related to interfacing, structural compatibility, design integration, cost, and long-term performance.

1.6 CONDITIONS LESS SUITABLE FOR EXOSKELETON SYSTEMS

i. Aesthetics must be concealed: Strict historical preservation rules or a desire for a traditional, non-industrial look make exposed steel problematic.

ii. Harsh climates prevail: Extreme temperature swings, corrosive environments (coastal, polluted), or high precipitation significantly increase thermal bridging, corrosion risk, and maintenance costs for exposed steel.

iii. Budget is tight: Fabrication precision, specialized coatings, robust fireproofing, and ongoing maintenance for exposed steel are more expensive.

iv. Fire safety is paramount for exposed elements: Exposed steel rapidly loses strength in fire, requiring costly and potentially visually intrusive fireproofing solutions.

v. Thermal performance is critical: Exposed steel acts as a thermal bridge, increasing energy consumption and condensation issues unless expensive thermal breaks are implemented.

vi. External vulnerability is a concern: The primary structure being on the exterior makes it susceptible to accidental damage or targeted attacks.

1.7 TYPES OF EXOSKELETON SYSTEMS

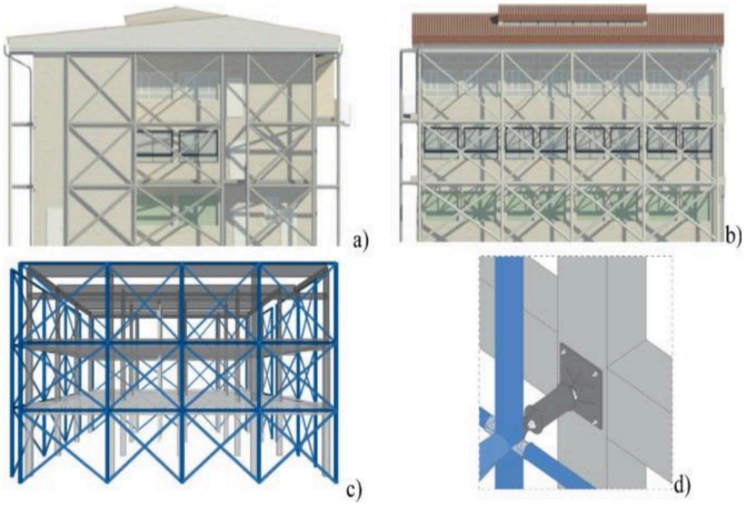
a) STEEL EXOSKELETON SYSTEM:-

Braced Steel Frames: These are external steel frames, often with diagonal bracing (like Buckling Restrained Braces - BRBs), that are connected to the existing RCC structure. They primarily aim to increase the building's lateral stiffness and strength, significantly improving its resistance to seismic loads and reducing story drift. These can be designed to remain elastic or incorporate dissipative elements for enhanced energy absorption during earthquakes.

Moment-Resisting Steel Frames: Similar to braced frames, these external steel frames are designed with moment connections to resist lateral forces through bending of the beams and columns. They can also increase the building's overall stiffness and reduce displacement.

Steel Diagrids: These are exoskeletons with a triangulated configuration of steel members that can efficiently resist both [25] vertical and lateral loads. They can be applied externally to the building's facade, offering a potentially less invasive retrofitting solution.

Cold-Formed Steel Systems: Lightweight steel systems using cold-formed profiles can be used to create exoskeletons that provide seismic reinforcement with a minimal increase in the building's mass. Some integrated systems also incorporate thermal insulation for energy efficiency.



i. Fig 1.7.1: Steel Exoskeletons

b) RC EXOSKELETON SYSTEM: -

External RC Frames or Walls: Similar to steel exoskeletons, external RC frames or shear walls can be added to the perimeter of an existing RCC building and connected to it. This increases the overall strength and stiffness of the structure.

RC Jacketing (as part of an exoskeleton approach): While traditionally considered a local retrofitting technique, RC jacketing of columns and beams can be integrated with an external RC frame to create a more comprehensive exoskeleton system.

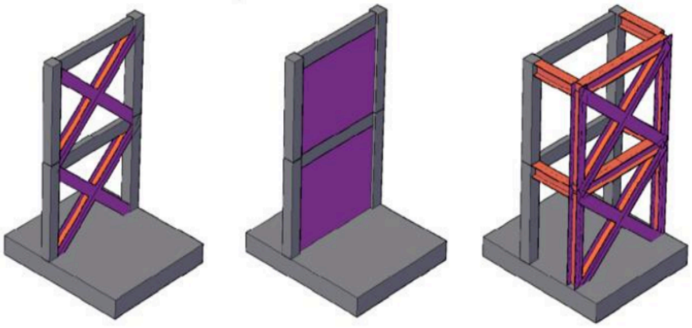


Fig 1.7.2: RC Exoskeletons.

c) HYBRID EXOSKELETON SYSTEM : -

Steel Exoskeletons with Dissipative Devices**:** To address the issue of increased stiffness potentially leading to higher seismic forces, steel exoskeletons can be combined with energy dissipation devices (e.g., viscous dampers, friction dampers) at the connections to the RCC frame.

Steel Exoskeletons with Sliding Systems: Some innovative approaches use sliding mechanisms (e.g., steel-PTFE bearings) in conjunction with steel exoskeletons to allow for controlled movement and reduce the transfer of excessive seismic forces to the retrofitted building.

Integrated Exoskeletons for Multi-Hazard Mitigation: Emerging concepts involve exoskeletons that not only enhance seismic performance but also improve energy efficiency (e.g., by integrating thermal insulation or solar panels) and potentially offer architectural upgrades.

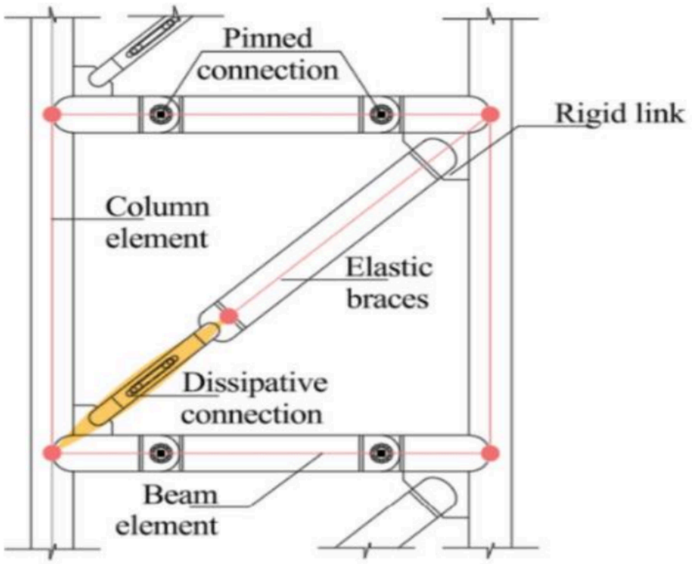


Fig 1.7.3: Hybrid Exoskeleton System.

1.8 BRACINGS VS EXOSKELETON SYSTEMS

Bracings and exoskeleton 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, [7] 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) Exoskeleton:

- Exoskeleton refers to an external structural framework that is added to or built around the main structure of a building. They function by a passive system that relies on its structural integrity and connections to the existing building to resist forces. In seismic retrofitting, it might incorporate energy dissipation devices for enhanced performance.
- Exoskeleton are especially effective in old buildings because they help control the structure's torsional response, decreasing the necessity for extensive internal bracing and [10] can be used as the primary load-bearing system for new buildings, potentially allowing for more open interior spaces and unique architectural designs.
- Commonly made of steel but can also be constructed from reinforced concrete.
- External steel braced frames wrapped around a building, diagrid structures forming the building's exterior, external concrete frames supporting the building's loads.

In summary, Bracing is like internal reinforcement for a building's skeleton & exoskeleton is like adding a whole new, stronger skeleton on the outside of the existing one. While both aim to improve a building's structural performance, they achieve this through different locations and scales of intervention. An exoskeleton might even incorporate bracing elements within its own external framework.

CHAPTER 2

LITERATURE REVIEW

Anna Reggio et al: The research paper focus [1] on investigating the performance of exoskeleton structures as structural control systems under seismic loading. The exoskeleton structure is modelled as a dynamic system whose mass (in principle, not negligible), stiffness and damping properties can be varied and, possibly, designed with the aim of controlling the response of the primary structure. [1] A case study is subsequently discussed, dealing with the seismic response of a mid-rise reinforced concrete frame, designed with non ductile behaviour, coupled to a steel diagrid-like lattice exoskeleton structure. Results of the seismic analyses show that the rigid coupling to the exoskeleton structure allows one to achieve a significant displacement and deformation control of the primary structure, as well as important reductions of its internal forces, in terms of both base and floor shear forces. By doing comparative study of a existing structure and exoskeleton structure they found improvement in Drift , [11] Reductions of the internal forces on the primary structure due to which [11] the need for strengthening the existing foundation below the primary structure is, consequently, avoided and Reduction in displacement.

Chiara Passoni et al: -The paper discusses the evolution of [1] a new method for the design of alternative solutions for a sustainable seismic upgrade of existing RC buildings is proposed [6] a 4-step procedure for the design of different kinds of dissipative and high-strength exoskeleton solutions is then provided, able to define interventions leading to equivalent seismic performances of the retrofitted buildings. Considered four models as with different specification [A.1] Model [6] of the RC frame elements – plastic hinges [A.2] Ultimate seismic capacity of existing beam and block flooring systems [A.3] Model of the masonry infills – masonry properties and nonlinear model [A.4] Total roof drift of the retrofitted building – nonlinear time history response. In this paper author want to say , use of Dissipative(use of dampers) and High strength solution (without Dampers) have their own significant as per requirement.

