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Analysis of Seismic Behavior in Multi-Storeyed Building on Sloping Ground with Soft-Storey at Different Levels

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Abstract: *Civil engineering's core lies in structural design and analysis, critical for ensuring the safety and stability of buildings. While traditional methods are efficient, technological advancements, particularly in software like ETABS, are revolutionizing in this field.This study highlights the significance of integrating modern software tools ETABS, with conventional methods to improve efficiency and accuracy in analysis of multi-storied buildings. The primary objective of this project is to conduct a comprehensive analysis of a multi-storied building situated on sloping ground, featuring a soft storey, under seismic forces. The focus is on evaluating storey displacements, drifts, and base shear to mitigate potential risks. The incorporation of bracings at soft stories is explored as a strategy to reduce deflections within IS standard's permissible limits.The integration of ETABS software alongside conventional methods not only accelerates the design process but also enhances accuracy, critical for mitigating structural vulnerabilities, especially in seismic-prone regions. This research contributes to advancing structural engineering practices, ensuring safer and more resilient built environments.*
Keywords: *ETABS, Seismic Forces, Soft-Storey.*

INTRODUCTION

All types of structural systems in buildings are primarily designed to support gravity loads, which include live loads (variable loads resulting from occupancy, furniture, and other temporary factors), dead loads (permanent loads such as the weight of the building itself, fixtures, and equipment) and snow loads (loads imposed by accumulated snow on roofs and other surfaces). But buildings also experience lateral loads, which come from forces that are perpendicular to the ground plane. These forces include wind, seismic activity (earthquakes), and in some cases, blasting. Adequate stiffness and resistance to lateral forces are essential for buildings. The ability of a structure to withstand deformation under stress is known as stiffness, and it is crucial for reducing sway or drift during lateral loading events. A building that is exposed to seismic or earthquake pressures is always vulnerable to damage, but if the building is sloped—for example, a building on a hill that slopes downward—the risk is much exacerbated as the vertical and horizontal irregularities of slope structures set them apart from plains structures.

1.1 Soft storey

A building's soft story is a level that is more adaptable than the stories above and below it. It can be described as a story in a building structure that is less stiff or resistant than the storey next to it. A storey is considered to be soft if its stiffness is just 70% that of the neighboring storey. The need for the soft-storey lies in various features like open spaces or commercial use, architectural design, parking or garage areas, construction methods and unintended consequences.

1.2 Shear Wall

Shear walls are structural components that can withstand forces parallel to the plane of the wall, or lateral forces. In addition to withstand gravity and vertical stresses, shear walls are made to withstand lateral loads from winds and earthquakes. It is employed to provide a structure sufficient rigidity and to increase its strength and stability. The uplift forces brought on by the wind's pull must be resisted by walls. Shear pressures that attempt to topple walls must be resisted. Wind's lateral force, which tries to push the walls in and pull them away from the building, must be resisted by the walls.

1.3 Bracings

The purpose of bracings is to stabilize girders during construction, distribute load effects, prevent wall studs from distorting, prevent building collapse, limit lateral movement and reduce damage to structure components. It aids in distributing the main beams' lateral and vertical loads equally and provide superior defense against seismic loads and fast-moving storms.

1.4 Objectives of the work

- To investigate the performance of soft story at various points on zone IV sloping ground.
- To calculate base shear, storey drifts, and displacements for the above building.
- To assess the lateral resisting system's (bracing on soft story) efficacy.

Literature review

Various researched/studies are done on the seismic resistance of different multi-storied building [1],[2], braced and unbraced[3] steel structures and have revealed that sloped buildings experience higher deflection and recommending setback structures[4], core and corner shear walls minimize storey drift and increase base shear[5], adding bracing at soft storey levels reduces storey drifts effectively[6], shear wall placement in improve stiffness and resistance to lateral seismic loads[7], there is an increase in the storey drift with increase in height[8]. It was also seen that base shear increases and storey drift decreases with increased SWA/FA ratio [9].

Methodology

In earthquake engineering, structures vibrate vertically, longitudinally, and transversely in response to seismic forces. The primary shaking is horizontal, however motion can occur in any direction. For structural design to meet building codes' specified deformation limits and provide enough vertical and lateral strength and stiffness, both gravity and lateral loads must be taken into account. In India, IS 1893(Part-1):2016, a regulation that describes methods for determining seismic design forces, governs seismic design. These forces rely on the mass of the structure, the seismic zone, the seismic coefficient, the significance of the structure, the stiffness, the kind of soil, and the ductility. In order to evaluate seismic loads on different structures, the code places a lot of attention on figuring out base shear and how it varies with height.

Methods of analysis

Some seismic analysis methods commonly applied are Equivalent static method, Pushover analysis method, Response spectrum method, Linear time history method and Nonlinear static analysis method.

Response Spectrum Method

The Response Spectrum approach, also known as the modal or mode superposition approach is based on the idea that a building's response can be represented as the sum of responses from different modes of vibration. Every mode makes a contribution with its unique frequency, modal damping, and distorted shape. The key steps involved in this method are as described in Figure 3.1.

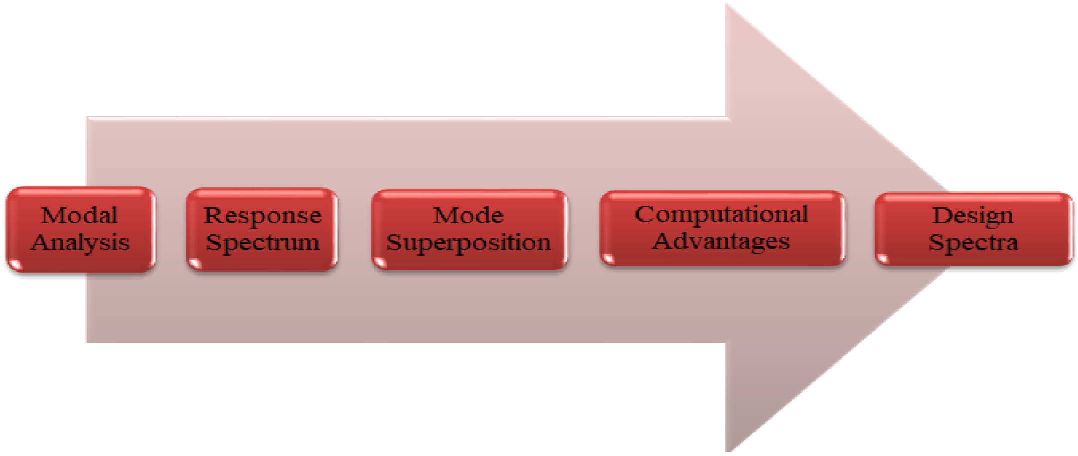

Fig 3.1: Steps of Response Spectrum Method

3.1 Case Study of G+20 Building with Soft-Storey

3.1.1 Description (General)

1. Type of Building - G+20 Commercial building
2. Number of storey - 21 storey
3. Column Size – 460 x 230 mm
4. Beam Size – 350 x 230 mm
5. Thickness of the Slab - 150 mm
6. Thickness of main wall - 230 mm
7. Thickness of the partition wall – 150mm
8. Height of wall - 3000 mm

3.1.2 Material Details

1. Grade of concrete & steel - M30 & Fe415
2. Type of construction - RCC framed structure
3. Type of wall – Brick masonry Wall
4. Density of RCC - 25 kN/m3
5. Density of wall - 20 kN/m

3.1.3 Load Calculations

1. Dead Load

Self-weight of the Slab = 0.15m x 25 kN/m^3 = 3.75 kN/m^2
Main wall load = 2.65m x 0.23m X 20 kN/m^3 = 12.19 kN/m
Partition wall load =2.65m x 0.15m x 20 kN/m^3 = 7.95 kN/m
Self-weight of Columns = 0.46m x 0.23m x 25 kN/m^3 = 2.645 kN/m
Self-weight of Beams = 0.35m x 0.23m x 25 kN/m^3 = 2.0125 kN/m
Floor Finish Load = 1 kN/m^2

2. Live Load = 3 kN/m^2

3.2 Modeling of the Building

The building model (Fig 3.2, 3.3, 3.4) was taken from the literature study of Seismic analysis of multi storey building on sloping ground and flat ground by using E-Tabs[4] and has been designed on the sloping ground for 5°, 8°, 11°, 15°, 20° & 25° angles. Soft storeys are also been introduced at intermediate floor levels i.e., at G level, 4^{th}, 8^{th}, 12^{th} & 16^{th} floors. This building is analyzed using Response Spectrum Method.

