World Journal of Advanced Engineering Technology and Sciences
eISSN: 2582-8266
Cross Ref DOI: 10.30574/wjaets
Journal homepage: https://wjaets.com/

(Research Article)

Rationale for updating earthquake design forces in modern building codes

Vail Karakale [1,*] and Fathi M Layas [2]

[1] *Department of Civil Engineering, Faculty of Engineering and Natural Sciences, Istanbul Medeniyet University, Istanbul, 34720, Turkey.*
[2] *Department of Civil Engineering, Faculty of Engineering, University of Benghazi, PO Box 1308, Benghazi, Libya.*

World Journal of Advanced Engineering Technology and Sciences, 2025, 14(01), 103-109

Publication history: Received on 28November 2024; revised on 11 January 2025; accepted on 13 January 2025

Article DOI: https://doi.org/10.30574/wjaets.2025.14.1.0005

Abstract

Modern seismic design codes aim to prioritize life safety by permitting controlled structural damage during significant earthquakes while preventing catastrophic failures. This philosophy aligns well with regions of low seismic frequency, where major earthquakes occur roughly every 50–100 years. The current approach uses reduction factors (R) to minimize the size of structural members, balancing safety and economic considerations over a building's typical 100-year lifespan. However, this methodology allows for irreparable damage to structures during major seismic events, which is deemed acceptable in areas with low seismic activity.

In high-risk regions, such as Istanbul, where the likelihood of a major earthquake within a short timeframe is considerably high, the economic viability of this approach is questionable. Frequent seismic activity could result in newly constructed buildings being irreparably damaged within a fraction of their intended service life, necessitating demolition and reconstruction. To address these inefficiencies, it is proposed that reduction factors be regionally tailored. Lower R-values in high-risk zones would limit structural damage to repairable levels, enhancing resilience, sustainability, and economic efficiency by extending the usable life of buildings.

Region-specific reduction factors could ensure that seismic design codes accommodate varying risk levels effectively. For example, in areas with low seismic risk, the current R-value may remain suitable. In contrast, high-risk regions would benefit from reduced R-values to mitigate economic and structural losses. Revising reduction factors in this way would align seismic design practices with regional risk profiles, improving the durability and sustainability of urban infrastructure in seismically active areas.

Keywords: Earthquake forces; Reduction factor (R); Seismic risk; Buildings; Seismic codes; Major earthquakes

1. Introduction

Modern building design codes employ a pragmatic approach to seismic safety, emphasizing the prevention of catastrophic failures while allowing for controlled structural damage during major earthquakes [1,2,3,4]. This philosophy prioritizes life safety over the preservation of the structure, acknowledging that buildings are unlikely to behave elastically under the immense forces of significant seismic events. The fundamental rationale behind this approach is both practical and economic [5].

The typical service life of a building is estimated at around 100 years. In seismic regions, the recurrence interval of major earthquakes—generally between magnitudes 6.5 and 7—ranges from 50 to 100 years. This timeline aligns with the stress accumulation in tectonic plates, meaning that a building is statistically likely to encounter at least one significant earthquake during its lifespan. Design codes therefore allow for controlled damage during these rare but

---

[*] Corresponding author: Vail Karakale. Email: vail.karakale@medeniyet.edu.tr

intense events, ensuring that the structure remains intact enough to save lives but accepting the possibility of irreparable damage.

This design philosophy is especially relevant in regions where seismic activity occurs with low to moderate frequency. A case in point is the Kahramanmaraş region in Turkey, which experienced a devastating magnitude 7.6 earthquake on February 6, 2023, Fig(1) [6]. This event released substantial energy stored in the Earth's crust, significantly reducing the probability of another large-scale earthquake in the region for the next 50 to 100 years. Under these circumstances, constructing new buildings in accordance with current design codes is economically viable, as these structures would likely reach their 100-year lifespan before encountering another comparable seismic event.

Design codes achieve this balance between safety and cost-effectiveness by introducing the concept of a reduction factor, R, (Response Modification Factor) which is a numerical value used to reduce the seismic forces that a structure must be designed to withstand. The R factor accounts for the energy dissipation capability and the inelastic behavior of a structure during an earthquake. It reflects how much the actual seismic forces can be reduced from the elastic response due to the structure's ability to yield and absorb energy. However, this reduction comes with the understanding that some structural elements may sustain irreparable damage during a major earthquake.

