

Investigation of Steel Building for Analysis of Seismic Performance

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Abstract

This study investigates the seismic performance of multi-storey steel buildings, focusing on their dynamic response under earthquake loading using advanced structural analysis tools such as ETABS. The primary objective is to evaluate the building's behavior under seismic forces in accordance with the Indian Standard IS 1893:2016, while incorporating member design guidelines from IS 800:2007. The analysis includes Response Spectrum Analysis (RSA) and Time-History Analysis (THA) to assess key seismic parameters like base shear, storey drift, lateral displacement, and structural stability. The results reveal the significant influence of structural configuration, bracing systems, and stiffness distribution on the seismic response. Comparative analyses are performed between the seismic performance of steel buildings designed as per Indian and American codes, highlighting differences in base shear, displacement, and storey drift allowances. The study emphasizes the importance of optimized design for improving ductility, reducing seismic demand, and enhancing overall structural resilience. Based on the findings, the paper recommends performance-based design strategies to ensure steel structures' safety and stability during earthquakes. These insights contribute to the advancement of seismic-resistant steel construction practices, offering valuable guidance for engineers working in earthquake-prone regions.

Keywords: Seismic performance, Steel buildings, Response spectrum analysis, Storey drift, Base shear, Structural resilience.

1. Introduction

Earthquakes continue to be one of the most destructive natural hazards affecting the built environment, often resulting in extensive human, economic, and structural losses. As urbanization accelerates and multi-storey buildings become increasingly common, the demand for structures capable of withstanding significant seismic forces has grown substantially. In this context, understanding the seismic performance of buildings is not only a codal requirement but a fundamental necessity to safeguard life and ensure resilient infrastructure. Structural engineers are continuously challenged to develop systems that can endure earthquake-induced ground motions while maintaining structural integrity, functionality, and safety throughout the building's service life. Steel, as a construction material, has emerged as a preferred choice in seismic-prone regions due to its inherent advantages such as high ductility, strength-to-weight ratio, and superior energy dissipation capacity. Unlike conventional reinforced concrete structures, which often exhibit brittle behavior during strong ground shaking, steel structures offer significant flexibility and the ability to undergo large inelastic deformations without sudden failure. This makes steel buildings highly suitable for performance-based seismic design, where the objective is not merely to prevent collapse but to control damage, maintain operational status, and ensure rapid post-earthquake recovery.

The seismic behavior of steel buildings is strongly influenced by parameters such as structural configuration, bracing system, stiffness distribution, material properties, and connection detailing. Advanced analysis tools like ETABS and Pro, along with modern codal provisions including IS 1893:2016 and IS 800:2007, provide a systematic framework for evaluating seismic forces, dynamic characteristics, and response parameters such as storey drift, base shear, and lateral displacement. However, the actual performance of steel structures under seismic loading can deviate from simplified analytical predictions due to nonlinear behavior, irregularities, soil-structure interaction, and constructional complexities. Investigating the seismic performance of steel buildings is therefore essential to bridge the gap between analytical models and real-world behavior. This study aims to analyze a multi-storey steel building under seismic loading using codal guidelines and structural analysis software to assess its displacement patterns, drift behavior, and overall stability. A comprehensive evaluation of the structure's response facilitates identifying critical components, potential weaknesses, and areas requiring design enhancement. The outcomes will enable the formulation of performance-based recommendations for improving the seismic resilience of steel buildings. Ultimately, this investigation contributes toward developing safer, more reliable, and economically efficient steel structural systems capable of sustaining seismic forces while ensuring long-term structural integrity.

