

**Original Research****SEISMIC ANALYSIS OF MULTISTORIED OPEN GROUND STORY BUILDING WITH DIAGONAL STRUT AND SHEAR WALLS**Mohankumar N. Bajad<sup>1\*</sup>, Rakhi D. Patil<sup>2</sup><sup>1,2</sup>Department of Civil Engineering, Sinhgad College of Engineering, Savitribai Phule Pune University, Pune, Maharashtra, India<sup>1</sup><https://orcid.org/0000-0003-1056-0178><sup>2</sup><https://orcid.org/0009-0007-5078-2345>**Received 30/08/2023****Revised 18/01/2024****Accepted 10/02/2024**

**Abstract:** The Open Ground Story (OGS) building is a functional need of all urban areas so cannot be eliminated. According to studies from previous earthquakes, when there is severe earthquake shaking, Reinforced Concrete (RC) frame buildings with open ground levels function badly. In this work, four models of G+14 RC frame buildings with and without a shear wall, coupled shear wall, and diagonal strut were modeled and analyzed using ETABS-2018 software's static and dynamic response spectrum method. Model 1 open ground story RC building without strut and the shear wall was compared to the other three models that included a shear wall, coupled shear wall, and diagonal strut. As a result of the findings, it has been determined that shear wall, coupled shear wall, and diagonal strut not only increased the stiffness but also reduced displacement. A model with a combination of shear wall and coupled shear wall showed a minimum base shear and overturning moment than all other models.

**Keywords:** Base shear; diagonal strut; seismic load; displacement; drift

**1. Introduction**

For the study, a 14-story reinforced concrete building with a zone IV shear wall was investigated. A dual system comprising a special moment-resistant frame and reinforced concrete shear walls has been used to resist lateral stresses. With the world's population

growing, there is a significant demand for housing and parking. Buildings with OGS are commonly developed in urban locations in a fast-growing country like India, where parking space on the ground floor is in high demand [1-3]. Earthquake calamities will never be eradicated by OGS building engineering technologies [4,5].

In general, the relatively stiff parts of a shear wall will resist all earthquake forces. Ductile coupling beams must connect coupled shear walls with limited ductility [1, 6]. Because they are subjected to substantial inelastic deformations at their ends, coupling beams must have a high ductility. The stiffening effect of the infill panel on the frame is frequently taken into account since it can significantly modify the behavior of the building in the elastic range [5, 7-9].

The shift from elastic to inelastic behavior of a building owing to infill can be somewhat difficult [10]. The impact can be reasonably duplicated by a diagonal strut of the same

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thickness as panel one, although the effective breadth varies depending on several parameters. [11-13]. Empirical formulae for strut stiffness are available based on tests conducted by various scientists [14].

### **1.1 Aim and Objectives**

The goal of this study was to analyze the G+14 RC-OGS residential building for displacement, drift, story shear, stiffness, and overturning moment using the shear wall, coupled shear wall, and diagonal strut.

The aim of this research was achieved through the following objectives:

- a) To analyze the G+14 OGS-RC residential building
- b) To find out the seismic performance of G+14 OGS-RC residential buildings with shear walls along longer spans.
- c) To determine the influence of shear walls along longer spans and coupled shear walls along shorter spans on G+14 OGS-RC residential buildings.
- d) To examine the effect of RC diagonal strut with an external wall on G+14 OGS-RC residential building.
- e) To compare the results of story shear, overturning moment, stiffness, drift, and displacement of all four buildings.

### **1.2 Literature Gap**

Despite several studies being conducted in this area, the concerns listed below have not been addressed or resolved in earlier studies published as books, journal papers, or reports.

For instance, there is still a dearth of studies on coupled shear walls in zone V along both directions.

In-depth research is therefore required to address these issues in future studies.

### **1.3 Major Contributions**

Support for hypotheses, information on individual efforts, methodologies that have been recognized, novel approaches, as well as advancements in the field of seismic building analysis are all described in the literature review section.

The focus of the current research is the seismic analysis of a multi-story RC open ground story building with RC diagonal struts and shear walls.

It was discovered that the work or technique described in this paper had never been done or applied before when compared to the existing level of scientific development in a field or the work that was done by others.

The investigation into the placement of diagonal struts and shear walls is therefore concluded to be similar to earlier work reported in the literature, but the combination of shear walls and coupled shear walls along opposing directions on a high-rise OGS building is entirely different from earlier work.

## **2. Literature Survey**

### **2.1 Noteworthy benefits**

Interstory distortions of RC-OGS buildings increase due to earthquake-induced motions because of inadequate strength and lateral stiffness which results in failure of structure [4,15].

Therefore, OGS buildings with shear walls and diagonal struts need to be investigated.

### **2.2 Highly Significant Issues**

The coupling effect provides large lateral stiffness, which helps to limit the displacement and drift of OGS buildings [16]. Coupling beams provide the best energy dissipation mechanism, distributing energy throughout the height of the structure and away from the base

without compromising wall stability, allowing OGS buildings to withstand small-moderate earthquake tremors [3,17]. Diagonal struts and shear walls both show less displacement of the structure while coupled shear walls provide an architecturally practical structural system hence better solutions for seismic assessment of OGS buildings will come up [18]. Shear walls and diagonal struts provide a lot of strength and stiffness in the direction of their orientation, which helps to reduce lateral sway and hence structural component damage [9,19]. The overturning effects on shear walls are significant because they can carry substantial horizontal forces [20]. Therefore, analysis of OGS buildings using diagonal struts, shear walls, and coupled shear walls is very important.

### **2.3 Limitations**

The use of diagonal struts for the whole building can create obstructions for openings [21-22]. Coupled shear walls can become congested for car parking if not provided at appropriate locations [23]. Analysis using shear walls and coupled shear walls may become uneconomical

due to heavy reinforcement [7, 24]. Therefore, further studies can be carried out in the future to overcome all the above limitations.

## **3. Methodology and Investigations with Proposed Approach**

### **3.1 Description of Building**

The building considered for this analysis as per clauses mentioned in Indian Standard codes [25-30] by using ETABS-2018 software is assumed to be a residential building situated in zone IV consisting of RC diagonal struts, shear wall, and coupled shear wall. Standard concrete (M 30) having a characteristic compressive strength of 150 mm Cube at 28 Days is  $30 \text{ N/mm}^2$  and steel (Fe 500) having an ultimate tensile strength of  $500 \text{ N/mm}^2$  is used. The structural plan of the building with column size  $300 \times 750 \text{ mm}$  and beam size  $2630 \times 600 \text{ mm}$  is as shown in Fig. 1 all dimensions of the plan are in mm. The X-direction and Y-direction have 10.54m and 19.08m Centre-Centre distance respectively.

