Seismic Analysis of RC Structure Using Different Country Codes

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Abstract- *This study explores the seismic performance of reinforced concrete (RC) structures using a comparative approach to evaluate three major seismic design codes: IS 1893:2016 (India), GB 50011-2010 (China), and the Turkish Earthquake Code 2018. A 60-meter-high RC building was modeled using STAAD.Pro software to assess structural behavior under seismic loads. Key performance parameters, including base shear, nodal deformation, and plate stress distribution, were analyzed. The findings highlight significant variations in design philosophies, with the Indian code demonstrating moderate deformation control, the Chinese code adopting a conservative approach, and the Turkish code emphasizing ductility and strength balance. These differences impact structural resilience and provide insights into enhancing global seismic safety standards. This study contributes to the understanding of regional seismic design practices and proposes recommendations for harmonizing international seismic codes to mitigate earthquake risks effectively. The results aim to advance engineering strategies for earthquake-prone regions.*

Keywords- Seismic analysis, RC structures, STAAD.Pro, IS 1893:2016, GB 50011-2010, Turkish Earthquake Code, comparative study.

I. INTRODUCTION

The increasing urbanization and the consequent rise of high-rise structures have significantly amplified the need for robust seismic design practices, especially in earthquake-prone regions. High-rise buildings, while architecturally and economically significant, pose unique challenges in terms of their seismic performance due to their height, mass distribution, and structural complexities. To mitigate the risks of seismic damage, countries adopt seismic design codes tailored to their regional seismicity, geological conditions, and construction practices. These codes, such as IS 1893:2016 in India, GB 50011-2010 in China, and the Turkish Earthquake Code 2018, play a crucial role in standardizing structural safety measures by specifying design spectra, load combinations, and detailing requirements. Comparing these codes helps uncover differences in design philosophies and evaluate their effectiveness in ensuring resilience in high-rise structures (Paul, Saha, & Dutta, 2017; Erdik, 2019).

Despite significant advancements in seismic engineering, global disparities in seismic design practices persist, often shaped by regional hazards and construction technologies. For instance, while the Indian code emphasizes cost-effectiveness with moderate deformation control, the Chinese code reflects a conservative approach with higher base shear values, and the Turkish code prioritizes ductility for energy dissipation. These variations highlight the necessity of harmonizing seismic standards to improve structural resilience and safety globally. This study employs STAAD.Pro software to perform a comparative seismic analysis of a 60-meter RC building, focusing on key performance metrics such as base shear, nodal displacement, and plate stress distribution. The findings aim to provide actionable insights for refining seismic design codes, ensuring the safety and sustainability of high-rise buildings in seismic zones (Chopra et al., 2017; Gülerce & Rezazadeh, 2016).

II. LITERATURE REVIEW

Recent studies in seismic performance assessment emphasize the critical role of advanced modeling techniques and country-specific seismic codes in ensuring the safety of reinforced concrete (RC) structures. Kapoor and Gupta (2021) used STAAD.Pro to analyze the seismic responses of tall buildings as per Indian, Chinese, and Turkish codes, highlighting significant differences in base shear and lateral drift. Similarly, Kumar and Prasad (2020) examined the variations in seismic load assumptions across these codes, revealing how regional design philosophies influence structural behavior. These studies underline the necessity of adapting design strategies to regional seismicity while leveraging computational tools to improve analysis accuracy.

Contemporary research also focuses on performance-based seismic design and energy dissipation mechanisms. Erdogan et al. (2019) discussed the Turkish Earthquake Code 2018's emphasis on ductility and the integration of energy dissipation devices for enhanced resilience. Zhou et al. (2020) evaluated China's GB 50011-2010, highlighting its probabilistic hazard approach and superior site-specific response spectra. Additionally, Liu et al. (2020) explored the applicability of advanced computational methods in refining seismic analysis under Chinese and international codes. These findings reflect the ongoing advancements in seismic engineering and the growing need for harmonized global standards to address the unique challenges posed by high-rise structures in earthquake-prone regions.

