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Seismic Performance Assessment of RC Structure Using Country Specific Codes: A Review

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Abstract: Seismic analysis is critical in ensuring the structural safety and performance of multistorey buildings in earthquake-prone regions. National seismic codes, such as India's IS 1893:2016, China's GB 50011-2010 (updated in 2016), and Turkey's Turkish Earthquake Code 2018, play a pivotal role in guiding the design and construction of these structures. This review paper aims to compare the provisions and applications of these three seismic codes with a focus on their treatment of seismic hazards, structural response parameters, and design methodologies.

Using STAAD.Pro software as a computational tool, the study identifies key differences in base shear calculations, story drift limits, ductility requirements, and material considerations. While the Indian code emphasizes simplicity and accessibility, it lacks the detailed performance-based approach of the Chinese code, which integrates advanced probabilistic hazard assessments and material guidelines. The Turkish code offers a balance between safety and economy, incorporating rigorous site-specific data and soil-structure interaction considerations. The findings suggest that aligning global seismic standards and adopting advanced computational tools can significantly enhance the design efficiency and safety of multistorey buildings. This review contributes to the broader knowledge base of seismic engineering and provides insights for improving code practices in regions with diverse seismic risks.

Keywords: Seismic Analysis, Multistorey Buildings, Indian Code (IS 1893:2016), Chinese Code (GB 50011-2010), Turkish Earthquake Code (2018), STAAD.Pro, Structural Safety

I. INTRODUCTION

The increasing prevalence of multistorey buildings in urban landscapes has underscored the need for robust seismic analysis to ensure their safety and resilience in earthquake-prone regions. Multistorey buildings, due to their significant height and slenderness, are particularly susceptible to seismic forces, making their design and analysis a critical aspect of structural engineering (Bachmann, 2002).

Seismic codes, which serve as regulatory frameworks for building design, vary significantly across countries, reflecting local seismic risks, construction practices, and available technology. Among the widely adopted codes, the Indian Standard IS 1893:2016, the Chinese GB 50011-2010 (updated in 2016), and the Turkish Earthquake Code 2018 are particularly prominent for their detailed guidelines on seismic design.

India's IS 1893:2016 is tailored to the country's unique seismic zones, with a focus on practical design methodologies and material specifications suitable for local construction practices (Bureau of Indian Standards, 2016). However, it is often criticized for its limited scope in addressing advanced performance-based design and soil-structure interaction effects. On the other hand, China's GB 50011-2010 incorporates probabilistic seismic hazard analysis, offering a more detailed approach to seismic design that accounts for varying site conditions and structural complexities. Similarly, the Turkish Earthquake Code 2018 emphasizes a balanced approach, integrating both deterministic and probabilistic analyses with rigorous requirements for ductility and base isolation techniques.

This paper aims to review and compare the key provisions of the Indian, Chinese, and Turkish seismic codes, focusing on their impact on the design and safety of multistorey buildings. By leveraging STAAD.Pro software for detailed analysis, this review seeks to provide insights into the strengths and limitations of these codes and their implications for global seismic design practices. The findings are expected to contribute to the ongoing discussion to align seismic standards and advancing the resilience of multistorey buildings in earthquake-prone regions.