Alessandro Prota et al: - They checked structural performances of the existing building against four different performance levels “Limit States” (LS) namely: Immediate

Occupancy (IO), Damage Limitation (DL), Significant Damage (SD), and Near Collapse (NC).They did Non-linear static ("pushover") analyses , and three dimensional (3D) finite element model (FEM) of the structure has been developed to carry out static and dynamic non-linear analyses by using SAP2000 software .

They performed analysis by retrofitting a structure in different way of exoskeleton structure as shown. They made two models SI-1 & SI-2 with different specification and did analysis

SI-1: in which exoskeleton system is designed to limit the IDRmax [inter-storey drift ratio] in compliance with the Italian code provision at DL limit state, and to avoid both the RC joint shear failure and any flexural failure at SD;

SI-2: in which exoskeleton system is designed

i) to limit the IDRmax in compliance with the Italian code provision at DL limit state,

ii) to avoid any yielding of the RC beams and columns at SD (significant damage) limit state but without monitoring the RC joint failure.

From analysis he found both the models are showing good results in comparison to existing RC building.

Jana Olivo et al: Study is focused on addressing this limitation through the introduction of an optimal tool based on a metaheuristic algorithm. [Their primary objective is to get close to the optimal solution, finding good, feasible solutions in an acceptable timescale.] Among all these stochastic techniques that appeared in Literature, population-based algorithms are the most adopted due to their promising converge capability and robustness. The main advantage of these algorithms is their potential parallelism, meaning that a population can simultaneously explore the search space in multiple directions because multiple offspring of the population act like independent agents .In this work, the optimal amount and placement of the exoskeletons as well as the optimal sizing of their constituent elements have been achieved by implementing an adapted version of the well-known Genetic Algorithm . The optimization process aims to attain the lightest possible solution while satisfying two crucial constraints. The first constraint is intended for maintaining the entire existing structure within the elastic field by imposing a maximum allowable inter-storey drift (limiting the damage to non-structural elements like partition walls and façade). The second restriction guarantees the compliance of the exoskeleton elements with the structural verifications. The implementation of this tool in the design process results in lightweight and cost efficient exoskeletons, successfully achieving the targeted outcomes and rendering this solution feasible for a retrofitting intervention. The research emphasizes the proposed optimization tool has been able to significantly reduce the weight and cost of the intervention.

Simone D'Amore et al: This paper explores the use of global intervention strategies using external low-damage frame exoskeleton systems for the seismic retrofit of existing reinforced concrete (RC) buildings. These systems, based on PREcast Seismic Structural System (PRESSS) technology, enhance the "plastic hinge" mechanism of traditional systems with a "Rocking & Dissipative" mechanism, allowing for energy dissipation and self-centering capabilities.

The study proposes an analytical Displacement-Based Retrofit (DBR) procedure for designing such interventions and validates it through non-linear static and dynamic analyses. The effectiveness of the low-damage technology is demonstrated by comparing it with a monolithic exoskeleton counterpart, focusing on their self-centering capabilities. The research highlights the potential of PRESSS technology to improve the seismic resilience of existing buildings and offers a comprehensive DBR procedure for its implementation.

Simone Labò et al: This paper proposes the use of diagrids as structural exoskeletons for the renovation of existing reinforced concrete (RC) buildings. The diagrid system is an inclined structural grid that can withstand both vertical and horizontal loads. Diagrids were initially proposed for tall new buildings to create structures with a strong architectural identity and without vertical columns.

The authors suggest that diagrids are suitable for the integrated renovation of existing buildings because they can be applied from the outside, avoiding the relocation of occupants. Diagrids can also be assembled in stages over time, increasing the economic sustainability of the interventions, and they can be designed in compliance with Life Cycle Thinking principles.

The paper introduces two methods for designing elastic diagrids for retrofit interventions. The first method is an analytical design method that extends previous studies on diagrid systems for tall new buildings. The second method involves defining design spectra to obtain the stiffness and strength of the diagrid exoskeleton, using sensitivity analyses on a simplified Single-Degree-Of-Freedom (SDOF) system. Both methods are applied to the structural retrofit design of a post-WWII European RC building, and the theoretical results are validated with nonlinear time history analyses.

Sources

L. Martelli et al: The paper investigates the use of an exoskeleton, an external steel self-supporting system, for the seismic retrofitting of existing buildings. The exoskeleton is connected to the existing building to protect it against seismic activity. The authors present a case study of a four-story reinforced concrete (RC) building retrofitted with an exoskeleton. The results show that the exoskeleton improves the seismic performance of the building.

Rocco Buda et al: The paper discusses the retrofit of existing reinforced concrete (RC) buildings using steel and RC exoskeletons. It addresses the structural, energy, and architectural problems of these buildings, proposing the use of an exoskeleton as an additive structure to avoid operational interruptions. The study includes push-over (PO) analyses to evaluate the performance of both steel and RC exoskeleton systems in retrofitting a case study building in Italy.

Fabio Mazza et al: The paper explores the use of dissipative steel exoskeletons (DEXs) for the seismic retrofitting of reinforced concrete (r.c.) framed buildings. It notes that while steel bracing systems with dissipative devices are commonly used for this purpose, the construction of an external double-skin arrangement is less explored. The author argues that DEXs offer advantages in terms of energy efficiency and functionality. DEXs can reduce the indirect costs and disruptions associated with traditional retrofitting methods that occur with dissipative endoskeletons. The paper introduces a procedure for sizing DEXs using overdamped elastic response spectra. This procedure designs the DEX by considering its rigid coupling with the existing structure and distinguishing between the mass and stiffness properties of the steel exoskeleton and the added damping of the dissipative bracing system. The study focuses on concentrically braced chevron frames with pinned joints and fluid viscous dampers (FVDs) for the damping systems. It assumes elastic-linear behavior for the steel frame members and nonlinear viscous behavior for the FVDs, with a storey-shear proportional distribution. The paper simulates the retrofitting of a six-story r.c. framed structure, typical of Italian residential buildings from the 1990s, in a high-risk seismic region. It examines three different external arrangements of DEXs: parallel (DEX.Pa), perpendicular (DEX.Pe), and a mixed solution (DEX.Mi). Nonlinear structural models are developed in OpenSEES to analyze the original and coupled structures, considering ductile and brittle failure modes. The seismic analyses confirm the effectiveness of the proposed DEX design and provide insights into the strengths and weaknesses of the different configurations.

2.1 RESEARCH GAP

i. Research on the effectiveness and optimal design of exoskeletons for retrofitting buildings with pre-existing structural damage or material degradation (e.g., corroded RC, aged masonry)

ii. Developing more efficient and less intrusive methods for connecting exoskeletons to existing structures, especially for historically significant buildings where drilling or extensive alterations to the original fabric are undesirable.

iii. Most research focuses on seismic or wind separately. There's a need for more integrated design approaches that consider the simultaneous or sequential effects of multiple hazards (e.g., wind-driven rain on corrosion, post-earthquake fire).

2.2 MY OBJECTIVES

1. Providing exoskeletal on outer part without disturbing the inner part of structure and maintaining the stability by RCC.
2. Reducing the storey drift and increasing stiffness under seismic and wind loading.
3. Comparing the performance of the building of G+6 storey of RCC building with and without exoskeletal structure.

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 exoskeleton.

3.2 CASE A: CONVENTIONAL MID-RISE FRAME

A G+6 residential RC building has been chosen. The building's floor layout is rectangular, measuring 13.717 m by 17.678 m in Y and X directions, respectively. With floor-to-floor heights calculated as indicated in Table 3.2, the building's total height (H) is 31.394 meters. Floors have a 15 cm RC slab with 16.85 cm floor thickness

Table 3.2.A: floor-to-floor heights calculated as.

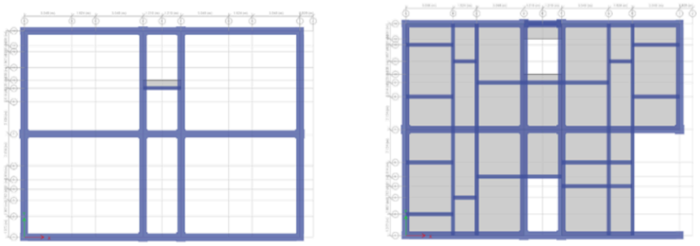
STORY	HEIGHT (m)	ELEVATION (m)	MASTER STORY
Head Room Slab	3.6576	31.394	No
Terrace	3.6576	27.7364	No
Sixth Floor	3.6576	24.0788	No
Fifth Floor	3.6576	20.4212	No
Fourth Floor	3.6576	16.7636	No
Third Floor	3.6576	13.106	No
Second Floor	3.6576	9.4484	Yes
First Floor	3.3528	5.7908	No
Ground Floor	2.438	2.438	No
Base		0	

Table 3.2.B: material and section properties of RC members for mid-rise frame.

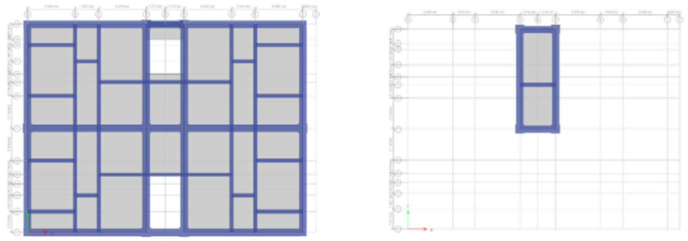
S NO	MATERIAL AND SECTION PROPERTIES	VALUES
1	Reinforcement bar	HYSD 550
2	Concrete grade	M20
3	Number of bays along X-direction	3
4	Number of bays along Y-direction	2
5	Total number of stories	G+6
6	Primary Beams dimension (RCC)	300 x 800 mm (PB1) 400 x 700 mm (PB2)
7	Secondary Beams dimension (RCC)	230 x 250 mm (SB1) 230 x 300 mm (SB2)
8	Outer Column dimensions (RCC)	500 x 500 mm
9	Slab thickness	150 mm

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 then slab portion.



