Non-Linear Pushover Analysis Over Sloping Ground for High Rise Building Using ETABS

Shankar G S[1], Koushik S[2]
[1]Assistant Professor, Department of Civil, SJM Institute of Technology, Chitradurga, Karnataka,
[2]PG scholar, Department of Civil, SJM Institute of Technology, Chitradurga, Karnataka, India
Email - [1] shankar.gs@sjmit.ac.in , [2] koushiks29346@gmail.com

Abstract: A common technique for assessing buildings' seismic resistance is pushover analysis, which is a kind of non-linear static analysis. Its attractive features include quicker modelling and simpler use compared to competing options. Pushover analysis is an essential tool for assessing both new and old structures. Reason being, big earthquake seismic demand cannot be predicted using linear analytical techniques. A multi-story G+10 building in seismic zones was subjected to a pushover analysis using the ETABS program. A better understanding of the building's behaviour under seismically generated pressures was achieved by the researcher by determining the maximum lateral moment and story displacement from the data.

Key Words: Pushover, sloping building, high rise, non-linear pushover, Etabs

1. INTRODUCTION

A two-stage procedure characterises seismic design. An effective structural system must be designed with proper respect to all the main seismic performance goals, including serviceability, life safety, and collapse prevention, and is often the first and most significant one. This is the most artistic part of seismic engineering, since the engineer's imagination is the only tool at his disposal to come up with a solution that satisfies the owner's, architect's, and other professionals' demands for a building's functional and financial constraints while simultaneously meeting seismic performance goals. Not formal mathematical formulation, but discretion, experience, and knowledge of seismic behaviour are the basic foundations of this creative process. An effective structural system may be roughly sized and configured using rules of thumb for stiffness and strength objectives derived from basic understanding of ground motion and elastic and inelastic dynamic response characteristics. In order to construct complex mathematical and physical models, a structural system must first be established. Such models are essential for assessing the current system's seismic performance and making adjustments to the behaviour characteristics of components (stiffness, deformation capacity, strength) to meet the performance requirements. Finding critical capacity parameters, prescribing acceptable values for them, and anticipating demands caused by ground motions are all part of the second step of design that should include a demand/capacity evaluation at all critical performance levels.

2. LITERATURE REVIEW

The design and analysis of high-rise buildings over sloping ground have become critical in earthquake engineering due to the complex interaction between the structure and the underlying soil. Non-linear pushover analysis (NPA) is a vital tool for evaluating the seismic performance of such buildings. This method allows for a detailed understanding of the structure’s behavior beyond the elastic limits, providing insight into potential damage under earthquake loading.

High-rise buildings built on sloping ground are subjected to additional challenges compared to those on flat terrain. The presence of sloping ground can lead to differential settlements and irregularities in the distribution of lateral forces, influencing the seismic performance of the structure. As noted by Kalkan and Kunnath (2006), the geometry of sloping terrains can significantly alter the distribution of forces and moments during an earthquake, making the analysis more complex compared to buildings on flat surfaces. They concluded that this irregular distribution affects the building’s dynamic characteristics and requires advanced analysis methods like NPA for accurate predictions.

Non-linear pushover analysis is increasingly employed for assessing the seismic response of buildings under earthquake loading. According to FEMA 440 (2005), NPA provides a simplified yet effective way to estimate the performance of structures by pushing them through a sequence of load increments, representing the behavior under increasing seismic demand. Unlike linear analysis, NPA accounts for material and geometric non-linearity, which are essential in capturing the inelastic behavior of structures during severe ground motion.

A study by Sadeghi et al. (2016) explored the application of NPA on buildings constructed on sloping ground. They demonstrated that when NPA is conducted using ETABS, it enables engineers to consider complex factors such as soil-structure interaction and non-linear material behavior, which are crucial for high-rise buildings situated on sloping sites. ETABS, with its advanced modeling capabilities, is particularly well-suited for simulating such complex interactions, allowing for a more accurate prediction of the building's seismic response.

ETABS is one of the most widely used software tools in structural engineering for the analysis and design of buildings. It provides comprehensive solutions for modeling, analyzing, and designing structures subjected to various loads, including seismic forces. According to Basu and Chopra (2007), ETABS supports both linear and non-linear analysis, including the pushover analysis, which is essential for evaluating the post-elastic behavior of structures.