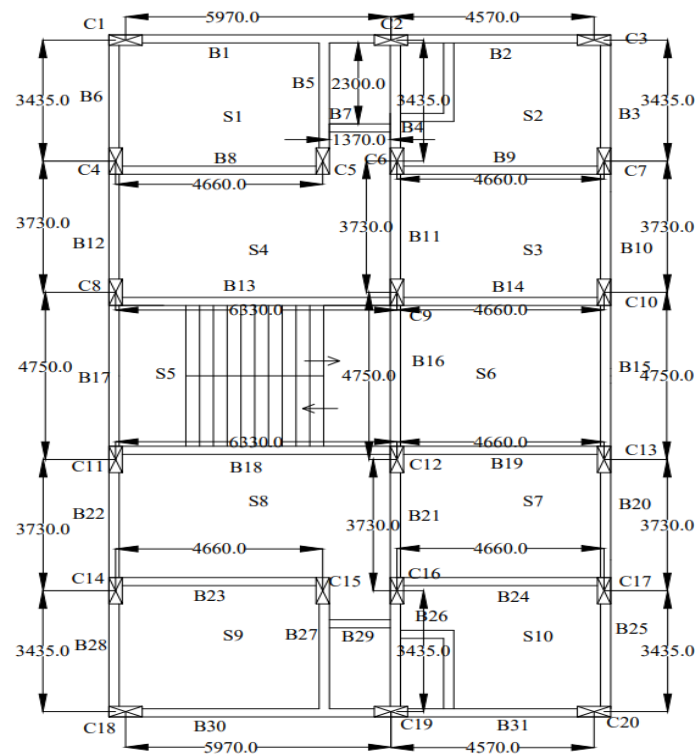


Figure 1. Plan of G+14 Building [Source: Authors]

### 3.2 Analysis

The purpose of this study is to look at how structures' orthogonal effects affect the properties of ground motion and structural response. A well-built structure should be able to withstand seismic motions in all directions equally.

Both the Equivalent Static Method (ESM) and the Response Spectrum Method (RSM) make an effort to calculate the force caused by an earthquake on a structure in terms of a collection of static forces that are applied at particular locations. It is assumed that the forces predicted in the members and at the supports using one of these approaches closely (but largely conservatively) match the set of forces that the structure will experience in the case of an earthquake based on the design (DBE). Keep in mind that a force distribution predicted by either of these approaches is a collection of

equal static forces, whereas an earthquake is a dynamic force.

The two approaches differ in that ESM is based on the structure's fundamental natural period of vibration whereas RSM is based on the first few natural periods. The accuracy of the seismic load estimation is predicted to increase with the number of natural periods taken into account. The most accurate results are anticipated when taking into account all modalities.

Four different RCC models were modeled for static and dynamic response spectrum analysis. Table 1 shows a description of each model. Some of the salient features of the frame are shown in Table 2 Tables 3, 4, 5, and 6 show a description of each model. As the building assumed a rigid structure hence to distribute load on each node semi-diaphragms are provided during analysis. 3D ETABS Models are shown in Fig. 2, 3,4, and 5.

3.2.1. Eccentricity in asymmetric structures

Seismic codes include various torsional requirements based on the seismicity of the area to construct buildings in earthquake-prone areas. Design eccentricity is introduced by seismic provisions to provide the most accurate assessment of the torsion value in buildings.

The unintentional eccentricity in any direction for structures alone, in the absence of more precise measurements, cannot be regarded as being less than 0.05 times the average building size measured perpendicular to the direction of application of the seismic action.

The accidental eccentricity is considered in the following way: the response spectrum approach is used to conduct a dynamic analysis of the structure without accidental eccentricity.

By introducing static torsional forces to the structure about the vertical axis of each level, the effects of accidental eccentricity are compounded.

**Table 1.** Introduction to models

Model No.	Description
Model 1	G+14 OGS residential building
Model 2	G+14 OGS residential building with shear walls along longer spans
Model 3	G+14 OGS residential building with shear walls along longer spans and coupled shear walls along shorter span
Model 4	G+14 OGS residential building with diagonal strut on external walls

Source: Authors

**Table 2.** Preliminary Data

Type of structure	Multi Story rigid jointed plane frame
Number of storeys	G+14
Zone considered	IV
Seismic Zone factor	0.24
Importance factor	1
Response reduction factor	5
Type of soil	Hard
Floor-to-floor height	Ground floor-3m Intermediate floor- 3m
Height of building	48m
Size of column	300 mm x 750 mm
Size of beam	300 mm x 600 mm
Depth of slab	150 mm
Thickness of wall	External =200 mm Internal =100mm
Material	M30 & Fe500
Live load	1.On roof =0.75kN/m <sup>2</sup> 2.On floor = 3kN/m <sup>2</sup>
Dead load	1. On floor= 1.5kN/m <sup>2</sup>

Source: Authors

**Table 3.** Model 1 Description

Model 1	G+14 OGS Regular Building
Number of storeys	G+14
Floor-to-floor height	Ground floor-3m Intermediate floor- 3m

**Table 4** Model 2 Description

Model 2	G+14 OGS building with shear wall
Number of storeys	G+14
Floor-to-floor height	Ground floor-3m Intermediate floor- 3m
Thickness of the shear wall	200 mm
Number of external shear walls	2
Number of internal shear walls	2
Shear wall material	M30 & Fe415
Lift weight	10kN

Source: Authors

**Table 5** Model 3 Description

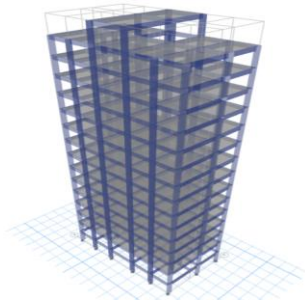
Model 3	G+14 OGS building with shear wall
Thickness of the shear wall and coupled shear wall	200 mm
Coupling beam size	200 mm x 600 mm
Number of external shear walls	6
Number of internal shear walls	2
Shear wall material	M30 & Fe415

Source: Authors

**Table 6** Model 4 Description

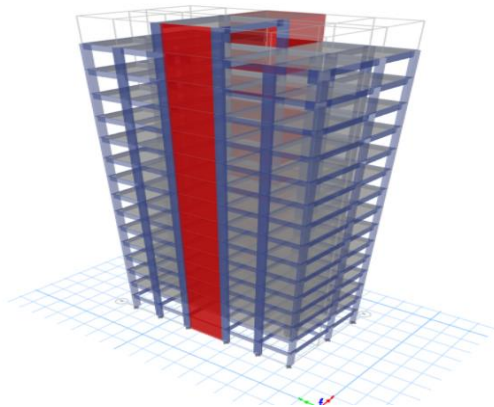
Model 3	G+14 OGS building with a diagonal strut
Number of storys	G+14
Thickness of wall	200 mm
Diagonal strut material	M25& Fe500