(a) Ground Floor Plan (b) First Floor Plan



(c) Plan of Second Floor to Terrace (d) Headroom

Fig 3.2.1A: Plan view of framing.

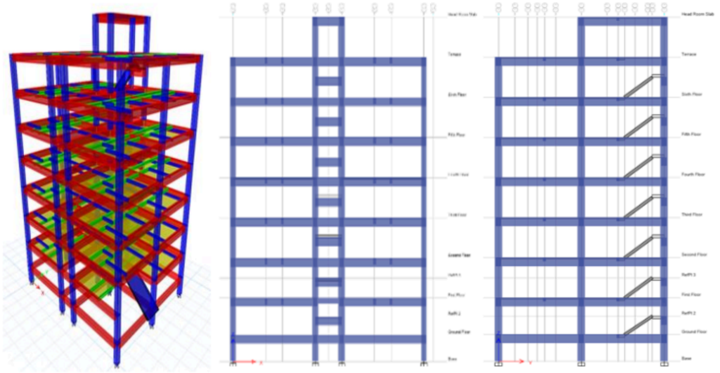


Fig 3.2.1B:Isometric View (a) Elevation in X Direction (b) Elevation in Y Direction.

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)
WLY	Wind load (as per IS 875:2015 Part 3)

3.2.2 LOAD CALCULATIONS

DEAD LOAD

Beam load calculation:

i) Load on GF below PB1 (internal wall) =(density of brick) X (height of floor) X (thickness of wall)

=23.55 X (3.353-0.35) X 0.127

=8.9815 KN/m

ii) Load on GF below PB1 (external wall) =(density of brick) X (height of floor) X (thickness of wall)

=23.55 X (3.353-0.35) X 0.23

=16.2657 KN/m

iii) Load on GF below PB2 =(density of brick) X (height of floor) X (thickness of wall)

=23.55 X (3.353-0.5) X 0.127

=8.5329 KN/m

iv) Load above GF below PB1& SB (internal wall) =(density of brick) X (height of floor) X (thickness of wall)

=23.55 X (3.6576-0.35) X 0.127

=9.8925 KN/m

v) Load above GF below PB1& SB (external wall) =(density of brick) X (height of floor) X (thickness of wall)

=23.55 X (3.6576-0.35) X 0.23

=17.9156 KN/m

vi) Load above GF below PB2 (internal wall) =(density of brick) X (height of floor) X (thickness of wall)

=23.55 X (3.6576-0.35) X 0.127

=9.4439 KN/m

vii) Weight of parapet wall =(density of brick) X (height of floor) X (thickness of wall)

=23.55X 1 X 0.23

=5.4165 KN/m

Slab load calculation:

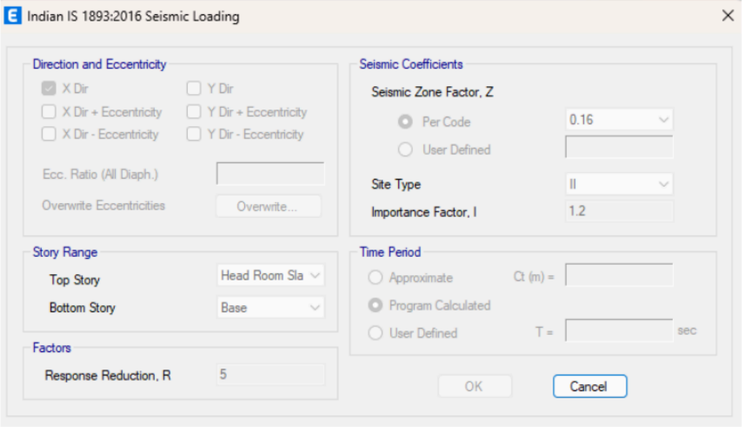
Floor finisher:(density of bedding material) X (thickness of filling) + (density of flooring tile) X (thickness of the flooring) = (20X0.05) + (26.7 X 0.025)

=1.7 KN/m2

LIVE LOAD

As per IS 875:1987 PART 2 for residential buildings rooms = 3KN/m2.

EARTHQUAKE LOAD



Indian IS 1893:2016 Seismic Loading

Direction and Eccentricity

☑ X Dir ☐ Y Dir
☐ X Dir + Eccentricity ☐ Y Dir + Eccentricity
☐ X Dir - Eccentricity ☐ Y Dir - Eccentricity

Ecc. Ratio (All Diaph.)

Overwrite Eccentricities

Seismic Coefficients

Seismic Zone Factor, Z
● Per Code: 0.16
○ User Defined

Site Type: II

Importance Factor, I: 1.2

Story Range

Top Story: Head Room Sla

Bottom Story: Base

Time Period

○ Approximate Ct (m) =
● Program Calculated
○ User Defined T = sec

Factors

Response Reduction, R: 5

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 :

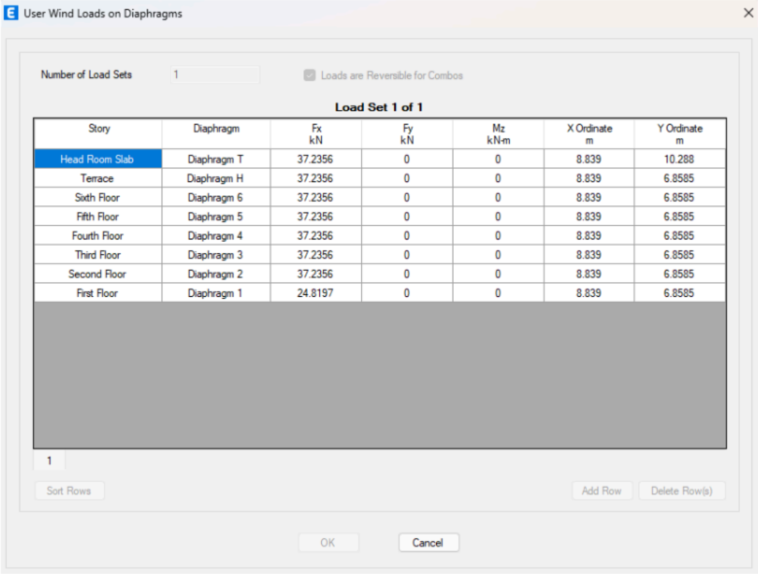
In CSI ETABS self-weight of the member is calculated by default no need to calculate separately. Beams are to be selected separately and assign the load as per calculation in gravity direction as distributed load. After the assigning of beam load floors are to be selected and dead weight and live load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



Number of Load Sets 1

☑ Loads are Reversible for Combos

Load Set 1 of 1

Story	Diaphragm	Fx kN	Fy kN	Mz kN-m	X Ordinate m	Y Ordinate m
Head Room Slab	Diaphragm T	37.2356	0	0	8.839	10.288
Terrace	Diaphragm H	37.2356	0	0	8.839	6.8585
Sixth Floor	Diaphragm 6	37.2356	0	0	8.839	6.8585
Fifth Floor	Diaphragm 5	37.2356	0	0	8.839	6.8585
Fourth Floor	Diaphragm 4	37.2356	0	0	8.839	6.8585
Third Floor	Diaphragm 3	37.2356	0	0	8.839	6.8585
Second Floor	Diaphragm 2	37.2356	0	0	8.839	6.8585
First Floor	Diaphragm 1	24.8197	0	0	8.839	6.8585

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

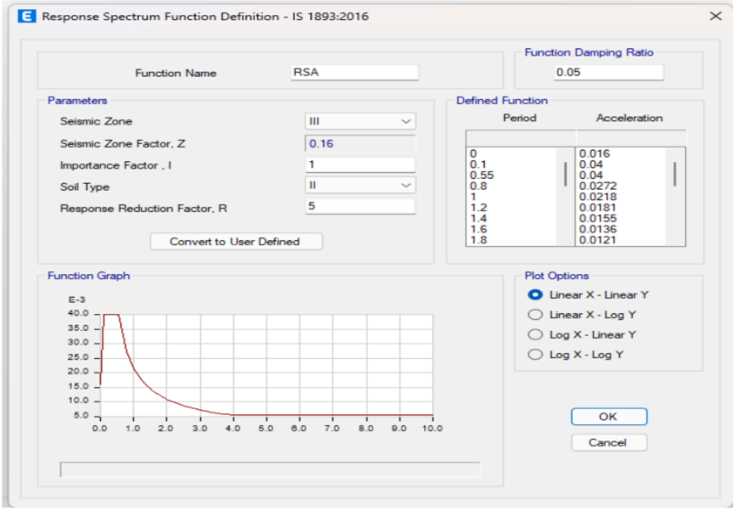
To study the dynamic behaviour of the structure we need go for dynamic analysis, that for high rise buildings dynamic analysis will help to get each story responses when a structure is subject to any lateral loading event. To study the seismic effect there are 2 different types of seismic dynamic analysis

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.



