

# Integration of Exoskeletal Structure in Mid Rise Structure

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**Abstract** - A structural designer's top concerns while designing and maintaining structures are stiffness and drift since a decrease in stiffness and an increase in drift can result in the breakdown of the entire structure, which can have negative effects on safety and the economy. ETABS, a tool commonly used to analyse structures under various loading conditions, is utilized in this study to examine the stability of an existing structure. The main goal of the study is to compare the mid-rise structure and exoskeletal system under lateral loading. The exoskeletal system upgrade improved the structure's lateral displacement, drift, and stiffness under seismic and wind loads, according to the analysis that was obtained. In order to improve the overall stability and performance of mid-rise structures under lateral loading circumstances, the study highlights the significance of the exoskeleton, offering important insight. The maximum lateral displacement for a structure without an exoskeleton is larger than that of a structure without one, according to analysis conducted under seismic and wind loads. This shows that exoskeletons reduce lateral displacement. The goal of the study is to determine which bracing orientation in steel exoskeletal constructions results in the greatest reduction in lateral displacement under lateral loading circumstances, as well as which bracing orientations cause the most lateral displacement loss. The efficacy of exoskeletal as a retrofitting technique is highlighted in the study. They act as a fixed supporting system for the structure, reducing the displacement under study in response spectrum analysis and increasing overall stiffness.

**Key Words:** Exoskeletal, Drift, Response Spectrum, bracings, Displacement, Seismic Load.

## 1. INTRODUCTION

An important development in structural engineering and architecture is the incorporation of exoskeletal structures into mid-rise buildings, which offers an alternative to traditional building practices. The exoskeleton, a supplementary, external structural framework, is created to enclose and support the main building structure in this novel method [1]. The main load-bearing system is this

exoskeleton, which is usually made of steel or reinforced concrete, relieving the internal structure of this duty. Numerous strong benefits are made possible by this division of structure and space. Exoskeleton systems have received a great deal of attention as a means of addressing the drawbacks of alternative solutions. Their successful and non-invasive biomimicry-based technique significantly reduces the structure's seismic loads by making the building more rigid and resistant to lateral pressures. First of all, exoskeletons provide improved structural performance, which is especially important in areas that are prone to earthquakes or strong winds [2]. The building's resilience and safety can be increased by designing the external frame to more successfully withstand lateral forces. Second, and perhaps more importantly from an architectural perspective, the exoskeleton makes it possible to create interior areas that are open and free of columns. Over the course of the building's life, this layout flexibility permits easier adaptation to changing needs and gives designers more creative freedom. Open-plan offices and adaptable retail spaces are only two of the many uses made possible by large, continuous floor plates [3].

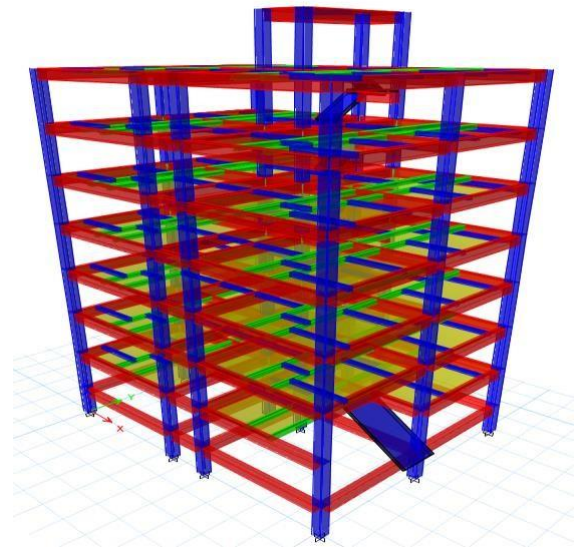
Exoskeletons provide advantages in terms of structure and space, but they also present intriguing opportunities for architectural expression. A key design element that adds to the building's aesthetic identity and establishes a unique visual presence is the external framework. Additionally, including sustainable design components is made possible by exoskeleton. It can accommodate rainwater collection systems, vertical green walls, sun shading devices, and other elements that improve environmental performance and energy efficiency. Although the idea of using exoskeletal structures in mid-rise building has its own set of prospects and challenges, it balances cost-effectiveness with the possibility of major functional and architectural advancements. The goal of creating more resilient, flexible, and sustainable built environments is what motivates this investigation into incorporating exoskeletons into mid-rise structures [4]. We must use dynamic analysis to examine the structure's dynamic behavior. For mid-rise buildings, dynamic analysis will assist in determining how each story will react to lateral loading events. To study the seismic effect, there are two different types of seismic dynamic analysis (a) Response spectrum analysis (b) Time history analysis. In this paper study done by considering Response spectrum analysis.

