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Comparative Study of Seismic Analysis of Vertically Irregular R.C. Frame Using Indian and Euro Code

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Abstract:The present study conducts a comparative evaluation of the seismic performance of reinforced concrete (RC) building frames designed in accordance with two globally accepted design codes: the Indian Standard (IS 1893:2016) and the European Standard (Eurocode 8). Structures with vertical irregularities are known to be more susceptible to seismic damage, particularly when appropriate strength and detailing measures are not implemented. High-rise buildings, especially those exhibiting geometric discontinuities, require a comprehensive assessment of their seismic response to ensure safety and resilience.

This research investigates a G+22 storey RC building characterized by vertical geometric irregularities. The seismic analysis is carried out using ETABS software, employing the Response Spectrum Method (RSM) to evaluate structural response parameters, including storey drift, overturning moment, storey shear, and lateral displacement in both principal directions.

The study highlights the practical differences between the two codes by comparing their design implications. In particular, it is observed that structures analyzed under IS 1893 tend to exhibit relatively lower response values that remain within acceptable limits, whereas Eurocode 8 analysis results in higher seismic demand due to its detailed spectral definitions and consideration of site-specific soil characteristics.

This comparison underlines that IS 1893 offers a more conservative design approach, particularly beneficial for seismically active regions. The research further emphasizes the relevance of adopting international standards, such as Eurocode 8, for improving construction practices and enhancing structural safety in regions influenced by global construction norms, including the Gulf countries.

I. INTRODUCTION

India, being one of the most seismically active regions in the world, has witnessed multiple devastating earthquakes in the past, making it essential to incorporate seismic-resistant design practices in civil infrastructure. The growing trend of high-rise and complex structural forms, especially in urban regions, has led to a rise in buildings with irregular configurations. These irregularities—particularly in geometry, mass, and stiffness—tend to compromise a structure's performance under seismic loading, especially in medium to high seismic zones.

Among the various types of irregularities, vertical irregularity poses a significant risk. This refers to abrupt changes in mass or stiffness along the height of a building—common examples being soft storeys or uneven mass distribution due to architectural choices. Such irregularities disturb the building's dynamic response, often making its behavior during earthquakes unpredictable and increasing the likelihood of structural failure. The performance of reinforced concrete (RC) buildings, particularly those incorporating open ground storeys or stepped profiles, has been repeatedly questioned after seismic events like Bhuj and Latur, which exposed weaknesses in existing design and construction methodologies.

As urban density increases, designers and architects are often forced to compromise on structural uniformity due to land constraints or functional requirements. For instance, ground floors are frequently allocated for parking in residential and commercial buildings, leading to significant reductions in stiffness and strength at lower levels. This condition, known as a "soft storey," is one of the most critical types of vertical irregularity and has historically contributed to collapses in seismic events.

From a design perspective, vertical irregularities make the structural analysis more complex and demand specialized attention during modeling and simulation.

The Indian Standard IS 1893:2016 provides guidelines for seismic design, including classification and treatment of irregular structures. Similarly, the European seismic design standard, Eurocode 8, offers robust provisions for addressing such irregularities through detailed analysis and structural detailing.

Modern-day computational tools like ETABS enable engineers to simulate and analyze the seismic behavior of irregular buildings more accurately. By using techniques such as Response Spectrum Analysis (RSA), engineers can evaluate critical parameters like storey drift, lateral displacement, and base shear under various code provisions.

While Indian codes address basic design needs, Eurocode 8 includes more refined criteria, especially for irregular structures. This has resulted in its widespread adoption in regions with stringent construction quality requirements, such as Gulf countries. Understanding the differences between these design frameworks is critical for improving the seismic performance of RC buildings in India and aligning them with international safety standards.

Therefore, the present study focuses on analyzing and comparing the seismic behavior of a vertically irregular G+22 reinforced concrete building using both IS 1893 and Eurocode 8. The intent is to examine the variation in dynamic response parameters and highlight the influence of vertical geometric irregularity on structural performance during seismic excitation. Through this comparative analysis, the research aims to offer valuable insights into code-based improvements and practical design recommendations for safer and more resilient infrastructure.

Fig-1 Vertical geometric irregularity in stepped building frames Fig-2 Vertical structural irregularity

II. LITERATURE REVIEW

A. General

Earthquakes cause major disruptions to infrastructure and economies. Modern building designs often incorporate vertical irregularities due to architectural needs, but these features adversely affect seismic performance. This section reviews the impact of such irregularities on building behavior during seismic events.