Source: Authors



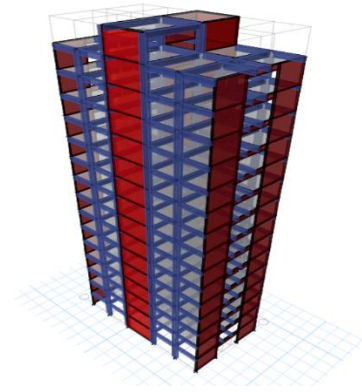
**Figure 2.** 3D ETABS Model 1 of G+14 building without strut and shear wall

Source: Authors



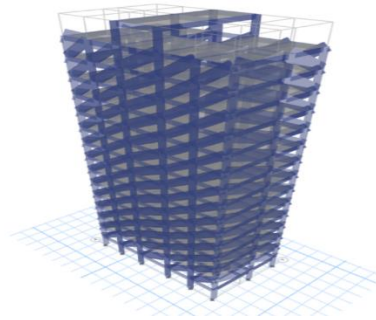
**Figure 3.** 3D ETABS Model 2 of G+14 building with shear wall

Source: Authors



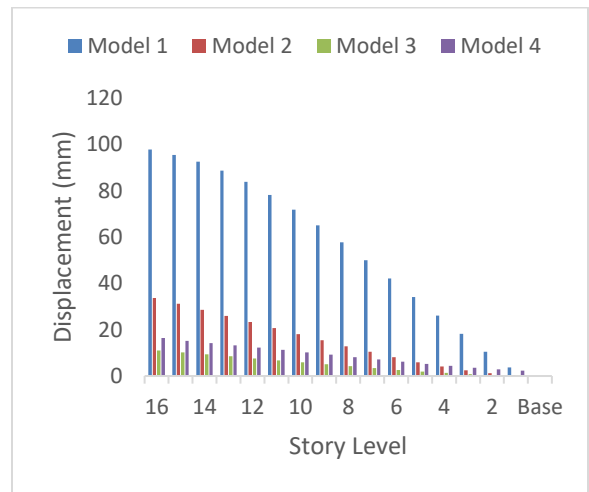
**Figure 4.** 3D ETABS Model 3 of G+14 building with shear wall and coupled shear wall

Source: Authors



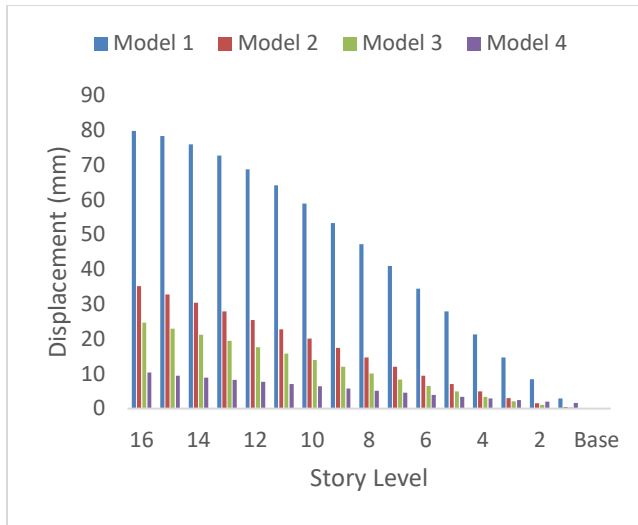
**Figure 5.** 3D ETABS Model 4 of G+14 building with equivalent diagonal strut

Source: Authors



**Figure 6.** Variation of story displacement with story level for different models along EQ<sub>x</sub>-direction

Source: Authors



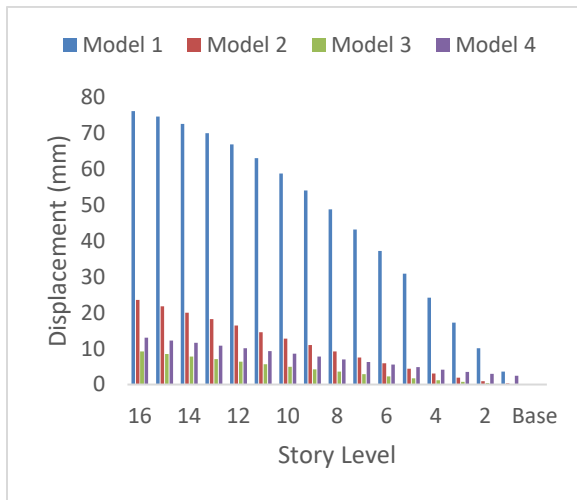
**Figure 7.** Variation of story displacement with story level for different models along EQ<sub>y</sub>-direction  
Source: Author

**4. Results**

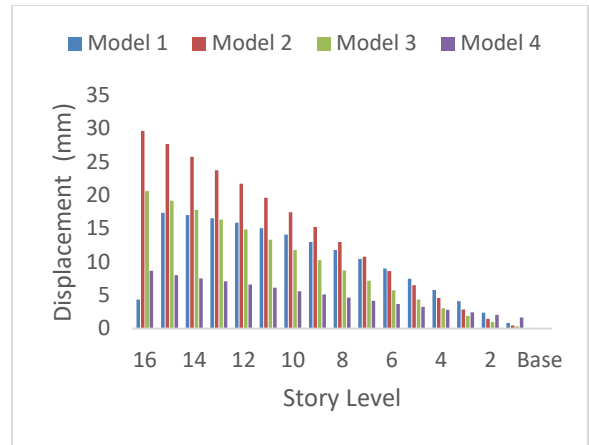
Results are presented graphically under different categories as follows.