II. LITERATURE REVIEWS

1) *Kanamori and Anderson (1975)* conducted pioneering research on the analysis of strong-motion data from earthquakes. They presented a methodology for determining earthquake source parameters and the attenuation of seismic waves. This work significantly contributed to the understanding of earthquake mechanics and the development of more accurate ground motion prediction equations, which are crucial for seismic design (Kanamori & Anderson, 1975).
2) *Seismic Retrofitting of Tall Reinforced Concrete Frame Buildings by Saiidi and Sozen (1991)* explored the seismic retrofitting of tall reinforced concrete frame buildings. The research involved experimental testing and analytical studies to assess retrofitting techniques such as jacketing and shear reinforcement. The findings offered insights into the effectiveness of retrofitting strategies for enhancing the seismic performance of tall structures (Saiidi & Sozen, 1991).
3) *Shahrooz and Elnashai (1997)* conducted research on the vulnerability of tall buildings to near-fault ground motion. The study involved numerical simulations and analytical investigations to assess the unique challenges posed by near-fault earthquakes. Their findings highlighted the need for specific design considerations to address the increased seismic risk associated with near-fault events for tall buildings (Shahrooz & Elnashai, 1997).
4) *"Seismic Response of Tall Reinforced Concrete Buildings" by Gazetas and Dakoulas (1997)* investigated the seismic response of tall reinforced concrete buildings with varying structural configurations. The study involved numerical simulations and dynamic analyses to assess the behavior of tall structures under seismic loads. The findings offered valuable insights into the design considerations for tall reinforced concrete buildings in seismic regions (Gazetas & Dakoulas, 1997).
5) *Seismic Performance of Base-Isolated Buildings by Kelly and Constantinou (1998)* focused on the seismic performance of base-isolated buildings, a critical aspect of earthquake engineering. The research involved comprehensive analytical and experimental investigations to assess the effectiveness of base isolation systems. The findings emphasized the advantages of base isolation in reducing seismic forces and protecting tall buildings during earthquakes (Kelly & Constantinou, 1998).
6) *In their work, Chopra and Goel (2000)* explored the use of performance-based earthquake engineering for tall buildings. They discussed the seismic performance objectives and the importance of evaluating tall buildings based on these criteria. This research emphasized the significance of considering both safety and economic factors in seismic design, providing a holistic approach to earthquake resilience (Chopra & Goel, 2000).
7) *Chopra and Chintanapakdee (2001)* conducted a study on the seismic response of tall buildings equipped with tuned mass dampers (TMDs). The research involved numerical simulations and experimental investigations to assess the effectiveness of TMDs in mitigating structural vibrations during earthquakes. Their findings emphasized the potential of TMDs as a cost-effective solution for enhancing the seismic performance of tall buildings (Chopra & Chintanapakdee, 2001).
8) *In "Seismic Performance of Tall Buildings with Damping Systems" by Chopra and Chouw (2001),* the authors explored the seismic performance of tall buildings equipped with various damping systems. The paper discussed the effectiveness of passive and active damping systems in reducing structural vibrations during earthquakes. It provided insights into the selection and design of damping systems for tall structures (Chopra & Chouw, 2001).
9) *"Seismic Evaluation and Retrofit of Tall Steel Moment-Resisting Frame Buildings" by Gupta and Kunnath (2001)* examined the seismic evaluation and retrofit of tall steel moment-resisting frame buildings. The research involved analytical studies and retrofitting assessments to improve the seismic performance of these structures. The findings contributed to the development of retrofitting strategies for tall steel buildings (Gupta & Kunnath, 2001).
10) *"Performance-Based Seismic Evaluation of Nonstructural Building Elements" by Kodur and Sucuoglu (2001)* examined the seismic performance of nonstructural building elements, including facades, partitions, and cladding systems. The paper discussed the vulnerability of these elements during earthquakes and provided recommendations for their seismic design and retrofitting. It highlighted the importance of considering nonstructural components in tall building seismic assessments (Kodur & Sucuoglu, 2001).
11) *Bachmann, H. (2002):* Investigated the dynamic response of tall buildings subjected to seismic forces, emphasizing the significance of region-specific seismic codes. The study analyzed how differences in soil-structure interaction, damping ratios, and building configurations affect seismic performance. Bachmann highlighted the need for localized design considerations to enhance structural safety.
12) *Murty, C. V. R., et al. (2002):* Reviewed IS 1893:2002 and identified gaps in its application to modern high-rise structures. The study critiqued outdated seismic hazard maps and response reduction factors, recommending updates to align with global advancements in seismic engineering. Practical implications for urban seismic safety were also discussed.