## 2. CONVENTIONAL MID-RISE FRAME

A G+6 residential RC building has been selected as the case study. The building's floor plan is rectangular, with Y and X measurements of 13.717 and 17.678 meters, respectively (see Fig -2). The building's overall height (H) is 31.394 meters, based on the floor-to-floor height calculations shown in Table 1. The floors are 16.85 cm thick with a 15 cm RC slab. Cross sections of the columns were obtained: Col. 50 × 50 cm<sup>2</sup>. The columns' longitudinal steel dimensions, taking reinforcement into account, were 4 Φ20 and 4 Φ16. The beam's cross-sections were 30 × 80 cm<sup>2</sup>, 40 × 70cm<sup>2</sup>, 23 × 25cm<sup>2</sup> and 23 × 30cm<sup>2</sup> are respectively for PB1, PB2, SB1 and SB2 where PB means Primary Beam and SB means Secondary Beam as shown in (see Fig -4).

**Table -1:** Floor to floor height of G+6 building

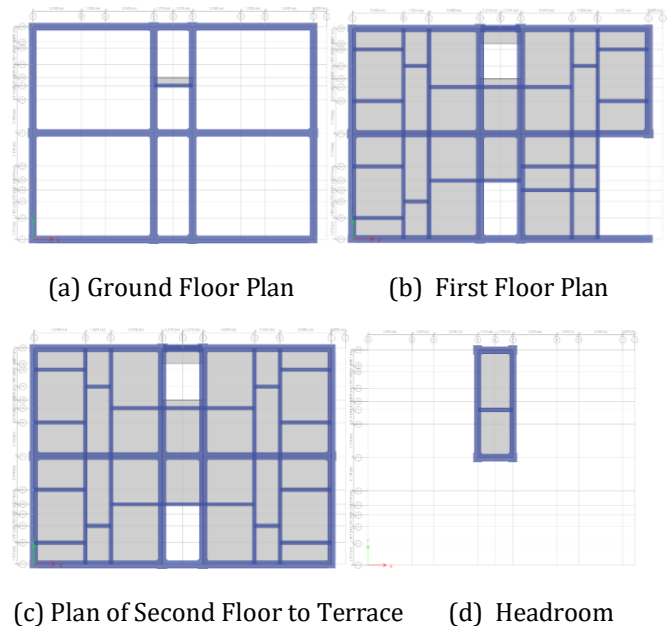
| STORY          | HEIGHT (m) | ELEVATION (m) | MASTER STORY |
|----------------|------------|---------------|--------------|
| Head Room Slab | 3.6576     | 31.394        | No           |
| Terrace        | 3.6576     | 27.7364       | No           |
| Sixth Floor    | 3.6576     | 24.0788       | No           |
| 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             |              |



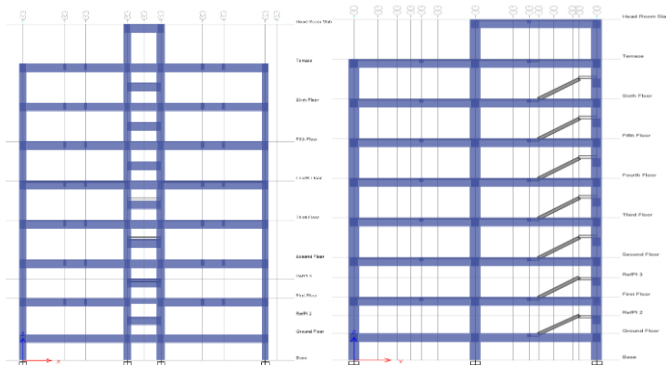
**Fig -1:** Isometric View

Total height of the structure is 31.394m which comes under mid-rise building as per basic design concept.