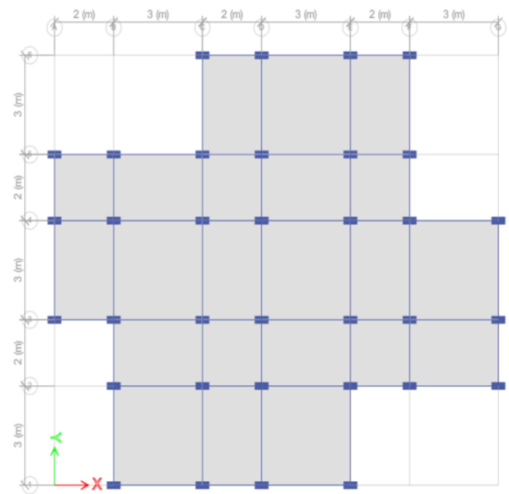

Fig 3.2: Plan of the building

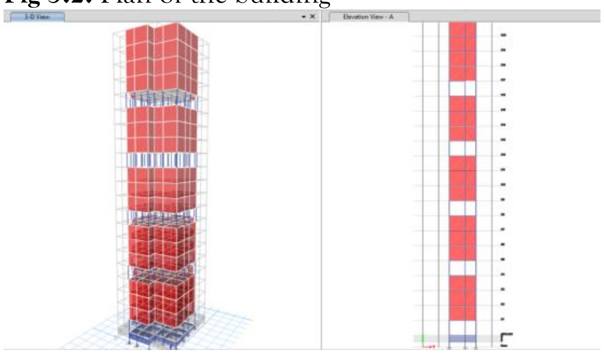

Fig 3.3: 3D & Elevated view of the building

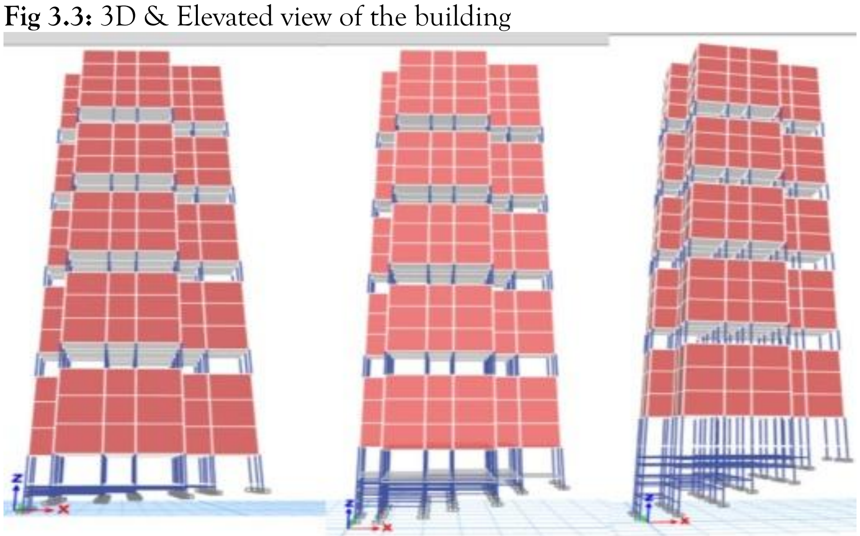

Fig 3.4: 3D view of building at 5°, 15°, 25° angle sloping ground with soft storey

3.2.1 Analysis of the building with soft storey on 5°sloping ground without bracing

The analysis of the building is done based on Response Spectrum Method taking a height of 65.311m. From the analysis we can find that the displacements, storey drifts and base shear are very high because of the soft storey (Fig 3.5, 3.6). This will make our structure vulnerable to lateral loads. Storey drifts are comparatively high than its limit and it has to be controlled.

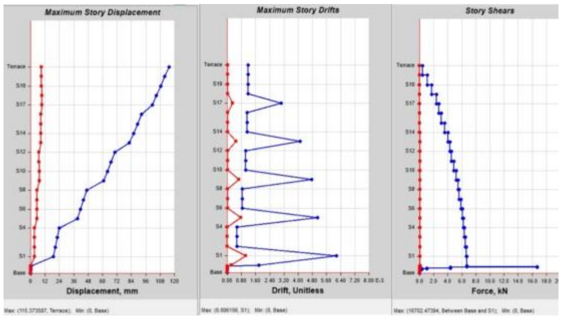

Fig 3.5: Analysis report of the building using response spectrum in X direction (RSX)

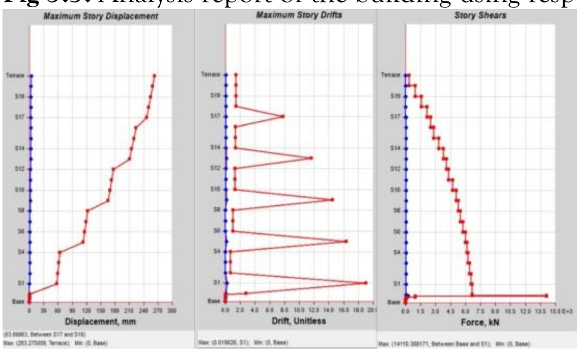

Fig 3.6: Analysis report of the building using response spectrum in Y Direction (RSY)

3.2.2 Analysis of the building with soft storey on 5°sloping ground with bracing at 4th floor

It can be seen from the figures (3.7, 3.8, 3.9) the bracings are been given to the soft storey at 4th floor. The storey displacements are within the limit and the storey drift at 4th floor was controlled by installing bracing in it, but the maximum storey drifts were very high. It has to be controlled.

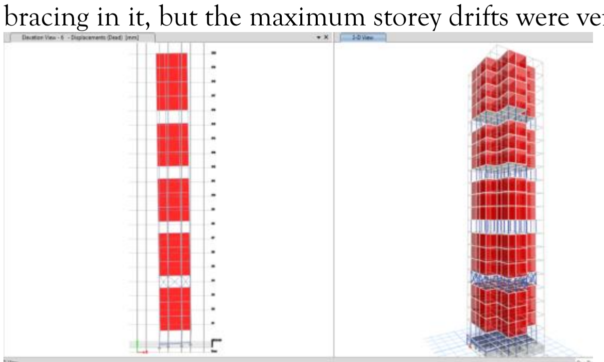
Fig 3.7: Elevation & 3D view of building on 5° sloping ground with bracing at 4th floor

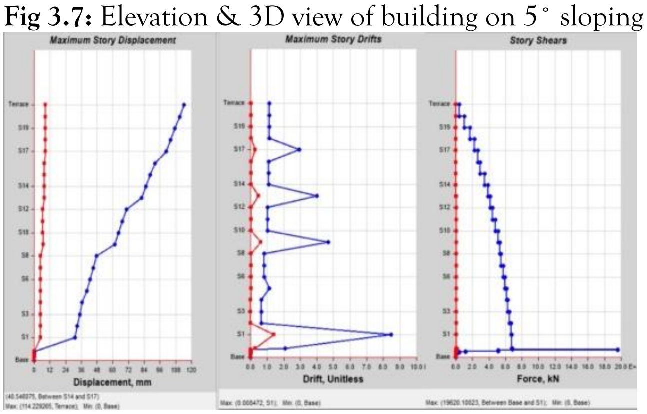

Fig 3.8: Analysis report of 5° sloping building with bracing at 4th floor using response spectrum in X Directi0on (RSX)

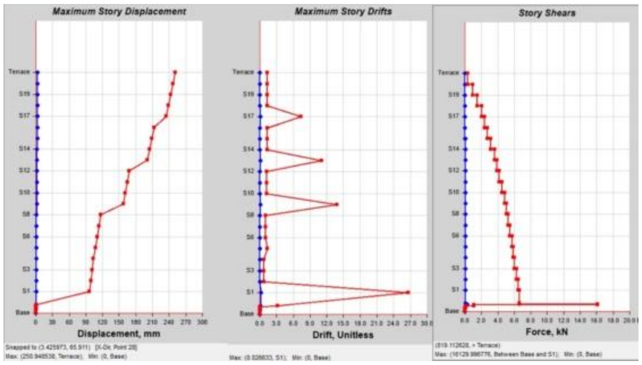

Fig 3.9: Analysis report of 5° sloping building with bracing at 4th floor using response spectrum in Y Direction (RSY)

3.2.3 Analysis of the building with soft storey on 5°sloping ground with bracings at 4th & 8th floor

The maximum storey displacements were within the limit and the storey drift at 4th & 8th floor were reduced due to the installation of bracings to the soft storey. This shows that bracings reduce drifts and displacements by increasing storey stiffness.

