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A REVIEW ARTICLE: MITIGATION STRATEGIES FOR SEISMIC DAMAGE IN STRUCTURES

Raihana M. Ejam[1*] and Hatem Hadi Obeid[2]

[1] MSC. Student, Department of Mechanical Engineering, University of Babylon, Iraq, Email: rehana.jassim.engh468@student.uobabylon.edu.iq.

[2] Professor, Department of Mechanical Engineering, University of Babylon, Iraq, Email: eng.hatem.hadi@uobabylon.edu.iq.

[*]Corresponding author

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ABSTRACT

This in-depth review article provides a comprehensive analysis of mitigation strategies for seismic damage in structures, focusing on the importance of understanding seismic properties and implementing advanced analysis techniques. The review underscores the critical role of structural properties, including stiffness, strength, and ductility, in designing earthquake-resistant structures. By exploring a range of seismic analysis methods, such as force-based, displacement-based, and numerical approaches, the review highlights the significance of a holistic approach in assessing structural response to seismic events. Moreover, the review delves into innovative methods like subspace system identification for damage detection and statistical analysis of seismic sequences, offering promising avenues for future research. The adoption of passive energy dissipation systems and base isolation techniques emerges as key strategies in reducing seismic damage and enhancing structural resilience. Additionally, the review discusses the potential of machine learning techniques in predicting seismicity rates and improving risk management in seismic-prone areas. By combining traditional and advanced methods, this review sets the stage for further developments in seismic damage mitigation strategies. The integration of technological expertise, scientific aptitude, and interdisciplinary approaches is highlighted as essential in ensuring the built environment adapts to unforeseeable natural forces. Ultimately, this review provides a foundational resource for academics, policymakers, and practitioners in the field of earthquake mitigation and structural safety.

KEYWORDS

Seismic Damage, Structural Resilience, Earthquake Mitigation, Passive Energy Dissipation, Base Isolation Techniques, Seismic Analysis Methods, Structural Retrofitting.

1. INTRODUCTION

1.1. General Overview

Knowledge of structural seismic features is fundamental for reducing damage in quakes and saving lives. Numerous approaches have been suggested on the issue of seismic safety, such as base isolation and the employment of a damper (Nath, Debnath, and Choudhury, 2018). Not only do we need to consider the properties of structural elements but also the non-structural components, such as facades and building contents, from damage (Palermo, Pampanin, Baird, and Riccio, 2011), (Baird, Palermo, Pampanin, Riccio, and Tasligedik, 2011). This becomes very important in the case of historic buildings over which the understanding of their characteristic helps to define accurate measurements of detection and protection (Cardani and Belluco, 2018).

Earthquakes influence the structures taking on great significance. The causes and results of structural instability due to earthquakes indeed are that forces or displacements have surpassed the buildings' maximum capacity. The other fact is that seismic retrofitting of existing structures under analysis also should consider a probabilistic approach given the high randomness and uncertainty of seismic wave occurrences.

Earthquakes of great magnitude are often accompanied by a sequence of smaller earthquakes with similar origins. Foreshocks are the vibrations that occur before the main shock. Aftershocks are those that occur after the primary shock. The majority of foreshocks are small and happen just a short time before an earthquake. Furthermore, not every earthquake is accompanied by a foreshock. Even while aftershocks can be quite big in both quantity and magnitude, both their frequency and magnitude eventually decline with time. Aftershocks are assumed to be the result of changes in stress imbalances generated by similar ruptures, whereas before-shocks are thought to be the precursors of a fault rupture that generates the big earthquake. There have previously been reports of aftershocks that are almost as large as the main event.

1.2. Overview of seismic properties of the structure

Seismic properties such as stiffness, strength, and ductility are crucial in the design and evaluation of structures for earthquake resistance. Park and Gioncu both emphasize the importance of ductility, with Park discussing methods for estimating it and Gioncu highlighting the differences in required and available ductility (Park, 1989), (Gioncu, 2000). Matthews underscores the significance of ground stiffness in geotechnical design, particularly concerning seismic methods (Matthews, 1997). Ricles focuses on the implications of material and geometric characteristics, such as high-strength steel, on inelastic flexural behavior, emphasizing the need for adequate ductility in earthquake-resistant design (Ricles, 1998).