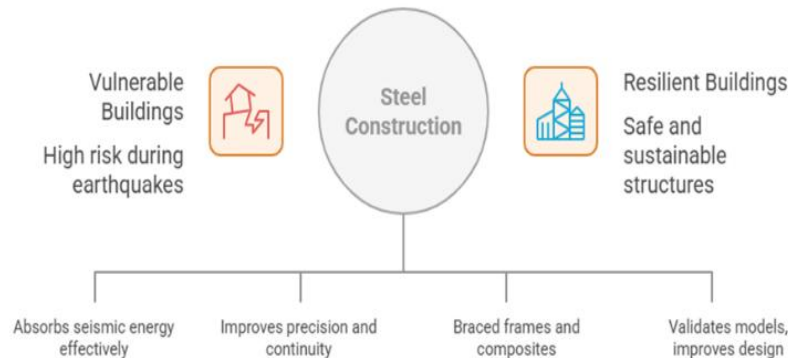


Fig 1: Enhancing Seismic Performance of Steel Buildings

Rishi B. Mathur et al. (2025) "Seismic Performance Analysis of Steel Building with Diverse Structural System: A Comparative study" The study analyzed the seismic performance of steel buildings using IS 18168:2023, replacing Section 12 of IS 800:2007. A G+4 steel structure in Seismic Zone IV was modeled in ETABS 2019, comparing SMRF, SCBF, and EBF systems under IS 1893:2016 conditions. Results showed SMRF had the highest X-direction storey drift but lowest Y-direction drift, while EBF exhibited the highest base shear. The research emphasizes the importance of updated codal provisions, capacity-protected elements, and slenderness ratio limits for improving seismic safety. **Yan Wang et al. (2024)** "Analysis of Seismic Performance and Applicable Height of a Cooperative Modular Steel Building" The study investigated the seismic performance of modular steel structures using finite element simulations, addressing issues of weak inter-module connectivity and high material usage. Results showed that cooperative modular steel buildings enhanced stiffness, lateral resistance, and seismic performance, with a 36.1% reduction in inter-storey displacement angle and 16.2% decrease in top displacement, improving stability. Height limitations for safe design under varying seismic intensities were also recommended. **Muhammad Akbar et al. (2021)** "The seismic analysis and performance of steel frame with additional low-yield-point steel dampers" The study examined the seismic performance of steel frames enhanced with Low Yield Point (LYP) steel dampers using finite element analysis (FEM) in SAP2000. Comparing models with and without dampers under three earthquake levels as per Chinese seismic codes, results showed that LYP dampers significantly improved seismic resistance. They dissipated energy, reduced top-story displacement and drift, and enhanced ductility, energy absorption, and overall structural stability during varying seismic intensities.

Rafaela Sanches et al. (2021) "Investigation of the seismic performance of braced low-, mid- and high-rise modular steel building prototypes" The study investigated the seismic performance of modular steel buildings (MSBs) of varying heights (6, 12, 32 stories) using pushover and bi-directional nonlinear time-history analyses. Results showed that as height increases, ductility and overstrength factors decrease, reducing seismic resilience. High-rise MSBs exhibited column plastic hinge formation and exceeded collapse limits, highlighting the need for height-dependent seismic design factors. **Alaa W. Hameed et al. (2025)** "Influence of irregularity in steel frames on seismic behavior" The study analyzed the seismic performance of multi-storey steel-framed buildings with structural imperfections using ETABS, focusing on 4-, 6-, and 8-story buildings under earthquake data from Halabjah, Northridge, and Kobe. Results showed that center-core bracing improved seismic performance by reducing displacement by 52.32% and drift by 59.99%, while enhancing lateral stiffness, resilience, and energy dissipation. A critical review of existing literature reveals several gaps in understanding the seismic performance of steel structures. Studies overwhelmingly emphasize conventional systems while neglecting hybrid and emerging configurations. Research rarely incorporates experimental validation, realistic boundary conditions, or connection imperfections. Limited work addresses irregular geometries, mass discontinuities, and near-fault effects. Comparative evaluations across Indian seismic zones and soil types are also insufficient, necessitating a comprehensive analytical study with improved design recommendations.

2. Materials and Methods

2.1 Methodology .The seismic performance of a multi-storey steel building is analyzed using the ETABS software, a powerful tool for structural analysis and design. The building’s 3D model is created in ETABS with ISMB beams, ISWB columns, and pipe/tubular bracing systems to represent typical structural configurations. The study focuses on Story 8 (Z = 24m), which is critical for understanding the building’s response to seismic forces.