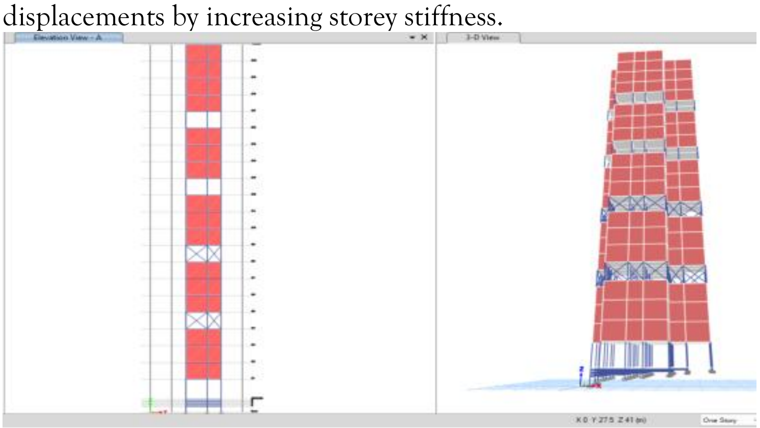

Fig 3.10: Elevation & 3D view of the building with bracings at 4th+8th floors on 5° sloping ground

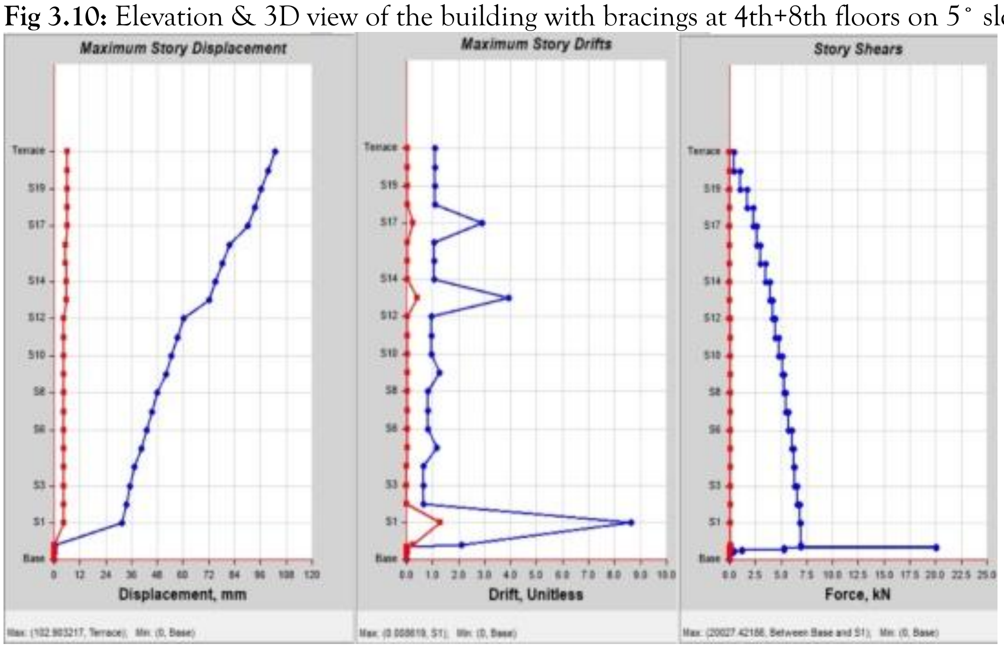

Fig 3.11: Analysis report of 5° sloping building with bracing at 4th+8th floor using response spectrum in X Direction (RSX)

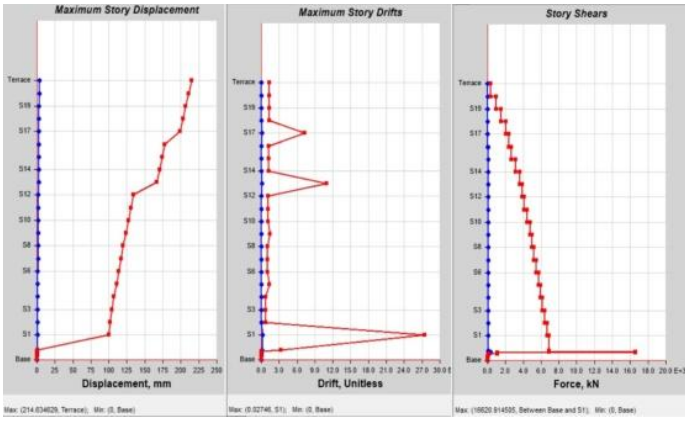

Fig 3.12: Analysis report of 5˚ sloping building with bracing at 4th+8th floor using response spectrum in Y Direction (RSY)

3.2.4 Analysis of the building with soft storeys on 5˚ sloping ground with bracings at 4th+8th+12th floors

The storey displacements were much reduced and the storey drifts at 4th, 8th & 12th floor were also reduced. But the maximum storey drift at S1 level is very high.

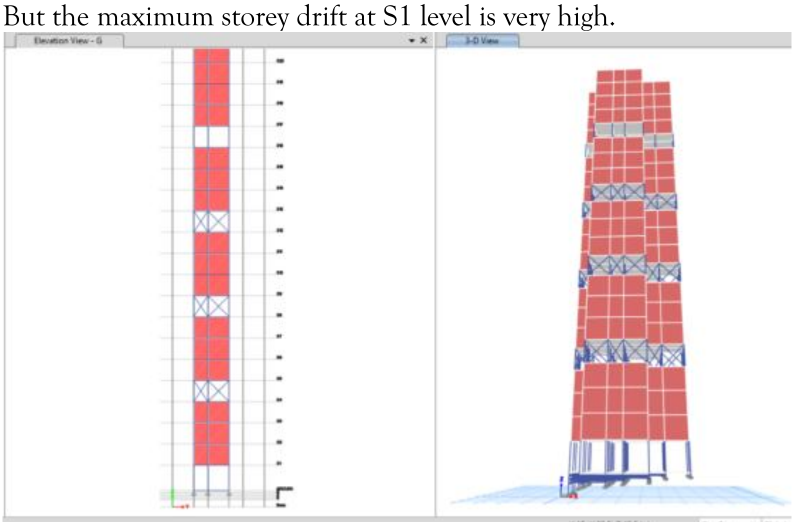

Fig 3.13: Elevation & 3D view of the building with bracings at 4th+8th+12th floors on 5˚ sloping ground

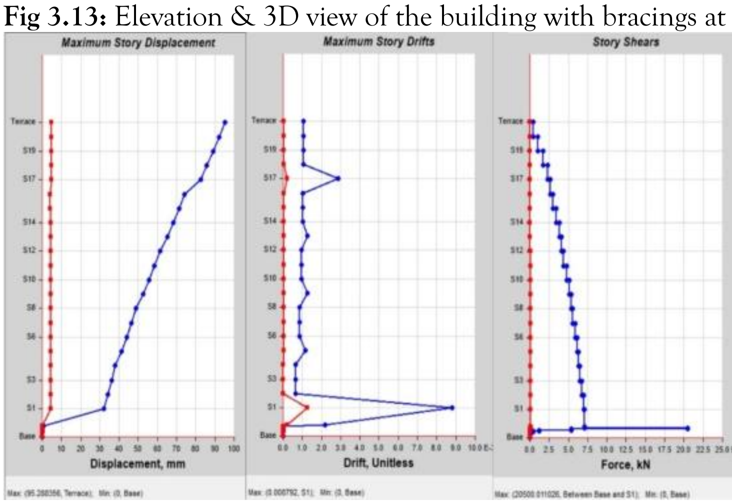

Fig 3.14: Analysis report of 5˚ sloping building with bracing at 4th+8th+12th floors using response spectrum in X Direction (RSY)

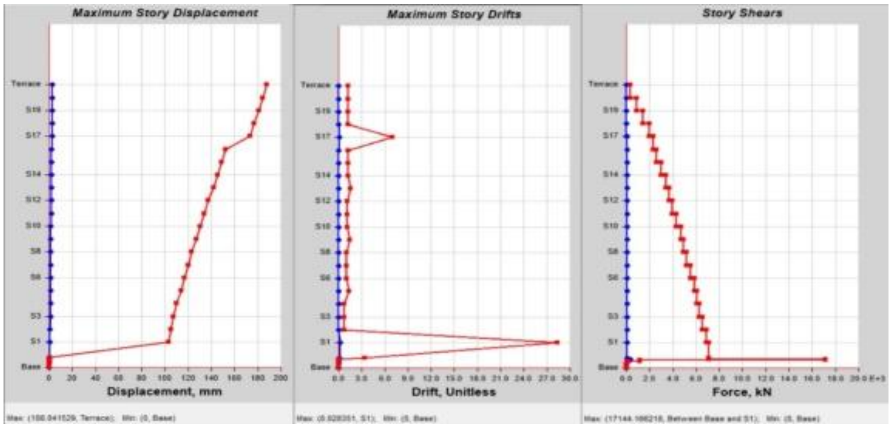

Fig 3.15: Analysis report of 5° sloping building with bracing at 4th+8th+12th floors using response spectrum in Y Direction (RSY)

3.2.5 Analysis of the building with soft storey on 5°sloping ground with bracings at 4th+8th+12th & alternate at (G+16th) floors

Bracings were been provided at 4^{th}, 8^{th}, 12^{th}, & alternate bracings are given at G+16^{th} floor. The storey displacement is very low, thus it is safe. The inter storey drifts are also reduced at each soft storey and brought within the limit, thus we can conclude that by installing bracings at soft storey level we can reduce maximum storey displacements and inter storey drifts which says that our structure can sustain to lateral loads.