The behavior of structures during seismic events is significantly influenced by their stiffness, strength, and ductility. Capecchi emphasizes the importance of stiffness distribution in multi-degree-of-freedom structures, as it affects local ductility demand (Capecchi, 1980). Chrysanidis highlights the role of elongation in the lateral buckling behavior of seismic walls, with increased ductility requirements leading to extensive tensile deformations (Chrysanidis, 2015). Mu discusses the impact of oblique stiffeners on the seismic behavior of steel plate shear walls, which can improve bearing capacity, stiffness, and energy dissipation (Mu, 2020). Homaei further underscores the influence of stiffness and strength irregularities in vertically irregular steel buildings, which can reduce structural ductility and seismic capacity (Homaei, 2017). These studies collectively demonstrate the critical role of stiffness, strength, and ductility in determining the seismic performance of structures.

1.3. Earthquakes measure

The magnitude and impact of earthquakes are measured by earthquake metrics. The quantity of energy produced at the source and the magnitude of an earthquake determine its size, whereas the intensity of an earthquake at a specific point determines its impact. Fig. 1 specifies the relevant components of an earthquake, including its measurements at the source and any place. (Villaverde, 2009).

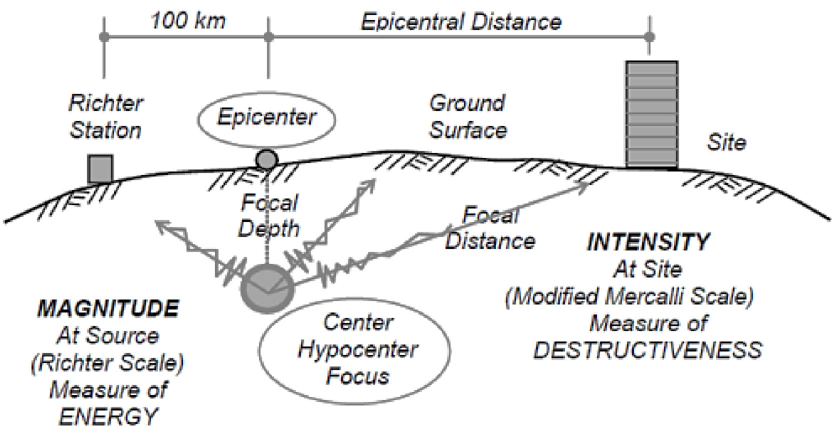

Fig. 1 measures of earthquake

Seismographs are used to record seismic waves. These are typically sensors that capture two horizontal and one vertical orthogonal component of ground motion. Seismographs can be made to record seismic ground motion's acceleration, velocity, or displacements. The most common seismological engineering devices are accelerometers, which measure acceleration. The ground acceleration a(t) is composed of three parts: ax (t), ay (t), and az (t). Seismograms are recorded data from a seismograph. So, the seismogram is a log of the variation in ground displacement over time., amplified by the seismograph's magnification factor, at the seismograph's installation site (Villaverde, 2009).

2. SEISMIC ANALYSIS

A range of seismic analysis methods for structures have been explored in the literature. Belostotsky provides an overview of these methods, including force-based, displacement-based, and numerical methods, with a focus on underground structures (Belostotsky, 2018). Şafak emphasizes the key processing steps in data record analysis which are the identification of the system and the damaging effect (Şafak, 2001). The author's preference is best applied to simple and robust methods. Fragiadakis places much emphasis on the use of advanced computer programs in the estimation of demand on structures, due to uncertainty and to ensure increases in future developments (Fragiadakis and Papadrakakis, 2008). Jeyasehar stresses the fact that the seismic performance evaluation is done through multiple steps of methodologies either experimental or computational, in which he deeply looked into the pseudo-dynamic testing method (Jeyasehar, Kumar, Muthumani, and Lakshmanan, 2009). Altogether, the researchers participated in a project on a narrow and significant area in which seismic analysis and the safety of structures are comprehensive and important.

