

International Journal for Science Review

Analyzing the Structural Resilience of Multi-Story Buildings to Earthquakes Using Deep Learning-Based Artificial Intelligence

Qarnila Ridhaniah Rahman*¹, Muh. Amin Rahman²

^{1,2}University of Technology Sulawesi, Jl. Talasalapang No. 51A, Karunrung, Rappocini District, Makassar, South Sulawesi, Indonesia

*Corresponding author: qarnila1205@gmail.com

ABSTRACT

This study aims to analyze the resilience of multi-storey building structures to earthquakes by utilizing artificial intelligence technology based on deep learning. In the context of increasing intensity and frequency of earthquakes in different regions of the world, the need for more sophisticated modeling and evaluation systems of building structures is becoming increasingly important. This research uses a qualitative approach with the literature study method (library research) to explore various results of previous research, scientific journals, and relevant technical reports. The main focus is on the application of deep learning models, such as convolutional neural networks (CNN) and recurrent neural networks (RNNs), in detecting, predicting, and evaluating the performance of building structures to seismic stress. The results of the study show that the application of deep learning is able to improve the accuracy in predicting structural damage and accelerate the decision-making process in disaster risk management. In addition, the technology can be used in real-time sensor data processing and earthquake simulation to identify potential structural collapses early. However, challenges such as limited training data, model complexity, and high computing requirements

KEYWORDS

Artificial Intelligence, Deep Learning, Structural Resilience, High-rise Buildings, Earthquakes.

remain obstacles to the widespread adoption of this technology. This study recommends the need for integration between conventional civil engineering approaches and artificial intelligence to create a more adaptive and efficient earthquake mitigation system.

1. INTRODUCTION

The earthquake phenomenon is one of the most destructive natural disasters and cannot be predicted with certainty, so it requires a building resilience system that is able to respond adaptively to seismic pressure (Zhou et al., 2020). High-rise buildings, particularly in urban areas with high population density, have a great risk of structural damage if not designed with adequate earthquake resistance (Moeini et al., 2021). Therefore, analysis of the resilience of multi-storey building structures is an important aspect in earthquake disaster planning and mitigation.

Various conventional approaches have been used in evaluating structural resilience, such as pushover analysis methods and response spectrums (Chopra, 2017). However, this approach has limitations in terms of flexibility and predictability against complex and varied earthquake scenarios. Along with technological developments, artificial intelligence (AI), especially deep learning, is beginning to be used as an alternative to model the response of structures to earthquakes more accurately and efficiently (Eslami et al., 2020).

Previous research has proven that deep learning algorithms such as Convolutional Neural Network (CNN) and Recurrent Neural Network (RNN) are capable of analyzing seismic data and detecting structural damage with high accuracy (Duarte & Sánchez, 2022; Alzubaidi et al., 2021). In addition, the application of AI in structural analysis has shown promising results in terms of damage prediction, classification of collapse types, and real-time processing of sensor data (Khandelwal et al., 2022; Kim & Cho, 2020). However, most of the research still focuses on simple types of structures and has not studied in depth the application of deep learning in high-rise buildings with high geometric and material complexity.

This is where the research gap lies that is the basis of this research, namely the lack of comprehensive studies that combine deep learning modeling with the analysis of the resilience of multi-storey building structures to specific earthquakes. In addition, some studies have not integrated AI models with empirical data from earthquake simulations or structural sensors on an ongoing basis (Li et al., 2023).

The urgency of this research is even higher given the increasing frequency of global earthquakes and the limitations of traditional analytical methods in dealing with more complex future seismic scenarios (Patel et al., 2021). Thus, it is necessary to develop a new approach that is able to provide more precise and fast analysis results in order to support the planning of safe and disaster-resistant building structures.

This study offers a novelty in the form of an integrative study between deep learning technology and the evaluation technique of the resilience of multi-storey building structures based on a comprehensive literature study, which has not been explored in depth in previous studies. The main objective of this study is to analyze the potential and effectiveness of the application of deep learning-based AI in assessing the resilience of multi-storey buildings to

earthquakes. The expected benefit is the availability of academic and conceptual references that can be the basis for the development of artificial intelligence-based structural disaster mitigation systems in the future.

Definition and Context of Structural Resilience of Multi-Storey Buildings

Structural resilience in multi-storey buildings refers to the ability of a building to maintain its structural functions, absorb energy, and recover from extreme disturbances such as earthquakes without experiencing total collapse. In the context of civil engineering, structural resilience not only includes the material strength of the building, but also involves the design of structural systems capable of evenly distributing seismic loads and reducing permanent damage. Multi-storey buildings have a higher structural complexity than single-story buildings, so they require more careful planning in dealing with lateral loads from earthquakes.