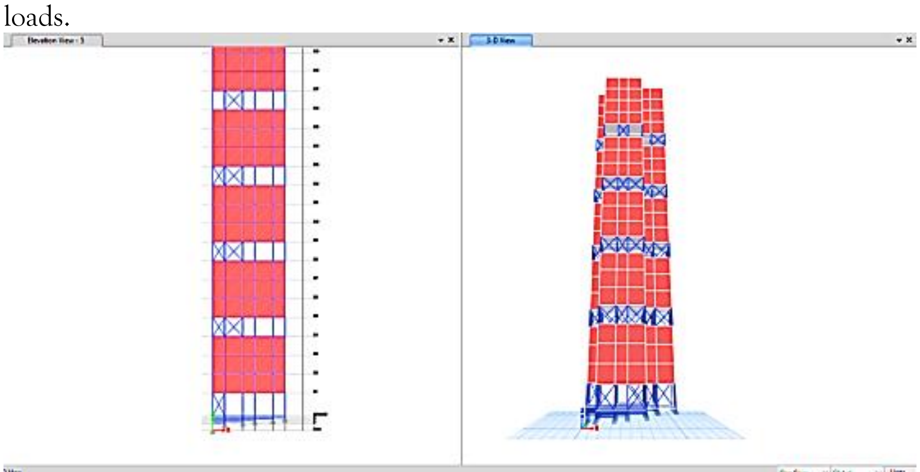

Fig 3.16: Elevation & 3D view of the building with bracings at 4^{th}+8^{th}+12^{th} floors on 5° sloping ground

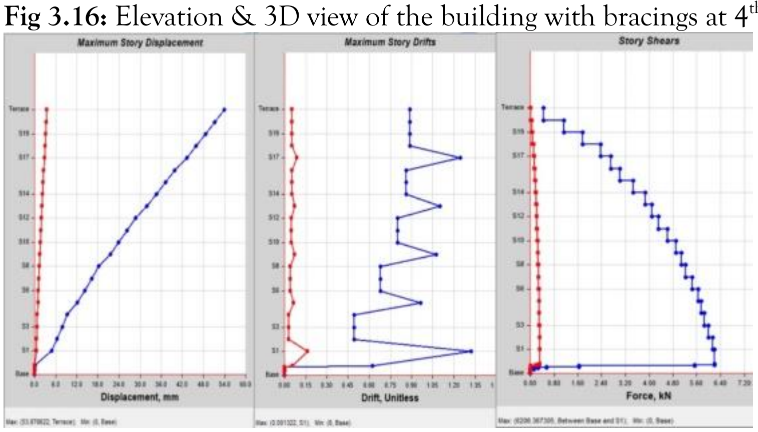

Fig 3.17: Analysis report of 5° sloping building with bracing at 4^{th}+8^{th}+12^{th} & alternate (G+16) floors using response spectrum in X Direction (RSX)

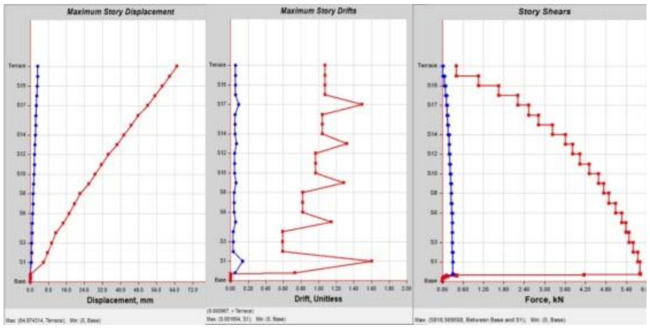

Fig 3.18: Analysis report of 5° sloping building with bracing at 4th+8th+12th & alternate (G+16) floors using response spectrum in Y Direction (RSY)

3.2.6 Analysis of the building with soft storey on 15° sloping ground without bracing

Here in this case of 15 degree sloping ground building, the height of the building increased to 68.6191m. As the sloping angle increases the structure becomes more vulnerable to lateral loads.

In this case of soft storey without bracing the storey displacements are very high and also inter storey drifts are also very high that the structure can fail at any moment. Hence there is need for controlling these effects in the structure.

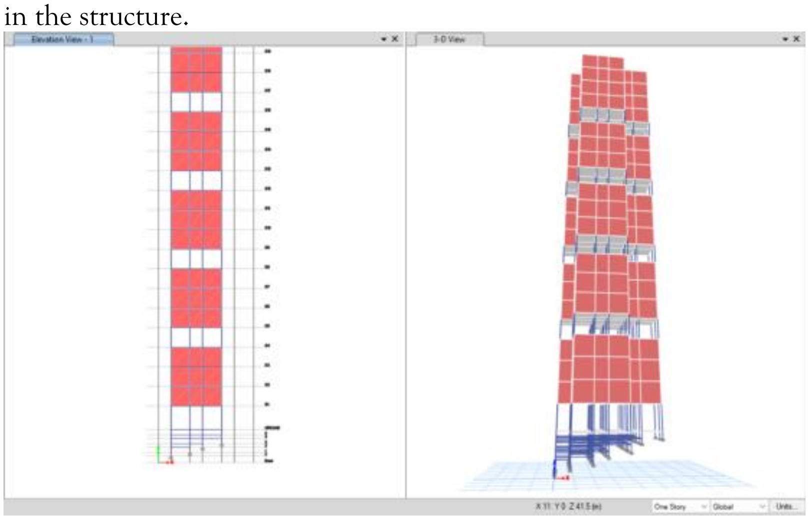

Fig 3.19: Elevation & 3D view of the building without bracings on 15° sloping ground

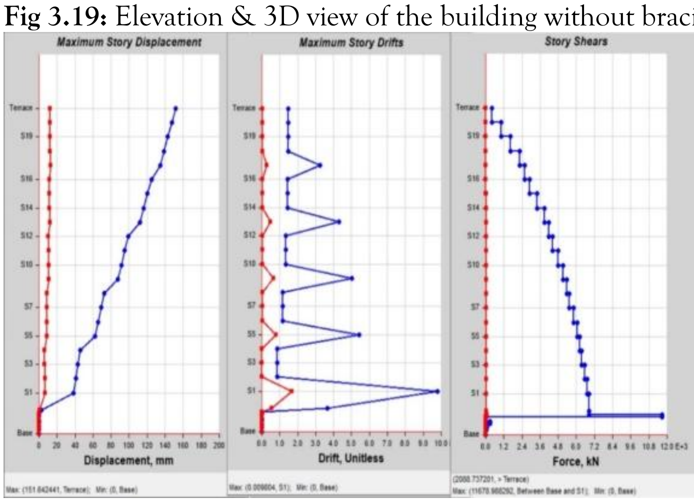

Fig 3.20: Analysis report of 15° sloping building without bracing using response spectrum in X Direction (RSX)

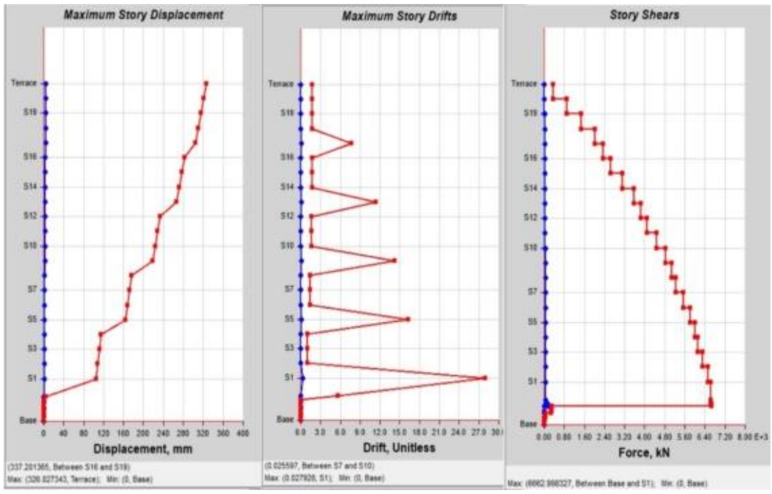

Fig 3.21: Analysis report of 15° sloping building without bracing using response spectrum in Y Direction (RSY)

3.2.7 Analysis of the building with soft storey on 15° sloping ground with bracing at 4th floor

Bracings are been provided at 4th floor of the structure for the response spectrum analysis. Even after installing bracing at 4th floor the storey displacement is not reduced and the inter storey drift at 4th floor is reduced but the maximum storey drift is very high at S1 level which is not safe for any kind of building.

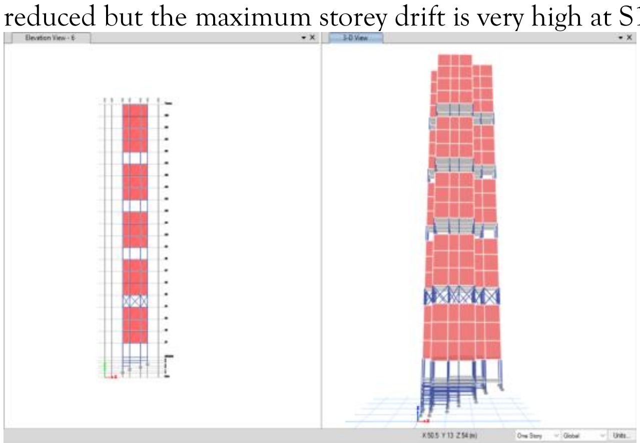

Fig 3.22: Elevation & 3D view of the building with bracing at 4th floor on 15° sloping ground

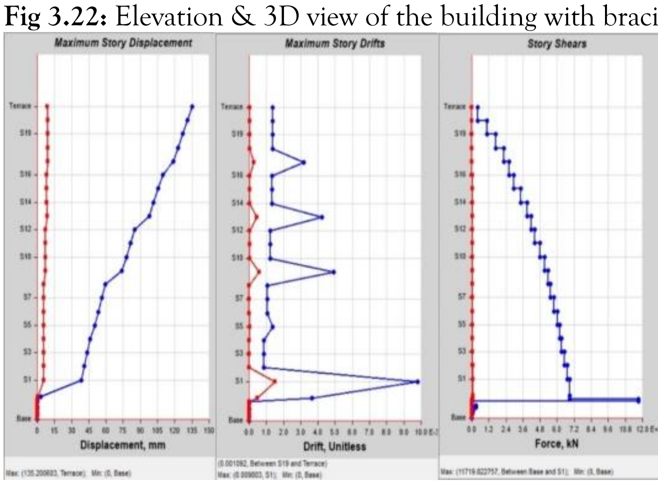

Fig 3.23: Analysis report of 15° sloping building with bracing at 4th floor using response spectrum in X Direction (RSX)