A study by Baker et al. (2018) highlighted the effectiveness of ETABS in performing non-linear pushover analysis for high-rise buildings. The software's integration of advanced seismic modeling capabilities, such as the ability to simulate various types of damping, soil-structure interaction, and material non-linearity, is critical when analyzing buildings on sloping ground. Furthermore, Cai et al. (2020) emphasized that ETABS' ability to model irregular ground conditions, including sloping terrains, makes it an ideal tool for engineers tackling the challenges of sloped sit

3. MATERIALS AND METHODOLOGY

3.1 Need of pushover analysis

Pushover analysis is a nonlinear static method used in structural engineering to assess building seismic behavior. It tracks damage transmission through the structure, allowing engineers to determine vulnerable locations, estimate seismo loads, and predict earthquake response. This fast, easy-to-apply method captures inelastic deformations and failure modes, making it useful in existing buildings, performance-based design, and evaluating structural response in earthquakes. It helps improve building safety and performance.Pushover analysis is a reliable method for testing structural performance under seismic loads, capturing inelastic effects like plastic hinges and force redistribution. It helps engineers assess seismic occurrences and failure types, revealing where and when a building yields. It is applicable to both new and existing constructions, ensuring safety and effectiveness during earthquakes. Pushover analysis also aids in assessing seismic reinforcement in contemporary structures, identifying faults caused by older code sets and enhancing resource efficiency. It provides a more impartial assessment of a structure's seismic performance, improving safety, sustainability, and economics.

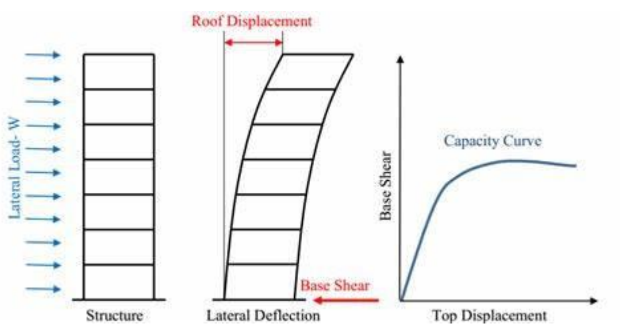


Figure 1Curves for the push over.

3.2 Force-Deformation Characteristics

Force-deformation parameters describe how a structural element or system responds to force or load, focusing on the force deformation curve. Understanding these parameters is crucial for studying seismic loads on structures. The yield point and plastic deformation occur when the structure yields and sustains a permanent strain. Strain hardening after yielding increases structure strength, while maximum strength and failure indicate damage or collapse. Hysteresis behavior, caused by energy loss through inelastic deformation, affects seismic performance. Understanding force-deformation behavior is essential for designing structures in seismically active zones to withstand external loads, ensuring stability under stress, and protecting lives and property during earthquakes.

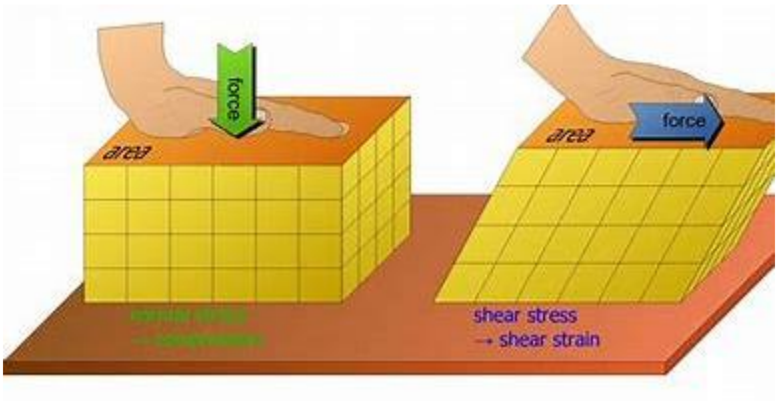


Figure 2Force deformation characteristics.

3.3 Pushover Analysis and Pushover Curve

Pushover analysis is a nonlinear static method used to estimate building seismic response, considering inelastic material behavior as the structure is loaded with increasingly laterally acting forces. It helps engineers evaluate susceptibility at weak regions, likelihood of progressive collapse, and other design or retrofitting issues. The capacity curve, or pushover curve, graphs pushover analysis results, showing the structure's design to handle growing seismic loads.

3.4 Methodology

Research is implemented on two regions of ground first on flat and another model on sloping ground as shown in Fig 3.

This project must contain everything below: Multistory buildings with varied slope angles (0°, 10°, 20°, 30°) seismically analysed using ETABS. Buildings are built and tested according to RC building standards using Special Moment Resisting Frames. R = 5, I = 1.0, medium soil type (Type I) locations experience seismic stress in zone III.