B. Vertical Irregularity in Structures

Vertical irregularities involve abrupt changes in mass, stiffness, geometry, or strength along a building's height. Common forms include soft storeys, mass irregularities, and setbacks. These variations alter the dynamic response of structures and increase seismic vulnerability. Codes such as IS 1893:2016 and Eurocode 8 classify and address these irregularities to enhance structural safety.

C. Code-Based Criteria

IS 1893:2016 defines five vertical irregularities: soft storey, mass irregularity, vertical geometry change, in-plane discontinuity, and weak storey.

Eurocode 8 sets detailed conditions for regularity, focusing on uniform mass/stiffness distribution, continuous load paths, and setback limitations to maintain seismic stability.

D. Impact from Past Earthquakes

Events such as the 2005 Kashmir and 2011 Christchurch earthquakes revealed severe failures in vertically irregular buildings, underscoring the need for strict codal compliance and design evaluation.

E. Summary of Past Studies

Various researchers have compared IS 1893 and Eurocode 8, highlighting that:

Eurocode generally predicts higher base shear due to stricter provisions.

Bracing and symmetry improve performance in irregular buildings.

Codal response reduction factors significantly affect design outcomes. Studies emphasize advanced modeling and detailed analysis for vertically irregular structures to ensure seismic resilience.

III. METHODOLOGY

A. Overview

This research aims to evaluate the seismic performance of a G+22 reinforced concrete (RC) building with vertical irregularities using ETABS 2016. The structure is analyzed under the provisions of IS 1893:2016 and Eurocode 8. Both static and dynamic methods, such as Equivalent Static Analysis (ESA) and Response Spectrum Analysis (RSA), are utilized. The methodology is structured in the following stages:

1) Literature Review: Reviewed prior studies, seismic design practices, and irregular structural behavior.
2) Model Development: Designed a vertically irregular RC frame with 6-meter bay widths in both X and Y directions.
3) Seismic Analysis: Performed using ETABS 2016 software.
4) Evaluation Parameters: Displacement, base shear, storey drift, and overturning moments are examined.
5) Code Comparison: Seismic results are compared using IS 1893 and Eurocode 8 criteria.

B. Data Sources

Indian Codes: IS 1893:2016, IS 456:2000, IS 875

European Codes: Eurocode 2 and Eurocode 8

Published international research papers and design manuals

C. Analytical Methods

1) Equivalent Static Analysis (ESA): A simplified method that calculates base shear using building mass and time period. Effective for regular, low-rise buildings.
2) Response Spectrum Analysis (RSA): A dynamic approach considering multiple vibration modes. Modal responses are combined using the CQC method to determine total seismic response.
3) Time History Analysis (THA): Uses actual or synthetic earthquake data to simulate building behavior over time. Helps validate displacement and drift patterns under real seismic records.
4) Pushover Analysis: A nonlinear static method to estimate capacity curves, representing how a building responds to gradually increasing lateral loads until failure.
5) Design Criteria – IS 1893:2016
6) Base Shear: V=Ah·WV = A_h \cdot WV=Ah·W, where AhA_hAh depends on zone factor (Z), importance factor (I), response reduction factor (R), and spectral acceleration (Sa/g)(Sa/g)(Sa/g).
7) Distribution of Shear: Lateral forces are distributed along the height based on floor mass and height from the base.
8) Seismic Zones & Factors: India is classified into Zones II to V. Zone factor (Z) ranges from 0.10 to 0.36. Importance factor (I) is 1.0 for normal buildings, 1.5 for essential facilities.
Response Reduction Factor (R): 3.0 for OMRF, 5.0 for SMRF.

D. Design Criteria – Eurocode 8

1) Ground Classification: Sites are categorized from Type A (rock) to E (soft soil), with special types S1 and S2 for liquefiable or sensitive soils.
2) Seismic Zones and Spectra: Elastic and design response spectra are defined for horizontal and vertical components based on ground type and seismic intensity.
3) Behavior Factor (q): Represents ductility and energy dissipation. Values are 1.5 (DCL), 3.9 (DCM), and 5.85 (DCH). For irregular elevation, q is reduced by 20%.
4) Importance Factor (I): Ranges from 0.8 (minor structures) to 1.4 (critical facilities), depending on risk level and structural role.