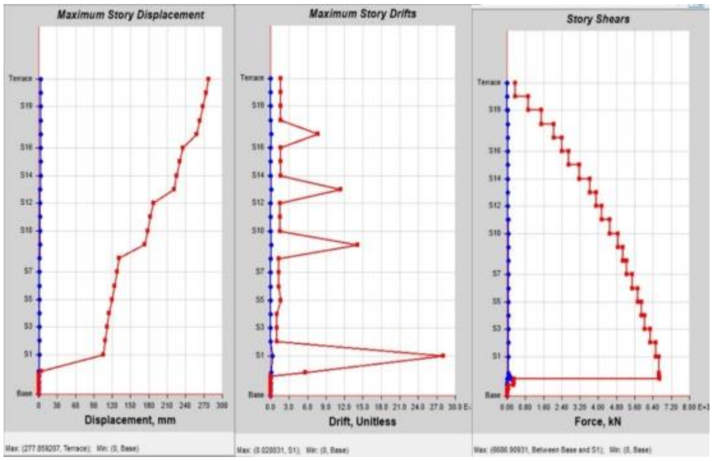

Fig 3.24: Analysis report of 15° sloping building with bracing at 4th floor using response spectrum in Y Direction (RSY)

3.2.8 Analysis of the building with soft storey on 15° sloping ground with bracing at 4th+8th floors

The storey displacement is reduced and it still can be reduced. The inter storey drifts are reduced at 4th & 8th floor but maximum storey drift are very high, thus have to be controlled.

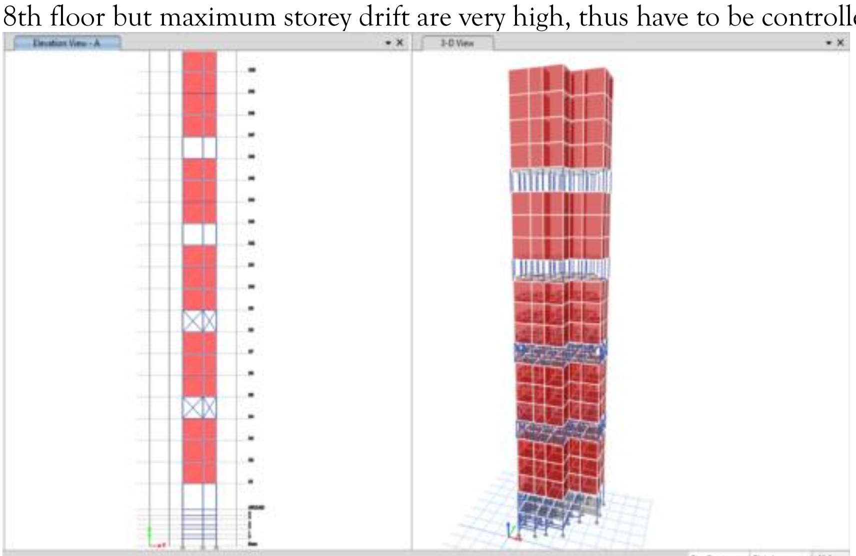

Fig 3.25: Elevation & 3D view of the building with bracing at 4th+8th floors on 15° sloping ground

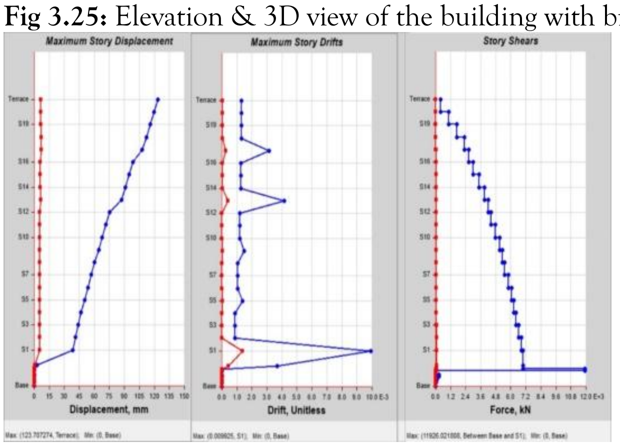

Fig 3.26: Analysis report of 15° sloping building with bracing at 4th+8th floor using response spectrum in X Direction (RSX)

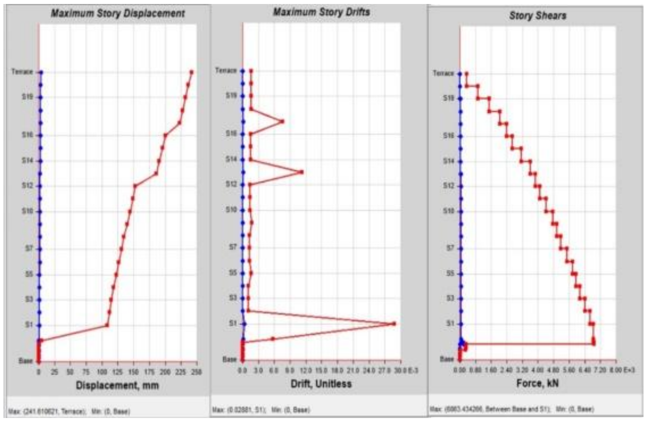

Fig 3.27: Analysis report of 15° sloping building with bracing at 4th+8th floors using response spectrum in Y Direction (RSY)

3.2.9 Analysis of the building with soft storey on 15°sloping ground with bracing at 4th+8th+12th floors

Bracings are been given at 4th, 8th & 12th floors and analyzed by using response spectrum method. The storey displacement is very much reduced and storey drifts at 4th,8th & 12th floor are also reduced but the overall maximum storey drift at S1 level is very high and it has to be controlled.

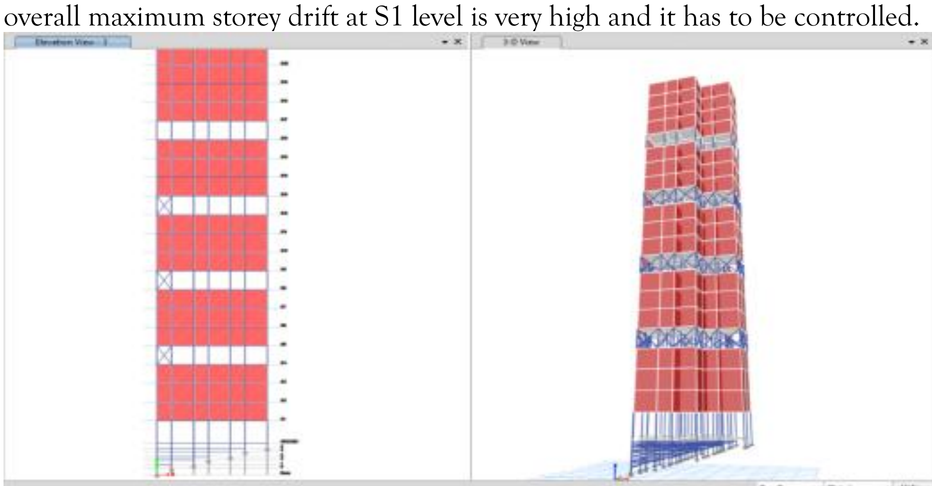

Fig 3.28: Elevation & 3D view of the building with bracing at 4th+8th+12th floors on 15° sloping ground

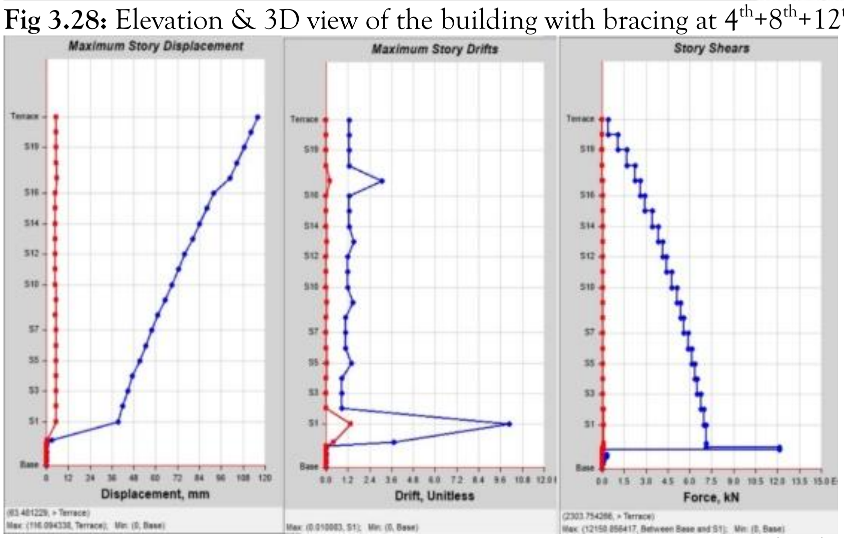

Fig 3.29: Analysis report of 15° sloping building with bracing at 4th+8th+12th floors using response spectrum in X Direction (RSX)