The main steps are:

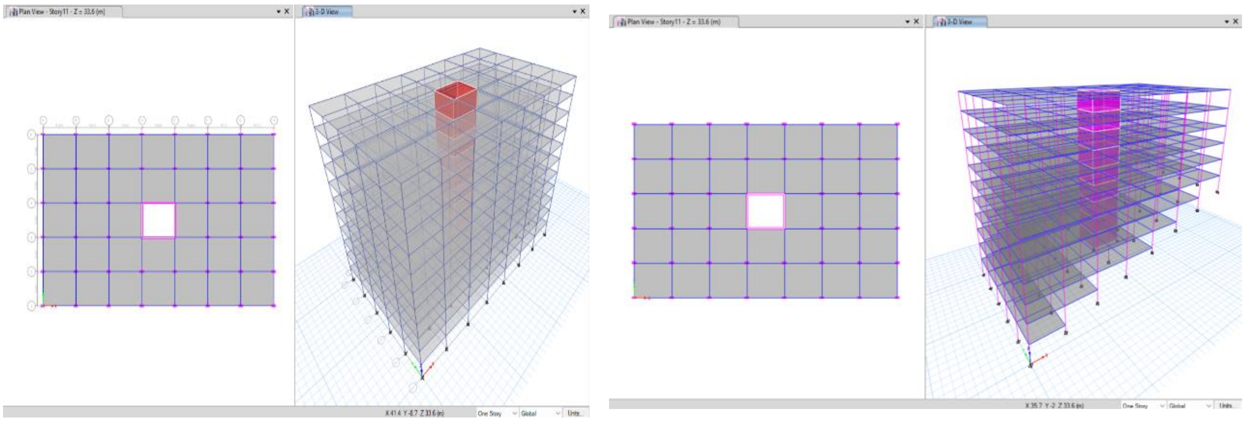
1. 3D Modelling: Create accurate active RC frame building models in the etabs utilising tilt conditions 0, 10, 20, and 30.

2. Seismic Loading Application: IS1893 (Part I) requires considering the site's seismic category, soil type, and building layout when calculating seismic loads.

3. Response Spectrum Analysis: All building layouts must be studied to determine earthquake performance.

4. Load Assignments: Regulations and best practices must be followed when assigning normal and concentrated loads (dead, live, seismic, etc.).

5. Analysis and Conclusion: Running ETABS models is necessary to compare slope affects and determine the structure's seismic reactivity. Finally, assess seismic performance and stability for each design.



a) b)

Figure 3 a) Model 1 on flat ground b) On sloping ground

Table 4.1 details the etabs model, a 10-story structure with eight bays facing the X-axis and six bays facing the Y-axis, with 6 and 5 meters spacing respectively.

Table 1 Model-1 data for base model

No. of Bays in X & Y Direction	8 Bays X 6 Bays
Spacing in X & Y Direction	X Direction = 6m Y Direction = 5m
Storeys	G+10 Storey
Material Grade	Concrete – M35 Rebar – Fe500
Member Sizes	Column – 400x750 Beam – 400x600 Slab – 175 Thk.
Load Details	Live load = 3 kN/m2. Floor Finish = 1.5 kN/m2
Seismic Analysis	Equivalent Static Analysis Pushover Analysis

3D view of building constructed in etabs for simulation and testing is as shown in the Fig 4

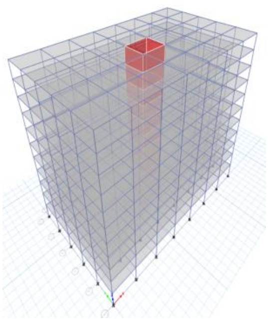


Figure 4 3D view of building

Plan view is an aerial perspective of a building's layout, including floors, rooms, walls, doors, windows, and other structural elements, allowing easy understanding of the floor's development style is as shown in Fig 5.

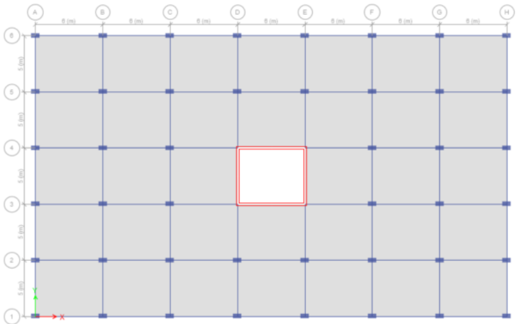


Figure 5 Plan view of building

An elevation view is a vertically drawn representation of a building's side, highlighting height, features, and characteristics, providing a visual representation for facade and overall view improvement and it is as shown in below figure

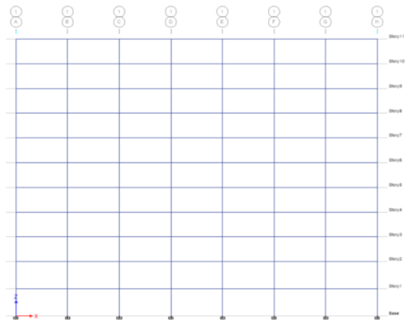


Figure 6 Elevation view of building

4. RESULTS AND DISCUSSION

Grade of concrete employed is M35 and load patterns are Dead Load (DL) refers to the fixed load on a structure after construction, including its own weight and attached structures. Live Load (LL) considers occupancy load and fixtures. Floor Finish (FF) is extra load caused by floor finishes. Earthquake Load X (EQX) and Y (EQY) are lateral loads based on seismic codes. Load cases determine the structure's stability under its own weight, live load impact, floor finish load case, and seismic load cases (EQX and EQY) for earthquake performance assessment.