III. METHODOLOGY

3.1 General

This chapter describes the systematic approach adopted to compare the seismic performance of RC structures based on Indian, Chinese, and Turkish seismic codes using STAAD.Pro software. The methodology encompasses structural modelling, load definition, seismic analysis, and data interpretation to evaluate critical parameters such as base shear, story drift, and displacement. The study focuses on understanding how tall buildings respond to seismic forces under different design philosophies.

The analysis centres on a 60-meter-tall high-rise building with dimensions of 15m x 12m and a story height of 3m. The building features RCC columns (0.35m x 0.30m), RCC beams (0.35m x 0.30m), and a slab thickness of 0.18m. Dead loads were calculated based on IS 875 Part 1:1987, while live loads were derived from IS 875 Part 2:1987. Seismic loads were incorporated according to the Indian (IS 1893:2016), Chinese (GB 50011-2010), and Turkish seismic codes, ensuring a comprehensive comparison.

3.2 Plan of the Building

3.3 Structure Properties

The study analysed RC frames with the following configurations:

- **Bay Dimensions**: 15m (X-direction), 12m (Y-direction)
- **Total Heights**:
    - G+5: 15m
    - G+10: 30m
    - G+15: 45m
    - G+20: 60m

3.4 Member Properties

Table 1 provides details of the structural member dimensions, consistent across all configurations:

Table 1. Structural Member Dimensions

Member	Dimensions (meters)
Beam	0.35 x 0.30
Column	0.35 x 0.30
Slab	0.18

3.5 Load Considerations and Combinations

- **Dead Load (DL)**: Self-weight with a factor of 1.5; member weight is 5 kN/m.
- **Live Load (LL)**: Floor weight of 3 kN/m².
- **Seismic Loads**: Parameters were derived from the respective codes.

3.6 Assumptions

- The structure is analysed as per IS 1893:2016, GB 50011-2010, and TÜRKIYE DEPREM YÖNETMELII.
- Models assume uniform, isotropic, and linearly elastic materials.
- Columns are fixed at the foundation.
- Floors are rigid in the horizontal plane.

3.7 Structural Analysis

The models were developed and analysed in STAAD.Pro for all configurations (G+5, G+10, G+15, G+20). Seismic loads from the Indian, Chinese, and Turkish codes were applied to assess critical parameters such as base shear, story drift, and displacement.

3.8 Input Parameter Comparison

Key seismic parameters compared across the codes are summarized in Table 2:

Table 2. Input Parameter Comparison

Parameter	IS 1893:2016	GB 50011:2010	Turkish Code
Zone Factor	0.36 (Zone V)	PGA = 0.4g (Zone 9)	PGA > 0.3g
Response	2.5	2–3 (Behaviour	2–3

Reduction Factor		Factor)	
Soil Type	Medium	Site Class 2 or 3	Site Class 2 or 3
Damping Ratio	5%	~0.05 (Equivalent)	5%
Period (X/Z) (Sec)	0.5	0.5	0.5

3.9 Results Overview

Critical results obtained through the analysis include:

- **Base Shear**: Comparative values reflecting the varying seismic intensity assumptions.
- **Nodal Displacement**: Maximum displacement values highlight the flexibility and resilience of structures.
- **Plate Stresses**: Stress distribution in X and Z directions provides insights into structural integrity.

This structured approach ensures the accuracy and relevance of the findings, offering a basis for evaluating the seismic resilience of RC structures under different international codes.

