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Analysis of Soft Storey Mechanism with Advanced Structural Configurations

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Abstract - *The presence of soft storeys in multi-storey building has been a critical concern in structural engineering, especially under seismic loading conditions. A soft storey, typically characterized by a significant reduction in stiffness or strength compared to adjacent storeys, often occurs due to architectural requirements such as open ground floor for parking. These irregularities can lead to catastrophic failures during earthquakes. This project focuses on the detailed analysis of soft storey behavior in a 15-storey reinforced concrete building using ETABS software. Loads are applied according to IS 875 for gravity loads and IS 1893 for Earthquake forces. Various advanced structural configurations such as bracings, Blade columns are incorporated to mitigate the adverse effect of soft storey mechanisms. Comparative studies are performed between conventional and improved configurations to assess changes in parameters like inter-storey drift, base shear, lateral displacement. The study aims to understand how different design configurations can improve the structural performance and overall stability of buildings with soft storeys. This research highlights the importance of early identification of soft storey vulnerabilities through computational modelling and analysis, ultimately contributing to safer building practices.*

Key Words: **Soft storey, Seismic, ETABS, Bracing, lateral Stiffness, Drift**

1.INTRODUCTION

Soft storey failures in multi-storey buildings have become a major concern in seismic-prone regions. A soft storey typically occurs at the ground level due to open spaces for parking or commercial use, leading to reduced stiffness and strength in that storey. This irregularity can cause severe structural damage or collapse during earthquakes. This project aims to analyze the behaviour of a 15-storey reinforced concrete building with a soft storey using ETABS Software. According to the seismic code IS 1893 (Part 1): 2016, a soft storey is mentioned as one whose lateral stiffness is less than 70% of that of the storey immediately above it or less than 80% of average lateral stiffness of the three storeys above.

1.1 Soft Storey Mechanism:

In many multi-storeyed buildings, the ground floor is often designed with fewer partition walls or open spaces for parking or commercial use. This results in a significant difference in stiffness between the ground level and the upper floors, which typically have more infill walls. This stiffness irregularity causes the upper storeys to behave as a rigid unit, while the ground storey experiences most of the lateral displacement during an earthquake. Such a condition, commonly referred to as a "soft storey" leads to excessive movement at the base of the structure, creating a swaying effect similar to that of an inverted pendulum. This amplifies the seismic force on the ground floor columns and beams, making them highly vulnerable. To ensure structural safety, it is crucial that these elements are designed with sufficient strength and ductility to resist such dynamic effects.

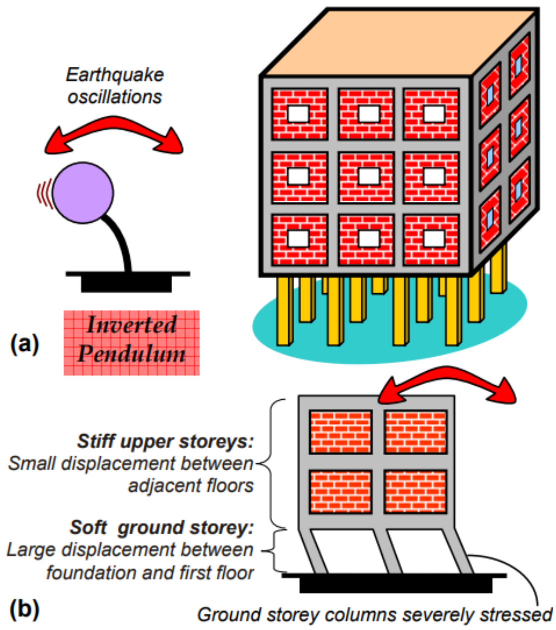

Fig -1: Soft Storey Mechanism

1.2 Purpose of the research:

The primary purpose of this research is to conduct a comprehensive analysis of the seismic performance of reinforced concrete buildings incorporating a soft storey at the ground level. Soft storeys, typically characterized by significantly reduced stiffness due to open spaces or weaker lateral load resisting elements, are highly vulnerable to seismic forces and have been a major cause of structural failure in past earthquakes.