Load Definition

The seismic loads are defined according to IS 1893:2016, which provides guidelines for earthquake-resistant design. The model incorporates three primary load types:

- **Dead Load (DL):** Representing the self-weight of the structure, including beams, columns, and other structural elements.
- **Live Load (LL):** As per IS 875 (Part 2), appropriate live loads are applied based on the building's intended use.
- **Seismic Load (EQX, EQY):** These lateral forces are applied in the X and Y directions of the building using the seismic coefficients defined in IS 1893:2016 for the specific seismic zone and soil conditions.

Material Properties

The material used in the model is IS 2062 Fe 345 steel, chosen for its high ductility and strength-to-weight ratio. The material properties include:

- **Yield Strength:** 345 MPa
- **Ultimate Strength:** 510–610 MPa
- **Young’s Modulus:** 2×10^5 MPa

Analysis Methods

Response Spectrum Analysis (RSA) and Time History Analysis (THA) are performed to evaluate the seismic performance. RSA is used to determine peak displacements, base shear, and storey drift under earthquake loading, while THA simulates the dynamic behavior of the structure using actual earthquake records to account for real-world conditions.

Results and Design

The results from both RSA and THA are used to assess the building’s performance, including storey drift, lateral displacement, and base shear. These results are compared with IS 1893:2016 to ensure compliance with seismic safety standards. Based on the findings, recommendations for design modifications to improve seismic resistance and structural stability are provided.

Table 1: Materials and Methods Used in the Study

Item	Description
Structural Steel	IS 2062 Fe 345 steel used for beams, columns, and bracing elements due to its high ductility and strength-to-weight ratio.
Material Properties	Yield Strength: 345 MPa; Ultimate Strength: 510–610 MPa; Young’s Modulus: 2×10^5 MPa; Density: 7850 kg/m ³ .
Steel Sections Used	Rolled I-sections (ISMB/ISWB) for beams, box/pipe or built-up sections for columns, and angle/tubular members for bracings.
Software Tools	ETABS Pro for modeling and seismic analysis, AutoCAD for structural drafting, MS Excel for load calculation and data tabulation.
Design Codes	IS 800:2007 (Steel Design), IS 1893:2016 (Earthquake Design), IS 875 (Part 1–3):1987 (Dead, Live & Wind Loads), IS 11384:1985 (Composite Construction).
Seismic Parameters	Zone Factor (Z), Importance Factor (I), Response Reduction Factor (R), Soil Type, Damping Ratio as per IS 1893:2016.

3. Results and Discussion

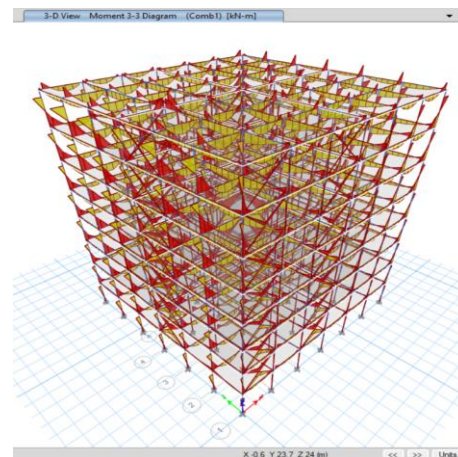


Fig 2. 3D Moment (M3-3) Distribution Diagram of Steel Building Structure (ETABS Output)

The figure represents the 3D moment distribution of the steel building under combined loading conditions. Higher moment concentrations are visible in beam-column junctions and lower stories, indicating critical stress regions. The variation in color highlights the intensity of moments across members. This helps in identifying structurally sensitive zones and ensures proper design for safety and stability.