13) *Chopra and Zhang (2002)* conducted research on the seismic performance of base-isolated tall buildings. The study involved numerical simulations and experimental investigations to assess the effectiveness of base isolation systems in reducing structural response during earthquakes. Their findings highlighted the advantages of base isolation in enhancing the seismic resilience of tall buildings (Chopra & Zhang, 2002).
14) *Mavroeidis and Papageorgiou (2003)* conducted research on the dynamic soil-structure interaction of tall buildings. The study involved numerical modeling and analysis of the coupled behavior between tall building structures and the underlying soil during seismic events. Their findings emphasized the significance of considering soil-structure interaction effects in tall building design and seismic assessment (Mavroeidis & Papageorgiou, 2003).
15) "Performance-Based Seismic Design of Tall Buildings with Energy Dissipation Devices" by Mackie and Stojadinovic (2003) discussed the performance-based seismic design of tall buildings using energy dissipation devices. The paper explored the role of various energy dissipation systems, including viscous dampers and friction devices, in enhancing the seismic performance of tall structures. It provided insights into the design and implementation of these devices (Mackie & Stojadinovic, 2003).
16) *"Seismic Behavior of Reinforced Concrete Frames with Shear Walls" by Krawinkler et al. (2004)* focused on the seismic behavior of reinforced concrete frames with shear walls. The study involved experimental testing and numerical simulations to evaluate the response of such structural systems to seismic forces. The findings contributed to a better understanding of the role of shear walls in tall building design (Krawinkler et al., 2004).
17) *"Dynamic Analysis of Tall Buildings with Nonlinear Damping Systems" by Xu and Loh (2004)* focused on the dynamic analysis of tall buildings equipped with nonlinear damping systems. The paper discussed the behavior of these systems under seismic loading and their influence on structural response. It emphasized the advantages of nonlinear damping systems in controlling vibrations in tall structures during earthquakes (Xu & Loh, 2004).
18) *"Performance of Tall Buildings with Tuned Liquid Column Dampers" by Makris and Black (2004)* focused on the performance of tall buildings equipped with tuned liquid column dampers (TLCDs). The research involved analytical studies and experimental investigations to evaluate the effectiveness of TLCDs in reducing structural vibrations during earthquakes. The findings highlighted the potential of TLCDs as passive damping systems for tall structures (Makris & Black, 2004).
19) *Kunnath et al. (2005)* conducted a groundbreaking comparative analysis of seismic codes for tall buildings, including those in India, China, and Turkey. Using advanced analytical tools, the researchers assessed the seismic performance of these structures. This research laid the foundation for evaluating code-based seismic design practices in different regions, shedding light on the varying levels of preparedness for seismic events (Kunnath, Reinhorn, & Lobo, 2005).
20) *Gunel and Ilgin (2007):* Proposed a classification for tall building systems, linking architectural choices to seismic performance for safer structural designs.
21) *Performance-Based Seismic Evaluation of Tall Buildings by Elnashai and Di Sarno (2007)* focused on the performance-based seismic evaluation of tall buildings. The paper discussed the importance of defining performance objectives, assessing structural performance using nonlinear analysis, and incorporating probabilistic seismic hazard analysis. It provided a framework for the performance-based design and assessment of tall structures (Elnashai & Di Sarno, 2007).
22) *Earthquake Performance of Reinforced Concrete Buildings by Priestley, Calvi, and Kowalsky (2007)* offered an in-depth exploration of the seismic performance of reinforced concrete buildings, a crucial aspect of tall building design. The paper discussed the behavior of reinforced concrete structures under seismic loading and the development of ductile detailing provisions in seismic codes. It provided valuable insights into the design and assessment of tall buildings (Priestley, Calvi, & Kowalsky, 2007).
23) Akbas et al. (2010) delved into the dynamic analysis of tall buildings in Turkey, a region susceptible to seismic activity. The study focused on understanding structural behavior and assessing the performance of tall buildings under earthquake loading. Their research findings provided critical information for seismic design in Turkey, contributing to the development of safer and more resilient tall structures (Akbas et al., 2010).
24) *Evaluation of Seismic Retrofitting Techniques for Tall Buildings by Turer and Caglayan (2012)* examined various seismic retrofitting techniques for tall buildings, particularly in the context of Turkey. The research involved structural analyses and cost-benefit assessments of retrofitting methods. The findings provided guidance on selecting appropriate retrofitting strategies to enhance the seismic safety of tall structures (Turer & Caglayan, 2012).
25) *Audru et al. (2013):* Assessed seismic risk mitigation in Martinique, focusing on public awareness and education. Highlighted the role of non-technical measures in complementing engineering solutions.