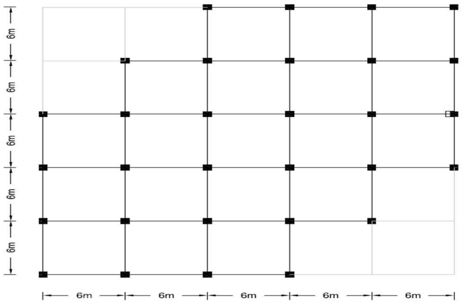
E. Drift Control

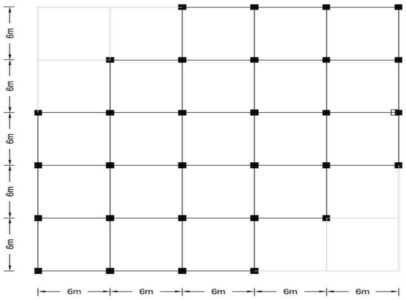
Drift limits play a vital role in design. IS 1893 restricts inter-storey drift to 0.004h, while Eurocode 8 permits up to 0.015h. This study evaluates drift response and its influence on performance and code compliance.

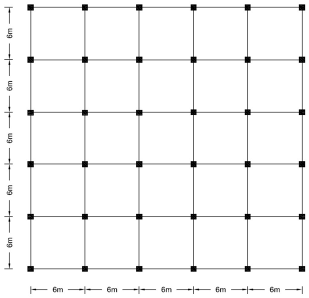
IV. STRUCTURAL MODEL DESCRIPTION

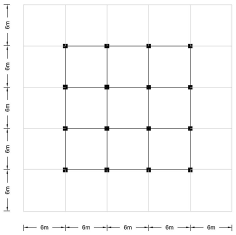
A. Problem Formulation

This study involves the seismic analysis of a G+22 reinforced concrete (RC) frame structure exhibiting vertical irregularity, using ETABS 2016 software. The building comprises five bays in both horizontal directions and is assessed using two primary seismic analysis methods: the Equivalent Static Method and the Response Spectrum Method, as per IS 1893:2016 and Eurocode 8.









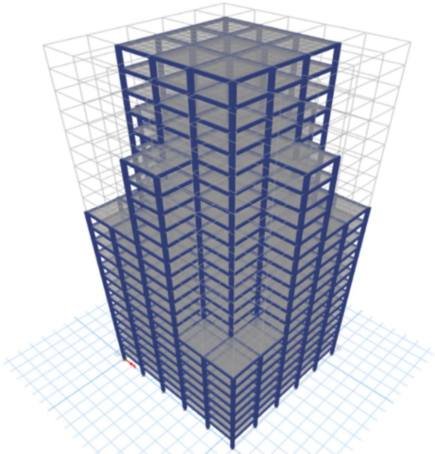


Fig-4-DRenderViewofbuilding

1) Analysis Methods

Four primary analysis techniques exist in structural dynamics: linear static, linear dynamic, nonlinear static, and nonlinear dynamic. For this study, linear elastic methods are employed, considering that the structure operates predominantly within the elastic range under design-level earthquake loading.

- EquivalentStatic Method (ESM): This approach simplifies earthquake forces into equivalent lateral loads. It is suitable for regular or moderately irregular structures and follows IS 1893:2016 provisions.
- Response Spectrum Method (RSM): A dynamic analysis method where the structure's natural periods are used to extract modal responses. ETABS automatically generates spectral forces in both X and Y directions for seismic Zone IV with 5% damping.

B. Structural Building Parameters

The building geometry and design parameters are listed below:

Table 4.1: Building Configuration

Parameter	Value
Building Plan	30 m × 30 m
Typical Storey Height	3.0 m
Ground Storey Height	3.2 m
Total Height	69.2 m
Slab Thickness	150 mm
Beam Sizes	300 × 450 mm
Column Sizes	450×450 mm, 550×550 mm, 600×750 mm
Soil Type	Medium
Model Type	Vertically Irregular RC Frame

Table 4.2: Loading Details

Load Type	Description
Dead Load	Auto-calculated by ETABS
Live Load	3 kN/m² (Imposed) + 1 kN/m² (Floor Finish)
Earthquake Load	As per IS 1893:2016 and Eurocode 8
Code of Practice	IS 456:2000, IS 1893:2016, EC 2, EC 8

Table 4.3: Material Properties

Material Property	Value
Concrete Grade	M35
Steel Grade	Fe500 (longitudinal), Fe250 (transverse)
Concrete Density	25 kN/m³

C. Structural Modelling in ETABS

ETABS 2016, developed by CSI, USA, is used for modeling, analysis, and design of the structure. It allows accurate simulation of RC frames under seismic conditions and supports both Indian and European code provisions.