## 3. GEOMETRICAL FEATURES OF RC STRUCTURES

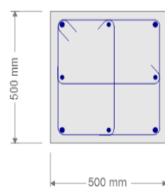


**Fig -2:** Configuration of structure frame Plan

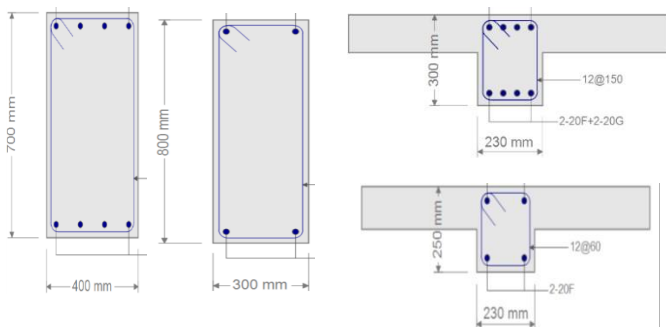


(a) Elevation in X Direction (b) Elevation in Y Direction

Fig -3: Configuration of structure frame elevation



(a) Column section



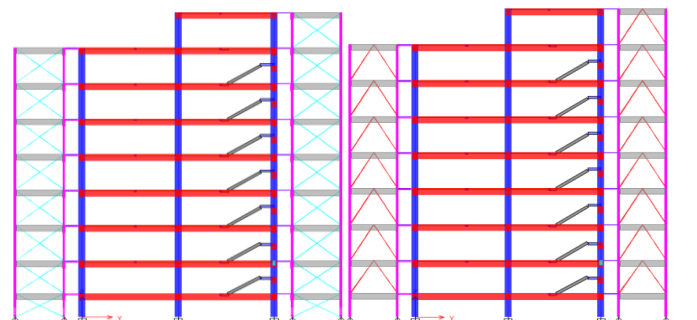
(b) Beam sections

Fig -4: Structural element cross-sections

#### 4. MODELLING

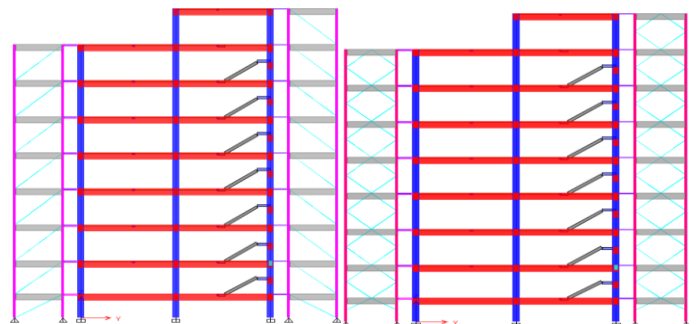
The traditional mid-rise frame considered in the study is a rectangular design ( $L/B = 1.289$ ) with dimensions of 17.678 m  $\times$  13.717 m and three bays along the X and two bays along the Y directions. The structure in question is 31.394 meters tall, contains G+6 levels, and features a headroom slab. Beyond the building's perimeter, an exoskeleton structure is accessible at a distance of 1.30 meters. The exoskeleton structure is connected to the building's multiple floor levels by links. The links were made of 120 mm-diameter steel rods.

Fig -2 (a, b, c, d) shows that the plans of the different floors of the structure differ, as shown by the study's assessment of the elevation and plan of the ordinary rectangular building (Fig -2, 3). The analysis begins with conventional mid-rise frames (Fig. 1) and moves on to X-braced (Fig -5a), V-braced (Fig -5b), diagonal-braced (Fig -5c), and diamond-braced (Fig -5d) structures. Fig -5 shows the elevation of every mid-rise frame along the positions of the exoskeletons, perpendicular to the building's frame at every outer column spot.



(a) X-braced

(b) V-braced



(c) Diagonal-braced

(d) Diamond-braced

Fig -5: Conventional frame with exoskeletal integration

Exoskeleton structures are made of steel of the Fe250 grade. A 120mm-diameter steel rod serves as the linkage, the diagonal beams of the exoskeleton structures are hollow circular beams (ISNB50M), and the columns are created from built-up box sections of two channel section ISMC200 with battening at 0.30 m intervals (Fig -6).

Releasing moments are employed to model the connections as axially stiff links. It is assumed that the Young's modulus (E) of the link is high. A high value of E is employed to make the connection as rigid as feasible and to maximize its axial stiffness. The exoskeleton structures were situated 130 cm from the center line of the building's exterior perimeter.