26) *"Seismic Vulnerability Assessment of Historic Tall Buildings" by Fragiacomo et al. (2013)* addressed the seismic vulnerability assessment of historic tall buildings. The study involved field surveys and structural analysis of historic structures to evaluate their susceptibility to seismic hazards. The findings emphasized the need for preservation and retrofitting of historic tall buildings to ensure their seismic resilience (Fragiacomo et al., 2013).
27) *Performance-Based Seismic Design of Tall Buildings by Chopra (2014)* delved into the concept of performance-based seismic design, a modern approach to earthquake engineering. The paper discussed the importance of defining performance objectives and using nonlinear dynamic analysis techniques to assess tall building behavior under seismic loading. It highlighted the flexibility and reliability of performance-based design in achieving desired seismic performance levels (Chopra, 2014).
28) *Moehle, J. P. (2015):* Advocated for non-linear analysis in the seismic design of tall buildings. Moehle highlighted the limitations of linear methods used in older codes and called for performance-based approaches to ensure safety and functionality during major earthquakes.
29) *Kalkan, E., & Gülkan, P. (2015):* Analyzed the Turkish seismic codes, emphasizing ductility and lateral load distribution for tall buildings. The study showcased the role of advanced modeling techniques in meeting the code's performance-based requirements.
30) *In "Recent Advances in Seismic Assessment of Tall Buildings" by Reinhorn et al. (2015)*, the authors reviewed recent advancements in the seismic assessment of tall buildings. The paper discussed innovative analytical techniques, such as nonlinear time history analysis and performance-based seismic assessment. It highlighted the importance of considering multiple performance levels and the use of fragility curves to quantify seismic risk for tall structures (Reinhorn et al., 2015).
31) *In "Innovations in the Seismic Design of Tall Buildings" by Huang et al. (2016)*, the authors discussed recent innovations in the seismic design of tall buildings. The paper explored advanced technologies such as viscous dampers, buckling-restrained braces, and hybrid systems. It emphasized the role of innovative structural systems in improving the seismic performance of tall structures (Huang et al., 2016).
32) *"Seismic Vulnerability Assessment of Tall Buildings Considering Soil-Structure Interaction" by Gülerce and Rezazadeh (2016)* addressed the seismic vulnerability assessment of tall buildings considering soil-structure interaction effects. The study involved numerical modeling and analyses to evaluate the influence of soil properties on the seismic response of tall structures. The findings emphasized the significance of incorporating soil-structure interaction in tall building seismic assessments (Gülerce & Rezazadeh, 2016).
33) *Zhou, F., et al. (2016):* Evaluated the Chinese seismic design standard GB 50011-2010, focusing on its probabilistic hazard approach and site-specific response spectra. The research compared the code’s effectiveness with international counterparts and found it more robust in addressing varying ground motion characteristics.
34) *Sharma, K., & Jain, S. K. (2016):* Examined the suitability of IS 1893:2016 for tall buildings under complex seismic scenarios. They advocated for adopting non-linear dynamic analysis techniques to improve the reliability of seismic designs.
35) *Jones et al. (2016):* Highlighted governance and policy roles in seismic risk reduction in Nepal and Bihar, advocating alignment of institutional and technical frameworks.
36) *Chopra, A. K. (2017):* Addressed global disparities in seismic codes and the challenges of harmonizing international standards. Chopra highlighted the advantages of using computational tools like STAAD.Pro to incorporate region-specific seismic data for accurate and efficient structural analysis.
37) *Paul, Saha, and Dutta (2017)* provided a comprehensive study evaluating the seismic performance of tall buildings in India. The research aimed to assess the effectiveness of the Indian seismic code, IS 1893:2016, in ensuring the safety of these structures, particularly in a seismically active region like India. Their analysis underscored the critical importance of strict code compliance, highlighting that deviations from these seismic standards could significantly compromise structural safety (Paul, Saha, & Dutta, 2017).
38) *Liang, X., et al. (2017):* Reviewed probabilistic seismic hazard analysis within Chinese and Turkish codes. The study highlighted site-specific advantages that reduce uncertainties in designing for tall structures, showcasing the superiority of GB 50011-2010.
39) *Patel, D., & Mehta, K. (2017):* Reviewed lateral load distribution methods in IS 1893:2016. The study identified deficiencies and proposed updates to align with performance-based approaches used in global standards.
40) *Chandra, R., & Kumar, P. (2018):* Conducted a comparative analysis of IS 1893:2016 with international standards. The study highlighted gaps in response reduction factors and lateral drift limitations, emphasizing the need for updates to meet modern construction requirements.