Material Definitions:

- Concrete (M35):
- Density: 25 kN/m³
- Poisson's Ratio: 0.2
- Modulus of Elasticity (IS 456): Ec=5000fckE_c = 5000\sqrt{f_{ck}}Ec=5000fck
- Eurocode 2 values derived from Table 3.1
- Steel:
- HYSD Fe500 for bending reinforcement
- Fe250 for shear reinforcement

1) Frame and Slab Sections

- The building includes:
- RCC frames with variable column sizes
- Uniform slab thickness
- Typical beam-slab floor system modeled as rigid diaphragms
- Figures 4.1(a)–4.1(d): Storey plans for different height segments
  Figure 4.2: 3D Line Diagram of Building
  Figure 4.3: 3D Rendered View

2) Load Patterns and Seismic Parameters

- Load Definitions:
- Dead Load (DL): Automatically applied via ETABS
- Live Load (LL): Applied on each floor as per IS 875
- Seismic Load (EQ): Defined for both X and Y directions
- ii. Seismic Inputs – IS 1893:2016
- Zone: IV
- Zone Factor (Z): 0.24
- Soil Type: Medium (Type II)
- Importance Factor (I): 1.2
- Response Reduction Factor (R): 3 (OMRF)
- Height: 69.2 m
- iii. Seismic Inputs – Eurocode 8 (EN 1998-1)
- Ground Acceleration (ag): 0.4g
- Ground Type: C
- Soil Factor (S): 1.5
- Spectrum Type: 2 (for Ms<5.5M_s < 5.5Ms<5.5)
- Spectrum Periods:
- TB = 0.1 s
- TC = 0.25 s
- TD = 1.2 s
- Behavior Factor (q): 3.12
- Correction Factor (λ): 1.0
- Structure Height: 69.2 m
- iv. Response Spectrum Functions:
  Defined in both X and Y directions using IS and EC parameters.
- v. Mass Source and Load Combinations:
  Defined per codal recommendations. Diaphragms and live load reduction factors are also applied.
- vi. Structural Design Codes Referenced:
- IS 456:2000 – Code for Plain and Reinforced Concrete
- EN 1992-1-1:2004 – Eurocode 2 Design of Concrete Structures

V. RESULTS AND INTERPRETATION

ANALYSIS RESULTS

This section presents the results of seismic analysis conducted on a G+22 vertically irregular reinforced concrete building frame. ETABS 2016 software was utilized to perform both Equivalent Static and Response Spectrum analyses, adhering to the provisions of IS 1893:2016 and Eurocode 8. The analysis includes critical seismic response parameters: storey shear, overturning moment, storey displacement, and storey drift, in both X and Y directions.

A. Storey Shear

Storey shear results provide insights into lateral force distribution across the building height. The comparison highlights the variations in structural response when evaluated under IS 1893 and Eurocode 8.

Maximum Storey Shear Values:

- *IS 1893:2016*:
  - EQ X: 379.33 kN
  - EQ Y: 379.33 kN
- *Eurocode 8*:
  - EQ X: 1138.06 kN
  - EQ Y: 1136.92 kN

Storey shear values were significantly higher under Eurocode 8 due to its stricter spectral shape and ground motion considerations.

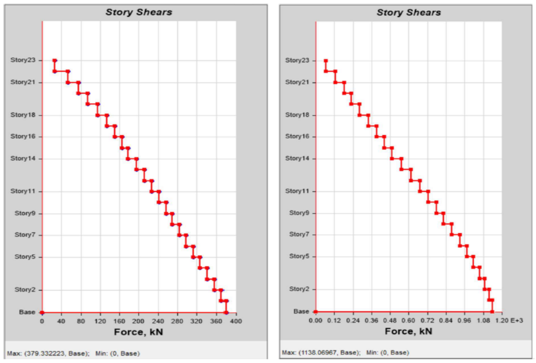


Fig 5.1- Storey shear according to IS code & Eurocode

B. Overturning Moment

Overturning moment is an indicator of rotational forces acting at the base of the building due to lateral seismic loads.

Maximum Overturning Moment Values:

IS 1893:2016:

X-Direction: 13642.96 kNm

Y-Direction: 13642.96 kNm

Eurocode 8:

X-Direction: 42821.58 kNm

Y-Direction: 42721.64 kNm

The Eurocode design results in higher overturning moments, consistent with the greater base shear values obtained.