Different structural systems have varying R factors based on their design and materials. For example

- Moment-Resisting Frames

These might have higher R factors because they can withstand significant lateral forces without collapsing.

- Shear Walls

Typically exhibit strong lateral resistance and may also have high R factors.

- Braced Frames

These can behave differently depending on how they are braced, leading to different R values.

The R factor is critical for it allows engineers to simplify the design process by using reduced seismic forces rather than full elastic force and ensures that structures can perform adequately during an earthquake, providing safety for occupants.

Figure 1 Irreparable Damage to One- and Two-Year-Old Buildings During the Kahramanmaraş Earthquake

The R factor is thus a key component in earthquake engineering that helps in designing buildings to effectively resist seismic forces based on their structural systems. This level of damage is an intentional trade-off, ensuring buildings remain functional and affordable in regions with infrequent seismic activity, while prioritizing the prevention of brittle collapse and the protection of lives. This approach reinforces the resilience and economic sustainability of modern seismic design principles.

2. The Case for Adjusting Design Forces in High Seismic Risk Regions

The rationale behind current seismic design codes is less practical in regions where the likelihood of a major earthquake within a short timeframe—such as 1 to 10 years—is exceptionally high. In such areas, the traditional approach of relying on high reduction factors (R) to lower design forces and construction costs can result in significant economic inefficiencies and long-term consequences.

Take Istanbul as an example, a region where seismic experts predict a high probability of a major earthquake occurring within the next seven years [7]. Applying a standard reduction factor, such as R=4 or 6, when designing new buildings in Istanbul could lead to structural designs that permit irreparable damage in the event of an earthquake. If such an earthquake strikes shortly after construction, these buildings may sustain damage so severe that demolition and reconstruction become necessary. The economic loss incurred by demolishing and rebuilding relatively new structures undermines the intended cost-effectiveness of the current design philosophy, as the building's economic and functional lifespan is cut drastically short.

In high-risk regions like Istanbul, modifying the reduction factor is essential to achieve a better balance between resilience and cost-efficiency. By reducing the R-value to 2 or even lower, structural designs can limit the extent of damage to repairable levels. This adjustment ensures that buildings remain safe and functional even after enduring a significant seismic event. For example, lower R-values result in structures with increased strength, stiffness, and redundancy, reducing the likelihood of severe damage that necessitates reconstruction.

2.1. This alternative approach has several advantages

- Buildings designed with lower R-values are better equipped to withstand major seismic events, requiring only moderate repairs instead of complete replacement.
- Avoiding the premature demolition of buildings preserves investments, minimizes economic disruptions, and reduces reconstruction costs.
- Limiting the need for frequent rebuilding in high-risk regions decreases construction waste and conserves natural resources, aligning with sustainable development goals.
- Stronger buildings with limited damage protect occupants and ensure the continued operation of essential infrastructure after an earthquake.

For regions where the seismic risk is both high and imminent, adopting reduced R-values in design codes is a pragmatic solution. This modification not only mitigates the potential for catastrophic economic losses but also aligns with the broader goal of creating more resilient, sustainable, and functional urban environments in areas prone to frequent seismic activity.

3. A Proposal for Region-Specific Reduction Factors (R)

To address the limitations of a uniform approach to seismic design, this proposal advocates for region-specific adjustment of the reduction factor (R) in seismic design codes. By tailoring R-values to reflect the unique seismic risks of different regions, it is possible to balance safety, economic viability, and resilience more effectively.

In areas with a high probability of major earthquakes occurring within a short timeframe, adopting lower R-values would ensure that buildings are designed to withstand seismic forces with minimal, repairable damage. This approach prioritizes maintaining the functionality of structures after an earthquake, thereby reducing the need for premature demolition and reconstruction—a critical consideration in regions where frequent seismic activity is expected.

The adjustment of R-values would be based on a detailed evaluation of each region’s seismic risk, including factors such as earthquake recurrence intervals, magnitudes, and local soil conditions [8]. Risk assessments should incorporate probabilistic seismic hazard analyses (PSHA) to provide accurate estimates of seismic activity over specified timeframes.

Regions with low-frequency seismic events, such as Kahramanmaraş, may retain the current R-value in the existing design codes. This higher R-value balances cost-effectiveness with the lower probability of frequent, significant earthquakes.