Shape of building changed after applying different types of loads on it and deformed shape due to different conditions are shown below,

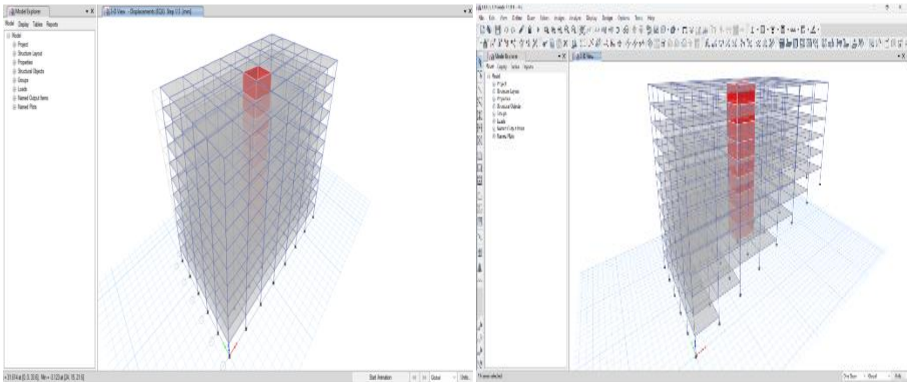


Figure 7 Deformed shape

Diaphragm CM measures the floor slab's horizontal displacement under EQY forces, indicating the building's potential earthquake-induced bending along the Y-axis and it is as shown in Fig 8.

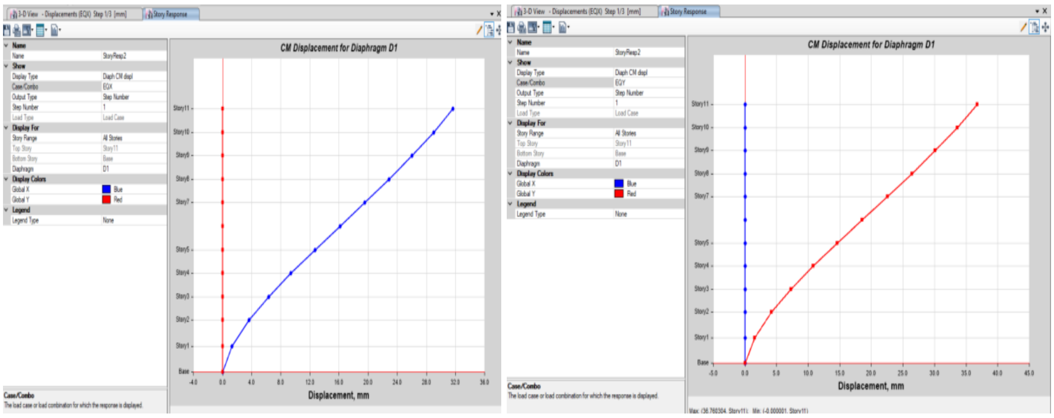


Figure 8 Diaphragm CM displacement in EQ X & Y

The DRIFT-EQX function measures lateral displacement during an earthquake, revealing horizontal movement caused by earthquake loads. Storey shear, or EQX, reveals the X-direction force on each level of a building, affecting its seismic response and susceptibility and it is as shown in Fig 9

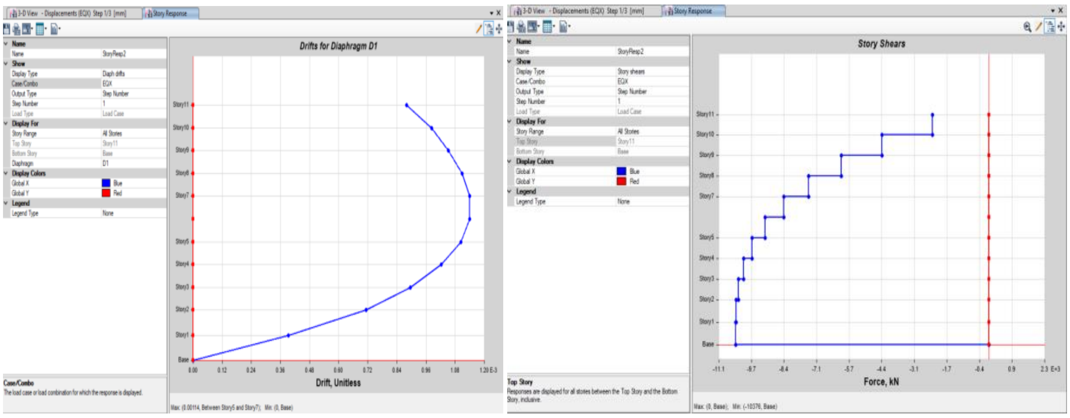


Figure 9 Drift EQX and Storey shear EQX

For result and analysis, tests conducted is time period, Equivalent static analysis, displacement, storey drift, base share and storey shear in both X, Y direction. Lastly Pushover analysis is carried on X and Y.