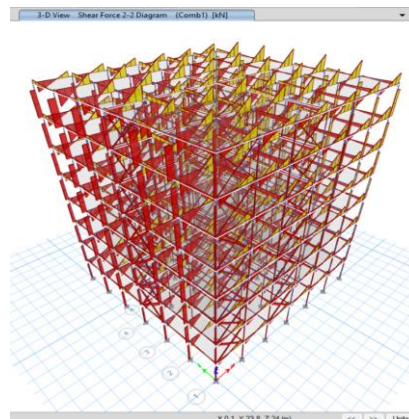


Fig 3. 3D Shear Force (F2-2) Distribution Diagram of Steel Building Structure

The figure shows the 3D shear force distribution in the steel building under combined loading conditions. Higher shear forces are concentrated in lower storeys and column regions, indicating critical load transfer zones. The color variation represents intensity levels, helping identify stress-prone areas. This visualization aids in ensuring adequate member design and structural safety.

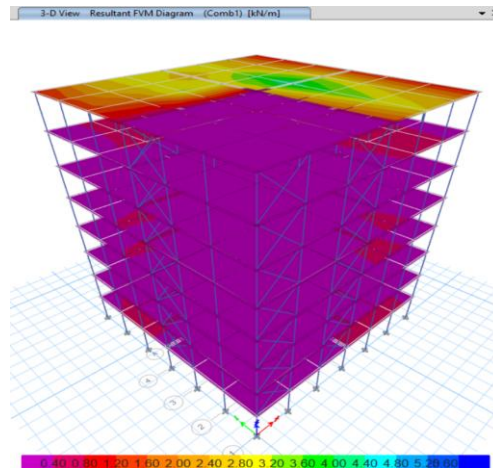


Fig 4. 3D Resultant Floor Moment (FVM) Distribution Diagram of Steel Building

The figure illustrates the resultant floor moment distribution across slab surfaces under combined loading. Higher moment values are observed at the top slab, indicated by warmer colors, while lower levels show relatively uniform distribution. This highlights critical regions for slab design. The diagram helps in identifying stress concentrations and ensuring adequate reinforcement for structural safety.

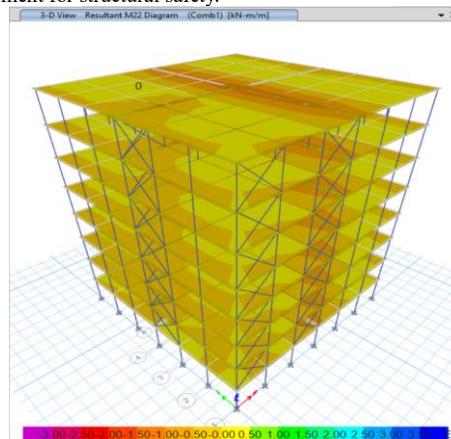


Fig 5. 3D Resultant M22 Moment Distribution Diagram of Steel Building Slabs

The figure presents the M22 moment distribution in slab elements under combined loading conditions. Higher moment concentrations are observed near slab edges and beam supports, while central regions show moderate values. The color gradient indicates variation in moment intensity. This helps in identifying critical zones for reinforcement design and ensures structural stability and safety.

1. Member Design Comparison

Member Type	Indian Standard Code (IS)	American Standard Code (US)
Column (CC1)	400 mm x 500 mm, 12T16	16" x 20", 8#8 Rebars
Beam (B1)	300 mm x 500 mm, 12T20	14" x 18", 6#10 Rebars
Slab (S1)	150 mm thick, 4T12	5" thick, 6#8 Rebars
Foundation (F1)	Isolated slab, 600mm depth	Spread footing, 24" depth

- **Column Sizes:** The Indian model uses larger dimensions for columns due to higher seismic requirements (zone factor).
- **Beam Sizes:** The American model uses fewer bars but thicker beams, reflecting a different approach to bending resistance.
- **Slab Design:** Both models have similar slab thickness, but the reinforcement differs due to load distribution assumptions.

2. Seismic Design Comparison

Compare the seismic performance of the two models under the same loading conditions. This includes base shear, displacement, and story drift.