IV. RESULTS AND DISCUSSION

Table 2 shows the results obtained from analysis;

Table 2. Comparative Analysis of Results

Parameter	**Indian Code (IS 1893:2016)**	**Chinese Code (GB 50011-2010)**	**Turkish Code (Turkish Earthquake Code 2018)**
Deformation Trends	G+5: 67.230 mm, G+10: 594.840 mm, G+15: 1379.64 mm, G+20: 2664.889 mm.	G+5: 184.220 mm, G+10: 680.405 mm, G+15: 1618.875 mm, G+20: 3156.270 mm.	G+5: 172.070 mm, G+10: 475.142 mm, G+15: 971.579 mm, G+20: 1920.443 mm.
Plate Stress (MPa)	X: G+5 = 0.836, G+10 = 3.95, G+15 = 5.86, G+20 = 7.8; Z: G+5 = 0.906, G+10 = 4.34, G+15 = 6.45, G+20 = 8.58.	X: G+5 = 1.9, G+10 = 3.59, G+15 = 5.34, G+20 = 6.34; Z: G+5 = 2.08, G+10 = 3.96, G+15 = 5.93, G+20 = 8.17.	X: G+5 = 2.86, G+10 = 4.17, G+15 = 5.55, G+20 = 7.36; Z: G+5 = 1.63, G+10 = 2.39, G+15 = 3.05, G+20 = 4.12.
Base Shear (G+20)	Fx = 1121.68 kN, Fy = 16402.37 kN, Fz = Not specified.	Fx = Not specified, Fy = 18542.98 kN, Fz = Not specified.	Fx = 1133.98 kN, Fy = 10662.36 kN, Fz = Not specified.
Overturning Moment	G+5: 206.649 kN-m, G+10: 809.152 kN-m, G+15: 1371.322 kN-m, G+20: 1850.482 kN-m.	G+5: 167.850 kN-m, G+10: 647.255 kN-m, G+15: 1210.628 kN-m, G+20: 1571.822 kN-m.	G+5: 210.420 kN-m, G+10: 725.341 kN-m, G+15: 1394.203 kN-m, G+20: 1869.585 kN-m.

Overview of Deformation Trends

The total nodal deformation of a structure under seismic loading is a critical metric for assessing its flexibility and resilience during earthquakes. Deformation values for buildings of different heights (G+5, G+10, G+15, and G+20) under Indian, Chinese, and Turkish seismic codes provide insights into the seismic design philosophies adopted by each country.

The Indian code demonstrates the lowest total nodal deformation across all building heights. The deformation increases steadily with building height, from 67.230 mm for G+5 to 2664.889 mm for G+20. This trend reflects a more conservative approach to deformation control, aiming for structural stability and minimal displacement during seismic events. The lower deformation values suggest stricter criteria for structural stiffness and seismic safety.

The Chinese code exhibits the highest deformation values among the three codes, with a range from 184.220 mm for G+5 to 3156.270 mm for G+20. These values reflect higher assumptions of seismic intensity or more flexible structural designs to accommodate energy dissipation during earthquakes. The significant increase in deformation with height indicates a design philosophy that prioritizes flexibility over rigidity.

The Turkish code presents moderate deformation values, ranging from 172.070 mm for G+5 to 1920.443 mm for G+20. This balanced approach emphasizes a compromise between structural flexibility and safety. The Turkish code aims to provide adequate deformation capacity to prevent structural failure while maintaining resilience.

The deformation trends highlight distinct seismic design philosophies. The Indian code emphasizes minimal deformation for enhanced stability, the Chinese code allows higher flexibility to absorb seismic energy, and the Turkish code adopts a balanced approach. These variations impact the overall building resilience, with each code addressing regional seismic hazards and structural requirements.

PLATE STRESS ANALYSIS

The stress distribution in the X and Z directions for buildings of varying heights under Indian, Chinese, and Turkish seismic codes is a critical parameter for understanding load distribution and structural response under seismic forces.

The plate stress values for the Indian code increase progressively with building height. The X direction stresses rise from 0.836 MPa for G+5 to 7.8 MPa for G+20, while Z direction stresses increase from 0.906 MPa to 8.58 MPa. This indicates a well-distributed load transfer mechanism, ensuring structural integrity under seismic loads.

The Chinese code exhibits slightly higher stresses at lower building heights. For G+5, the stresses are 1.9 MPa (X direction) and 2.08 MPa (Z direction), increasing to 6.34 MPa and 8.17 MPa for G+20, respectively. The stress distribution reflects a design philosophy that emphasizes base-level strength for seismic resistance.