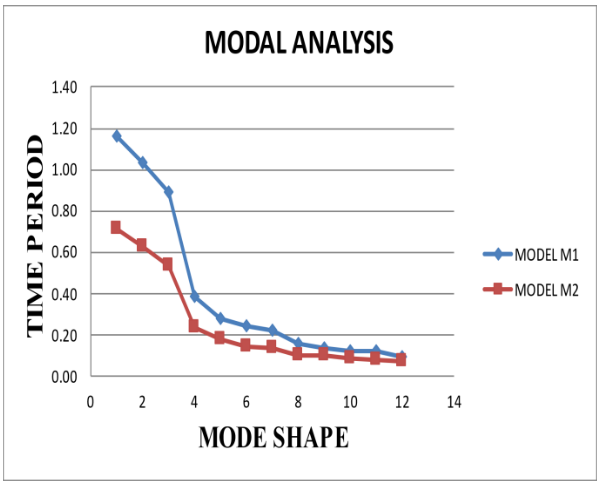
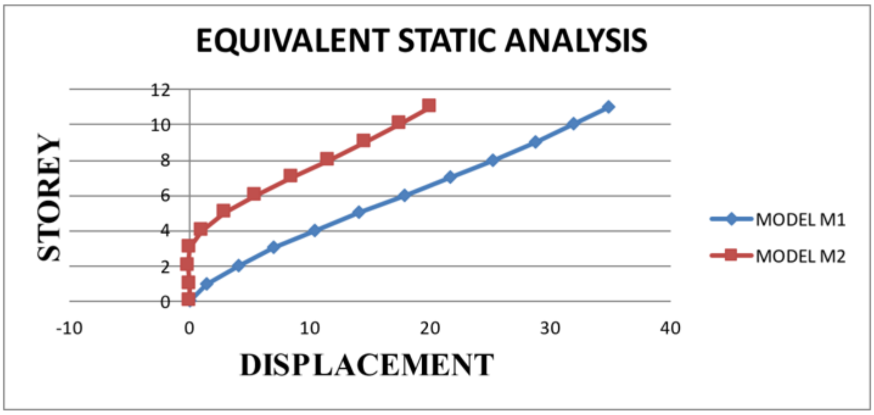


Figure 10Mode vs Time Period

Both structures experience the most displacement on Storey11, the terrace, with Model M1 experiencing more than Model M2. Sloping buildings show less displacement compared to flat-ground buildings as showed in Fig 11



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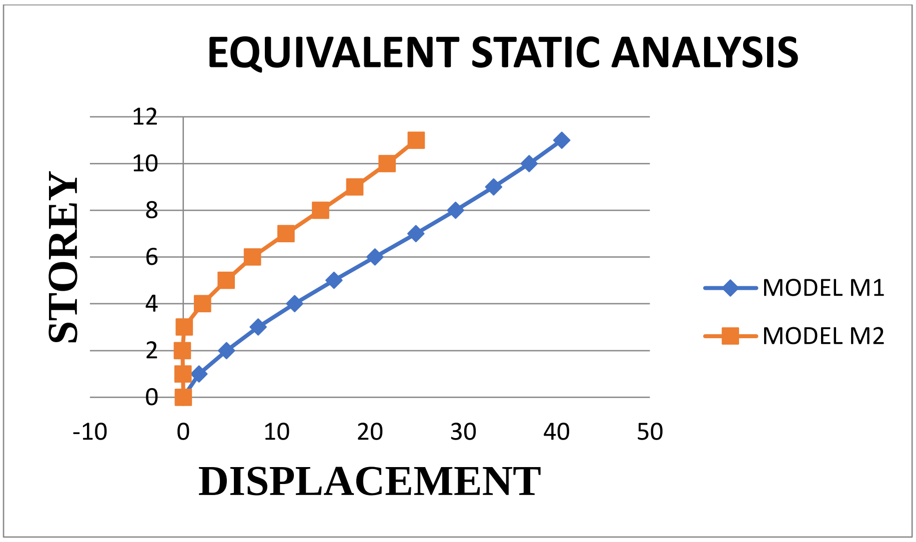
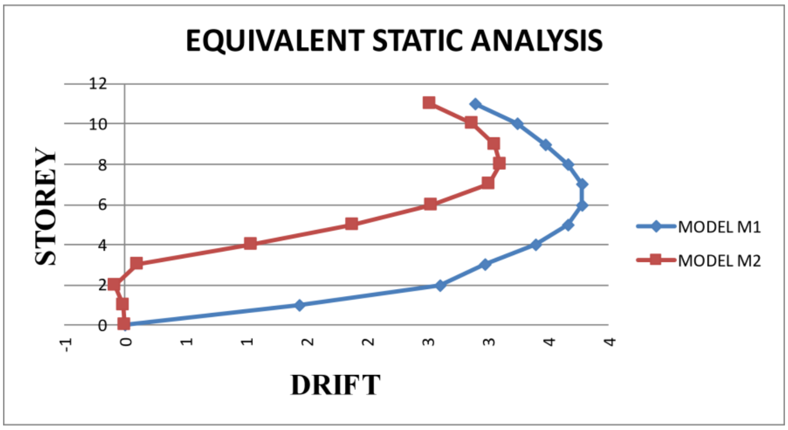