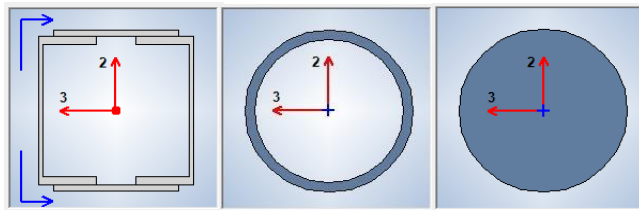


Fig -6: Exoskeletal frame Section

### 5. LATERAL FORCE ASSESSMENT

Static analyses were conducted using ETABS software to evaluate the current RC structure's performance in terms of lateral force resistance. This Response Spectrum approach was used to perform linear dynamic analysis in ETABS for frames of all five configurations: – rectangular mid-rise RC frame, X-braced, V-braced, Diagonal-braced and diamond-braced [5-6]. Throughout the following sections, the frame without an exoskeleton is referred to as a conventional mid-rise frame. A total of five models were examined, including four frames with exoskeleton structures and one standard frame. The response spectrum for Zone III as stated in IS:1893-2016 [7] was taken into account during the analysis. A response reduction factor (R) of 3.0 and an importance factor (I) of 1.0 have been considered. The process of response spectrum analysis entails calculating the responses in each vibrational mode and combining them using appropriate modal combination criteria.

#### 5.1 Floor Displacement

As frame considered in this paper was rectangular in plan, so we need maximum displacement along X & Y direction due to lateral force in respective direction. The max displacement along respective direction shown in Table 2.

Table -2: Maximum floor displacements in X-direction and Y-direction

| Story         | Elevation (m) | Conventional mid rise frame |                    | X-braced frame     |                    | V-braced           |                    | Diagonal-braced    |                    | Diamond-braced     |                    |
|---------------|---------------|-----------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
|               |               | X - direction (mm)          | Y - direction (mm) | X - direction (mm) | Y - direction (mm) | X - direction (mm) | Y - direction (mm) | X - direction (mm) | Y - direction (mm) | X - direction (mm) | Y - direction (mm) |
| Headroom Slab | 31.394        | 0.17                        | 21.725             | 0.134              | 19.237             | 0.125              | 19.058             | 0.14               | 19.378             | 0.131              | 19.296             |
| Terrace       | 27.7364       | 0.156                       | 20.75              | 0.134              | 17.579             | 0.116              | 17.618             | 0.136              | 17.964             | 0.123              | 17.671             |
| Sixth Floor   | 24.0788       | 0.135                       | 19.423             | 0.116              | 15.773             | 0.099              | 16.029             | 0.117              | 16.38              | 0.105              | 15.911             |
| Fifth Floor   | 20.4212       | 0.115                       | 17.302             | 0.099              | 13.488             | 0.083              | 13.898             | 0.1                | 14.222             | 0.089              | 13.674             |
| Fourth Floor  | 16.7636       | 0.098                       | 14.524             | 0.084              | 10.889             | 0.07               | 11.395             | 0.084              | 11.665             | 0.074              | 11.127             |
| Third Floor   | 13.106        | 0.115                       | 11.312             | 0.072              | 8.142              | 0.06               | 8.698              | 0.074              | 8.882              | 0.063              | 8.43               |
| Second Floor  | 9.4484        | 0.118                       | 7.846              | 0.052              | 5.417              | 0.039              | 5.979              | 0.049              | 6.04               | 0.042              | 5.751              |
| First Floor   | 5.7908        | 0.069                       | 4.256              | 0.03               | 2.863              | 0.038              | 3.41               | 0.039              | 3.28               | 0.033              | 3.256              |
| Ground Floor  | 2.438         | 0.205                       | 1.597              | 0.126              | 1.074              | 0.14               | 1.528              | 0.146              | 1.251              | 0.133              | 1.437              |
| Base          | 0             | 0                           | 0                  | 0                  | 0                  | 0                  | 0                  | 0                  | 0                  | 0                  | 0                  |

Finally, complete content and organizational editing before formatting. Please take note of the following items when proofreading spelling and grammar:

#### 5.2 Floor Stiffness

The maximum story stiffness induced in frames in X direction and Y directions respectively due to lateral force in their respective direction of different configurations provided in Table 3. The table presents a drastic increase in the stiffness of exoskeleton frame as compared to conventional mid-rise frame. However, exoskeleton structures X-braced frame shows maximum story stiffness.