Shokravi gives in this paper a complete study of the application of structure vibration excitation-based system identification to damage detection of civil structures (Shokravi, 2020). (Woodward, 2012) underscores the cogency of a three-dimensional approach in assessing the magnetotelluric data and characterizing the deformed regions, whereas Lesage offers a general description of the volcanoes' shallow velocity structure, derived from a combined analysis of seismic and laboratory measurements (Lesage, Heap, and Kushnir, 2018). In (Limbeck, 2021) work, it is demonstrated that a machine learning approach for induced seismic forecasting in the Groningen gas field beats up the traditional techniques such as the Baket method. The wide spectrum of methods and techniques that are documented in these papers, among others, underlines the inherent diversity in the subject matter analysis.

The family of statistical methods of analyzing the seismic moment sequence logizes time clustering structures, positions and non-Poissonian moments (Telesca, 2002). For offshore jacket structures when considering the Structural Reliability Analysis (SRA), which can be computed with the help of First- or Second-Order Reliability Methods (FORM/SORM) as well as with the Monte Carlo Simulation Method (MCS), there has been uncertainty in material properties, dimensional geometries, and operating environments which have been assessed (Shittu, 2020). The collection of building data for seismic vulnerability and risk assessments is crucial, with newer technology-based methods showing potential (Stone, 2018). (Abass and Jarallah, 2022) discussed various seismic evaluation techniques and methods used in different international codes, including the Capacity Spectrum Method (CSM), Displacement Coefficient Method (DCM), N2 method, and Coefficient method. These methods involve performing pushover analysis, converting the structure to an equivalent SDOF system, and estimating the target displacement or seismic demand on the structure. The seismic analysis in (Attiyah, Hussain, 2021) perspective refers to the use of the seismic plastic hinge model, which is typically used for nonlinear dynamic analysis in seismic design, to analyze the behavior of structures under blast loads, even though the validity of this approach is questionable.

Lastly, landscape architects can play a role in designing public open spaces to support seismic resilience, with key themes including multifunctionality, networks, and social resilience (French, 2019).

2.1. structural analysis methods:

2.1.1. Force-Based Method:

The force-based method is a procedure for analyzing statically indeterminate structures. Researchers primarily work with force quantities as the primary variables.

- Basic Idea: Treat various forces (internal forces, support reactions) as unknown parameters.
- Equilibrium Equations: Equilibrium equations (based on statistics) are used to find these forces.
- Material Information: Material properties (stress-strain relationships) are needed primarily for calculating deflections (Menon, D., Meher Prasad, A., Varughese, J.A., 2018).
- Advantages:

a. Smaller deflections for similar members.

b. Redundancy in load-carrying capacity (allows for force redistribution).

c. Increased stability.

- Applicability:

a. Suitable for both beams and frames.

b. Commonly used for analyzing statically indeterminate structures.

2.1.2. Displacement-Based Method:

The displacement-based method (also known as the stiffness method) is another approach for analyzing indeterminate structures. Researchers view displacements and slopes as primary unknowns.

- Basic Idea: Express local force-displacement relationships in terms of unknown member displacements.
- Stiffness Matrix: Requires stiffness values of members (stiffness matrix).
- Advantages:

a. Provides a rational procedure for analyzing indeterminate structures.

b. Allows determination of unknown forces and moments using slope and deflection information.

- Applicability:

a. Effective for analyzing sophisticated structures with many redundant constraints.

b. Widely used in seismic design and dynamic analysis.

2.2. Relevance and Applicability:

Researchers have come to understand how critical it is to create strong design techniques that lower the likelihood of earthquake-related structural damage.

• Paradigm Shift: More logical displacement-based design techniques must replace the traditional force-based approach.

• Uniform Risk Structures: The goals of displacement-based techniques are uniform risk structures and damage limitation.

New Developments:

• Direct Displacement-Based Design (DDBD): This approach, which computes design displacements directly, is proposed by researchers. The structure is transformed into a corresponding system with one degree of freedom, and P-Δ and higher mode effects are taken into account (Pal, M., Choudhury, S., 2022).

• Unified Performance-Based Seismic Design: Promoted to modify the design process to account for member performance levels and drift (Pal, M., Choudhury, S., 2022).

In summary, both methods have their place, but displacement-based approaches offer advantages in rationality and control over structural behavior. Researchers continue to refine these methods for broader applicability across various building types and structures (Menon, D., Meher Prasad, A., Varughese, J.A., 2018), (Pal, M., Choudhury, S., 2022).