b)

Figure 11 a) Displacement vs storey in X direction b) Displacement vs storey in Y direction

Almost identical drift values were found for two structures, but model M2 exhibits drift reversal in sloped ground, causing the lower storey to displace more than the upper as showed in Fig 12.



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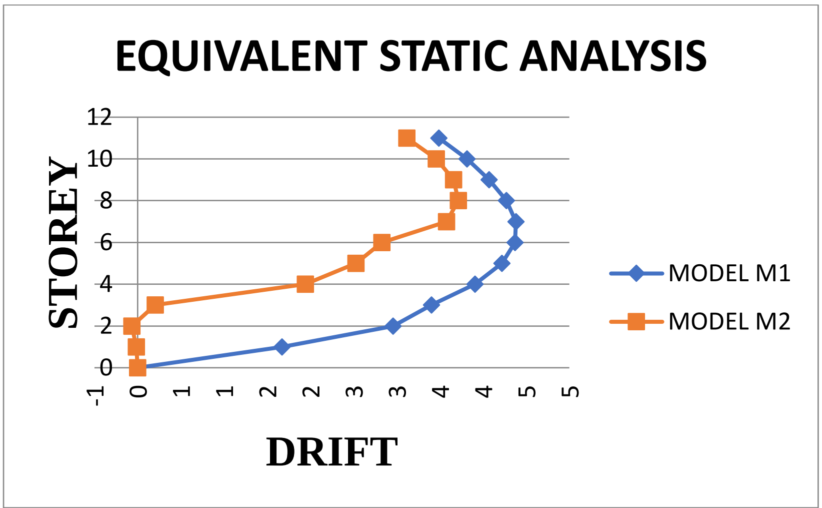

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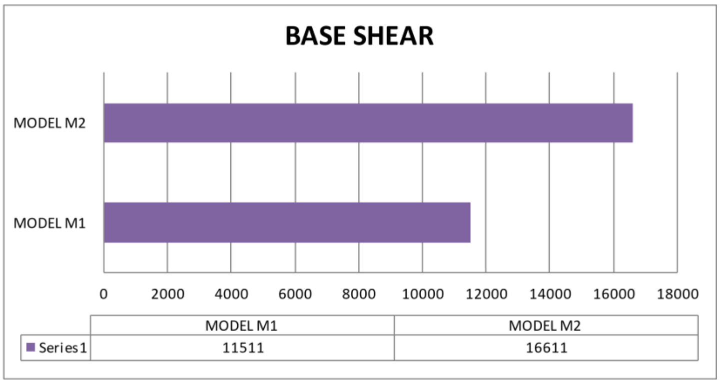
Figure 12 a) Storey Drift vs Storey in X direction b) Storey Drift vs Storey in Y

The table shows that Model M2 is the most vulnerable to seismic effects, requiring a more robust seismic-resistant design. Compared to level ground buildings, those on slopes are more likely to collapse after an earthquake, highlighting the need for seismic-resistant construction as showed in Fig 13.