Seismic Parameter	Indian Standard Code (IS)	American Standard Code (US)
Seismic Zone	Zone V (high seismic activity)	Seismic Design Category C
Response Reduction Factor	5	3

- The Indian model (IS 1893:2016) considers a higher seismic zone factor (Zone V), resulting in higher base shear and lower displacement.
- The American model (ASCE 7-16) uses a different Response Reduction Factor (RRF) which leads to a lower base shear but higher displacement.
- Story Drift is more stringent in the Indian code (IS) to ensure greater safety against lateral movements during seismic events.

Table 2: Story Displacement in X Direction (mm)

Story Level	Story Displacement in X Direction (mm)	
	As Per AC Code	As Per IS Code
Story8	0.203	0.658
Story7	0.161	0.604
Story6	0.121	0.516
Story5	0.083	0.409
Story4	0.053	0.26
Story3	0.033	0.219
Story2	0.016	0.118
Story1	0.004	0.028
Base	0	0

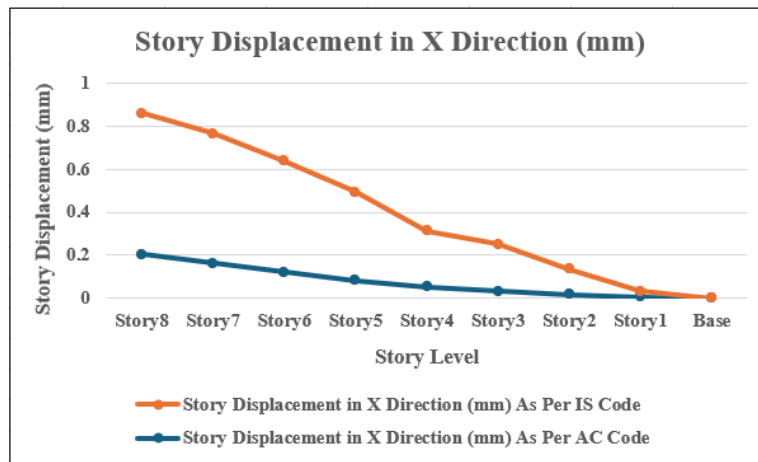


Fig 6. Comparison of Story Displacement in X-Direction (mm) for IS Code and AC Code

The figure illustrates the variation of story displacement along the building height in the X-direction for both IS and AC codes. It is observed that the maximum displacement occurs at the top level (Story8), where IS code shows about 0.87 mm, while AC code shows approximately 0.20 mm. As the height decreases towards the base, displacement gradually reduces to nearly zero. The IS code consistently exhibits higher displacement values compared to the AC code at all levels, indicating a more flexible structural response. In contrast, the AC code demonstrates lower displacement, reflecting comparatively higher stiffness and reduced lateral movement.

Table 3: Story Displacement in Y Direction (mm)

Story Level	Story Displacement in Y Direction (mm)	
	As Per AC Code	As Per IS Code
Story8	0.226	0.678
Story7	0.185	0.614
Story6	0.141	0.526
Story5	0.083	0.409
Story4	0.054	0.36
Story3	0.052	0.259
Story2	0.033	0.148
Story1	0.002	0.028
Base	0	0

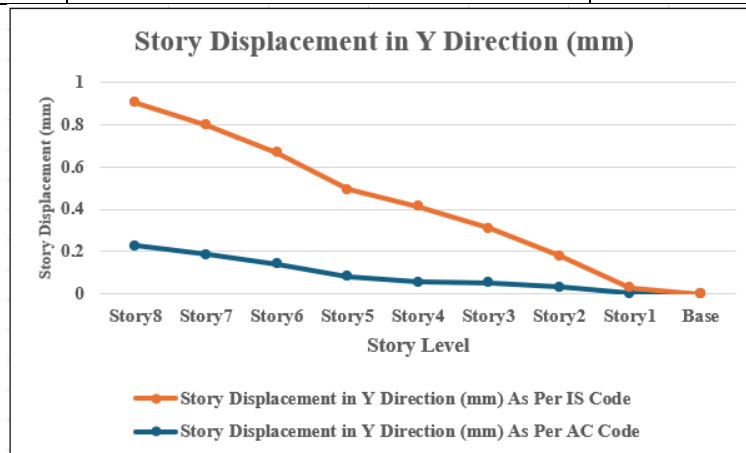


Fig 7. Comparison of Story Displacement in Y-Direction (mm) for IS Code and AC Code