Response Spectrum Function Definition - IS 1893:2016

Function Name: RSA

Function Damping Ratio: 0.05

Parameters

Seismic Zone: III

Seismic Zone Factor, Z: 0.16

Importance Factor , I: 1

Soil Type: II

Response Reduction Factor, R: 5

Defined Function

Period	Acceleration
0	0.016
0.1	0.04
0.55	0.04
0.8	0.0272
1	0.0218
1.2	0.0181
1.4	0.0155
1.6	0.0136
1.8	0.0121

Plot Options

● Linear X - Linear Y

○ Linear X - Log Y

○ Log X - Linear Y

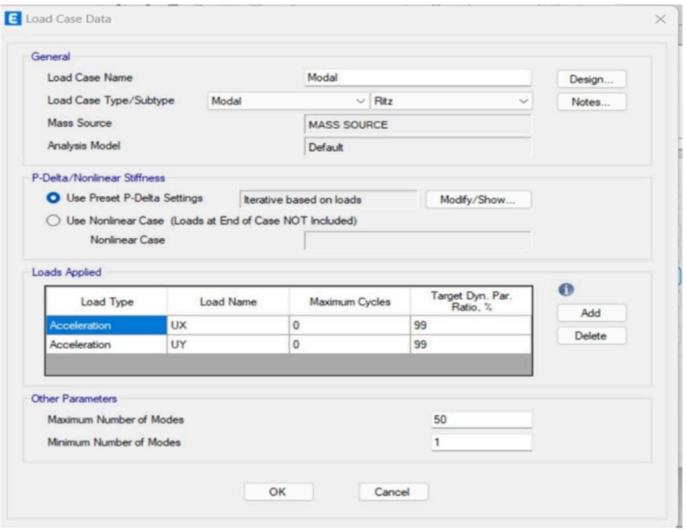
○ Log X - Log Y

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.



Load Case Name: Modal

Load Case Type/Subtype: Modal / Ritz

Mass Source: MASS SOURCE

Analysis Model: Default

● Use Preset P-Delta Settings: Iterative based on loads

○ Use Nonlinear Case (Loads at End of Case NOT Included)

Nonlinear Case:

Load Type	Load Name	Maximum Cycles	Target Dyn. Par. Ratio, %
Acceleration	UX	0	99
Acceleration	UY	0	99

Maximum Number of Modes: 50

Minimum Number of Modes: 1

Fig 3.2.4: Model analysis definition.

3.2.5 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 3.2.5: 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 X-BRACED EXOSKELETON

A G+6 story building with beams, columns and slabs at floor level. Attached with X-braced exoskeletons at periphery of structure.

A rectangular design (L/B = 1.289) with dimensions of 17.678 m × 13.717 m and three bays along the X and two bays along the Y directions characterizes the conventional mid-rise frame taken into consideration in the study. The structure under consideration has a headroom slab and is 31.394 meters tall.

A 1.30-meter-distance exoskeleton structure is available beyond the building's perimeter. Links connect the building's several floor levels to the exoskeleton construction. Steel rods with a 120mm diameter made up the linkages. The study's consideration of the conventional rectangular building's plan and elevation demonstrate that the plans of the various floors of the structure differ.

Table 3.3.1: material and section properties of X-braced exoskeletons

SL NO	MATERIAL AND SECTION PROPERTIES	VALUES
1	Steel grade	Mild steel
2	Diagonal beam (hollow circular beams)	ISNB50M
3	Linkage rod dia	120mm
4	Total number of stories	G+6
5	Spacing of exoskeleton from periphery of building	1300mm
6	Column of Exoskeleton (battening at alternate intervals of 0.30 m)	Built-up box section of 2 ISMC200

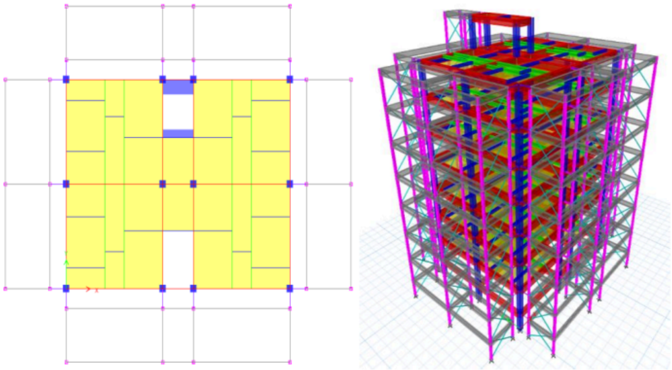


Fig 3.3: Plan & 3D view of X-braced exoskeleton.

3.4 CASE C: CONVENTIONAL FRAME WITH V-BRACED EXOSKELETON.

A G+6 story building with beams, columns and slabs at floor level. Attached with V-braced exoskeletons at periphery of structure.

A rectangular design (L/B = 1.289) with dimensions of 17.678 m × 13.717 m and three bays along the X and two bays along the Y directions characterizes the conventional mid-rise frame taken into consideration in the study. The structure under consideration has a headroom slab and is 31.394 meters tall.

A 1.30-meter-distance exoskeleton structure is available beyond the building's perimeter. Links connect the building's several floor levels to the exoskeleton construction. Steel rods with a 120mm diameter made up the linkages. The study's consideration of the conventional rectangular building's plan and elevation demonstrate that the plans of the various floors of the structure differ.

Table 3.4: material and section properties of V-braced exoskeleton

SL NO	MATERIAL AND SECTION PROPERTIES	VALUES
1	Steel grade	Mild steel
2	Diagonal beam (hollow circular beams)	ISNB50M
3	Linkage rod dia	120mm
4	Total number of stories	G+6
5	Spacing of exoskeleton from periphery of building	1300mm
6	Column of Exoskeleton (battening at alternate intervals of 0.30 m)	Built-up box section of 2 ISMC200

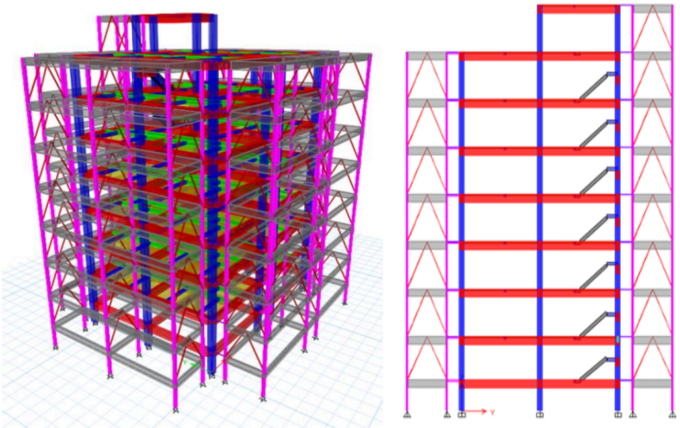


Fig 3.4: 3D view and elevation of V-braced exoskeleton.

3.5 CASE D: CONVENTIONAL FRAME WITH DIAGONAL-BRACED EXOSKELETON.

A G+6 story building with beams, columns and slabs at floor level. Attached with V-braced exoskeletons at periphery of structure.

A rectangular design (L/B = 1.289) with dimensions of 17.678 m × 13.717 m and three bays along the X and two bays along the Y directions characterizes the conventional mid-rise frame taken into consideration in the study. The structure under consideration has a headroom slab and is 31.394 meters tall.

A 1.30-meter-distance exoskeleton structure is available beyond the building's perimeter. Links connect the building's several floor levels to the exoskeleton construction. Steel rods with a 120mm diameter made up the linkages. The study's consideration of the conventional rectangular building's plan and elevation demonstrate that the plans of the various floors of the structure differ.

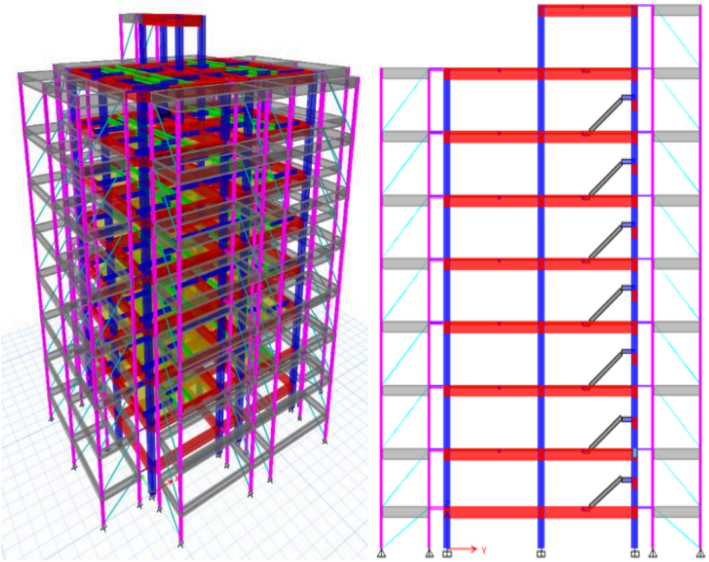


Fig 3.5: 3D view and elevation of Diagonal-braced exoskeleton.

Table 3.5: material and section properties of Diagonal-braced exoskeleton

SL NO	MATERIAL AND SECTION PROPERTIES	VALUES
1	Steel grade	Mild steel
2	Diagonal beam (hollow circular beams)	ISNB50M
3	Linkage rod dia	120mm
4	Total number of stories	G+6
5	Spacing of exoskeleton from periphery of building	1300mm
6	Column of Exoskeleton (battening at alternate intervals of 0.30 m)	Built-up box section of 2 ISMC200

3.6 CASE E: CONVENTIONAL FRAME WITH DIAMOND-BRACED EXOSKELETON.

A G+6 story building with beams, columns and slabs at floor level. Attached with Diamond-braced exoskeletons at periphery of structure. A rectangular design (L/B = 1.289) with dimensions of 17.678 m × 13.717 m and three bays along the X and two bays along the Y directions characterizes the conventional mid-rise frame taken into consideration in the study. The structure under consideration has a headroom slab and is 31.394 meters tall.