The Turkish code demonstrates higher X direction stresses at lower building heights, starting at 2.86 MPa for G+5 and peaking at 7.36 MPa for G+20. The Z direction stresses are comparatively moderate, ranging from 1.63 MPa to 4.12 MPa, highlighting localized stress concentration in critical structural components.

The Indian code focuses on balanced stress increments with height, ensuring overall stability. The Chinese code prioritizes base-level strength, while the Turkish code emphasizes resistance in the X direction with moderate Z direction values. These differences underscore the impact of national seismic codes on stress management strategies.

BASE SHEAR ANALYSIS

The base shear values for G+5 buildings reveal varying load distributions. The Indian code exhibits moderate values with 126.134 kN (Fx), 601.845 kN (Fy), and 127.466 kN (Fz). The Chinese code shows significantly higher values in Fy (1697.41 kN) and Fz (282.95 kN), reflecting stringent seismic safety measures. The Turkish code presents the highest Fx value (466.76 kN), emphasizing lateral force resistance.

For G+10 buildings, the Indian code records balanced values (583.236 kN in Fx and 4781.155 kN in Fy), highlighting vertical load resistance. The Chinese code displays higher values in Fy (5443.77 kN), while the Turkish code focuses on Fx with 668.26 kN but exhibits lower Fy (3765.41 kN).

The G+15 base shear values reflect similar trends. The Indian code emphasizes uniform load distribution, with 852.04 kN in Fx and 9746.80 kN in Fy. The Chinese code prioritizes horizontal forces, with the highest Fy value (11133.24 kN). The Turkish code shows moderate resistance with 779.92 kN in Fx and 5907.51 kN in Fy.

In G+20 buildings, the Indian code maintains robust values across all directions, including 1121.68 kN in Fx and 16402.37 kN in Fy. The Chinese code peaks at 18542.98 kN in Fy, while the Turkish code balances lateral and vertical stability with 1133.98 kN in Fx and 10662.36 kN in Fy.

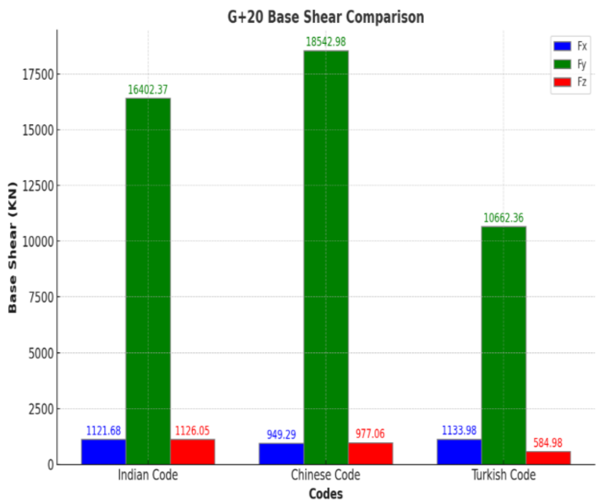

Figure 1. G+20 Base Shear Comparison

The Indian code adopts a conservative approach to distribute forces evenly, while the Chinese code prioritizes horizontal load resistance. The Turkish code emphasizes lateral forces, reflecting distinct regional design priorities.

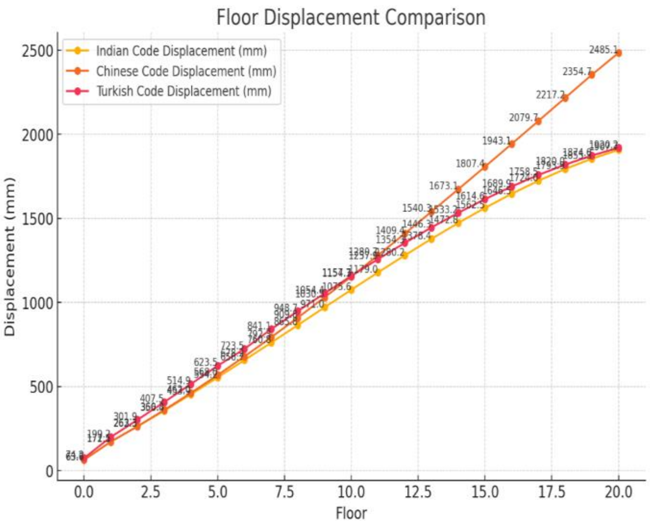

Figure 2. Displacement vs Floor for Different Codes (G+20)