This study utilizes ETABS Software to perform a Dynamic analysis of multi-storeyed RC Structures with soft storey, focusing primarily on two configurations one is concrete bracing and other one is with blade columns. These two design strategies are selected for their practicality and effectiveness in modifying the lateral stiffness. The research aims to assess and compare the seismic response of soft storey buildings in their original and modified forms, examining critical parameters such as inter storey drift, base shear, displacement profiles and modal behavior. Through this comparative study, the objective is to determine which configuration provides better performance under suitable structural recommendations for mitigating soft storey effects in future designs.

Ultimately, the study aspires to contribute to safer structural practices in earthquake-prone regions by offering data-driven insights and practical solutions to the engineering challenges posed by soft storey configurations.

2. Literature Review

The behaviour of soft storey structures under seismic loads has been a significant focus of recent research.

[1] Teba salim Ibrahim & Halla Jasem Mohammed(2024) – Effect of soft storey locations on the Nonlinear Time History analysis of Multistoreyed Reinforced concrete Buildings, Civil and Environmental Engineering.
In this paper investigated the influence of soft storey locations on the non linear time history analysis of multistoreyed reinforced concrete buildings. Their work highlights how the placement of a soft storey can critically affect the dynamic response and vulnerability of a building during an earthquake.

[2] A.A. Mali & P.M. Mohite (2023)- Seismic behavior of building with soft storey: Review, International journal for Research in Applied Science & Engineering Technology.
In this research conducted a comprehensive review of the seismic behavior of buildings with soft storeys. They emphasized the need for a deeper understanding of failure mechanisms, suggesting that the presence of a soft storey can severely compromise the overall seismic resilience of structures.

[3] Trishir Patel & Milli Shakhla (2024)- Seismic performance of soft storey Building with Dampers, International Research journal of Engineering and Technology.
Explored the performance of soft storey buildings enhanced with dampers. Their findings demonstrate that the incorporation of dampers can significantly improve seismic performance by controlling displacement and reducing structural damage.

[4] Akshay Shaji et al. (2019) – Seismic Analysis of Soft storey Buildings, International Journal of Scientific & Engineering Research.
Analyzed the seismic performance of soft storey buildings, identifying critical issues such as increased inter storey drift and vulnerability to collapse under seismic excitation. Study reinforces the importance of robust design approaches to ensure safety.

[5] Pravesh Gairola & Sangeeta Dhyani(2019) – Seismic analysis of open soft storey Building for Different Models, International Journal of Engineering Research & Technology.
Study focused on the seismic analysis of open soft storey buildings for different models. Their results suggest that various design modifications can influence the dynamic characteristics and help in achieving better seismic performance for such structures.

3. STRUCTURAL ANALYSIS

Three distinct models were selected for the analysis.

- Model 1 : Structure with soft storey
- Model 2 : Structure with Concrete brace at corners
- Model 3 : Structure with blade columns

A structural model of a 15-storey building was modelled, featuring bays spaced 5m apart and an uniform floor plan. The base of the structure considered as rigid. Modelling and analysis were done using the ETABS Program. The study focused on evaluating the structural behavior by examining inter-storey displacement, drift and base shear along X and Y axes. Design parameters, including dimensions and loading, were determined based on the provisions of IS 456:2000 and IS 875.

Table -1: Structure Data

1	Structure Dimensions	20m x 20m
2	Occupancy	Commercial
3	Number of Floors	15 Floors (Stilt+14 Floors)
4	Floor Height	3m
5	Column Size	450x450mm
6	Beam Size	300x450mm
7	Slab Thickness	150mm
8	Beam Size	300x450mm
9	Grade of Concrete	M30
10	Grade of Steel	Fe500

11	Dead Load	Self weight
12	Wall Load including Plaster	20 kN/m³
13	Live Load	4 kN/m²
14	Seismic Zone	IV
15	Site Type	II
16	Zone Factor	0.24
17	Importance Factor (I)	1.0
18	Response Reduction Factor	5
19	Damping Ratio	5%
20	Analysis	Dynamic Analysis