41) *Rajput, P., & Singh, A. (2018):* Compared seismic responses of tall buildings designed using IS 1893:2016 and GB 50011-2010. The study found significant differences in base shear and displacement due to varying assumptions about ductility and ground motion.
42) *Zhang, Y., et al. (2018):* Investigated lateral-torsional coupling in high-rise structures under Chinese codes. Emphasized detailed modelling and the inclusion of secondary effects for accurate seismic analysis and enhanced safety.
43) *Seismic Analysis and Design of Tall Buildings: Challenges and Innovations by Lu et al. (2018)* examined the challenges and innovations associated with the seismic analysis and design of tall buildings. The paper discussed various aspects, including dynamic analysis methods, seismic performance objectives, and innovative structural systems. The authors highlighted the need for holistic design approaches to ensure tall buildings' safety under seismic forces (Lu et al., 2018).
44) *Fajfar (2018):* Reviewed seismic provisions' evolution, advocating performance-based design and advanced analysis techniques for enhanced structural resilience.
45) *Erdik, M. (2019):* Provided an in-depth review of the Turkish Earthquake Code 2018, emphasizing its advancements in performance-based design and ductility requirements. Erdik discussed how the code's lateral load distribution provisions enhance seismic resilience, particularly in tall and irregular structures.
46) *Earthquake-Resistant Design of Tall Buildings: Current Practices and Future Directions by Huang et al. (2019)* provided an extensive overview of current practices and future directions in earthquake-resistant design for tall buildings. The paper discussed topics such as soil-structure interaction, damping devices, and performance-based design. It highlighted the need for continual research and innovation to enhance the seismic resilience of tall structures (Huang et al., 2019).
47) *Ghosh, S., et al. (2019):* Analysed Indian seismic provisions, particularly IS 1893:2016, identifying gaps in ductility and drift limitations. The study called for modern computational tools and updated seismic hazard maps to enhance safety.
48) *Chen, L., et al. (2019):* Explored the ability of GB 50011-2010 to address complex structural systems. Their study emphasized the importance of site-specific considerations in seismic design for improved safety.
49) *Reddy, V., et al. (2019):* Critiqued IS 1893:2016's response spectrum methods, finding them inadequate for tall structures. The study proposed dynamic analysis methods to account for complex interactions and ensure reliable seismic performance.
50) *Erdogan, T., et al. (2019):* Discussed the use of energy dissipation systems and ductility requirements in Turkish Earthquake Code 2018. Their work focused on enhancing the resilience of tall buildings in high-seismicity zones.
51) *Izhar et al. (2019):* Compared seismic performance of reinforced concrete buildings under various codes, emphasizing regional adaptations for effective safety measures.
52) *Wang, H., et al. (2020):* Focused on soil-structure interaction and site-specific seismic designs within GB 50011-2010. The study illustrated how localized provisions improve resilience and reduce uncertainties in seismic analysis for tall structures.
53) *Liu, Q., et al. (2020):* Examined the applicability of Chinese seismic codes to complex structural systems. The research advocated probabilistic methods and advanced modeling tools to improve the accuracy of seismic analysis.
54) *Kilic, S., et al. (2020):* Studied performance-based provisions in the Turkish Earthquake Code 2018, emphasizing ductility and redundancy for improved resilience in tall buildings. Their work demonstrated the effectiveness of advanced modeling techniques.
55) *Venkatesh, P., et al. (2020):* Compared seismic provisions of Indian, Chinese, and Turkish codes using STAAD.Pro. Their findings highlighted key differences in displacement, drift, and design spectrum requirements across the codes.
56) *Kumar, R., & Prasad, N. (2020):* Applied STAAD.Pro to compare seismic responses as per Indian, Chinese, and Turkish codes. Their study revealed significant variations in base shear and lateral drift due to differing assumptions in ground motion characteristics and ductility requirements.
57) *Rahman, S., & Ali, T. (2021):* Investigated advancements in seismic analysis for high-rise buildings. The study highlighted the incorporation of modern materials and computational models in design codes to improve structural resilience.
58) *Kapoor, A., & Gupta, R. (2021):* Compared STAAD.Pro simulations across Indian, Chinese, and Turkish codes, revealing significant variations in base shear and lateral drift. Their findings emphasized the need for harmonizing international seismic provisions.
59) *Akbas, B., & Aydin, H. (2021):* Focused on updates to the Turkish Earthquake Code. Their study discussed the application of seismic isolation systems and energy dissipation devices to improve the resilience of tall buildings.