High-risk zones like Istanbul, where a major earthquake is anticipated within the next decade, would require reduced R-values, potentially around 2 or less. This adjustment would limit damage to repairable levels, ensuring the long-term usability and economic sustainability of buildings.The revised design codes would categorize regions into seismic zones based on their specific risk profiles, similar to existing seismic zoning maps.Each zone would have clearly defined R-values, along with guidelines for their application in structural design, considering factors such as building types, importance categories, and local construction practices.

Buildings designed with lower R-values in high-risk zones will sustain less damage during earthquakes, preserving their structural and functional integrity.By preventing premature demolition and reconstruction, this approach minimizes economic disruptions and preserves investments in infrastructure. Reducing the need for reconstruction decreases construction waste and resource consumption, aligning with global sustainability goals.Ensuring repairable damage reduces the risk of complete structural failure, enhancing life safety during seismic events.

4. Use of Time-Dependent Poisson Models

Time-dependent Poisson models enhance traditional Poisson processes by incorporating the time elapsed since the last earthquake. In these models, the likelihood of an earthquake increases as more time passes without an event. They are particularly useful for estimating the probability of future earthquakes based on the time since the last significant quake.

4.1. Time-dependent probability models in seismology provide valuable insights into earthquake prediction by considering several factors

4.1.1. Historical Seismicity Data

This includes detailed records of past earthquakes—such as their magnitudes, locations, depths, and dates. Analyzing this data helps identify patterns and establish frequency distributions, which are essential for understanding seismic behavior over time.

4.1.2. Geological and Geophysical Data

Detailed maps of active faults, including their lengths, orientations, and slip rates, are critical for predicting where earthquakes are likely to occur. Additionally, sediment cores and other geological indicators reveal past seismic activity, helping refine our understanding of fault dynamics.

4.1.3. Seismological Data

This encompasses recorded seismic waveforms from prior earthquakes, which provide insights into the characteristics and impacts of different seismic events. Understanding how ground shaking affects various geological conditions is vital for assessing potential risks.

4.1.4. Statistical Models and Parameters

These include probabilistic models that describe the likelihood of earthquakes occurring over time, based on historical and geological data. Information about the time since the last significant earthquake on a fault is crucial for making time-dependent predictions.

4.1.5. Tectonic Plate Movement Data

Data on the movements of tectonic plates, including rates of relative motion and interactions at plate boundaries, is essential for risk assessments. This information helps identify areas that may be more prone to seismic activity.

4.1.6. Geodetic Data

Continuous monitoring systems, such as GPS and InSAR (Interferometric Synthetic Aperture Radar), track land deformation and movement over time, offering insights into ongoing tectonic activity.

By integrating these diverse data sources, time-dependent hazard models can more accurately assess the likelihood of future earthquakes. The combination of historical seismicity, geological, geophysical, and statistical data creates a comprehensive framework for understanding seismic risks and enhancing predictive capabilities.

These time-dependent hazard models can be utilized to estimate an optimized value of R, which represents the resistance of buildings to earthquake forces. This estimation takes into account the costs associated with rehabilitating structures after an earthquake occurs.

In this context, R is not a fixed value; it fluctuates based on the time elapsed since the last earthquake. As time passes without seismic activity, the risk of a future earthquake may increase, suggesting that buildings might need to be designed or retrofitted differently to withstand potential impacts.By recognizing that Rchanges over time, urban planners and engineers can implement more strategic approaches to building design and infrastructure development in earthquake-prone areas. This dynamic assessment helps in:

4.1.7. Optimizing Building Designs

Engineers can tailor construction methods and materials to ensure that buildings are adequately prepared for seismic forces, depending on how much time has passed since the last event.

4.1.8. Cost-Effective Rehabilitation

Understanding the relationship between R and time since the last earthquake allows for better financial planning. Resources can be allocated more effectively to reinforce existing structures or design new ones in anticipation of future seismic events.

4.1.9. Enhanced Risk Management

By applying these models, communities can improve their overall resilience to earthquakes. This proactive approach not only protects lives but also minimizes economic losses by ensuring that buildings can better withstand the forces of an earthquake when they occur.

Leveraging time-dependent hazard models to determine an optimized value of R facilitates informed decision-making, leading to safer buildings and more resilient communities in seismically active regions.