Components and Determinants of Structural Durability

The durability of a multi-storey building structure is influenced by a number of factors, such as the type of structural system (e.g., moment frame, sliding wall, or combined system), the quality of the building materials, the design geometry, and the construction method. Structural elements such as columns, beams, and joints must be designed to have high ductility, i.e. deformation ability without loss of strength. In addition, external factors such as soil conditions, seismic zones, and earthquake history in the region also determine the level of resilience needed. Resilience evaluation is carried out through linear and non-linear analysis, simulation tests, and modeling of structural responses to earthquake scenarios.

The Relevance of Structural Resilience in Disaster Mitigation

The concept of structural resilience is very important in disaster mitigation strategies, as it can reduce the potential for life and economic losses caused by building damage when an earthquake occurs. Buildings designed with sustainability principles in mind are not only able to protect their occupants, but can also minimize disruption to social and economic functions in urban areas. In the modern era, the integration of technologies such as structural sensors, real-time monitoring, and artificial intelligence has become a new approach in optimizing the evaluation and improvement of the resilience of multi-storey building structures.

2. METHODS

This research uses a qualitative approach with the type of literature study (library research), which aims to explore, understand, and analyze various scientific sources related to the resilience of multi-storey building structures to earthquakes using artificial intelligence technology based on deep learning. The literature study was chosen because it allows researchers to explore the latest theories, empirical findings, and technological approaches that have been developed and published in the context of similar research (Zed, 2008).

The data sources in this study consist of secondary data obtained from various scientific publications, including Scopus and Web of Science-indexed international journals, conference proceedings, academic books, technical reports, as well as relevant articles in research repositories such as ScienceDirect, IEEE Xplore, SpringerLink, and Google Scholar. Inclusion criteria in the selection of sources include articles that discuss the resilience of structures to

earthquakes, applications of deep learning in structural engineering, and studies published in the last 10 years to maintain the relevance and timeliness of information (Ridwan, 2015).

The data collection technique was carried out through a systematic review of the relevant literature, starting with the identification of keywords such as structural resilience, multi-story buildings, earthquake engineering, and deep learning in structural analysis. This process is continued with the stage of filtering articles based on abstracts and topic suitability, then conducting an in-depth reading of the selected literature. To ensure the validity of the data, a process of theoretical triangulation and comparison between sources was carried out (Moleong, 2019).

The data analysis method used is content analysis, which is the process of critically reviewing the content of the literature to identify thematic patterns, research gaps, and scientific contributions from the application of deep learning to the resilience of building structures. The analysis was carried out inductively by grouping findings based on main themes, such as the type of algorithm used, the effectiveness of damage prediction, the integration of sensor data, and the technical challenges faced in its implementation. With this method, the research can provide a complete synthesis of the potential of artificial intelligence in improving the structural resistance of buildings to earthquakes.

3. RESULTS AND DISCUSSION

The following data is the result of a selection process for a number of scientific articles that discuss the topic of resilience of multi-storey building structures to earthquakes with the application of artificial intelligence technology, especially based on deep learning. From various academic sources such as ScienceDirect, IEEE Xplore, SpringerLink, and Google Scholar, 10 articles have been screened that meet the inclusion criteria, namely the relevance of the topic, the level of up-to-date (last 10 years), and the quality and reliability of the publication. The table below presents key information from the selected articles, including authors, years, research focus, AI methods used, as well as key findings from each study.

Table 1. Selected Literature Data in Literature Studies

Author & Year	Article Title	Key findings
Alzubaidi et al. (2021)	CNN architecture review and its application in engineering	<i>CNN is effective in the classification of structural damage based on visual imagery.</i>
Duarte & Sánchez (2022)	Deep learning in structural health monitoring	<i>DL improves the accuracy of damage detection compared to traditional methods.</i>
Li et al. (2023)	Evaluate the seismic performance of high-rise buildings with an AI approach	<i>The AI model is able to predict the response of structures to earthquakes in real-time.</i>

Khandelwal et al. (2022)	Structural damage detection using IoT and DL sensors	<i>The integration of IoT and DL sensors supports early detection and predictive maintenance.</i>
Kim & Cho (2020)	Detection of concrete damage with DL and digital image correlation	<i>The model provides more accurate damage prediction results than visual techniques.</i>
Eslami et al. (2020)	ML&DL review in structural health monitoring	<i>DL is capable of managing big data and improving monitoring efficiency.</i>
Moeini et al. (2021)	Seismic performance of post-earthquake high-rise buildings	<i>The need for AI integration for more complex risk analysis.</i>
Patel et al. (2021)	Earthquake-resistant structure innovation in the digital age	<i>The use of AI accelerates responses in disaster evaluation and mitigation.</i>
Zhou et al. (2020)	Earthquake risk assessment and structural vulnerability	<i>AI and GIS synergize in the structural risk mapping of multi-storey buildings.</i>
Chopra (2017)	Fundamentals of structural dynamic analysis of earthquakes	<i>A basic reference in understanding the structural response to dynamic loads.</i>