3. METHODS TO REDUCE SEISMIC HAZARDS ON STRUCTURES

Numerous conventional and novel techniques have been designed to mitigate seismic harm to structures. (Wada, 2009, 2011) and (Priya, 2014) all highlight the effectiveness of passive energy dissipation systems, such as tuned mass dampers, friction dampers, and tuned liquid dampers, in reducing damage in moderate seismic zones and wind-predominant regions. (Wada, 2009, 2011) also emphasizes the benefits of retrofitting with post-tensioned rocking walls and steel dampers, which can control deformation patterns and reduce damage during earthquakes. (Matsagar, 2008) further supports the use of base isolation techniques, such as elastomeric bearings and sliding systems, in reducing seismic response and damage in retrofitted structures. These methods collectively offer a comprehensive approach to mitigating seismic damage in buildings.

(Mitchell, 1994) discusses retrofitting techniques for bridges, including the use of restrainers and improvements to bearing supports. (Soltani, 2014) emphasizes the importance of site selection criteria for sheltering after earthquakes, with accessibility and proximity to affected homes being key factors. (French, 2019) portrays how public shared spaces such as squares, parks, and entertainment areas are important in maintaining seismic resilience within the city by emphasizing multifunctionality, networking, and social resilience. (Nishi, 2019) directs attention toward another element – the strength of the elastomeric seismic protection isolators, which might serve as the basis for classification. These studies demonstrated that a variety of measures need to be implemented simultaneously, which includes both the structural and nonstructural protection undertakings.

According to (Shapira, 2016) and (Limbeck, 2021), the creativity of strategies and modern techniques makes the possibility of concluding seismic damage very much tangible. Shapira's integrated model for earthquake casualty assessment considers human sensitivity and also emphasizes vulnerability and resilience as a factor of concern, On the other hand, Limbeck uses machine learning techniques for predicting seismicity rates in the Groningen gas field which implies the potential for better risk management with the advent of technologies. On the part of (Mignan, 2021), a complete survey and meta-analysis works are touted as the way to go to understanding seismic hazard risks, for instance, on geothermal sites. Seismic studies jointly indicate that the usage of a combination of traditional methods such as base isolation and retrofitting coupled with innovative methods like model construction through a more advanced method and machine learning reduce earthquake damage by as much as 70 to 80 percent.

In the same vein, although (Bahekdra, 2019) and (Marioni, 2004) are different studies, they largely show the effectiveness of seismic base isolation, with (Bahekdra, 2019) expounding on the use of lead rubber bearings and friction isolators, respectively. (Muradyan, 2022) suggests a type of seismic isolator that is made of steel, rubber and reinforced concrete. Those kinds of seismic isolators have passed many seismic tests and have proved themselves highly efficient. (Lazar, 2011) accentuates the fact that a seismic design within this approach should be static and response-based where numerous seismic steps should be implemented to decrease the seismic risk. So, these methods either by taking the process away from the known ones to the outside part of the earthquake zone or improving the current system will help to make stronger structures with speedier reactants.

In the author's opinion, one of the most successful methods or strategies for mitigating seismic damage in structures is the combination of passive energy dissipation systems and base isolation techniques. Researchers like Wada, Priya, Matsagar, and others have highlighted the effectiveness of these methods in reducing damage in buildings located in seismic zones.

Passive energy dissipation systems, such as tuned mass dampers, friction dampers, and tuned liquid dampers, are designed to absorb and dissipate seismic energy, thereby reducing the impact of seismic forces on structures. These systems act as shock absorbers, helping to minimize structural damage and improve overall resilience during earthquakes.

Base isolation techniques involve decoupling the building from the ground using elastomeric bearings or sliding systems. By isolating the structure from the ground motion, base isolation helps to reduce the transfer of seismic forces to the building, thereby decreasing the risk of structural damage.

The combination of passive energy dissipation systems and base isolation techniques offers a comprehensive approach to mitigating seismic damage. By incorporating both methods, buildings can benefit from enhanced protection against seismic forces, improved structural stability, and increased resilience to earthquakes.