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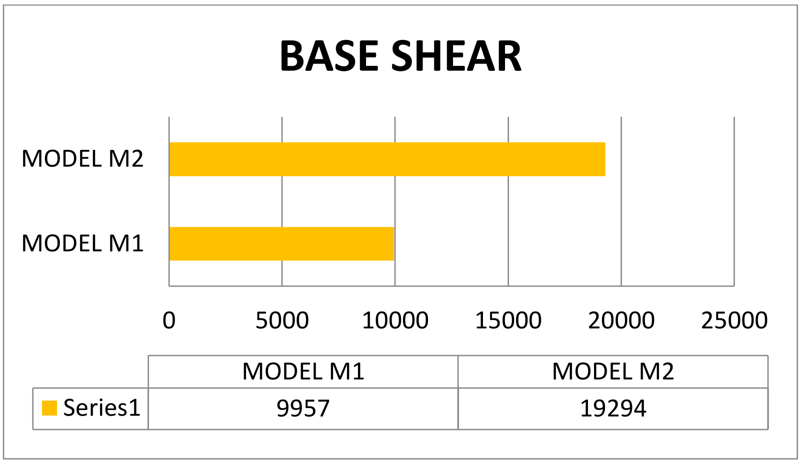

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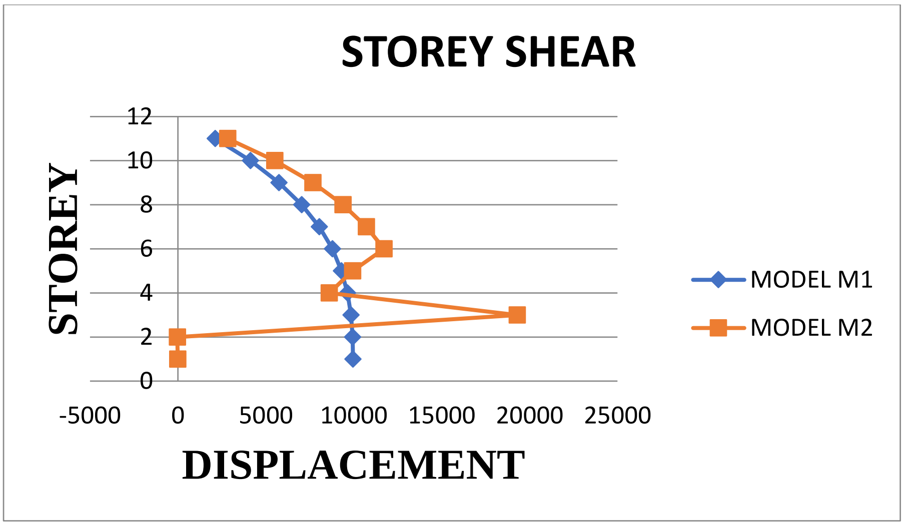
Figure 13 a) Base Shear in X Direction b) Base Shear in Y Direction

The table reveals that Model M1's storey shear in the X-direction is linearly varying, while Model 2's shear varies nonlinearly across different storeys as showed in Fig 14.



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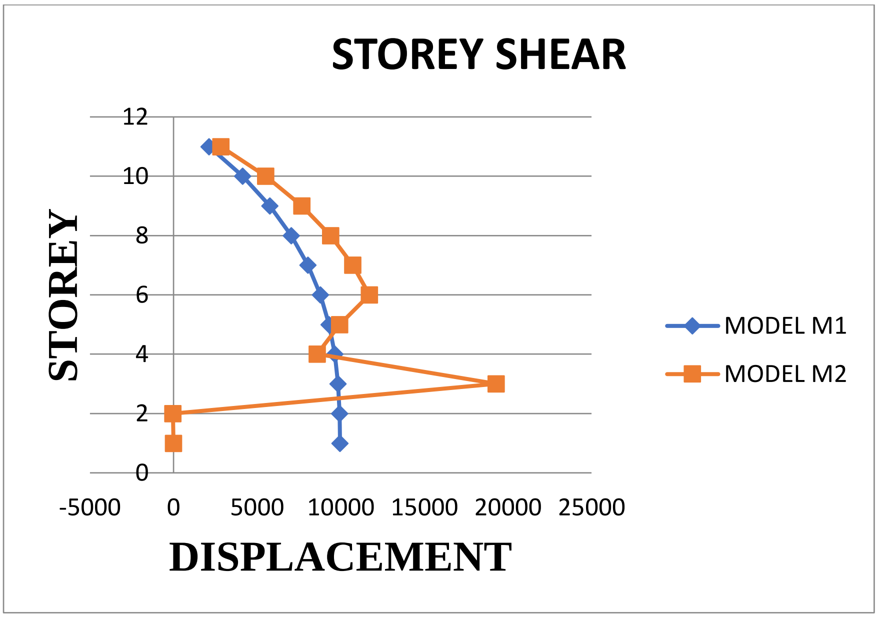
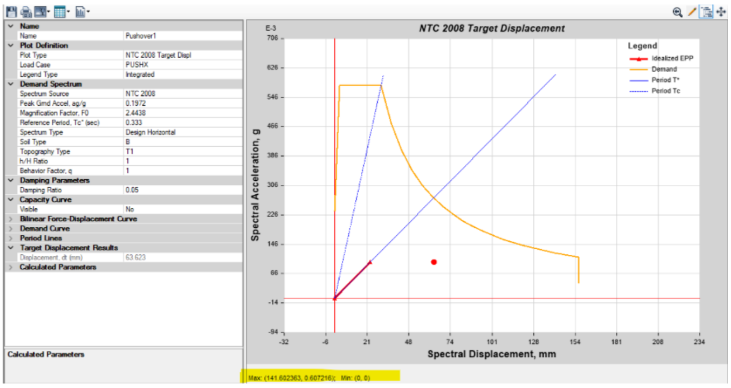


b)