**4.1 Story Displacement**

Displacement for all models along the EQ<sub>x</sub> direction is shown in Fig. 6 and displacement along the EQ<sub>y</sub> direction is shown in Fig. 7



**Figure 8.** Variation of story displacement with story level for different models along RS<sub>x</sub>-direction  
Source: Author



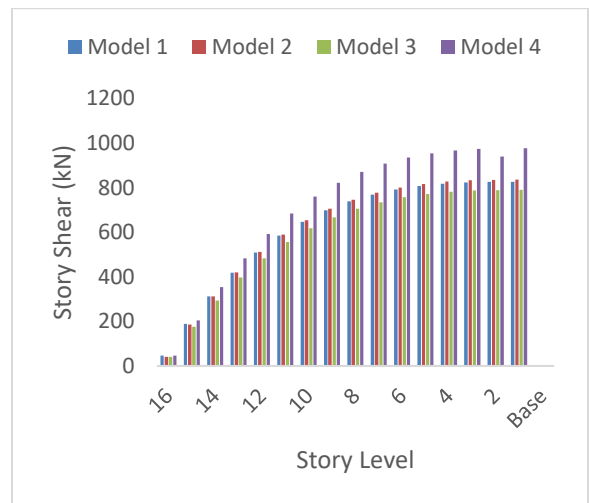
**Figure 9.** Variation of story displacement with story level for different models along RS<sub>y</sub>-direction  
Source: Authors

For displacement of all models along the RS<sub>x</sub> direction is shown in Fig. 8 and along the RS<sub>y</sub> direction is shown in Fig. 9

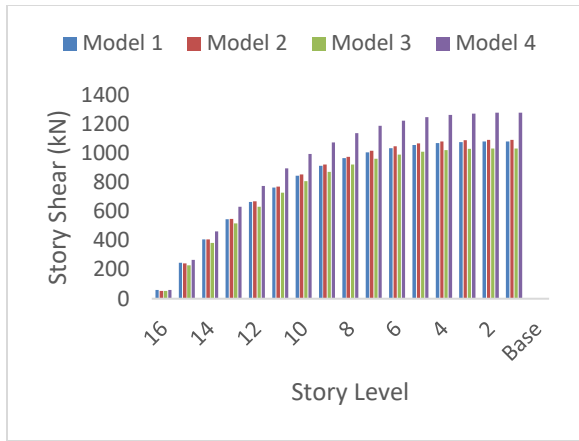
**4.2 Story Shear**

Story shear for all models along EQ<sub>x</sub> direction is shown in Fig. 10 and along EQ<sub>y</sub> direction is shown in Fig. 11

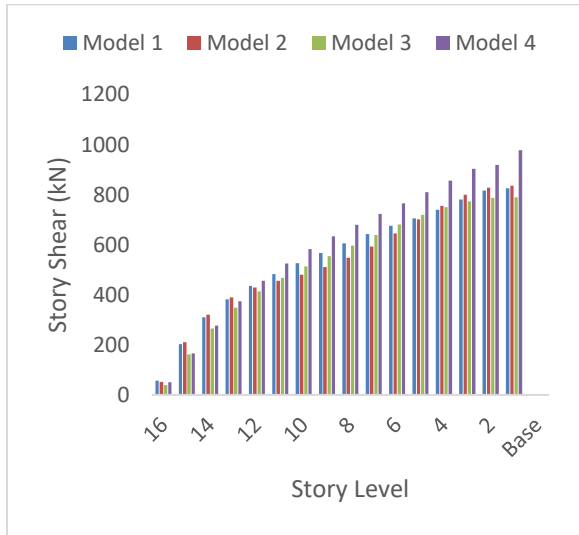
Story shear along the RS<sub>x</sub> direction is shown in Fig. 12 and along the RS<sub>y</sub> direction is shown in Fig. 13



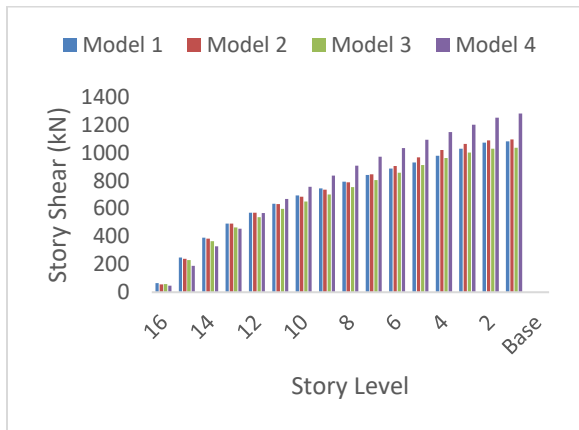
**Figure 10.** Variation of story shear with story level for different models along EQ<sub>x</sub>-direction  
Source: Authors



**Figure 11.** Variation of story shear with story level for different models along EQ<sub>Y</sub>-direction  
Source: Authors



**Figure 12.** Variation of story shear with story level for different models along the RS<sub>X</sub> direction  
Source: Authors

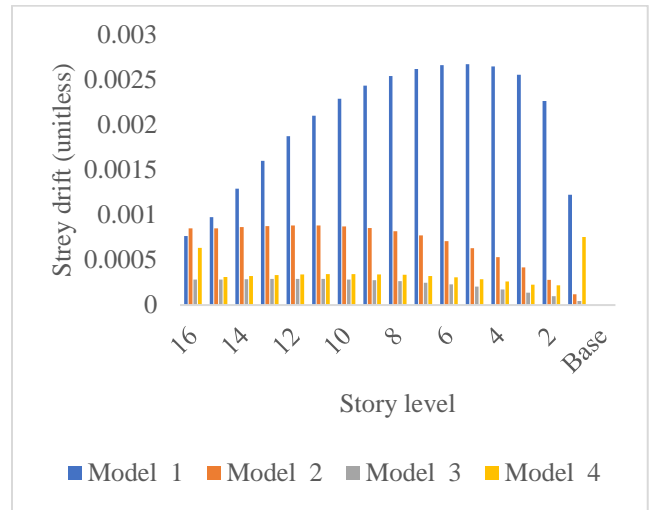


**Figure 13.** Variation of story shear with story level for different models along RS<sub>Y</sub>-direction  
Source: Authors

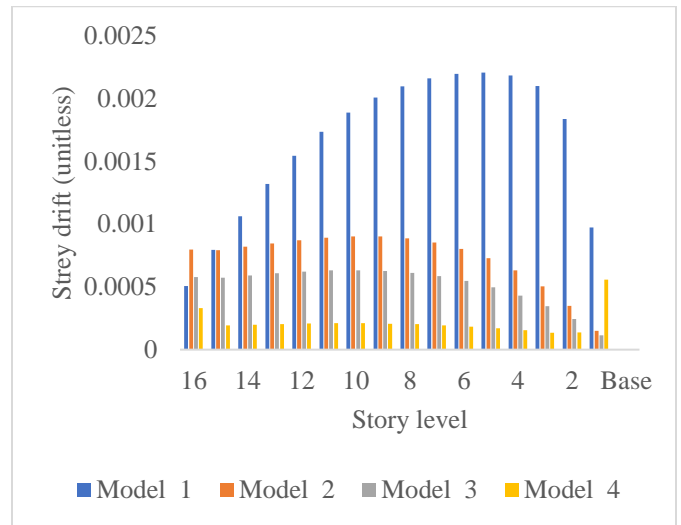
### 4.3 Story Drift

Story drift for all models along EQ<sub>x</sub> direction is shown in Fig. 14 for and along EQ<sub>y</sub> direction is shown in Fig. 15