A 1.30-meter-distance exoskeleton structure is available beyond the building's perimeter. Links connect the building's several floor levels to the exoskeleton construction. Steel rods with a 120mm diameter made up the linkages. The study's consideration of the conventional rectangular building's plan and elevation demonstrate that the plans of the various floors of the structure differ.

Table 3.6: material and section properties of Diamond-braced exoskeleton

SL NO	MATERIAL AND SECTION PROPERTIES	VALUES
1	Steel grade	Mild steel
2	Diagonal beam (hollow circular beams)	ISNB50M
3	Linkage rod dia	120mm
4	Total number of stories	G+6
5	Spacing of exoskeleton from periphery of building	1300mm

6	Column of Exoskeleton (battening at alternate intervals of 0.30 m)	Built-up box section of 2 ISMC200

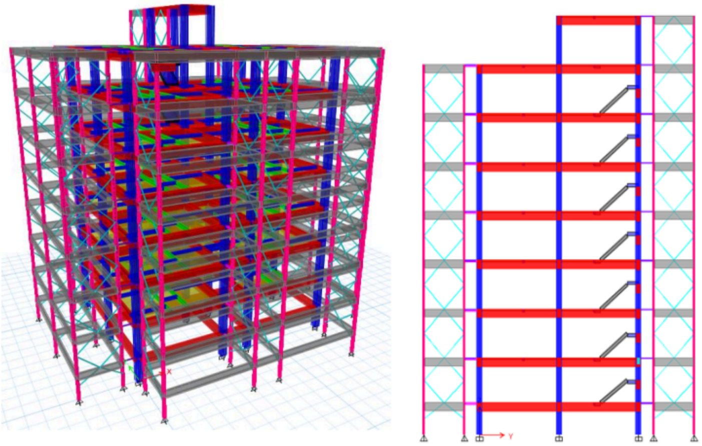


Fig 3.6: 3D view and elevation of Diamond-braced exoskeleton.

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 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 buildings subjected to lateral loading. Maximum is 23.833 mm at top story (Head room) under the response spectrum analysis in the global-X direction.

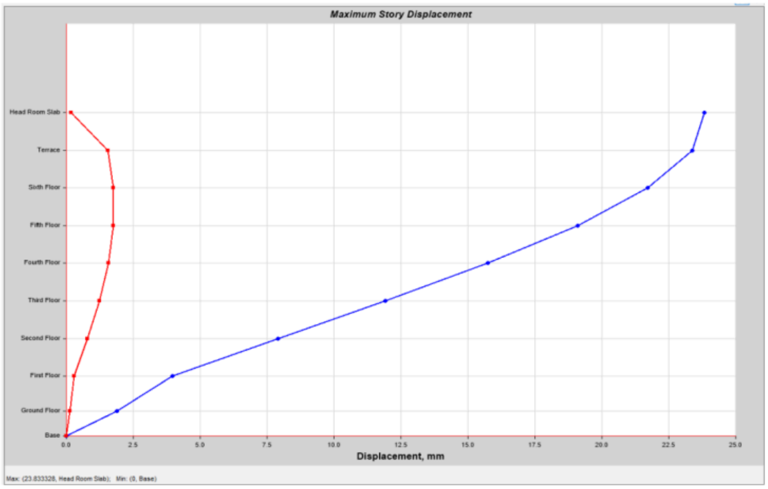


Fig 4.1.1: Maximum storey displacement of CASE A.

Storey drift: Storey drift in 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 0.001101 between the storey 1 and 5, exactly at storey 3.

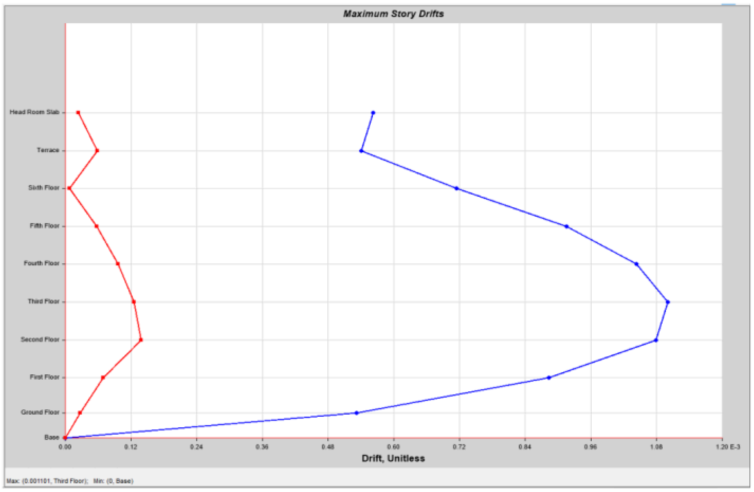
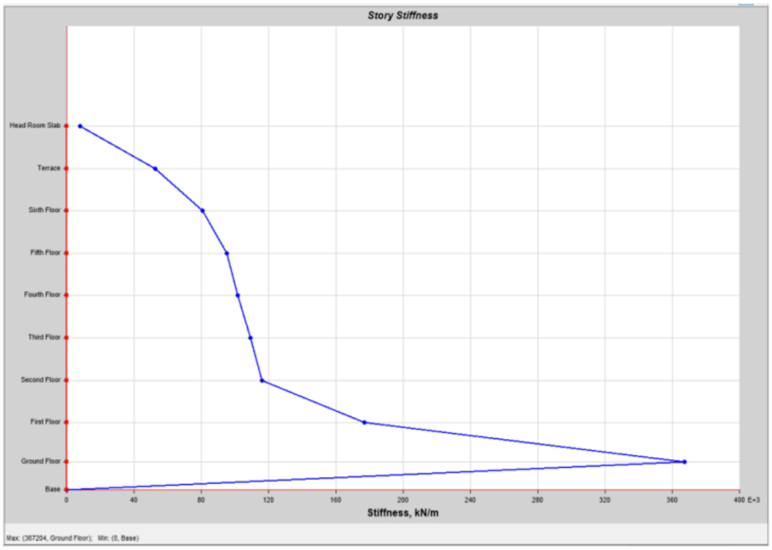


Fig 4.1.2: Maximum storey drifts of CASE A.

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.

4.2 CASE B:

A G+6 story building with beams, columns and slabs at floor level. Attached with X-braced exoskeletons at periphery of structure.

Storey displacement: Storey displacement in 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 buildings subjected to lateral loading. Maximum is 21.657 mm at top story (Head room) under the response spectrum analysis in the global-X direction. There is a decrease in displacement because of attachment of exoskeleton.

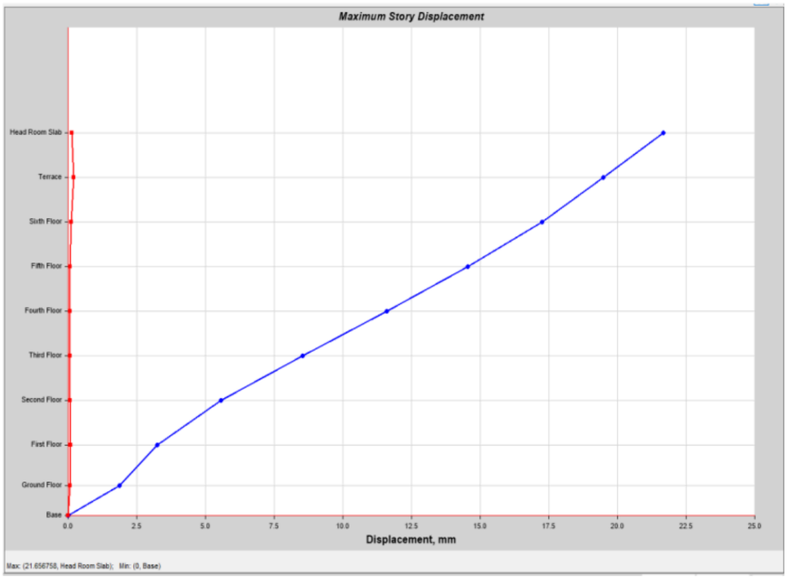
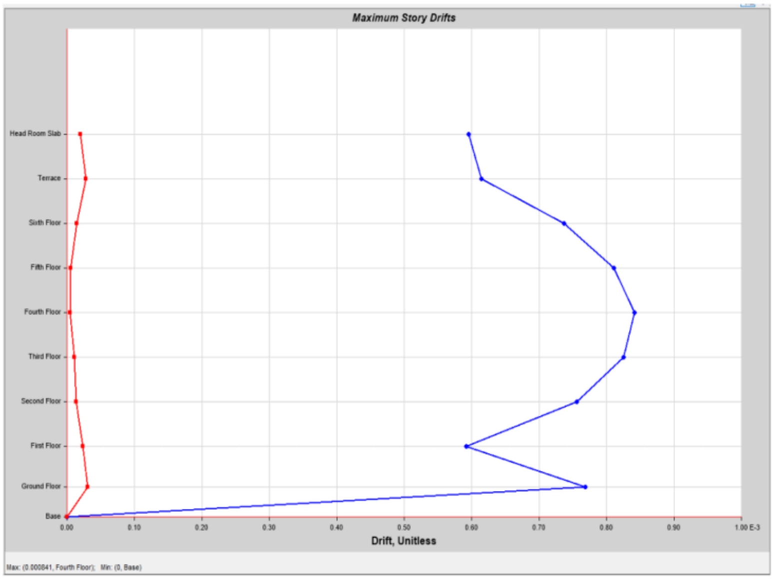


Fig 4.2.1: Maximum storey displacement of CASE B.