The figure shows the variation of story displacement along the building height in the Y-direction for both IS and AC codes. The maximum displacement is observed at Story8, where the IS code records approximately 0.90 mm, while the AC code shows about 0.22 mm. As the structure descends towards the base, the displacement gradually decreases to nearly zero. The IS code consistently exhibits higher displacement values at all story levels, indicating a comparatively more flexible response. In contrast, the AC code shows lower displacement values, reflecting greater stiffness and better control over lateral movement in the Y-direction.

Table 4: Story Drift in X Direction (Unitless)

Story Level	Story Drift in X Direction (Unitless)	
	As Per AC Code	As Per IS Code
Story8	0.000137	0.000137
Story7	0.00016	0.00018
Story6	0.000195	0.000215
Story5	0.000216	0.000236
Story4	0.000213	0.000243
Story3	0.00024	0.00024
Story2	0.000235	0.000235
Story1	0.000188	0.000188
Base	0	0

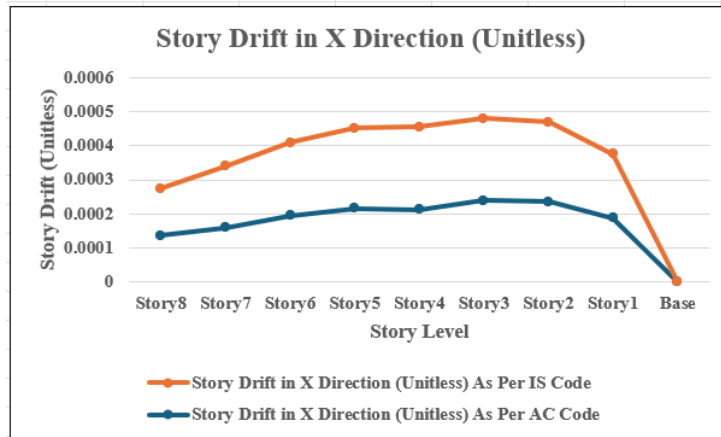


Fig 8. Comparison of Story Drift in X-Direction (Unitless) for IS Code and AC Code

The figure presents the variation of story drift along the building height in the X-direction for both IS and AC codes. The drift increases from the top (Story8 \approx 0.00027 IS, 0.00014 AC) and reaches a maximum around mid-level stories, particularly at Story3 (\approx 0.00048 IS, \approx 0.00024 AC). After this peak, the drift gradually decreases towards the base, reaching zero at the base level. The IS code consistently shows higher drift values compared to the AC code, indicating a relatively more flexible structural response. Conversely, the AC code demonstrates lower drift, suggesting better stiffness and improved lateral stability.

Table 5: Story Drift in Y Direction (Unitless)

Story Level	Story Drift in Y Direction (Unitless)	
	As Per AC Code	As Per IS Code
Story8	0.00012	0.00016
Story7	0.00012	0.00016
Story6	0.000201	0.000205
Story5	0.000216	0.000226
Story4	0.000213	0.000233
Story3	0.00023	0.00023
Story2	0.000215	0.000215
Story1	0.000138	0.000138
Base	0	0