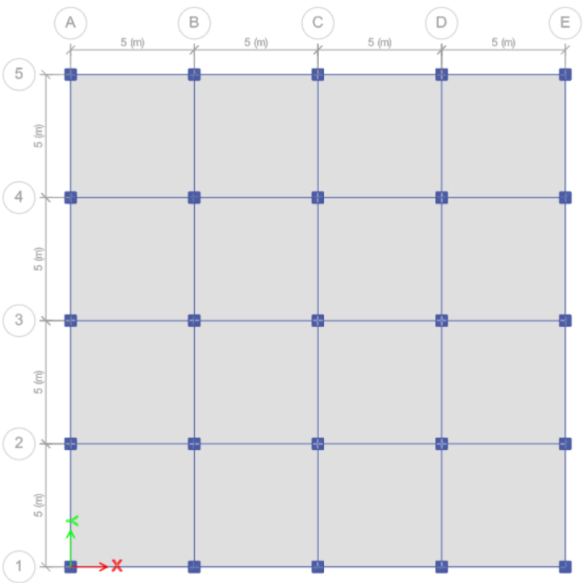

Fig -2: Plan Dimension of the structure

3.1 Model 1- Structure with soft storey:

The ETABS model consists of a 15-storey reinforced concrete moment-resisting frame building with a soft storey at ground floor. Floor to Floor height is 3m, columns are modeled as 450mmx450mm sections and beams as 300mmx450mm sections. DL and LL loads are applied as per IS 875 (Part 1& 2), and seismic loads are assigned according to IS 1893 (Part 1) for seismic zone IV. Both static and Dynamic analyses (Response Spectrum) are conducted. The base is considered as Rigid, and slabs are modeled as membrane elements.

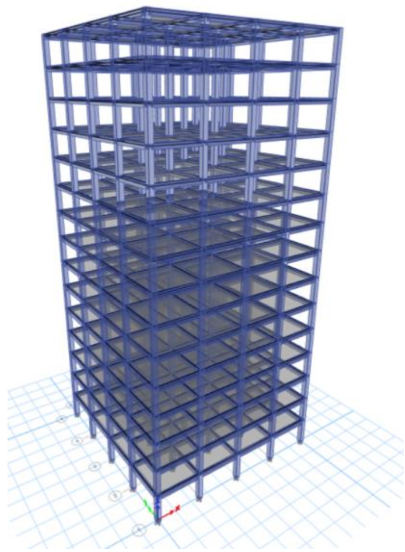

Fig -3: 3D rendered view of Model-1 : Structure with soft storey

3.2 Model 2-Structure with Concrete brace at corners:

In this model, additional concrete braces are provided at the corners of the soft storey to enhance lateral stiffness and improve seismic performance. The diagonal braces are modelled with appropriate cross sectional properties. These braces are connected between adjacent columns and beams at the soft storey corners for first two storeys. The inclusion of braces is expected to mitigate excessive lateral displacements and inter-storey drifts in the soft storey level. The diagonal braces act primarily in compression during seismic events, resisting lateral forces effectively and preventing large deformations at soft storey level.

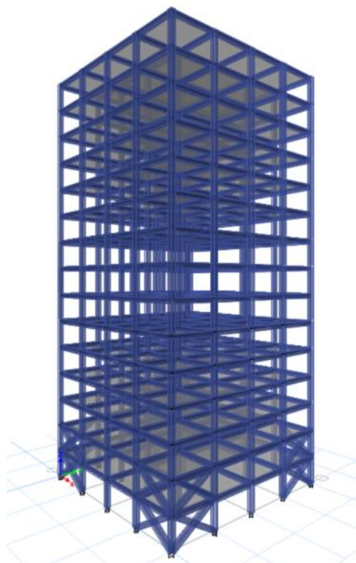

Fig -4: 3D rendered view of Model-2 : Structure with concrete Brace at corners

3.3 Model 3-Structure with blade columns:

The conventional square column are replaced with blade columns to enhance the lateral stiffness and strength of the structure. The blade columns, being elongated in one direction, are more effective in resisting lateral loads and thus improve the seismic performance, particularly at the soft storey level. The blade columns are modelled with dimensions of 750mmx300mm, oriented to provide maximum resistance against the expected direction of seismic forces.