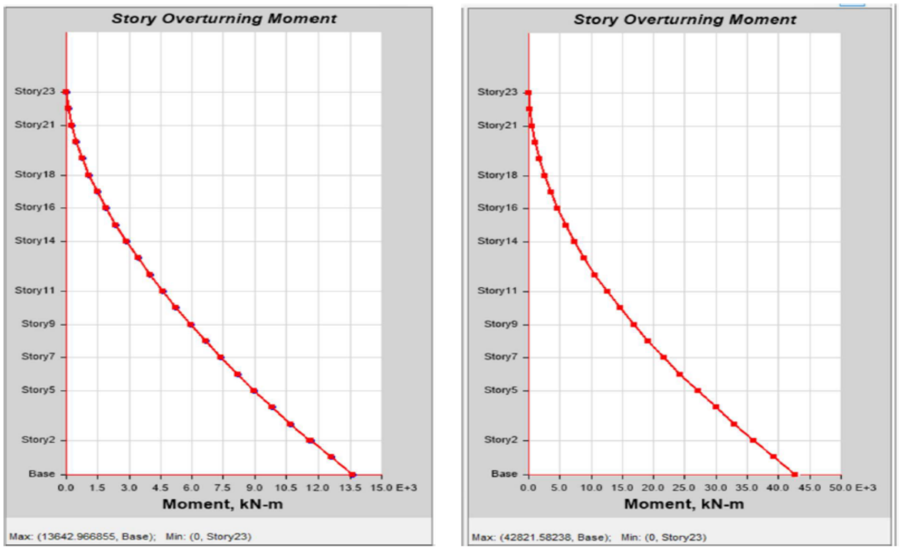


Fig 5.4- Overturning Moment according to IS code &Eurocode

C. Storey Displacement

Storey displacement measures the lateral deflection of each storey relative to the building base. This parameter is crucial for evaluating overall deformation.

Maximum Storey Displacement Values:

IS 1893:2016:
X-Direction: 12.36 mm
Y-Direction: 12.36 mm

Eurocode 8:
X-Direction: 38.80 mm
Y-Direction: 38.06 mm

The results show a threefold increase in displacement under Eurocode due to its comprehensive dynamic input parameters.

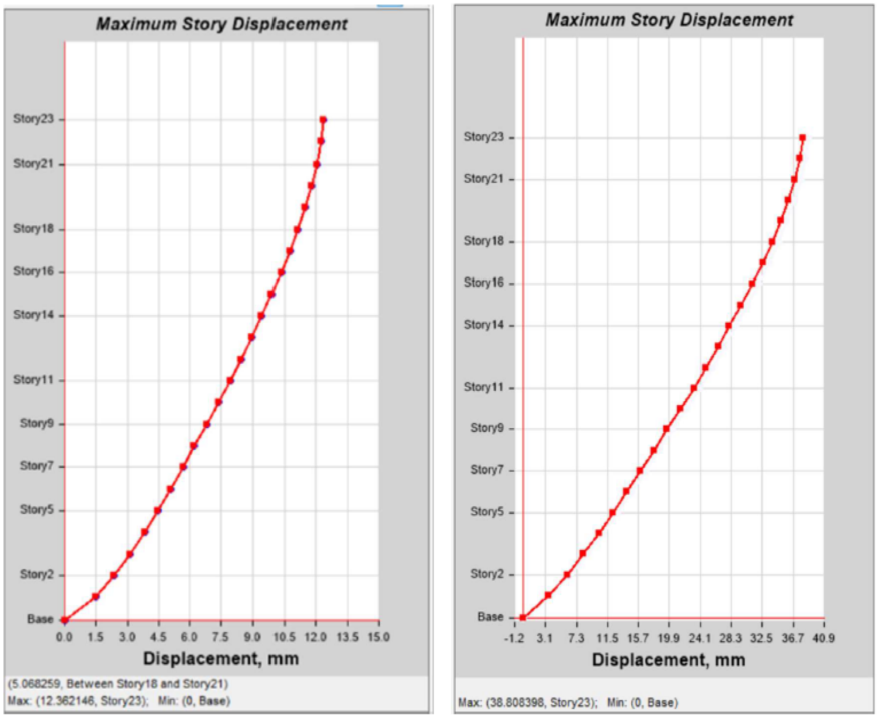


Fig 5.7- Storey Displacement according to IS code & Eurocode

D. Storey Drift

Storey drift is defined as the relative displacement between two successive storeys. It is an important criterion in limiting damage during earthquakes.