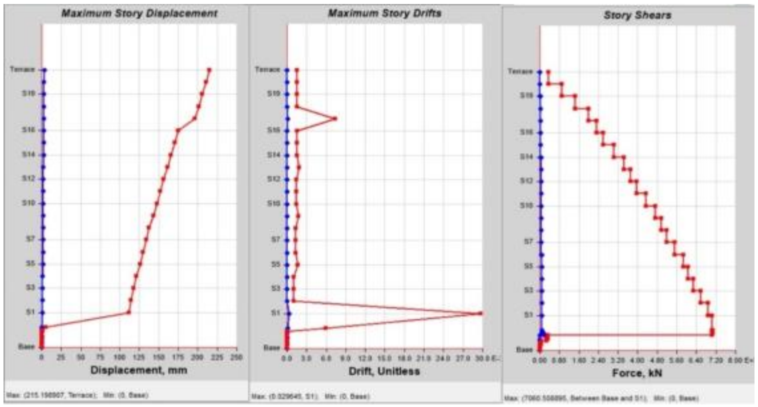

Fig 3.30: Analysis report of 15° sloping building with bracing at 4th+8th+12th floors using response spectrum in Y Direction (RSY)

3.2.10 Analysis of the building with soft storey on 15°sloping ground with bracing at 4th+8th+12th & alternate at (G+16th) floors

Bracings are been given at 4th, 8th, 12th and alternate bracings are given at G + 16th floors for response spectrum analysis. The storey displacement is brought to a very low level and the storey drifts are also reduced to the limit by installing bracings at each soft storey. Thus the structure is safe for living.

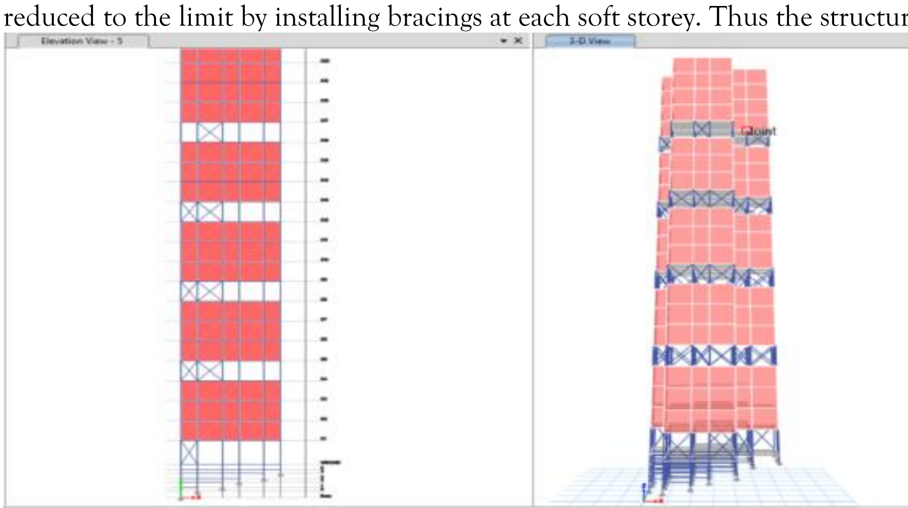

Fig 3.31: Elevation & 3D view of the building with bracing at 4th+8th+12th & alternate at (G+16th) floors on 15° sloping ground

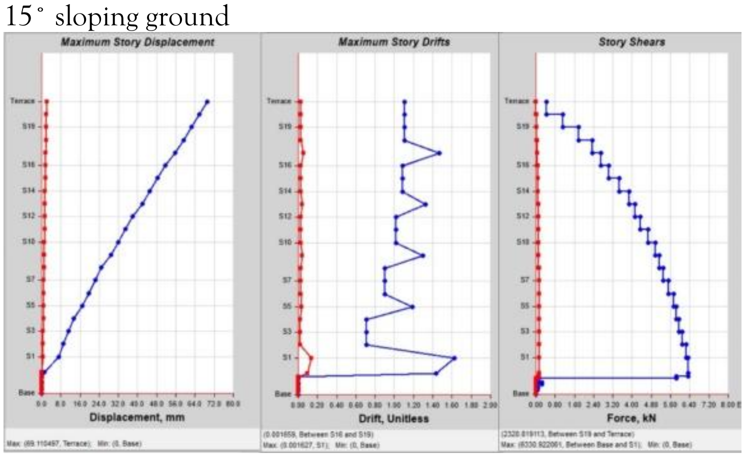

Fig 3.32: Analysis report of 15° sloping building with bracing at 4th+8th+12th & alternate at (G+16th) floors using response spectrum in X Direction (RSX)

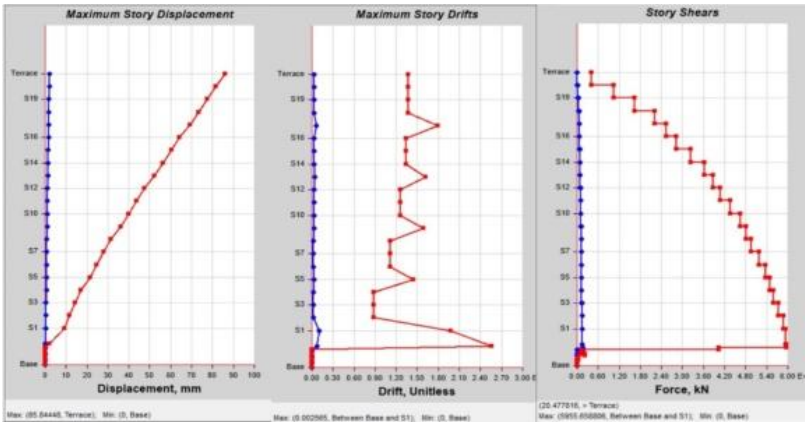

Fig 3.33: Analysis report of 15° sloping building with bracing at 4th+8th+12th & alternate at (G+16th) floors using response spectrum in Y Direction (RSY)

3.2.11 Analysis of the building with soft storey on 25°sloping ground without bracing

Height of the building is increased to 71.5944m. The storey displacement and the storey drifts are very high due to the absence of bracings at the soft storey level. Thus they have to be reduced.

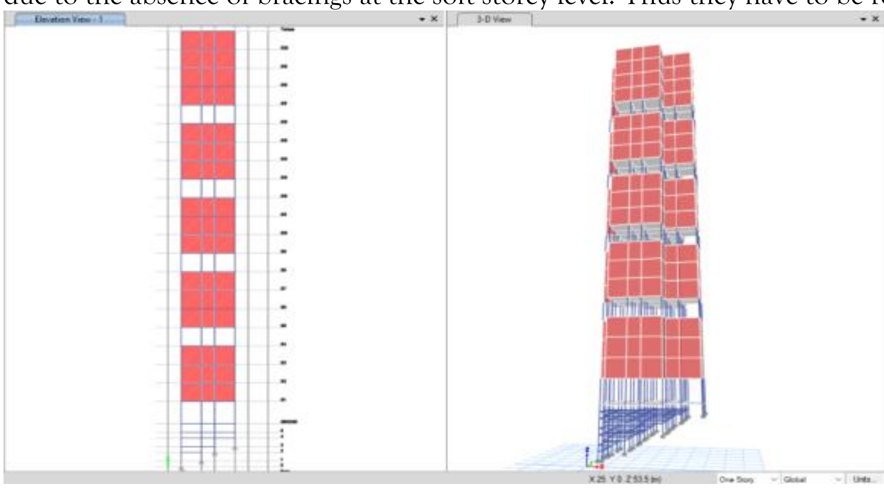

Fig 3.34: Elevation & 3D view of the building without bracing on 25° sloping ground

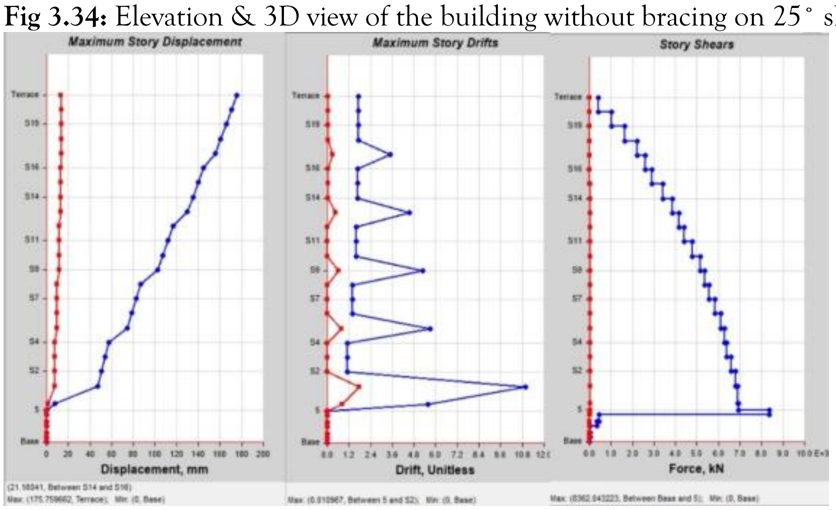

Fig 3.35: Analysis report of 25° sloping building without bracing using response spectrum in X Direction (RSX)