In zones of relatively low frequency of major earthquakes (e.g., recurrence intervals of 50–100 years), maintaining the current R-value of 4 is reasonable. The design philosophy in such regions focuses on cost efficiency, accepting the possibility of irreparable damage during rare seismic events.

In high-risk zone, where a significant earthquake is predicted within a short timeframe, reducing the R-value to 2 or less would prioritize durability and repairability. This adjustment would ensure that buildings constructed in the next decade remain operational after a major seismic event, avoiding the economic and societal costs associated with frequent reconstruction.

By adopting region-specific reduction factors, seismic design codes can better reflect the diverse risk profiles of different areas, creating safer, more resilient, and economically sustainable communities in both high- and low-risk seismic regions.

5. Conclusion

Current seismic design codes effectively balance safety and economic feasibility in regions with low-frequency seismic activity, allowing for controlled structural damage while preventing catastrophic collapse. However, these codes often fail to account for the unique challenges posed by high-risk regions, where the probability of a major earthquake within a short timeframe is significantly elevated. In such areas, the economic and structural implications of using uniform reduction factors (R) can result in substantial inefficiencies, particularly when newly constructed buildings face premature demolition due to irreparable damage.

To address this gap, a region-specific approach to seismic design is imperative. By revising reduction factors to reflect the distinct seismic risk profiles of different areas, buildings can be designed to sustain only minor, repairable damage even during significant earthquakes. For high-risk regions like Istanbul, lowering the R-value would prioritize durability and ensure the continued functionality of structures, reducing the economic burden of frequent reconstruction. Conversely, in low-risk areas, maintaining current R-values would remain a cost-effective and practical approach, given the infrequency of major seismic events.

This proposed adjustment to reduction factors represents a critical advancement in seismic design philosophy. It offers several benefits

- Enhanced Resilience
  - Buildings are better equipped to withstand seismic forces while remaining operational, supporting faster recovery after earthquakes.

- Economic Sustainability
  - Avoiding premature reconstruction ensures that buildings fulfill their intended service life, reducing economic losses and preserving investments.

- Environmental Responsibility
  - Decreasing the need for rebuilding minimizes construction waste and resource consumption, aligning with global sustainability goals.

- Urban Safety
  - Improved design standards bolster the safety and reliability of urban infrastructure, safeguarding lives and communities in seismically active regions.

Revising reduction factors to align with regional seismic risk is a vital step toward creating more durable, sustainable, and economically efficient structures. By tailoring seismic design to the specific needs of each region, this approach enhances the resilience of urban infrastructure while ensuring that the economic and social costs of seismic events are minimized. This shift in seismic design codes has the potential to transform the way we build in high-risk areas, fostering safer and more sustainable communities worldwide.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] "NEHRP Recommended Seismic Provisions for New Buildings and Other Structures 2015 Edition". FEMA P-1050 . National Earthquake Hazards Reduction Program. https://www.nehrp.gov/library/guidance_new.htm

[2] CEN (2004), "Eurocode 8: Design of structures for earthquake resistance -Part 1: General rules, seismic actions and rules for buildings", European Standard EN 1998-1:2004. European Committee for Standardisation, Brussels, Belgium..

[3] ORGANIZATION FOR EARTHQUAKE RESISTANT PLANNING AND PROTECTION, Greek Code for Seismic Resistant Structures -EAK2000, Greece; 2000

[4] TBEC-2018. Turkey Building Earthquake Code; Disaster and Emergency Management Presidency of Turkey: Ankara, Turkey, 2018.

[5] AH-S. Ang et al. "Cost optimal design of RC buildings" Reliability Engineering & System Safety (2001), https://doi.org/10.1016/S0951-8320(01)00058-8

[6] V. Karakale, E. Özgür, and Ş. Ataoğlu, “Site Observations on Buildings’ Performance in Hatay Province after Kahramanmaraş Earthquakes”, ECJSE, vol. 10, no. 3, pp. 506–516, 2023, doi: 10.31202/ecjse.1253284.

[7] https://www.duvarenglish.com/istanbul-to-be-hit-by-major-quake-in-next-7-years-with-64-chance-kandilli-observatory-professor-warns-news-61894

[8] F. M. Layas, V. Karakale, R. E. Suleiman, “Developing design response spectra for Benghazi city including soil magnification effects”. Building Engineering 2024, 2(1), 1190.https://doi.org/10.59400/be.v2i1.11901.