Overall, the successful implementation of passive energy dissipation systems and base isolation techniques has been shown to significantly reduce seismic damage in structures, making them key strategies in ensuring structural safety and minimizing the impact of seismic events.

4. CONCLUSION:

The threat of seismic events to structural integrity is an ever-present concern in earthquake-prone regions. This review has underscored the critical role of understanding seismic properties, employing rigorous analysis methods, and implementing effective mitigation strategies. Our comprehensive examination reveals that:

a. Structural Properties:

- The interplay of stiffness, strength, and ductility is paramount in designing earthquake-resistant structures.
- Material selection and geotechnical considerations are foundational to resilient design.

b. Analysis Techniques:

- A combination of traditional and advanced analytical methods provides a robust framework for assessing seismic response.

- Innovations in damage detection and statistical analysis of seismic sequences offer promising avenues for future research.

c. Mitigation Strategies:

- The adoption of passive energy dissipation systems and base isolation techniques represents a leap forward in hazard reduction.
- Embracing a risk-based approach to design and retrofitting can significantly enhance structural resilience.

Ultimately, the determination of a seismically risk-free environment is multifaceted in that it entails a mixture of technological expertise, scientific aptitude, and forethought in making policies. While we take on more and more knowledge on the topic, providing technology innovation and interdisciplinary approaches will be a key element in ensuring the built environment adapts to the unforeseeable natural forces.

The key findings and contributions of this review article on mitigation strategies for seismic damage in structures are as follows:

1. Importance of Structural Properties: The review emphasizes the critical role of understanding structural properties such as stiffness, strength, and ductility in designing earthquake-resistant structures. Researchers like Park, Gioncu, Matthews, and Ricles have highlighted the significance of these properties in seismic resistance.
2. Analysis Techniques: The article discusses a range of seismic analysis methods, including force-based, displacement-based, and numerical approaches. Researchers like Belostotsky, Şafak, Fragiadakis, and Jeyasehar have explored different methods for assessing seismic response and structural safety.
3. Mitigation Strategies: The review outlines traditional and innovative methods for reducing seismic damage in buildings. Strategies such as passive energy dissipation systems, base isolation techniques, and retrofitting with post-tensioned rocking walls have been shown to effectively mitigate seismic hazards.
4. Integration of Traditional and Modern Approaches: The article underscores the importance of combining traditional principles with advanced technologies for minimizing seismic damage and ensuring structural safety. Researchers like Shokravi, Woodward, Lesage, and Limbeck have demonstrated the value of modern techniques in enhancing seismic resilience.
5. Risk-Based Approach: The review advocates for a risk-based approach to design and retrofitting, emphasizing the need to consider both structural and nonstructural protection measures. By embracing a comprehensive risk assessment strategy, structural resilience can be significantly enhanced.

Overall, the review article highlights the importance of a holistic approach that integrates traditional knowledge with modern advancements to effectively mitigate seismic damage and ensure the safety and resilience of structures in earthquake-prone regions.
This observation sums up all the article's main points, stating such an approach is necessary for seismic damage mitigation and enabling chances for further development of the field to occur in the future.

5. SUMMARY

This summary gives the most highlighted points in this article and helps the future researcher to understand the principles of seismic properties and mitigation strategies.

Aspect	Key Points	Suggestions for Future Research
Seismic Properties	- Stiffness, strength, and ductility are crucial for earthquake-resistant design.	- Investigate novel materials with enhanced properties.
	- Force-based methods analyze structures using seismic forces.	- Develop hybrid methods that combine force-based and displacement-based approaches.
	- Displacement-based methods consider structural displacements.	- Explore adaptive strategies that adjust design parameters during seismic events.
Mitigation Strategies	- Passive energy dissipation systems (e.g., dampers) reduce seismic damage.	- Optimize damper placement and characteristics for different building types.
	- Base isolation techniques isolate structures from ground motion.	- Investigate the long-term effects of base isolation on building performance.
Technological Integration	- Combine traditional methods with advanced technologies (e.g., AI, ML) for seismic resilience.	- Explore AI-driven predictive models for early warning systems.
	- Machine learning can enhance seismic risk assessment and response planning.	- Develop AI algorithms to predict post-earthquake damage and prioritize recovery efforts.

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