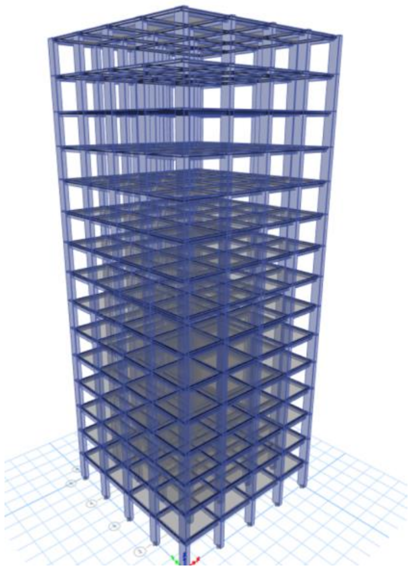

Fig -5: 3D rendered view of Model-3 : Structure with Blade columns

4. Outcome of Analysis

A detailed comparative analysis of the three models – Model 1 (structure with soft storey), Model 2 (structure with concrete diagonal braces at corners) and Model 3 (structure with Blade Columns) was performed using ETABS software. Static and dynamic analysis were performed as per IS 1893 (Part 1). The following key parameters were evaluated:

4.1 Storey Displacement:

Model 1 : Exhibited the maximum lateral displacement due to the flexibility of soft storey. The displacement profile was irregular, showing a sudden increase at the soft storey level.

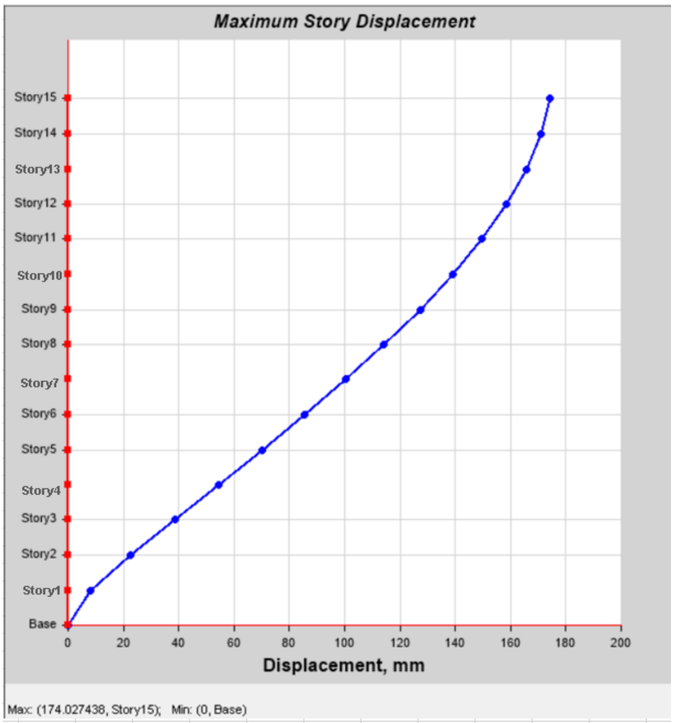

Chart -1: Max. Displacement of Model-1 : Structure with Soft Storey

Model 2: showed a significant reduction in lateral displacement due to increased lateral stiffness provided by the diagonal concrete braces. The displacement profile became smoother.

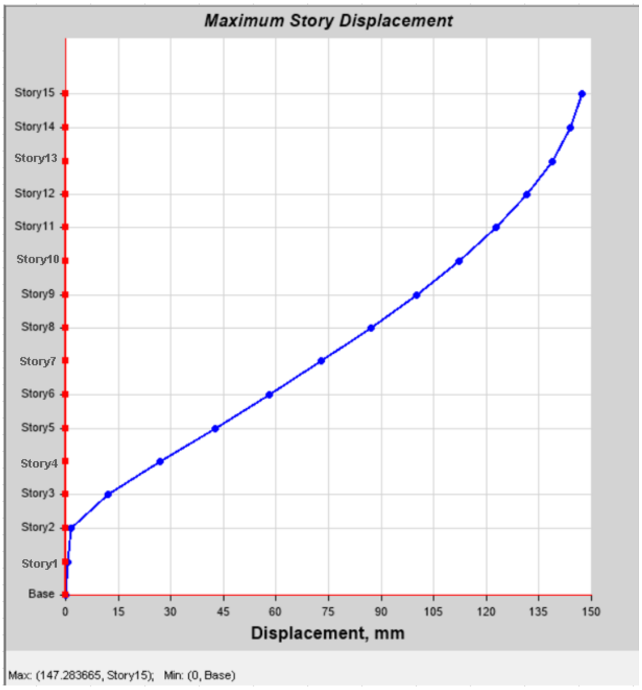

Chart -2: Max. Displacement of Model-2 with Bracing

Model 3 : Showed a high reduction of displacement in one direction due to elongated column orientation compared to Model 1. The blade column enhanced the lateral stiffness, resulting in a uniform displacement pattern, although slightly higher than Model 2 in minor axis of blade column. Strengthening required to reduce displacement in other direction.