Maximum Storey Drift Values:

- *IS 1893:2016*:
  - X-Direction: 0.000416
  - Y-Direction: 0.000416
- *Eurocode 8*:
  - X-Direction: 0.001217
  - Y-Direction: 0.001084

Drift values under Eurocode 8 exceeded those of IS 1893 by almost three times, indicating a more flexible response due to lower damping and higher spectral acceleration.

Each parameter demonstrates that the Eurocode-based design yields more conservative and detailed seismic responses compared to IS 1893:2016, thus affirming the influence of international standards on structural safety in seismically active regions.

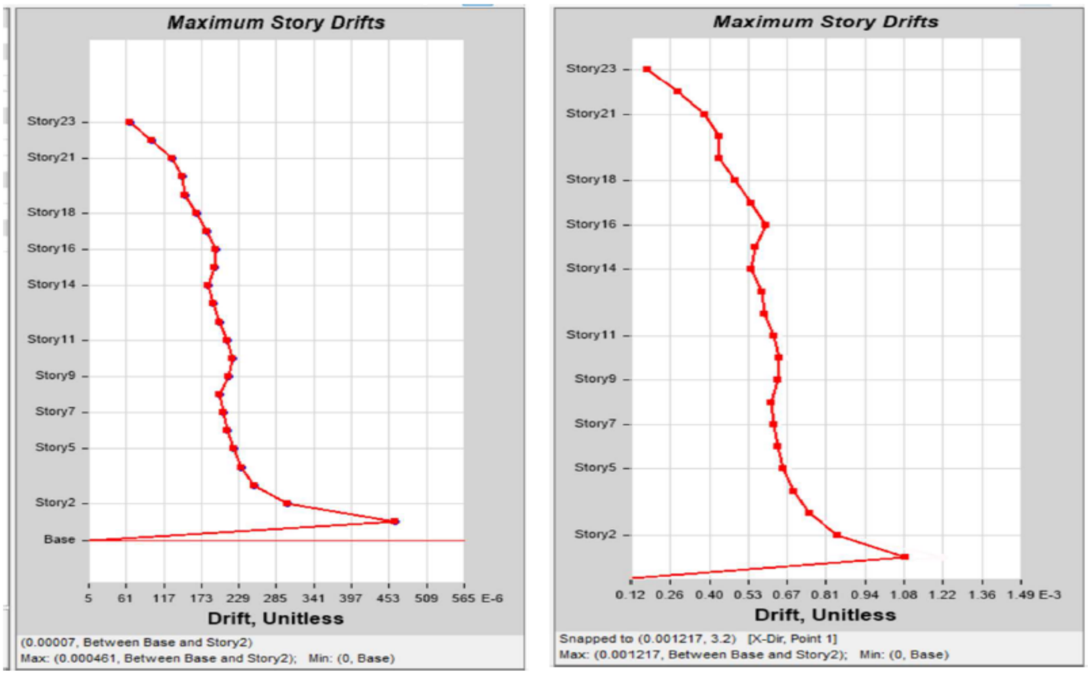


Fig 5.10- Storey Drift according to IS code & Eurocode

VI. CONCLUSION

This research focuses on the dynamic analysis of structural characteristics affecting a building's durability, stability, and safety by comparing seismic performance across IS 1893:2016 and Eurocode 8.

The analysis shows that the base shear calculated under Eurocode 8 is approximately 67% higher than that determined by IS 1893:2016. This difference stems from the higher response reduction factor applied in the Indian standard. Despite this, storey shear values remain consistent between the two codes in both directions.

Storey displacements are more significant under Eurocode due to higher base shear demands, with the difference increasing along the height of the structure. Similarly, the storey drift predicted using Eurocode is up to 65% higher than that under IS 1893.

The structure analyzed under IS 1893 demonstrates favorable results in terms of displacement, drift, and shear, maintaining values well within codal limits. Maximum drift is consistently observed at the first storey level in both code-based models.

Overall, IS 1893:2016 delivers comparatively better performance in this study context, suggesting its effectiveness in ensuring safety and serviceability for vertically irregular high-rise buildings.

Scope for Future Work

To broaden the understanding of seismic behavior, future studies may incorporate advanced nonlinear techniques such as Pushover and Time History Analysis. Additional investigations could consider combined vertical and plan irregularities to examine interaction effects. Moreover, exploring structural enhancements through lateral load-resisting components such as bracings and shear walls can further improve seismic resilience and stability.

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