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 buildings under lateral loading. Maximum storey drift is 0.000841 between the storey 1 and terrace, exactly at storey 4. There is a decrease in story drift because of attachment of exoskeleton.



Max: (0.000841, Fourth Floor); Min: (0, Base)

Fig 4.2.2: Maximum storey drift of CASE B.

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.

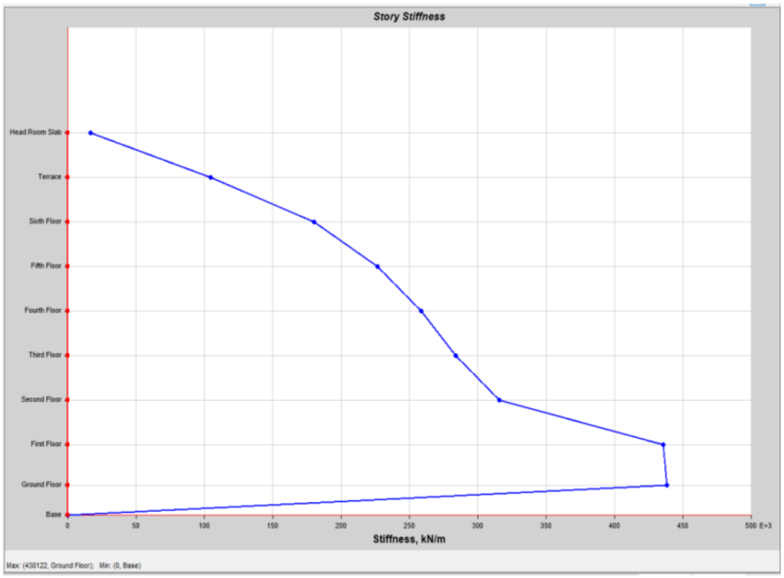


Fig 4.2.3: storey stiffness of CASE B.

4.3 CASE C:

A G+6 story building with beams, columns and slabs at floor level. Attached with V-braced exoskeletons at periphery of structure.

Storey displacement: Storey displacement in 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 buildings subjected to lateral loading. Maximum is 21.555 mm at top story (Head room) under the response spectrum analysis in the global-X direction. There is a decrease in displacement because of attachment of exoskeleton.

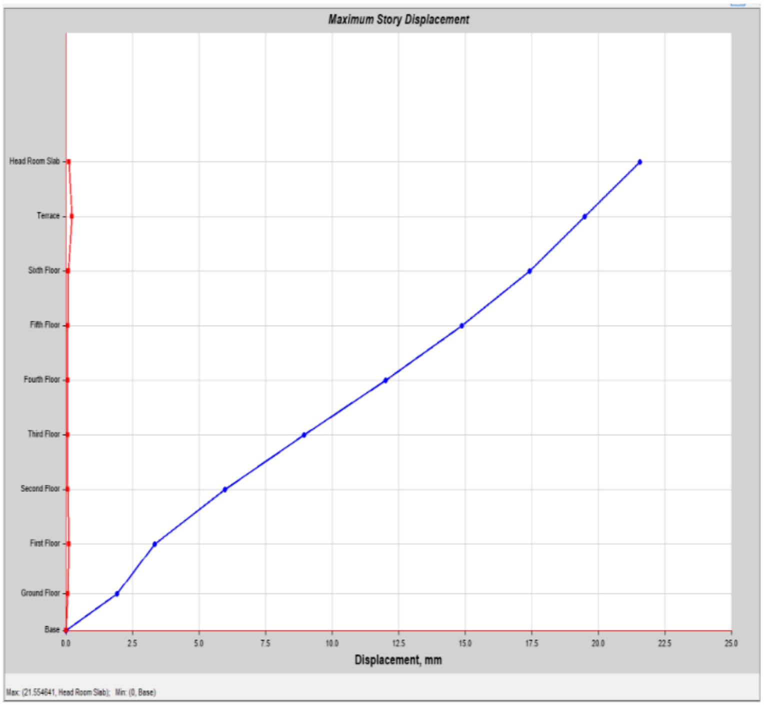


Fig 4.3.1: Maximum storey displacement of CASE C.

Storey drift: Storey drift in 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 buildings under lateral loading. Maximum storey drift is 0.000834 between the storey 1 and Terrace, exactly at storey 4. There is a decrease in story drift because of attachment of exoskeleton.

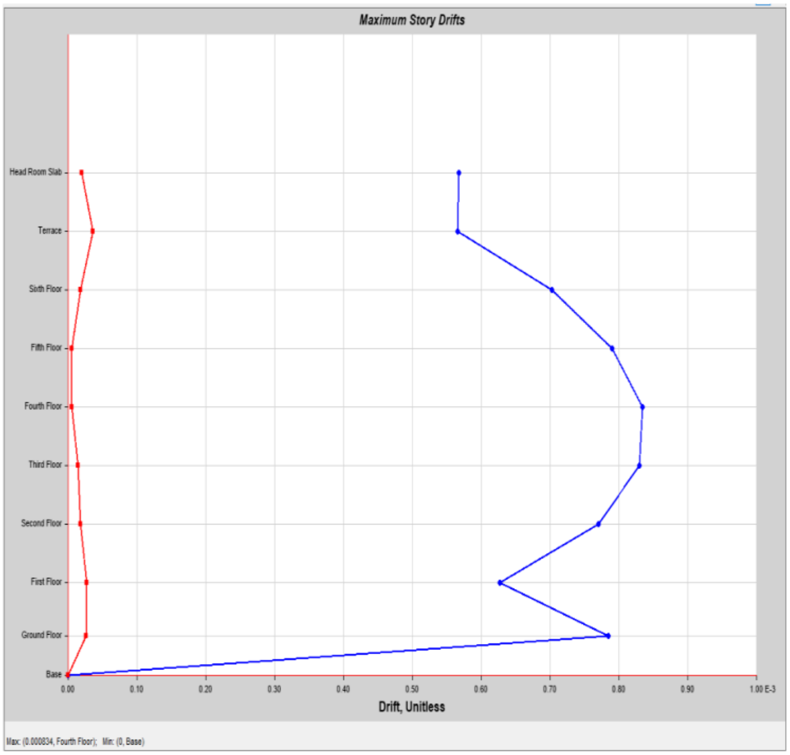


Fig 4.3.2: Maximum storey drift of CASE C.

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.

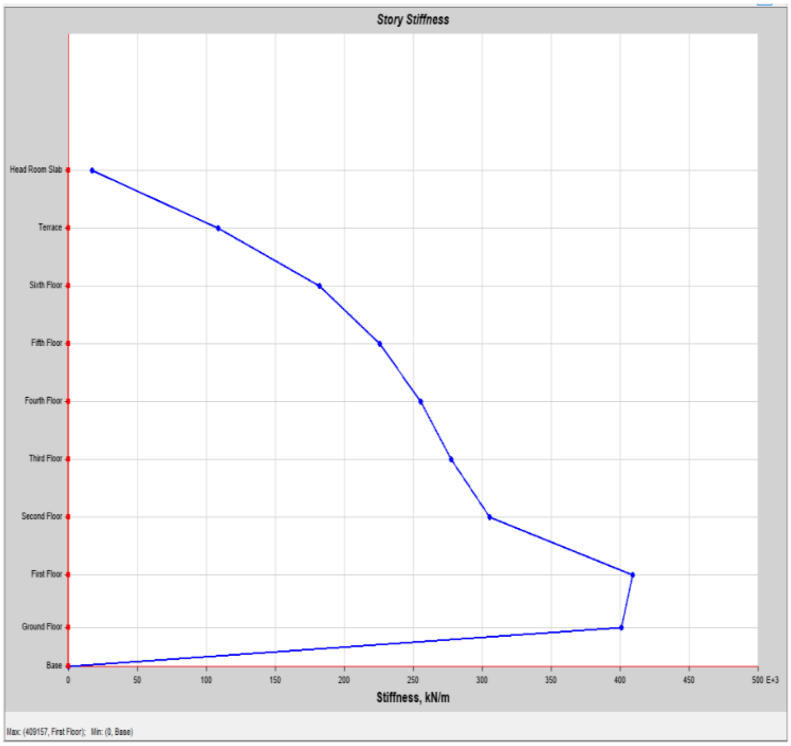


Fig 4.3.3: storey stiffness of CASE C.

4.4 CASE D: A G+6 story building with beams, columns and slabs at floor level. Attached with Diagonal-braced exoskeletons at periphery of structure.

Storey displacement: Storey displacement in 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 buildings subjected to lateral loading. Maximum is 21.865 mm at top story (Head room) under the response spectrum analysis in the global-X direction. There is a decrease in displacement because of attachment of exoskeleton.

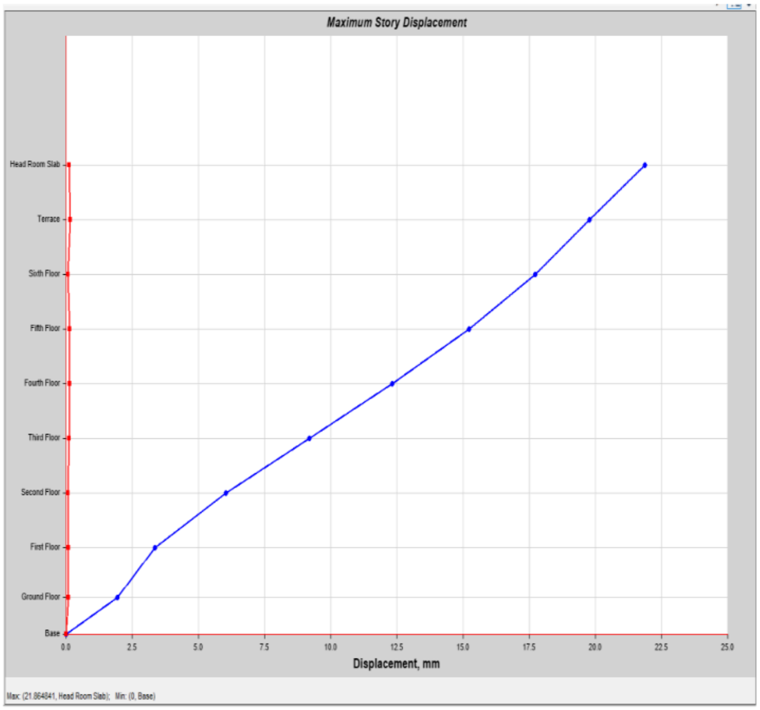


Fig 4.4.1: Maximum storey displacement of CASE D.