Story drift for all models along the RS<sub>x</sub> direction is shown in Fig. 16 and along the RS<sub>y</sub> direction is shown in Fig. 17

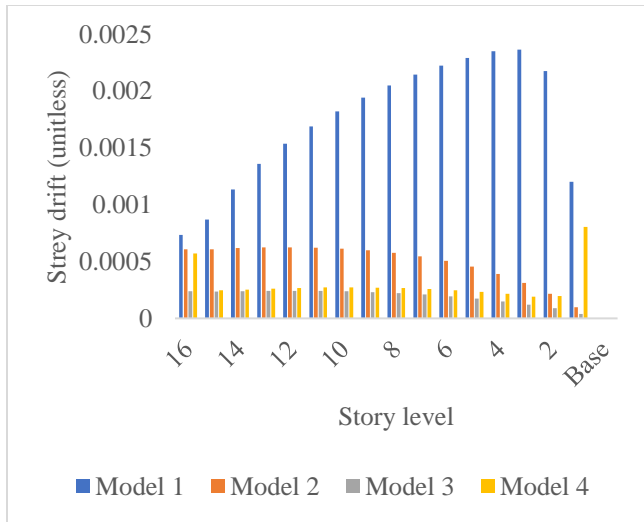


**Figure 14.** Variation of story drift with story level for different models along EQ<sub>X</sub>-direction  
Source: Authors

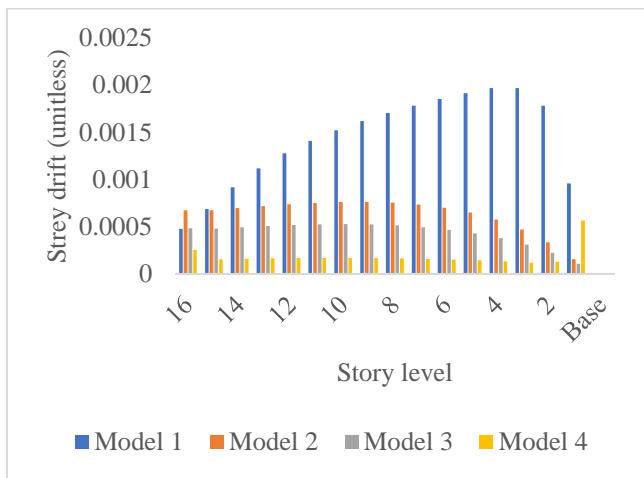


**Figure 15.** Variation of story drift with story level for different models along EQ<sub>Y</sub>-direction  
Source: Authors





**Figure 16.** Variation of story drift with story level for different models along  $RS_x$ -direction  
Source: Authors

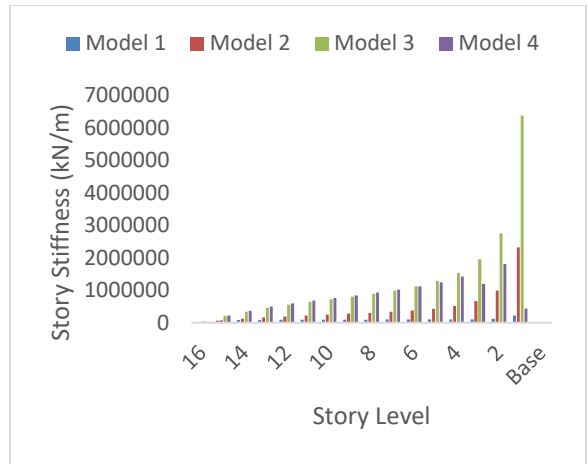


**Figure 17.** Variation of story drift with story level for different models along  $RS_y$ -direction  
Source: Authors

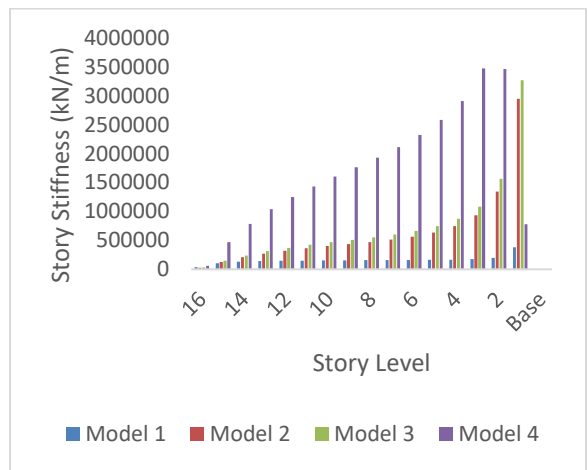
**4.4 Story Stiffness**

Story stiffness for all models along the  $EQ_x$  direction is shown in Fig. 18 and along the  $EQ_y$  direction is shown in Fig. 19

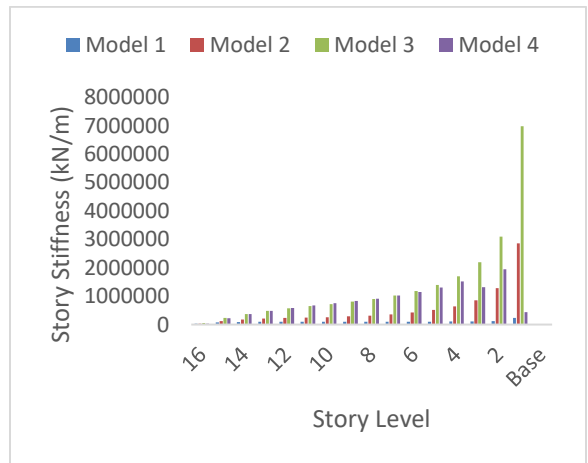
Story stiffness for all models along the  $RS_x$  direction is shown in Fig. 20 and along the  $RS_y$  direction is shown in Fig. 21.