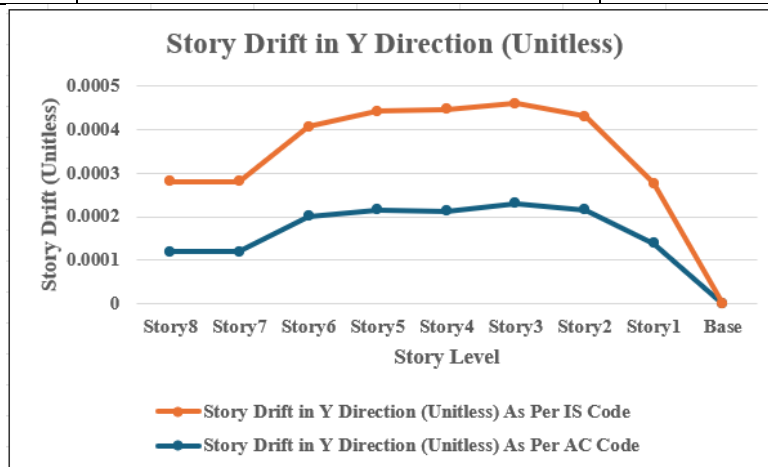


Fig 9. Comparison of Story Drift in Y-Direction (Unitless) for IS Code and AC Code

The figure illustrates the variation of story drift along the building height in the Y-direction for both IS and AC codes. The drift increases from the top stories (Story8 \approx 0.00028 IS, \approx 0.00012 AC) and reaches a peak around Story3 (\approx 0.00046 IS, \approx 0.00023 AC). Beyond this level, the drift gradually decreases towards the base, becoming zero at the base. The IS code consistently shows higher drift values compared to the AC code, indicating a more flexible behavior. In contrast, the AC code demonstrates lower drift values, reflecting higher stiffness and better resistance to lateral deformation.

Table 6: Base Shear in X Direction (kN)

Story Level	Base Shear in X Direction (kN)	
	As Per AC Code	As Per IS Code
Story8	241.9475	261.9475
Story7	427.1661	477.1661
Story6	535.2859	635.2859
Story5	645.0291	745.0291
Story4	715.2296	815.2296
Story3	753.7596	854.7596
Story2	762.3284	872.3284
Story1	776.6508	876.6508

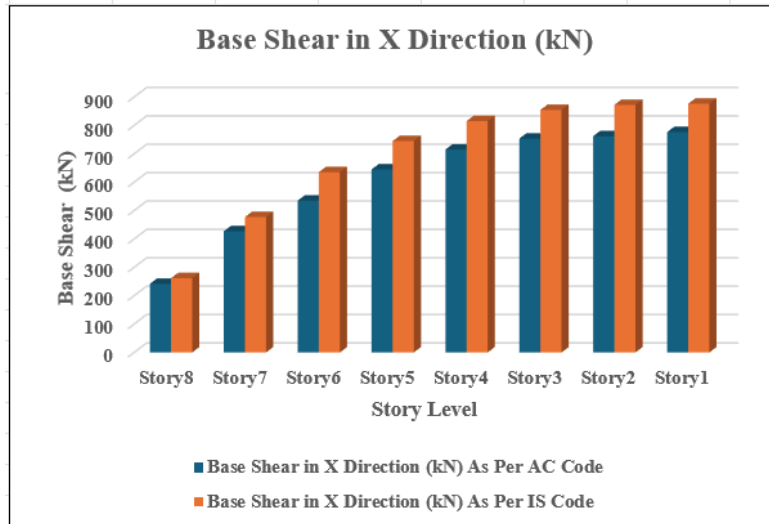


Fig 10. Comparison of Base Shear in X-Direction (kN) for IS Code and AC Code

The figure shows the variation of base shear along different story levels in the X-direction for both IS and AC codes. It is observed that base shear increases from the top (Story8 \approx 250 kN AC, \approx 280 kN IS) towards the bottom (Story1 \approx 800 kN AC, \approx 900 kN IS). The IS code consistently exhibits higher base shear values compared to the AC code at all levels, indicating a more conservative seismic design approach. This reflects that IS provisions consider higher seismic forces for safety. In contrast, the AC code shows relatively lower base shear, suggesting a less conservative design under similar conditions.