Table -3: Maximum story stiffness in X-direction and Y-direction

| Story         | Elevation (m) | Conventional mid rise frame |                      | X-braced frame       |                      | V-braced             |                      | Diagonal-braced      |                      | Diamond-braced       |                      |
|---------------|---------------|-----------------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
|               |               | X - direction (kN/m)        | Y - direction (kN/m) | X - direction (kN/m) | Y - direction (kN/m) | X - direction (kN/m) | Y - direction (kN/m) | X - direction (kN/m) | Y - direction (kN/m) | X - direction (kN/m) | Y - direction (kN/m) |
| Headroom Slab | 31.394        | 7820.144                    | 14424.083            | 16712.41             | 12465.97             | 17102.64             | 13895.75             | 16698.64             | 13738.75             | 16714.53             | 12389.21             |
| Terrace       | 27.7364       | 52658.3                     | 73273.349            | 104449.5             | 133354.2             | 108333.5             | 140410.86            | 105978.3             | 137576.8             | 104221.3             | 133606.7             |
| Sixth Floor   | 24.0788       | 80722.45                    | 102327.75            | 180218.7             | 220833               | 181980.7             | 222767.1             | 177198.8             | 216200.4             | 180125.3             | 220627.4             |
| Fifth Floor   | 20.4212       | 95288.89                    | 112114.12            | 226608.5             | 269514.7             | 225562               | 266724.94            | 218654.9             | 257182.6             | 226297.1             | 268987.9             |
| Fourth Floor  | 16.7636       | 101707.7                    | 117692.47            | 258715.5             | 305287               | 255511.5             | 298269.06            | 246543.3             | 285655.7             | 258354.2             | 304271.5             |
| Third Floor   | 13.106        | 109186.5                    | 120301.78            | 283949.2             | 331884.8             | 277281.2             | 322431.38            | 265493.3             | 306466.8             | 283284.3             | 330410.6             |
| Second Floor  | 9.4484        | 116143                      | 123876.64            | 315838.5             | 355887.8             | 305304               | 338834.63            | 289006.2             | 319312.9             | 314712.5             | 352202.1             |
| First Floor   | 5.7908        | 177043.2                    | 155358.51            | 435559.8             | 466240.7             | 409156.8             | 420847.82            | 391189.2             | 400874.7             | 420809.8             | 440189.4             |
| Ground Floor  | 2.438         | 367204.3                    | 346271.94            | 438122               | 714423.6             | 400841.6             | 495926.31            | 398296.8             | 582056.3             | 406641.5             | 521092.2             |
| Base          | 0             | 0                           | 0                    | 0                    | 0                    | 0                    | 0                    | 0                    | 0                    | 0                    | 0                    |

#### 5.3 Maximum Story Drift

Story drift in mid-rise buildings under lateral loading refers to the relative displacement between adjacent stories due to horizontal forces such as wind or seismic activity. As these forces act upon the structure, each story undergoes horizontal movement, resulting in differential displacements along the building height [8]. The phenomenon of story 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. There is a decrease in story drift because of integration of exoskeletal as observed from Table 4.