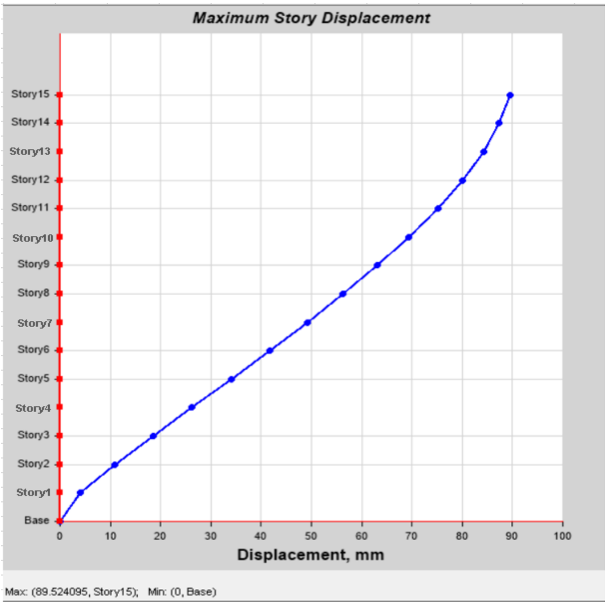

Chart -3: Max. Displacement of Model-3 with Blade column

4.2 Storey Drift:

Model 1 : Experienced excessive storey drift at the soft storey level, exceeding permissible limit prescribed by IS 1893.

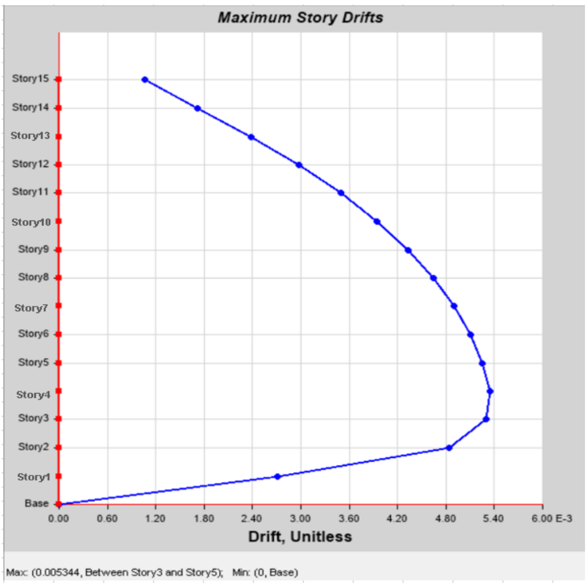

Chart -4: Max. Storey Drift of of Model-1 : Structure with Soft Storey

Model 2 : Recorded the lowest storey drift among the three models due to the effective triangulation provided by the bracing system.

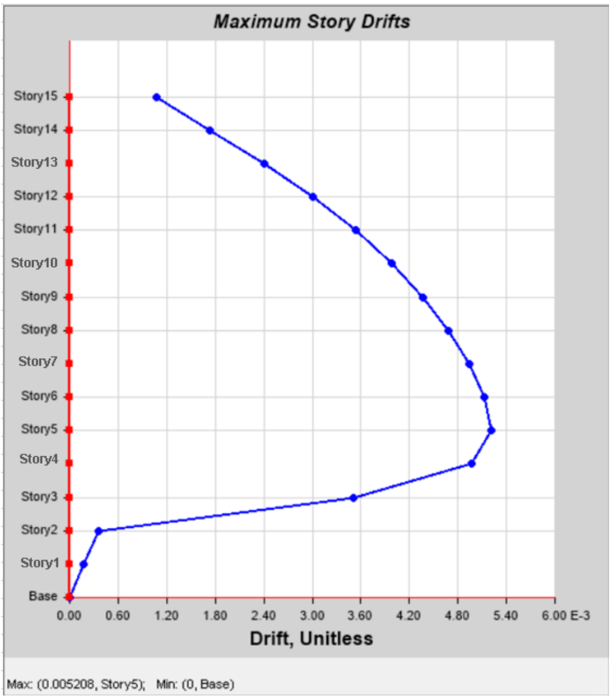

Chart -5: Max. Storey Drift of of Model-2 with Bracing

Model 3 : Achieved substantial drift control in one direction at top storey but it was slightly less effective compared to the braced configuration model, At soft storey level needs combined configuration required to reduce drift.