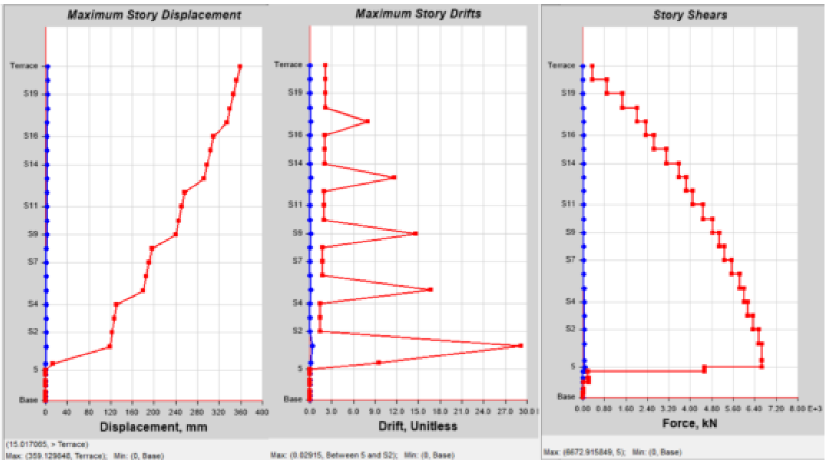

Fig 3.36: Analysis report of 25° sloping building without bracing using response spectrum in Y Direction (RSY)

3.2.12 Analysis of the building with soft storey on 25°sloping ground with bracings at 4th floor

Bracings are been given at 4th floor for response spectrum analysis. The storey displacement still have to be reduced and the inter storey drifts at 4th floor is reduced but the maximum storey displacement is very high that have to be reduced.

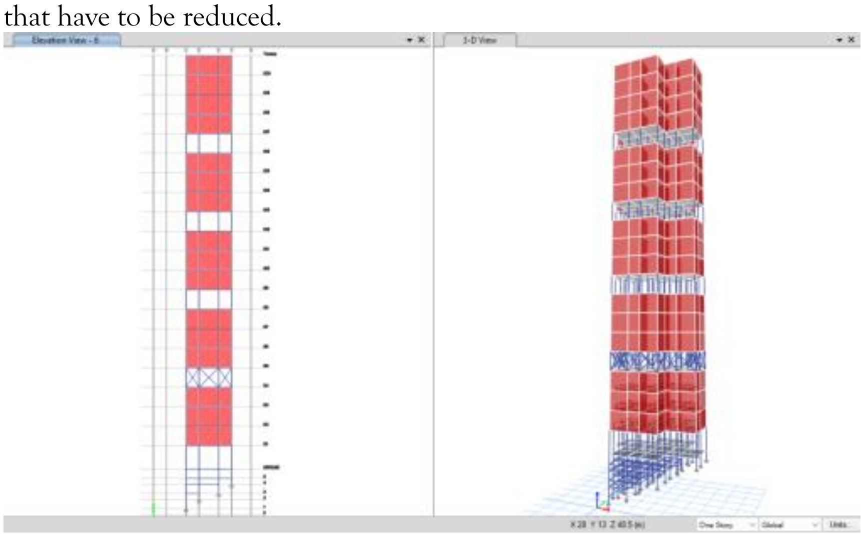

Fig 3.37: Elevation & 3D view of the building with bracing at 4th floor on 25°sloping ground

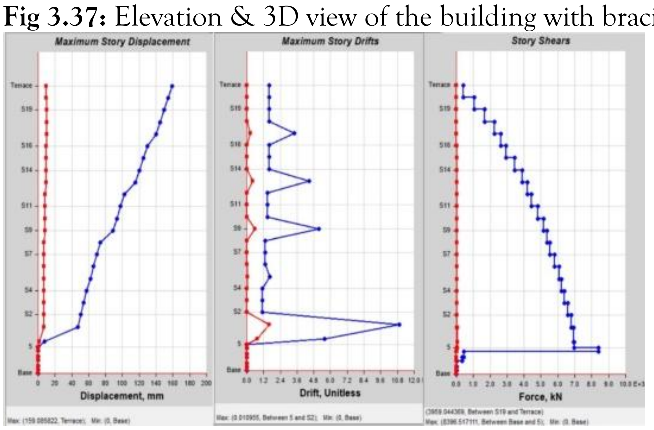

Fig 3.38: Analysis report of 25° sloping building with bracing at 4th floor using response spectrum in X Direction (RSX)

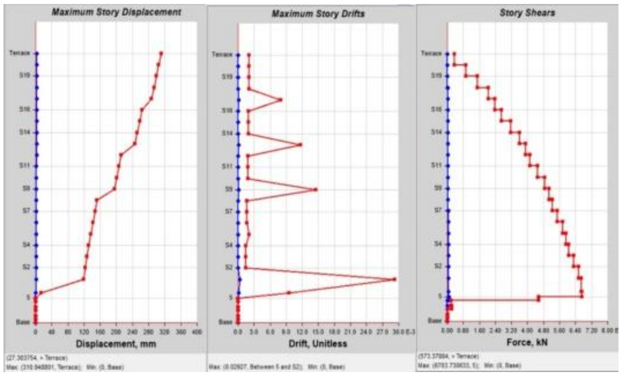

Fig 3.39: Analysis report of 25° sloping building with bracing at 4th floor using response spectrum in Y Direction (RSY)

3.2.13 Analysis of the building with soft storey on 25° sloping ground with bracings at 4th+8th floors

The storey displacement was reduced but the storey drift is yet very high and have to be reduced.

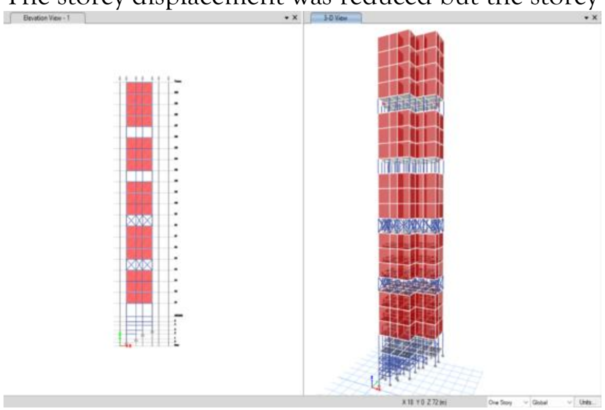

Fig 3.40: Elevation & 3D view of the building with bracing at 4th+8th floors on 25° sloping ground

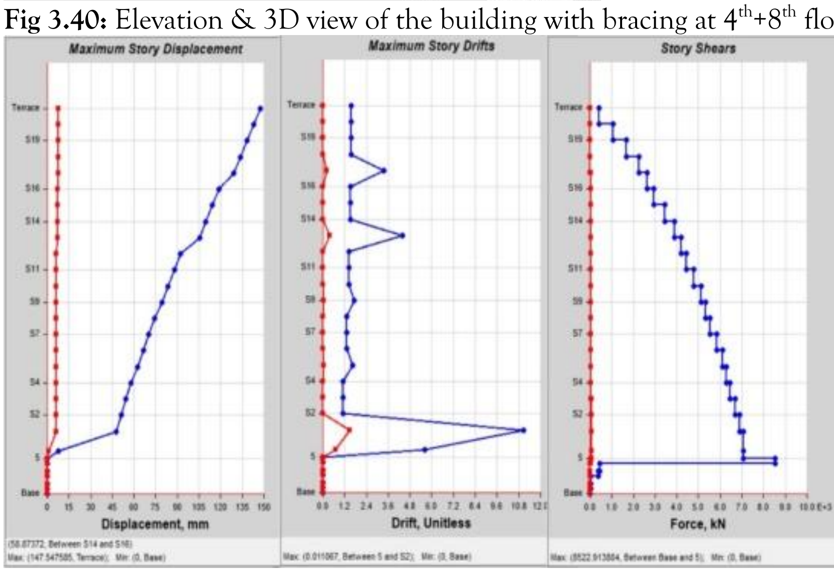

Fig 3.41: Analysis report of 25° sloping building with bracing at 4th+8th floors using response spectrum in X direction (RSX)

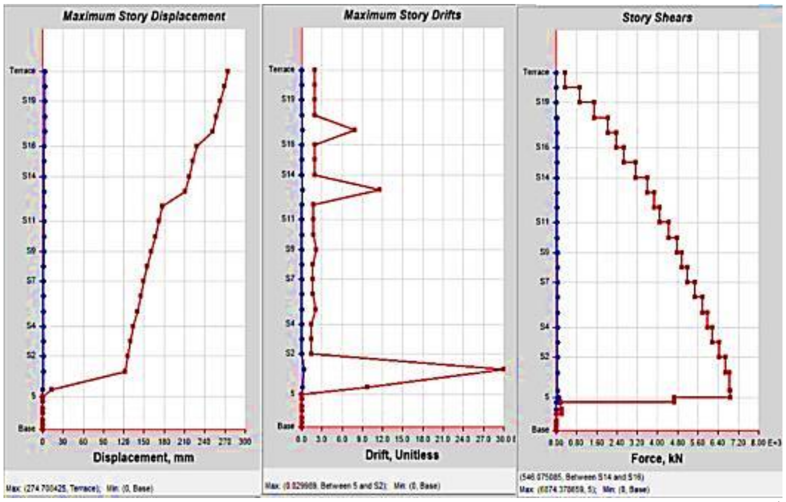

Fig 3.42: Analysis report of 25° sloping building with bracing at 4th+8th floors using response spectrum in Y Direction (RSY)

3.2.14 Analysis of the building with soft storey on 25°sloping ground with bracings at 4th+8th+12th floors

The storey displacements are at safer level, but the inter storey drifts are very high and have to be reduced.