Figure 14 a) Base Shear in X Direction b) Base Shear in Y Direction

The Model M1 is stronger at a 607mm displacement, capable of withstandng up to 141 kN in shear force, while the Model M2 can only withstand 42 kN showed in Fig 15.



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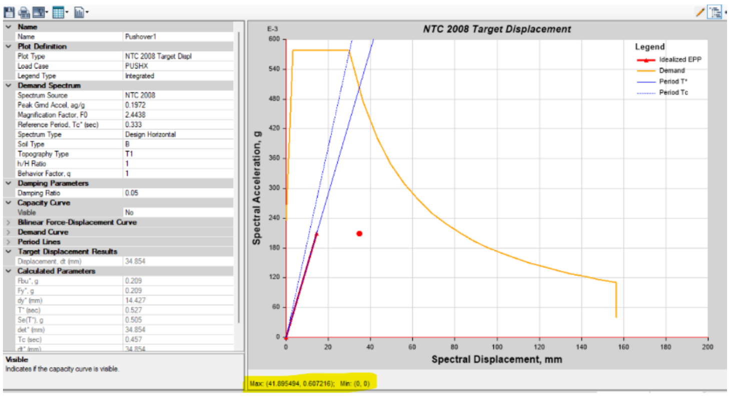

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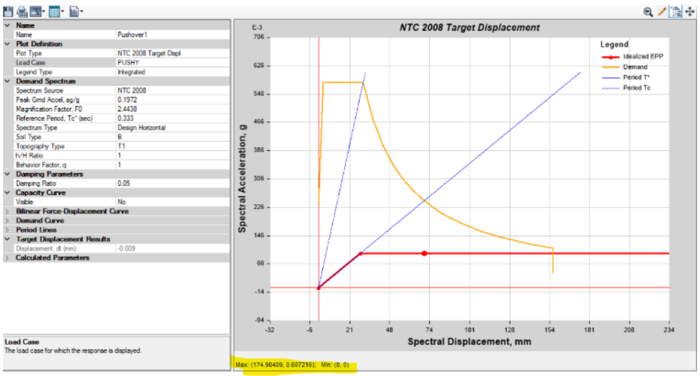
Figure 15 a) Performance point for PushX for model1 b)Performance point for PushX for model2



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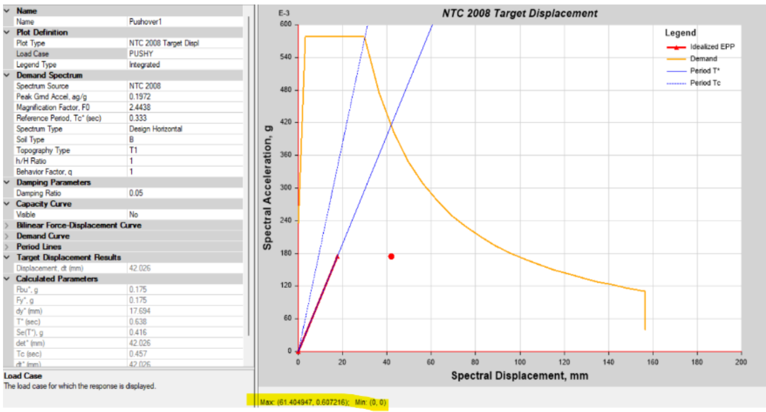

b)

Figure 16 a) Performance point PushY for Model1 b) Performance point PushY for Model2

Model M1 exhibits greater strength than Model M2 at 607mm displacement, capable of absorbing up to 175 kN of shear force in the Y direction showed in Fig 16.

5. CONCLUSION

The analysis reveals that Model M1 has a longer duration and greater flexibility compared to Model M2, which is built on level ground. The Y direction displacement is larger due to shorter dimensions. Storey drift is lower than allowed limits, but Model M2's reversal highlights the need for extra design considerations. Model M1 does not include storey shear, but Model M2 does in some circumstances. Model M1 outperforms Model M2 in the Pushover test due to greater shear force carrying capacity. Future scope can be further enhanced by performing a more dynamic analysis and modeling and comparing high-rise buildings.

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