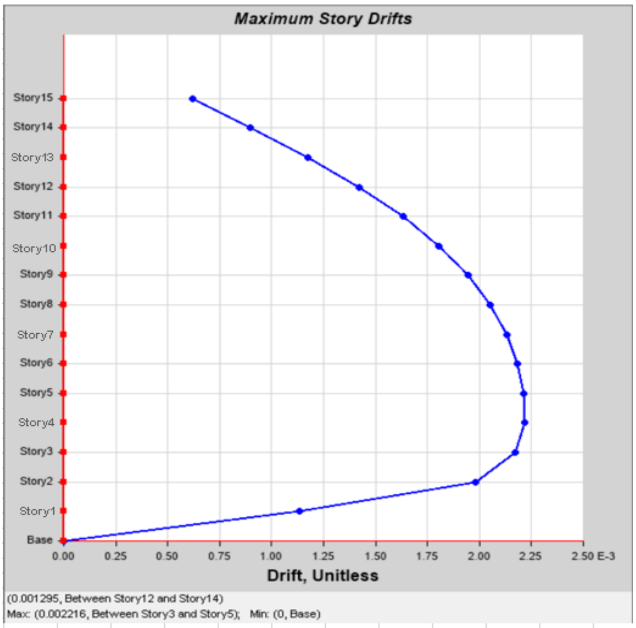

Chart -6: Max. Storey Drift of of Model-3 with Blade column

4.3 Storey Stiffness:

Model 1 : Displayed a significant drop in stiffness at a soft storey, causing a sudden change in lateral resistance.

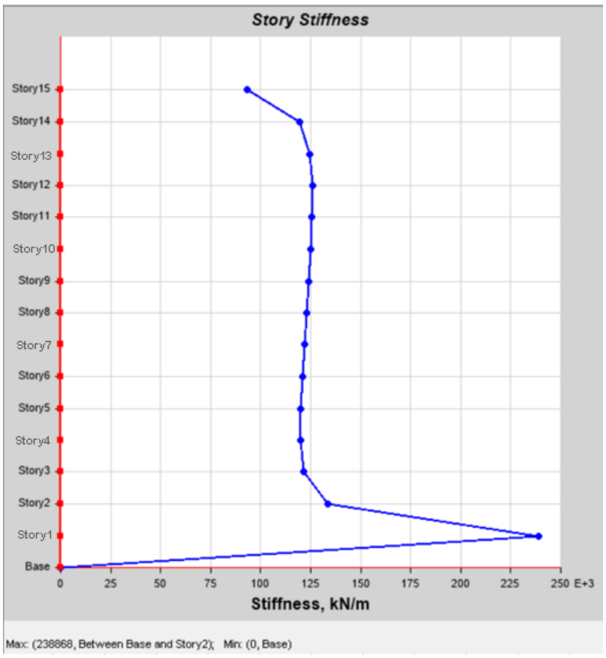

Chart -7: Max. Storey Stiffness of Model-1 : Structure with Soft Storey

Model 2 : Demonstrated a substantial increase in soft storey stiffness at the ground level due to the presence of diagonal braces.