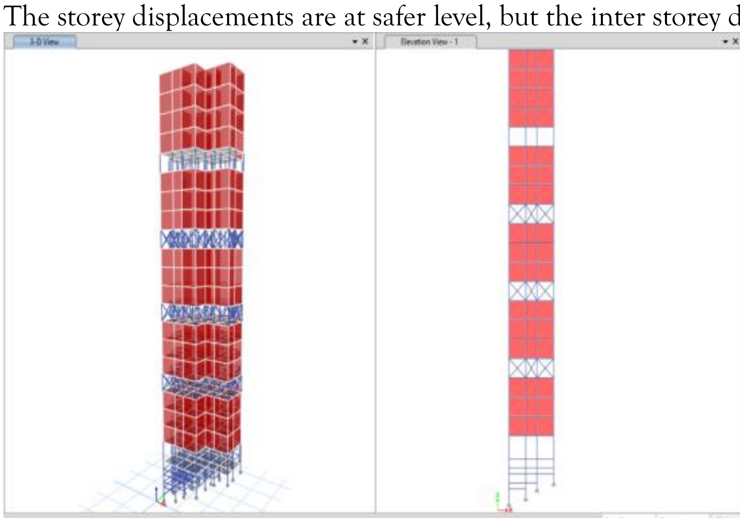

Fig 3.43 Elevation & 3D view of the building with bracing at 4th+8th+12th floors on 25°sloping ground

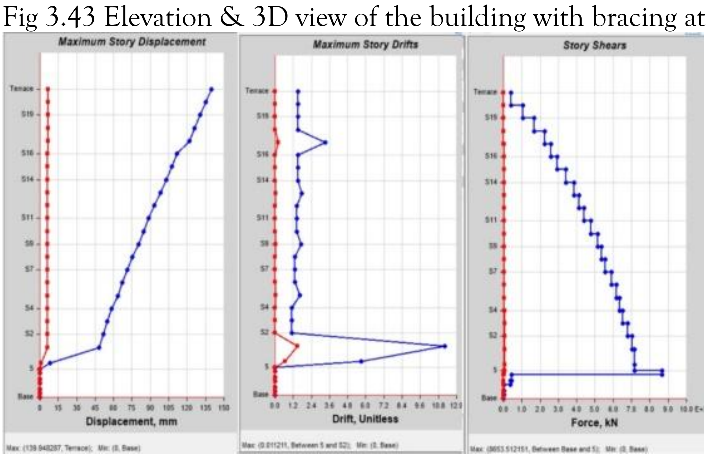

Fig 3.44: Analysis report of 25° sloping building with bracing at 4th+8th+12th floors using response spectrum in X Direction (RSX)

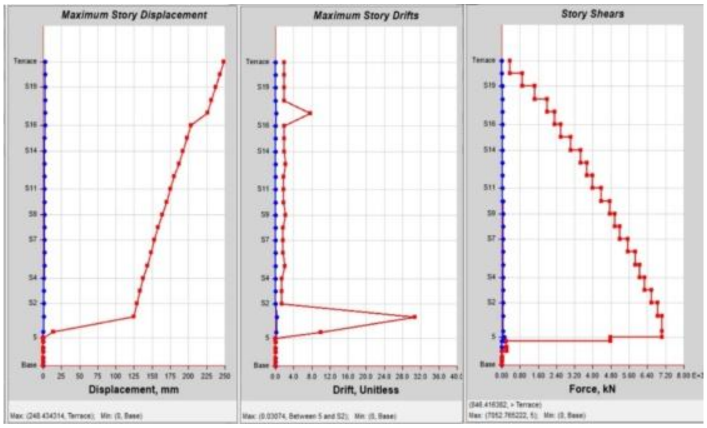

Fig 3.45: Analysis report of 25° sloping building with bracing at 4^{th}+8^{th}+12^{th} floors using response spectrum in Y Direction (RSY)

3.2.15 Analysis of the building with soft storey on 25°sloping ground with bracings at 4th+8th+12th & alternate at (G+16th) floors

Bracing are been installed at 4th, 8th, 12th and alternate bracings at G + 16th floors for response spectrum analysis. The storey displacement and inter storey drifts are reduced and brought it within their safer limit. Thus we can conclude that by installing bracings at soft storey we can reduce the displacement and drifts.

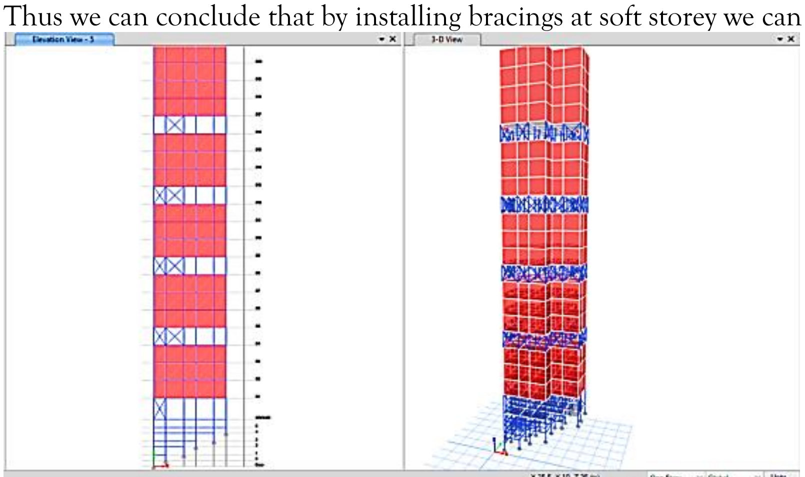

Fig 3.46: Elevation & 3D view of the building with bracing at 4^{th}+8^{th}+12^{th} & alternate at (G+16^{th}) floors on 25°sloping ground

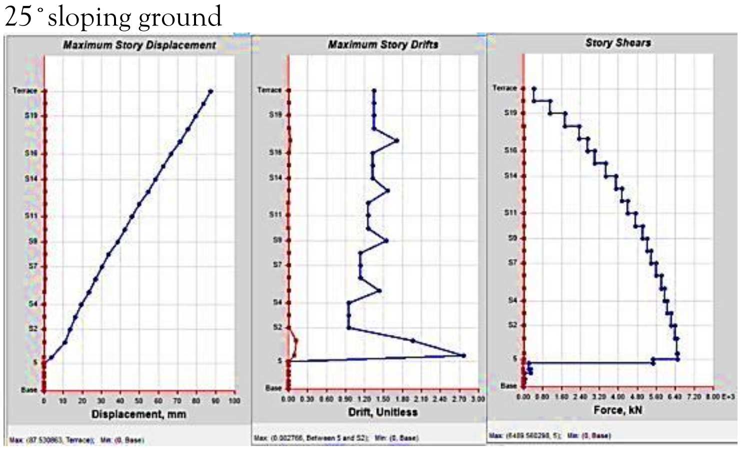

Fig 3.47: Analysis report of 25° sloping building with bracing at 4^{th}+8^{th}+12^{th} & alternate at (G+16^{th}) floors using response spectrum in X Direction (RSX)

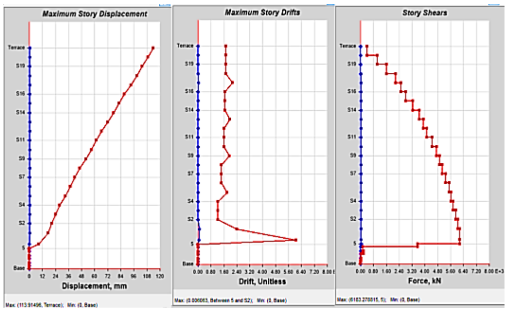

Fig 56: Analysis report of 25° sloping building with bracing at 4th+8th+12th & alternate at (G+16th) floors using response spectrum in Y Direction (RSY)

CONCLUSION

- The analysis found that bracings at the soft storey were an efficient way to control calculated base shear, drifts, and storey displacements.
- The initial maximum displacements for buildings at 5°, 15°, and 25° without bracing were 175.75 in RSX and 341.48 in RSY. In order to further minimize displacement, bracings were installed at all soft storey levels, attaining values below 100mm. Bracings were first used at the fourth and eighth stories. This decreased lateral displacements and increased storey stiffness.
- The installation of bracing ensured structural safety by reducing inter-storey drift values, which were initially high at 0.0109 in RSX and 0.029 in RSY.
- After bracing, the base shear values in RSX and RSY increased from 16.7023kN and 14.1103kN, respectively, to 20.5kN and 17.144kN, respectively.

These findings suggest that by reducing lateral displacements, inter-story drifts, and raising base shear values, bracings at soft storey levels strengthen the structure.

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