Storey drift: Storey drift in 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 buildings under lateral loading. Maximum storey drift is 0.000863 between the storey 1 and Terrace, exactly at storey 3. There is a decrease in story drift because of attachment of exoskeleton.

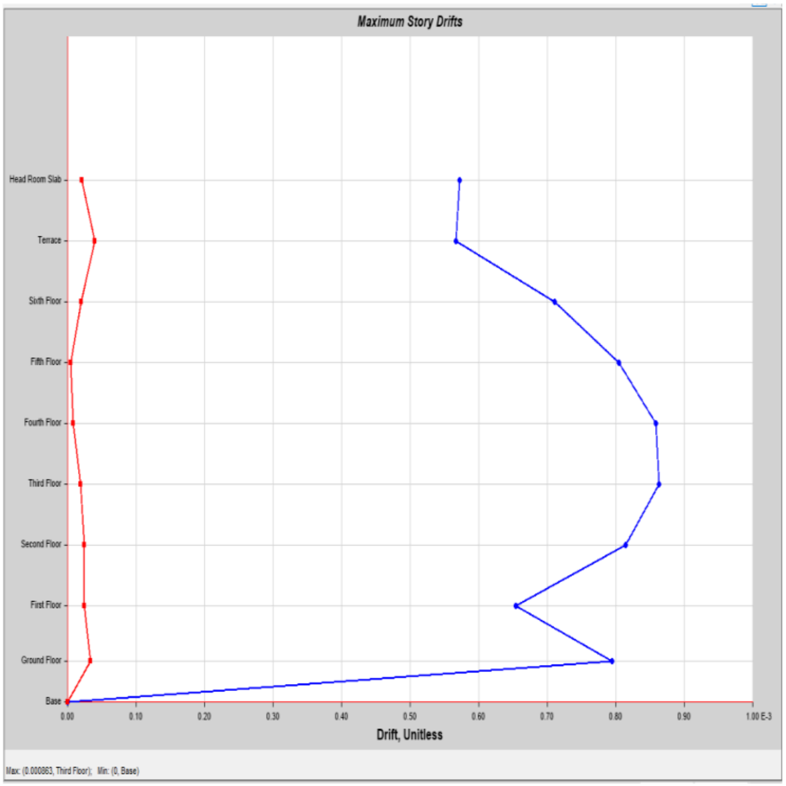


Fig 4.4.2: Maximum storey drift of CASE D.

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.

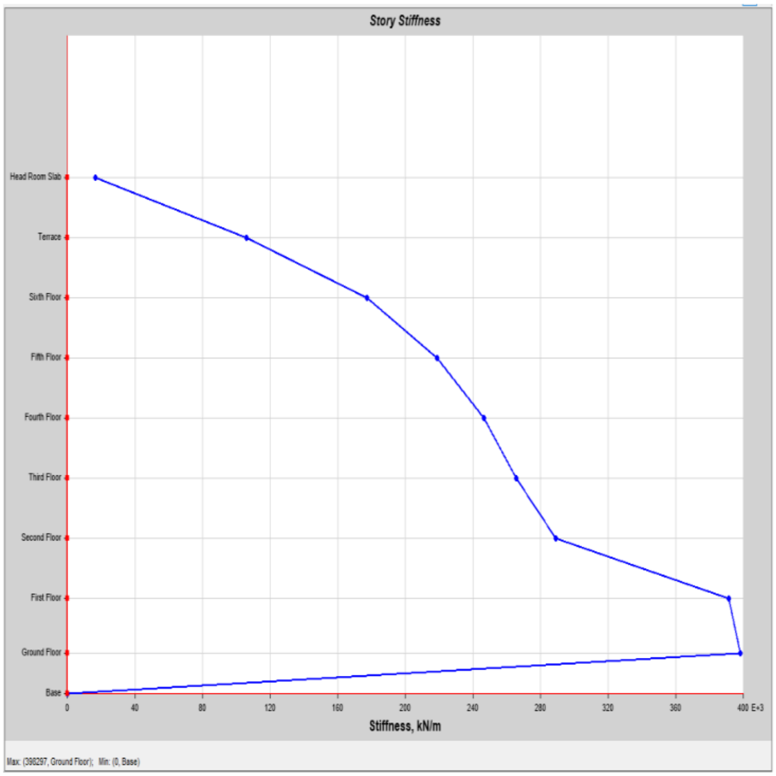


Fig 4.2.3: storey stiffness of CASE D.

4.5 CASE E: A G+6 story building with beams, columns and slabs at floor level. Attached with Diamond-braced exoskeletons at periphery of structure.

Storey displacement: Storey displacement in 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 21.713 mm at top story (Head room) under the response spectrum analysis in the global-X direction. There is a decrease in displacement because of attachment of exoskeleton.

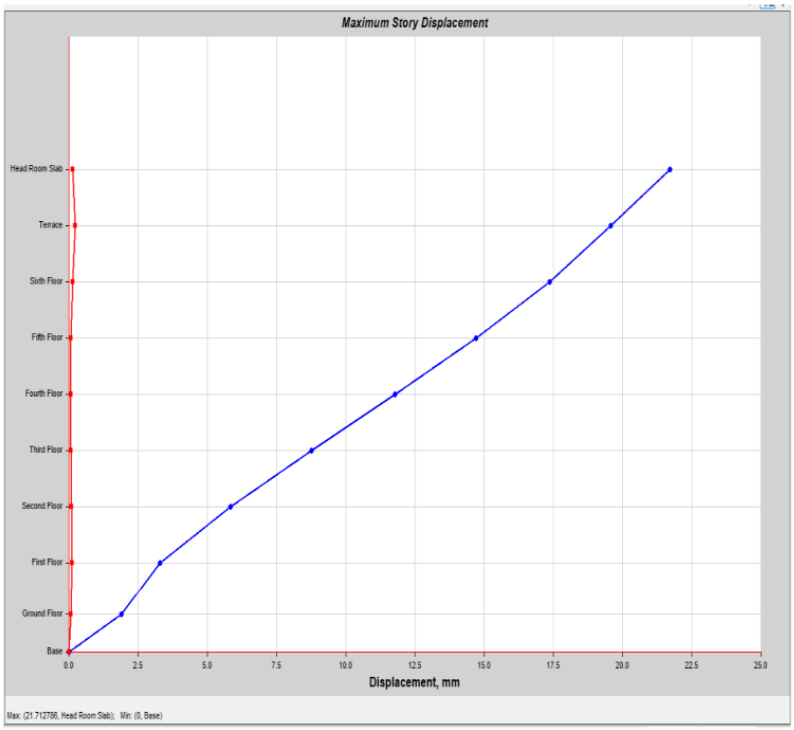


Fig 4.5.1: Maximum storey displacement of CASE E.

Storey drift: Storey drift in 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 under lateral loading. Maximum storey drift is 0.000831 between the storey 1 and Terrace, exactly at storey 4. There is a decrease in story drift because of attachment of exoskeleton.

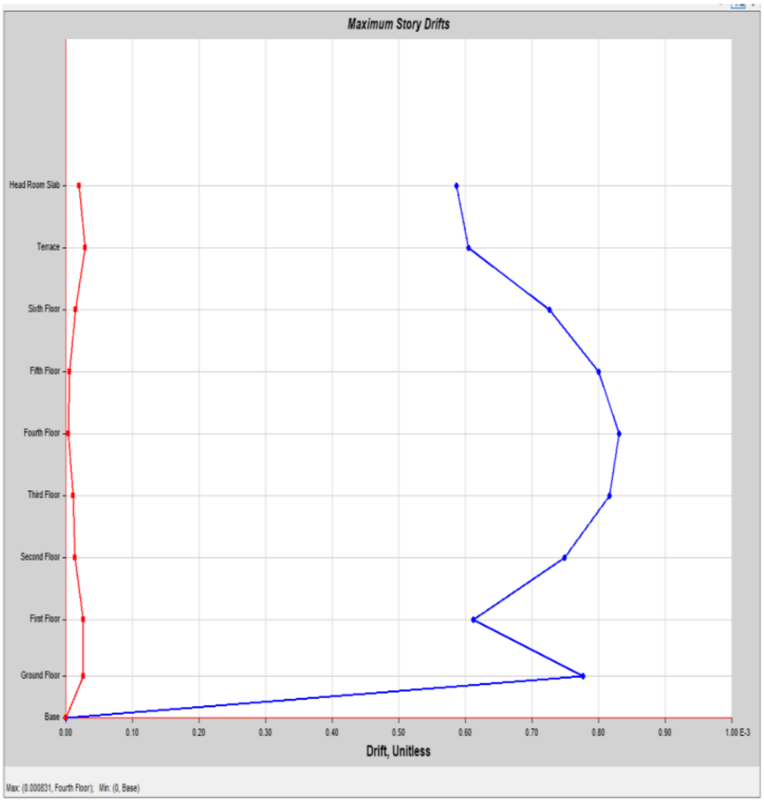


Fig 4.5.2: Maximum storey drift of CASE E.