Table -4: Maximum story drift in X-direction and Y-direction

| Story          | Elevation (m) | Conventional mid-rise frame |                    | X-braced frame     |                    | V-braced           |                    | Diagonal-braced    |                    | Diamond-braced     |                    |
|----------------|---------------|-----------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
|                |               | X - direction (mm)          | Y - direction (mm) | X - direction (mm) | Y - direction (mm) | X - direction (mm) | Y - direction (mm) | X - direction (mm) | Y - direction (mm) | X - direction (mm) | Y - direction (mm) |
| Head Room Slab | 31.394        | 0.000563                    | 2.40E-05           | 0.000595           | 2.00E-05           | 0.000568           | 2.00E-05           | 0.000572           | 2.00E-05           | 0.000587           | 2.00E-05           |
| Terrace        | 27.7364       | 0.000541                    | 5.80E-05           | 0.000615           | 2.80E-05           | 0.000566           | 3.60E-05           | 0.000567           | 3.90E-05           | 0.000604           | 2.90E-05           |
| 6th Floor      | 24.0788       | 0.000715                    | 8.00E-06           | 0.000737           | 1.40E-05           | 0.000703           | 1.80E-05           | 0.000711           | 1.90E-05           | 0.000726           | 1.40E-05           |
| 5th Floor      | 20.4212       | 0.000915                    | 5.80E-05           | 0.000811           | 5.00E-06           | 0.00079            | 5.00E-06           | 0.000804           | 4.00E-06           | 0.0008             | 6.00E-06           |
| 4th Floor      | 16.7636       | 0.001044                    | 9.60E-05           | 0.000841           | 4.00E-06           | 0.000834           | 6.00E-06           | 0.000858           | 8.00E-06           | 0.000831           | 4.00E-06           |
| 3rd Floor      | 13.106        | 0.001101                    | 0.000126           | 0.000825           | 1.10E-05           | 0.00083            | 1.50E-05           | 0.000863           | 1.90E-05           | 0.000816           | 1.10E-05           |
| 2nd Floor      | 9.4484        | 0.001078                    | 0.000138           | 0.000756           | 1.40E-05           | 0.000771           | 1.80E-05           | 0.000815           | 2.40E-05           | 0.000749           | 1.30E-05           |
| 1st Floor      | 5.7908        | 0.000883                    | 6.90E-05           | 0.000592           | 2.30E-05           | 0.000627           | 2.70E-05           | 0.000654           | 2.50E-05           | 0.000611           | 2.60E-05           |
| Ground Floor   | 2.438         | 0.000532                    | 2.70E-05           | 0.000768           | 3.10E-05           | 0.000785           | 2.60E-05           | 0.000794           | 3.40E-05           | 0.000777           | 2.60E-05           |
| Base           | 0             | 0                           | 0                  | 0                  | 0                  | 0                  | 0                  | 0                  | 0                  | 0                  | 0                  |

## 2. RESULTS AND 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.

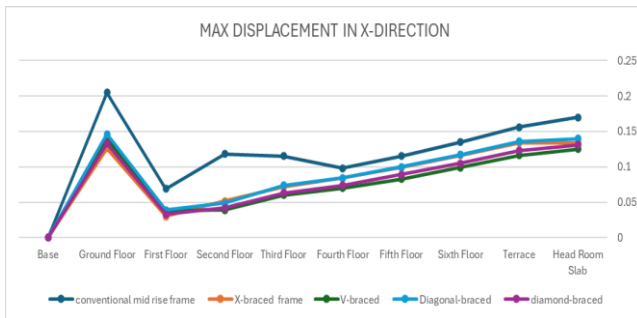


Fig -7: Maximum displacement in X-direction

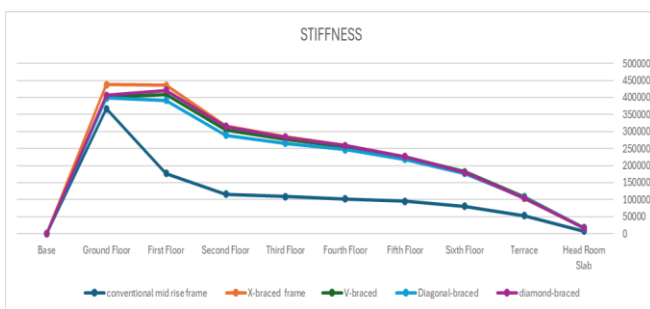


Fig -8: Stiffness of structure for different bracings

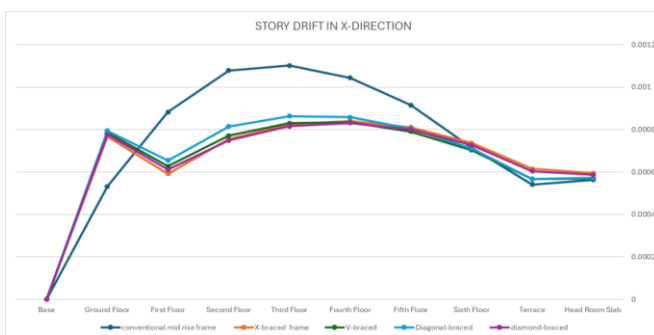


Fig -9: Story drift in X-direction

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 (Fig -7) and story drift (Fig -9) in the diaphragm. So, this work can be considered as a reference

for the design and execution of the any mid-rise structure which is going to be constructed in India by considering exoskeletal system which increase the performance of the story stiffness (Fig -8). 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.

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