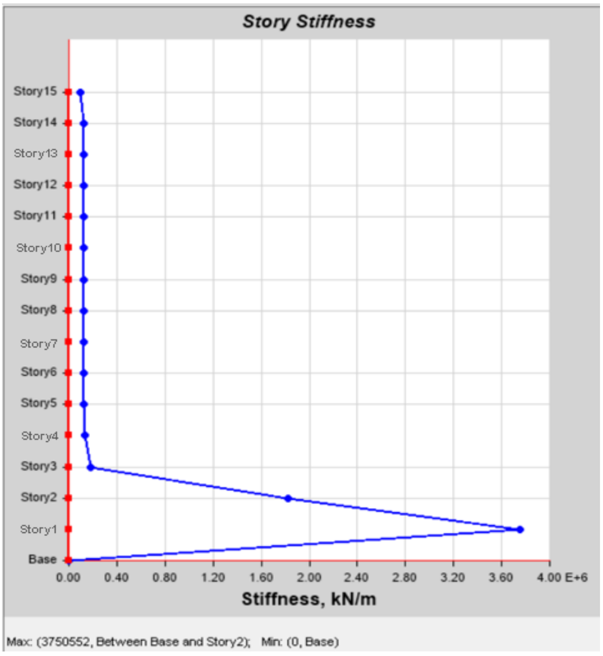

Chart -8: Max. Storey Stiffness of Model-2 : Structure with Bracing

Model 3 : It had a improved soft storey stiffness at storey compared to model 1. The use of blade columns provided enhanced lateral stiffness, though not as high as the braced structure in model 2. But in other direction stiffness is improved by adding other configurations.

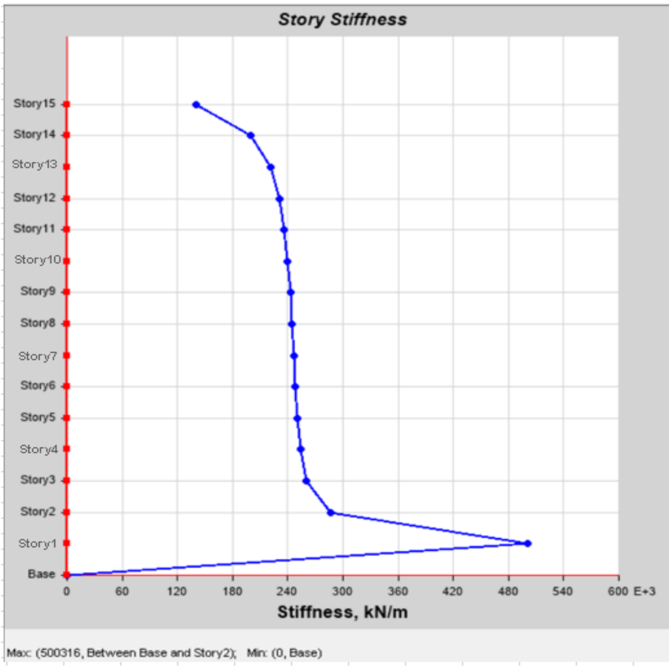

Chart -9: Max. Storey Stiffness of Model-3 : Structure with Blade Column

4.3 Performance Summary:

Table -2: Summary

Parameter	**Model 1 (soft storey)**	**Model 2 (With Bracing)**	**Model 3 (With Blade Columns)**
Storey Displacement	Highest	Lowest	Moderate reduction
Storey Drift	Highest (Irregular)	Lowest (Controlled)	Reduced (Smooth)
Storey Stiffness	Very Low at soft storey	Very High	Improved
Base Shear	Lowest	Moderate	Slightly Higher
Time Period	Longest	Shortest	Medium
Overall Performance	Poor	Best	Medium

5. CONCLUSIONS

Based on the comparative analysis of the three models, the following conclusions are drawn:

The structure with a soft storey Model 1 exhibited poor seismic performance due to reduced storey stiffness, excessive lateral displacement, and higher inter-storey drift at the ground level, indicating the vulnerability of unstrengthen soft storey buildings.

Provision of diagonal concrete braces at the soft storey significantly enhanced the lateral stiffness and seismic performance. Braces worked efficiently by forming a triangulated system that resisted lateral forces effectively, resulting in the lowest storey displacement, drift, and time period among all models.

Replacement of conventional square column with blade columns at the soft storey also improved the lateral performance of structure in one direction and other direction required additional configuration. The blade column performed most effectively along their major depth (strong axis), providing greater stiffness and strength in that direction.

Although both blade columns and diagonal bracing techniques improved seismic performance, diagonal bracing was found to be slightly more effective in controlling displacements and drifts. Bracing system or modified columns are essential for ensuring the seismic safety and stability of multi storeyed reinforced concrete structures in seismic-prone areas.

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