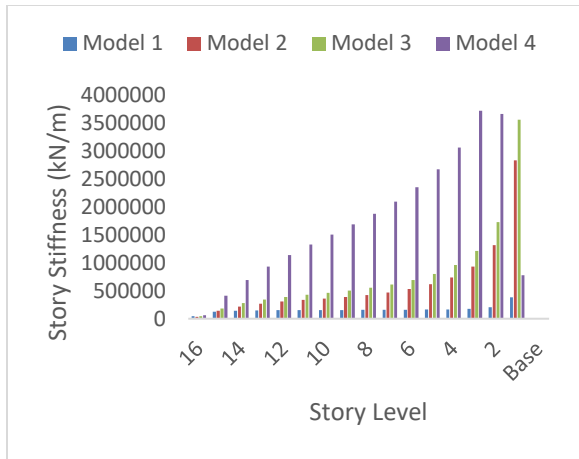
**Figure 18.** Variation of story stiffness with story level for different models along  $EQ_x$ -direction  
Source: Authors



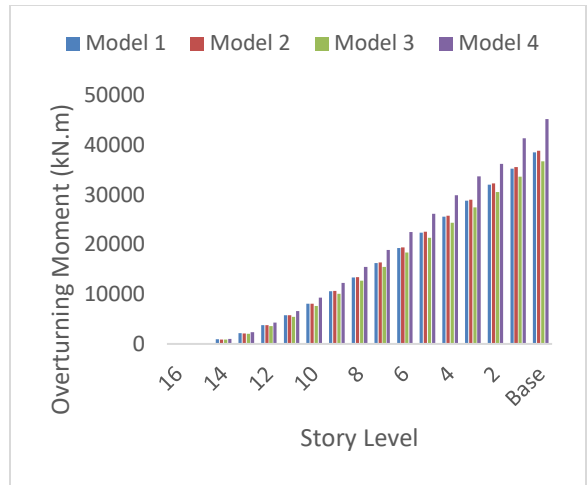
**Figure 19.** Variation of story stiffness with story level for different models along  $EQ_y$ -direction  
Source: Authors



**Figure 20.** Variation of story stiffness with story level for different models along the  $RS_x$  direction  
Source: Authors



**Figure 21.** Variation of story stiffness with story level for different models along  $RS_y$ -direction  
Source: Authors

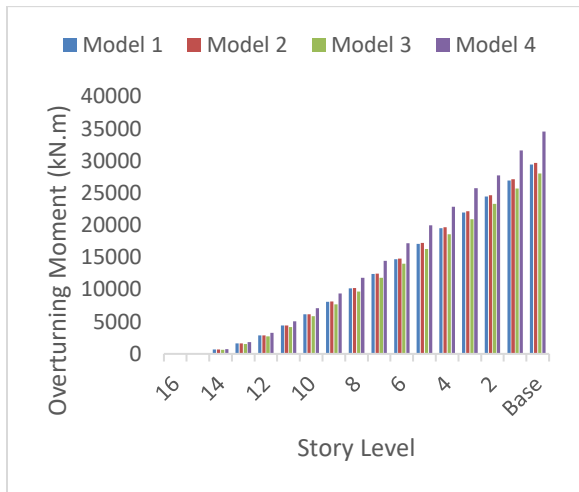


**Figure 23.** Variation of the overturning moment with story level for different models along  $EQ_y$ -direction  
Source: Authors

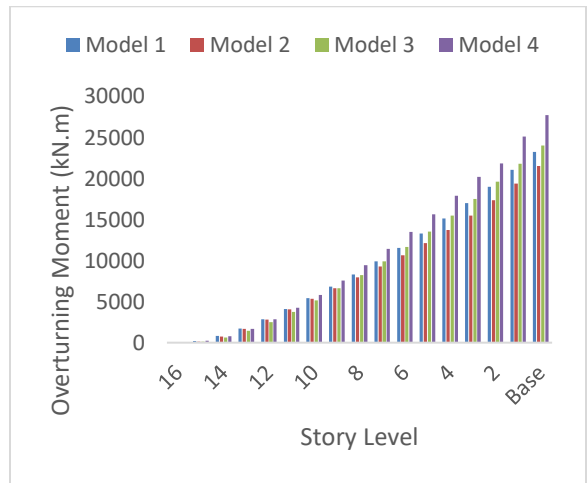
#### 4.5 Overturning Moment

The overturning moment for all models along the  $EQ_x$  direction is shown in Fig. 22 and along the  $EQ_y$  direction is shown in Fig. 23

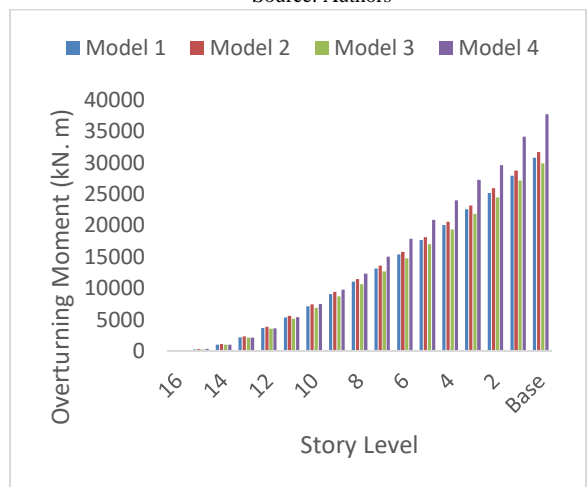
The overturning moment for all models along the  $RS_x$  direction is shown in Fig. 24 for and along the  $RS_y$  direction is shown in Fig. 25



**Figure 22.** Variation of the overturning moment with story level for different models along  $EQ_x$ -direction  
Source: Authors



**Figure 24.** Variation of the overturning moment with story level for different models along  $RS_x$ -direction  
Source: Authors



**Figure 25.** Variation of the overturning moment with story level for different models along  $RS_y$ -direction  
Source: Authors

**5. Discussion on Results**

The obtained results are discussed under different categories as follows

**5.1 Displacement**

Table 7 shows the overall results of displacement.

The model I was more susceptible to the earthquake. Static analysis of this model showed maximum displacement along the EQ<sub>x</sub> direction as 97.66 mm and along the EQ<sub>y</sub> direction as 79.78 mm. Dynamic analysis of this model showed maximum displacement RS<sub>x</sub> direction as 76.14 mm and along RS<sub>y</sub> direction as 63.19 mm

Model 2 showed maximum displacement along EQ<sub>x</sub> and EQ<sub>y</sub> direction as 33.71 mm and 35.16 mm which was 65% and 56% less than Model 1. And along RS<sub>x</sub> and RS<sub>y</sub> direction as 23.60 mm and 29.64 mm which was 70% and 53% less than model 1 respectively. As the shear wall was provided along the Y direction, the bending

moment carried by the heavy structural wall reduces the displacement in both directions.