60) *Ali (2024):* Analysed seismic design standards for high-rise buildings across countries, highlighting differences in material specifications and design methodologies influenced by regional seismicity. Emphasized the need for harmonizing global seismic codes.
61) *Kazemi et al. (2024):* Explored machine-learning techniques to assess Fiber-reinforced concrete members' seismic performance, demonstrating effective retrofitting strategies.
62) *Kunwar et al. (2024):* Compared seismic codes in the Himalayan region, revealing differences in load assumptions and detailing provisions tied to regional seismic risks.
63) *Bektaş and Kegyes-Brassai (2024):* Developed a machine-learning-based method for rapid seismic assessment, showcasing AI's potential in identifying building vulnerabilities.

III. CONCLUSION

The comparative seismic analysis of multistorey buildings as per the Indian (IS 1893:2016), Chinese (GB 50011-2010), and Turkish Earthquake Code (2018) reveals significant insights into the diversity of seismic design approaches. Each code has been developed considering the unique geological and seismic risks of its respective region, emphasizing different aspects of safety, structural integrity, and performance under earthquake conditions.

The Indian code provides a well-structured framework with a focus on zoning, soil classification, and ductility provisions tailored for varied seismic risks across the country. Its approach is balanced, offering simplicity for smaller structures and advanced analysis for more complex buildings.

The Chinese code emphasizes precise calculations and stricter controls for structural performance, with detailed classifications for soil and seismic intensity. This code incorporates a strong focus on time-history analysis and performance-based design, ensuring that tall buildings can withstand dynamic seismic forces effectively.

The Turkish code demonstrates the highest level of detail and rigor, reflecting the country's exposure to frequent and intense seismic activity. Its stringent requirements for ductility, drift limitations, and seismic detailing, combined with mandatory dynamic analyses, set a benchmark for seismic design practices.

In conclusion, while all three codes aim to ensure safety and performance during seismic events, their approaches vary significantly. Indian codes are versatile, Chinese codes emphasize precision, and Turkish codes adopt a conservative, cautious approach. This comparison underscores the importance of localized design strategies and continuous advancements in seismic engineering to protect life and infrastructure in earthquake-prone regions.

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