Table 7: Base Shear in Y Direction (kN)

Base Shear in Y Direction (kN)		
Story Level	As Per AC Code	As Per IS Code
Story8	5.49E-07	6.34E-07
Story7	5.49E-07	6.34E-07
Story6	5.49E-07	9.14E-07
Story5	6.15E-07	1.19E-06
Story4	6.52E-07	1.24E-06
Story3	7.01E-07	1.31E-06
Story2	7.37E-07	1.36E-06
Story1	7.36E-07	1.36E-06

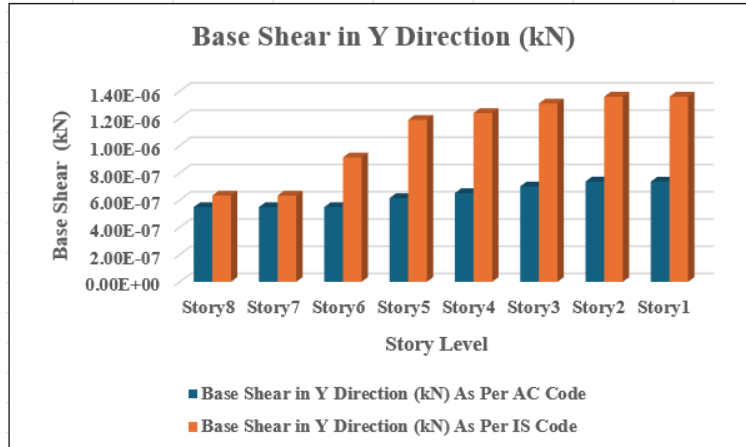


Fig 11. Comparison of Base Shear in Y-Direction (kN) for IS Code and AC Code

The figure illustrates the variation of base shear along different story levels in the Y-direction for both IS and AC codes. The values gradually increase from Story8 ($\approx 6.0 \times 10^{-7}$ kN AC, $\approx 6.5 \times 10^{-7}$ kN IS) to Story1 ($\approx 7.8 \times 10^{-7}$ kN AC, $\approx 1.4 \times 10^{-6}$ kN IS). It is observed that the IS code consistently produces higher base shear values compared to the AC code, indicating a more conservative seismic design approach. The AC code shows comparatively lower values, reflecting reduced seismic force consideration. Overall, IS code ensures greater safety by accounting for higher lateral seismic forces.

3. Material Usage Comparison

Compare the material utilization and any cost implications for both models, based on the steel and concrete weights.

Material	Indian Standard Code (IS)	American Standard Code (US)
Steel Weight	15 tons	16 tons
Concrete Volume	300 m ³	310 m ³
Reinforcement Weight	8 tons	9 tons

- The steel weight and reinforcement required in the Indian model is slightly lower, which might indicate a more material-efficient design due to the higher seismic load consideration.
- The concrete volume in the American model is slightly higher, possibly due to larger beam and column sizes, as well as different assumptions about dead load.

4. Conclusion

This research paper highlights the critical importance of seismic performance evaluation in multi-storey steel buildings, particularly in earthquake-prone regions. By using advanced analytical tools such as ETABS, this study investigates the dynamic response of a typical steel building under earthquake loading, with a focus on seismic parameters like base shear, storey drift, and lateral displacement. The findings suggest that while steel structures are inherently advantageous due to their high ductility and energy dissipation capacity, their performance under seismic forces is highly sensitive to factors like structural configuration, bracing system, and stiffness distribution. The analysis revealed that the Indian design codes, IS 1893:2016, provide more stringent seismic parameters, especially in terms of displacement and story drift, ensuring a higher level of structural safety. The study also compared the performance of steel buildings designed as per Indian and American codes, showing notable differences in base shear and drift allowances. Based on the results, it is evident that steel buildings, when designed with optimized member details and bracing systems, can achieve superior seismic resilience. In conclusion, the study not only emphasizes the need for comprehensive seismic analysis using modern software tools but also advocates for performance-based design improvements to enhance the resilience of steel structures against seismic hazards. These insights will assist in the development of safer, more efficient buildings that comply with both national and international standards.

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