OVERTURNING MOMENT ANALYSIS

The overturning moments for buildings of varying heights under Indian, Chinese, and Turkish codes highlight differences in structural behavior. The Indian code demonstrates steady increases, from 206.649 kN-m for G+5 to 1850.482 kN-m for G+20, reflecting its conservative design approach. The Chinese code presents moderate values, peaking at 1571.822 kN-m for G+20. The Turkish code shows higher moments at lower stories but converges at 1869.585 kN-m for G+20.

The Indian code ensures consistent safety with increasing height, while the Chinese code balances flexibility and stability. The Turkish code emphasizes resistance in lower stories, reflecting different design philosophies for overturning moment control in tall buildings.

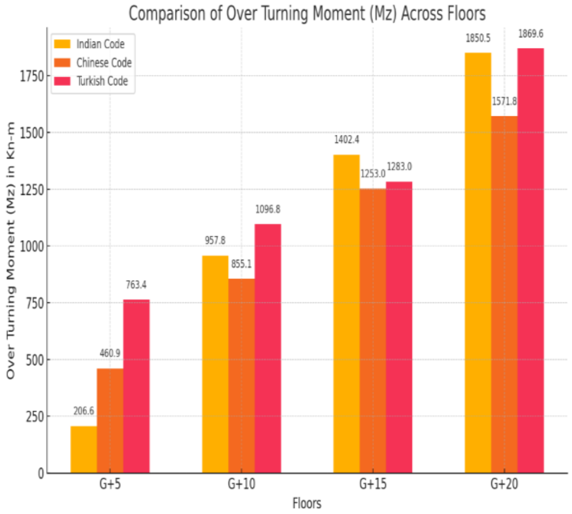

Figure 3. Comparison of Over Turning Moment (Mz) Across Floors

CONTRIBUTION TO SEISMIC ENGINEERING AND DESIGN PRACTICES

The findings from the displacement and drift analysis of G+20 structures under Indian, Chinese, and Turkish codes contribute significantly to the knowledge base of seismic engineering, particularly for regions prone to earthquakes. By analyzing and comparing the structural responses of tall buildings under these three international codes, this study provides critical insights into how varying seismic design philosophies affect the behavior of structures under seismic loads.

V. CONCLUSION

This study provides a comparative assessment of seismic performance in RC structures using Indian, Chinese, and Turkish seismic codes. Key findings highlight significant differences in design philosophies, reflecting diverse regional seismic priorities:

1. **Displacement Trends:**
    - The Indian code minimizes displacement (11%–62% less than others), emphasizing stability.
    - The Chinese code allows higher displacements (20%–50% more than the Indian code), promoting energy dissipation.
    - The Turkish code strikes a balance, achieving moderate displacements.
2. **Story Drift and Base Shear:**
    - Indian code restricts drift and base shear, enhancing structural safety.
    - Chinese code exhibits higher drift and base shear due to stringent seismic load considerations.
    - Turkish code demonstrates balanced drift and shear control, prioritizing ductility.
3. **Overturning Moments and Design Philosophy:**
    - Turkish code focuses on lower-story resistance, while Indian and Chinese codes ensure balanced overturning moment distribution.

The Indian code is conservative and accessible, ideal for basic seismic designs. The Chinese code is suited for regions with varied seismicity, while the Turkish code represents a modern, performance-based approach, setting a benchmark for advanced seismic practices.

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