Model 3 showed maximum displacement along EQ<sub>x</sub> and EQ<sub>y</sub> direction as 11.04 mm and 24.7 mm which was 89% and 69% less than model 1 respectively. And along RS<sub>x</sub> and RS<sub>y</sub> direction as 9.24 mm and 20.61 mm which was decreased by 87% and 68% than model 1 respectively. In this case, the coupled shear wall provided along the X direction showed less displacement due to its coupling effect, and the normal shear wall provided along the Y direction showed maximum displacement.

Model 4 showed maximum displacement along EQ<sub>x</sub> and EQ<sub>y</sub> direction as 16.38 mm and 10.4 mm which was 84% and 87% less than model 1 respectively. And along RS<sub>x</sub> and RS<sub>y</sub> direction as 13.02 mm and 8.68 mm which was decreased by 83% and 86% than model 1 respectively. The RC diagonal struts act as a heavy component which results in resistance of building diagonally hence showing less displacement.

**Table 7.** Overall results of displacement

Analysis type	Displacement (mm)						
	Model 1	Model 2	Comparison with Model 1	Model 3	Comparison with Model 1	Model 4	Comparison with Model 1
<b>Eqx</b>	97.66	33.71	-65%	11.04	-89%	16.38	-83%
<b>Eqy</b>	79.78	35.16	-56%	24.7	-69%	10.4	-87%
<b>RSx</b>	76.14	23.6	-69%	9.24	-88%	13.02	-83%
<b>RSy</b>	63.19	29.64	-53%	20.61	-67%	8.68	-86%

**5.2 Story Drift**

Table 8 shows the overall results of story drift.

The model I showed maximum story drift along the EQ<sub>x</sub> direction as 0.002676 and along the EQ<sub>y</sub> direction as 0.002205. Dynamic analysis of this model showed maximum displacement along the RS<sub>x</sub> direction as 0.002365 and along the RS<sub>y</sub> direction as 0.001969.

In model 2 showed maximum story drift along EQ<sub>x</sub> and EQ<sub>y</sub> direction as 0.000884 and

0.000902 which is 67% and 60% less than model 1 respectively. And along RS<sub>x</sub> and RS<sub>y</sub> direction as 0.000626 and 0.000763 which was 74% and 61% less than model 1 respectively. The drift of rigid frame constructions was also affected by the column's cross-sectional length and width, as well as the column's shear value.

Due to the presence of a shear wall, there were fewer beams and columns in the building in model 2 than in model 1.

Model 3 showed drift along EQ<sub>x</sub> and EQ<sub>y</sub> direction as 0.000291 and 0.000632 which was 88% and 70% less than model 1. And along RS<sub>x</sub> and RS<sub>y</sub> direction as 0.000243 and 0.000527 which was 90% and 74% less than model 1. Maximum story drift occurred along the Y direction is 0.000632 due to the presence of a regular shear wall. Similar to model 2, there were a smaller number of beams and columns in the building than in models 1 and 2 resulting in lower drift of the building.

Model 4 showed maximum story drift along EQ<sub>x</sub> and EQ<sub>y</sub> direction as 0.000756 and 0.000557 which was 70% and 75% less than the model. And along RS<sub>x</sub> and RS<sub>y</sub> direction as 0.000806 and 0.000564 which was 66% and 72% less than model 1. As RC diagonal struts were provided along both directions, the struts provided heavy reinforcement which possessed less displacement of structure hence, the relative deflection of any story in the model was less.

**Table 8.** Overall results of story drift

Story Drift (unitless)							
Analysis type	Model 1	Model 2	Comparison with Model 1	Model 3	Comparison with Model 1	Model 4	Comparison with Model 1
Eq <sub>x</sub>	0.002676	0.000884	-67%	0.000291	-89%	0.000756	-72%
Eq <sub>y</sub>	0.002205	0.000902	-59%	0.000632	-71%	0.000557	-75%
RS <sub>x</sub>	0.002365	0.000626	-74%	0.000243	-90%	0.000806	-66%
RS <sub>y</sub>	0.001969	0.000763	-61%	0.000527	-73%	0.000564	-71%

### 5.3 Base Shear

Table 9 shows the overall results of base shear.

Model 1 showed base shear for EQ<sub>x</sub> direction was 826.13 kN and for EQ<sub>y</sub> direction it was 1081.87 kN

Model 2 showed maximum base shear along EQ<sub>x</sub> and RS<sub>x</sub> direction was 835.67 kN which was 1.2% more than model 1. Maximum base shear along EQ<sub>y</sub> and RS<sub>y</sub> Y direction was 1094.37 kN and 1.2% more than model 1. Base shear mainly depends on the weight of the structure hence in this case weight of the shear wall along a longer span (Y direction) was added extra weight to the building hence base shear is greater than model 1.

Model 3 showed base shear along EQ<sub>x</sub> and RS<sub>x</sub> direction was 789.88 kN which was 4.4% less than model 1. Maximum base shear along EQ<sub>y</sub> and RS<sub>y</sub> direction was 1034.4 kN and 4.4% less than the model. Due to the coupled shear wall, the shear wall 12 columns weight was reduced than model 1. Hence it showed less base shear than model 1.

Model 4 showed base shear along EQ<sub>x</sub> and RS<sub>x</sub> direction was 977.17 kN which was 18.5 % more than model 1. Maximum base shear along EQ<sub>y</sub> and RS<sub>y</sub> direction was 1279.67 kN and 18.5% more than model 1. In the case of model 4, it was maximum than models 1, 2, and 3; as the self-weight of diagonal struts increases the total seismic weight of the building.

**Table 9.** Overall results of base shear

Base Shear (KN)							
Analysis type	Model 1	Model 2	Comparison with Model 1	Model 3	Comparison with Model 1	Model 4	Comparison with Model 1
Max of (Eq <sub>x</sub> , RS <sub>x</sub> )	826.13	835.67	+1.2%	789.88	-4.4%	977.17	+18.3%
Max of (Eq <sub>y</sub> , RS <sub>y</sub> )	1081.87	1094.37	+1.2%	1034.4	-4.4%	1279.67	+18.3%

### 5.4 Story Stiffness

Table 10 shows the overall results of story stiffness.

Model 1 showed maximum stiffness along the EQ<sub>x</sub> direction as 224725 kN/m and along the EQ<sub>y</sub> direction as 378870 kN/m. Dynamic analysis of this model showed maximum stiffness along the RS<sub>x</sub> direction as 229122 kN/m and along the RS<sub>y</sub> direction as 381029 kN/m. It was the lowest stiffness among all the stiffness data obtained from other models. It was mainly due to the absence of an infill wall at ground level as well as no structural wall and diagonal strut was provided in the normal building.