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.

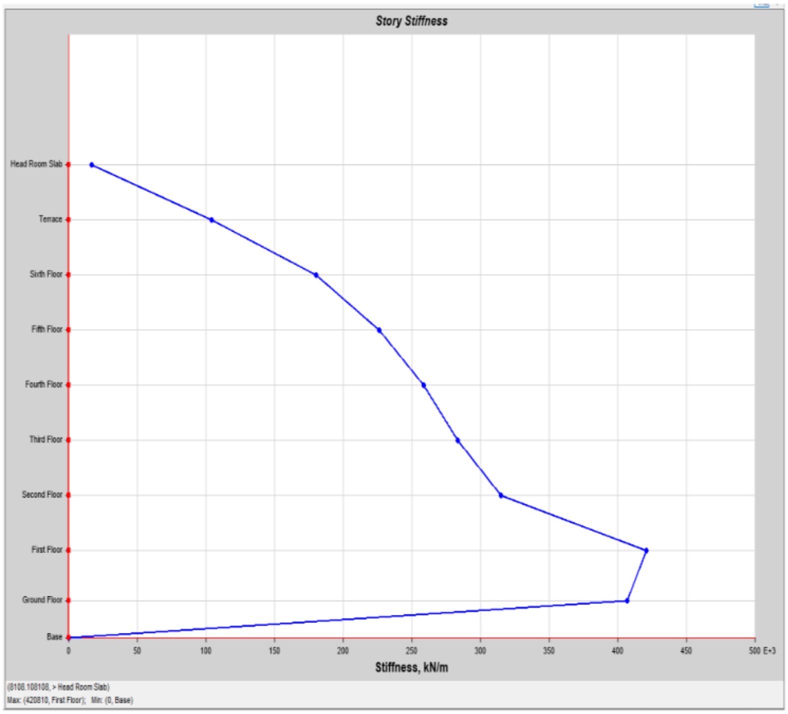


Fig 4.5.3: storey stiffness of CASE E.

CHAPTER 5

COMPARISION OF RESULTS

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

CASE A: Maximum is 28.833 mm at top story (Head room).

CASE B: Maximum is 21.657 mm at top story.

CASE C: Maximum is 21.555 mm at top story.

CASE D: Maximum is 21.865 mm at top story.

CASE E: Maximum is 21.713 mm at top story.

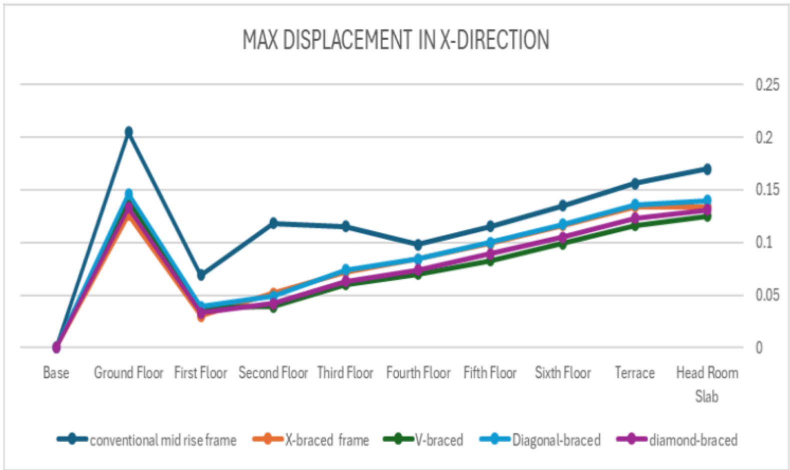


Fig 5.1: Comparative results of story displacement under R S A.

The aforementioned graph demonstrate a significant decrease in the maximum displacement values at each storey in frames of all configurations. On the other hand, the

V-braced (CASE C) frame in exoskeleton buildings exhibits the greatest reduction in displacement. Which shows that after the placement of the Exoskeleton 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 0.001101 at storey 3.
CASE B: maximum storey drift is 0.000841 at storey 4.
CASE C: maximum storey drift is 0.000834 at storey 4.
CASE D: maximum storey drift is 0.000863 at storey 3.
CASE E: maximum storey drift is 0.000831 at storey 4.

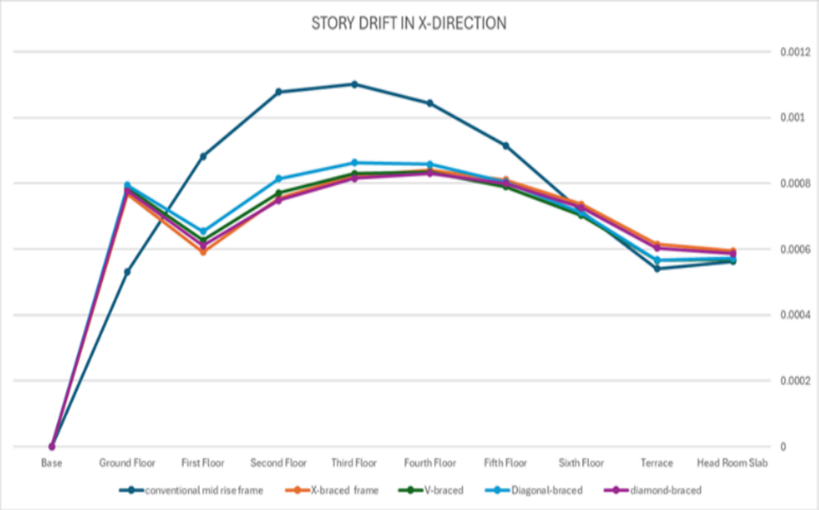


Fig 5.2: Comparative results of story drift under R S A .

From the results obtained for all five cases after the placement of the exoskeleton structural system in the building framing there is 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.

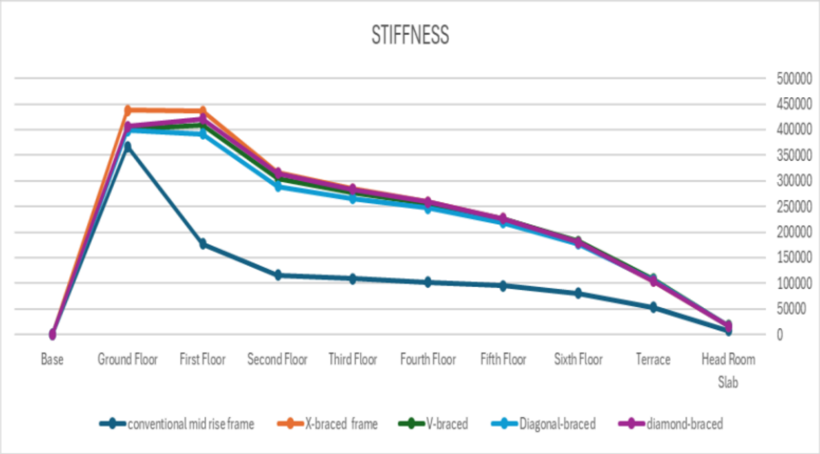


Fig 5.3: Comparative results of story stiffness under R S A.

The graph present a drastic increase in the stiffness of exoskeleton frame as compared to conventional mid-rise frame. However, in exoskeleton structures X-braced frame showing maximum story stiffness.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

Exoskeleton integration into mid-rise buildings is an effective retrofit approach, particularly when there are functional and spatial limitations. The present work examines the performance of exoskeleton structures in the lateral force regulation of conventional RC frames. The current study utilizes rigid links with hinged connections, one of the several braced configurations that connect the exoskeleton to the conventional mid-rise RC frame.

As a result, the analysis of five distinct building frames demonstrates that there are significant differences in how well a building performs under lateral loading. The response spectrum analysis also analytically demonstrates that the installation of an exoskeletal structural system without the use of a damping system automatically reduces story displacement and storey drift in the diaphragm. So, this work can be considered as a reference for the design and execution of the of any mid-rise structure which is going to be constructed in India by considering exoskeletal system which increase the performance of the storey stiffness. Additionally, exoskeletal systems can be efficiently designed using this study for a variety of performance goals at various risk levels. The exoskeletal system is therefore shown to be a safe choice for the mid-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 exoskeleton-structural system as an efficient choice of Seismic Frame Resisting System for buildings. These issues are briefly summarized here.

a) Integrated Retrofitting for Existing Buildings:

Seismic and Energy Upgrades: This is arguably the most significant area of growth. Steel exoskeletons offer a non-invasive way to dramatically improve the seismic performance of older, vulnerable reinforced concrete and masonry buildings without disrupting occupants. Future systems will increasingly integrate thermal insulation, shading devices, and even BIPV (Building-Integrated Photovoltaics) to simultaneously enhance energy efficiency, transforming outdated structures into high-performance, sustainable assets. This "seismic energy coat" concept is gaining significant traction.

b) Advanced Materials and Smart Technologies:

High-Performance and Specialty Steels: Expect wider adoption of advanced high-strength steels, stainless steels (for enhanced corrosion resistance and aesthetics), and potentially even ultra-lightweight alloys.

c) Multi-functional and Responsive Exoskeletons:

Integrated Systems: Beyond just structure and façade, exoskeletons will increasingly integrate various building systems:

d) Adaptive and Dynamic Structures: Exoskeletons could become truly adaptive, with elements that can actively adjust to changing environmental conditions (e.g., kinetic shading systems that respond to sun path, or active damping systems for wind vibrations).

The integration of exoskeletal structures into mid-rise buildings represents a significant advancement in architectural and structural engineering,

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