Model 2 showed maximum stiffness along EQ<sub>x</sub> and EQ<sub>y</sub> direction as 2314837 kN/m and 2949281 kN/m which was 10.3 times and 7.8 times respectively higher than model 1. And along RS<sub>x</sub> and RS<sub>y</sub> direction as 2859787 kN/m and 2833522 kN/m which was 12.4 times and 7.44 times respectively higher than model 1. It was due to the shear wall, the shear wall has more strength, stiffness, and lateral load

resisting capacity hence, for seismic forces it showed a good hold over the building.

Model 3 showed maximum stiffness along EQ<sub>x</sub> and EQ<sub>y</sub> direction as 288547 kN/m and 3269657 kN/m which was 28.4 times and 8.6 times respectively higher than model 1. And along RS<sub>x</sub> and RS<sub>y</sub> as 299004kN/m and 3563929 kN/m which was 30.5 times and 9.35 times respectively higher than model 1. Stiffness mainly depends on the displacement of the building hence, in the case of model 3 displacement was very less along the X direction therefore, there was a higher increase in the stiffness along the X direction of model 3.

Model 4 showed maximum stiffness along EQ<sub>x</sub> and EQ<sub>y</sub> direction as 294840 kN/m and 3432468 kN/m which was 31.2 times and 9.1 times respectively lesser than model 1. And along RS<sub>x</sub> and RS<sub>y</sub> direction as 304044 kN/m and 357110.80 kN/m which was 32.69 times and 6.27 times respectively lesser than model 1. Story stiffness was maximum in the case of model 3 along X direction as coupled shear wall provided along X direction span.

**Table 10.** Overall results of story stiffness

Story Stiffness (KN/m)							
Analysis type	Model 1	Model 2	Comparison with Model 1	Model 3	Comparison with Model 1	Model 4	Comparison with Model 1
Eq <sub>x</sub>	224725	2314837	+10.3%	288547	+28.4%	294840	+31.2 %
Eq <sub>y</sub>	378870	2949281	-7.8%	3269657	-8.6%	3432468	-9.1%

<b>RSx</b>	229122	2859787	+12.5%	299004	+30.5%	304044	+32.69 %
<b>RSy</b>	381029	2833522	-7.44%	3563929	-9.35%	357110.80	-6.27%

### 5.5 Overturning Moment

Table 11 shows the overall results of the overturning moment.

Model 1 showed the maximum overturning moment along the EQ<sub>x</sub> direction as 29404.01 kN.m and along the EQ<sub>y</sub> direction as 38506.475 kN.m. Dynamic analysis of this model showed the maximum overturning moment along the RS<sub>x</sub> direction as 23237.63 kN.m and along the RS<sub>y</sub> direction as 30762.11 kN.m. This moment was more than all other models.

Model 2 showed the maximum overturning moment at the base along EQ<sub>x</sub> and EQ<sub>y</sub> direction as 29671.36 kN.m and 38856.58 kN.m which was 1% more than model 1 for both directions. And along RS<sub>x</sub> direction and RS<sub>y</sub> direction as 25519.19 kN.m and 31686.05 kN.m which was 7.4% and 3% respectively more than model 1. It was due to the shear wall, as the presence of a shear wall reduces the weight of beams and columns in that area.

Model 3 showed the maximum overturning moment at the base along EQ<sub>x</sub> and EQ<sub>y</sub> direction as 28045.81 kN.m and 36727.82 kN.m which was 4.5% less than model 1 for both directions. And along RS<sub>x</sub> and RS<sub>y</sub> direction as

24455.25 kN.m and 29920.41 kN.m which was 4.16 % and 2.75% less than model 1 respectively. It was due shear wall and coupled shear wall, as it reduces the weight of the beam and columns in that area. The total overturning moment of such coupled shear wall structures subjected to horizontal loading is divided into two components: primary bending moments M1 and M2 induced in the walls by the shear forces in the coupling beams, and an axial bending moment T1 induced in the walls by the shear forces in the coupling beams, multiplied by a distance l between the neutral axes of the walls. Hence model 3 showed the lowest overturning moment than models 1, 2, and 4.

Model 4 showed the maximum overturning moment at the base along EQ<sub>x</sub> and EQ<sub>y</sub> direction as 34534.31 kN.m and 45224.93 kN.m which was 17.5% more than model 1 for both directions. And along RS<sub>x</sub> and RS<sub>y</sub> direction as 27753.36 kN.m and 37711.08 kN.m which was 20% and 22.5% more than model 1 respectively. The RC diagonal struts contribute to an increase in the weight of the structure hence, this results in the highest overturning moment of model 4 than models 1, 2, and 3.

**Table 11.** Overall results of overturning moment

Analysis type	Overturning Moment (KN.m)						
	Model 1	Model 2	Comparison with Model 1	Model 3	Comparison with Model 1	Model 4	Comparison with Model 1
<b>Eqx</b>	29404.01	29671.36	1%	28045.81	-4.6%	34534.31	17.4%
<b>Eqy</b>	38506.475	38856.58	1%	36727.82	-4.6%	45224.93	17.4%
<b>RSx</b>	23237.63	25519.19	9.81%	24455.25	-4.16	27753.36	19.4%
<b>RSy</b>	30762.11	31686.05	3%	29920.41	-2.74%	37711.08	22.6%

## 6. Conclusions

Building with diagonal struts was stiffer and less displaced than building with shear walls or coupled shear walls. Base shear was decreased in G+14 OGS residential buildings with shear walls along longer spans and coupled shear walls along shorter spans with a combination of shear wall and coupled shear wall by 4.4% for both X and Y direction in both static and dynamic analysis than the reference model which was the minimum of all three models. In the case of a G+14 OGS residential building with shear walls along longer spans and coupled shear walls along shorter spans with a combination of shear wall and coupled shear wall stiffness along the static X direction was the maximum of all the stiffness which was about 28.5 times more than the reference model and along the dynamic X direction was about 30.5 times more than the reference model. G+14 OGS residential buildings with shear walls along longer spans and coupled shear walls along shorter spans provided with the combination of shear wall and coupled shear wall showed the lowest value of overturning moment up to 4.5% less than the reference model along static X and Y in both directions.

### List of Abbreviations

DBE: Design based on earthquake;

EQx: Linear static X direction;

EQy: Linear static Y direction;

ESM: Equivalent Static Method;

ETABS: Extended Three-Dimensional Analysis of Building System;

OGS: Open ground story;

RC: Reinforced concrete;

RSM: Response Spectrum Method;

RSx: Linear dynamic X direction

RSy: Linear dynamic Y direction

### Conflicting Interests

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All authors have contributed to this research. The authors did the investigations and wrote the manuscript. All authors read and approved the final manuscript.

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