The results of the literature review show that deep learning (DL), especially Convolutional Neural Network (CNN) architecture, is the most dominant method in research related to the resilience of multi-storey building structures to earthquakes. Most studies use CNN for visual classification of structural damage, either through digital imagery, sensor data, or vibration data. This shows that CNN has an advantage in recognizing complex and repetitive visual patterns, which is particularly useful in the context of automatic and rapid evaluation of post-earthquake structures.

Several articles such as those of Khandelwal et al. (2022) and Patel et al. (2021) highlight the importance of integration between Internet of Things (IoT)-based sensor technology with DL algorithms in structural monitoring systems. Through the real-time data collected by these sensors, deep learning models can efficiently process and identify early indications of malfunction. This gives an idea that research trends are not only leading to predictive modeling, but also to the development of sensor-based intelligent systems for dynamic risk mitigation.

From the analysis of articles such as Li et al. (2023) and Eslami et al. (2020), it was found that a combination of models such as CNN-RNN or CNN-LSTM showed better performance in analyzing sequential or temporal seismic data. This hybrid model is able to capture the spatial and temporal relationships of structural data, making it suitable for predicting the dynamic response of multi-storey buildings to earthquakes. This confirms that the selection of the right

DL architecture has a major influence on the accuracy and reliability of the structural resilience prediction model.

Although deep learning technology promises high accuracy, some studies such as those raised by Moeini et al. (2021) and Duarte & Sánchez (2022) underscore real-world implementation challenges, such as limitations of quality training data, limitations of computing, and lack of integration with conventional structural engineering frameworks. In addition, there have not been many studies that have examined the performance of DL in the context of buildings with complex structural designs or with high non-linearity characteristics in severe earthquake zones. This shows that there is a research gap that can be used as a basis for further studies.

Several articles, such as those from Patel et al. (2021) and Zhou et al. (2020), provide strong evidence that the application of AI in general, including machine learning and deep learning, provides significant added value in the disaster mitigation process. With the ability to predict early and continuously monitor, high-rise buildings can be categorized based on the level of damage risk, so that decision-making in emergency response can be done more efficiently. This signifies that AI is not only a technical tool, but also an important part of strategic planning for urban disaster mitigation.

Based on a review of the literature analyzed, it can be concluded that although DL technology shows great potential, its implementation still requires technical standards and supporting policies. Collaboration between structural experts, data scientists, and policymakers is urgently needed to develop models and systems that are adaptive and widely applicable in a variety of geographic and architectural contexts. These findings reinforce the urgency of transdisciplinary research in order to optimize the resilience of multi-storey buildings to earthquakes using an artificial intelligence-based approach.

Discussion

In recent decades, rapid urbanization has driven the construction of high-rise buildings in earthquake-prone areas, particularly in developing countries such as Indonesia, Turkey, and the Philippines. This increases the need for a building structure system that is not only sturdy, but also able to survive and recover from earthquake disasters. Facts show that most earthquake victims are caused by building collapses (UNDRR, 2022), so structural resilience is a very urgent issue. This is where the role of artificial intelligence technology, especially deep learning, becomes increasingly relevant.

From the results of the literature review, it was found that the Convolutional Neural Network (CNN) is the most widely used algorithm in the detection and classification of structural damage. CNN has the ability to extract visual features automatically, making it very effective in processing image data such as concrete cracks, deformation changes, or structural surface damage. These findings are in line with feature extraction theory in deep learning that allows systems to learn automatically from complex data without manual intervention (LeCun et al., 2015).

A study by Khandelwal et al. (2022) shows that the integration of IoT-based sensors with AI provides great potential in realizing real-time structural health monitoring (SHM) systems. This phenomenon is in line with the concept of smart buildings and smart cities, where buildings can monitor their own conditions and provide early warning of the risk of collapse.

In the midst of high earthquake frequency, this kind of system can provide a rapid response to hazards, as well as be part of a more intelligent and adaptive national disaster mitigation system.

However, a major challenge in the application of deep learning in structural contexts is the availability of adequate training data. Some articles indicate that the accuracy of the model is highly dependent on the data used, both in terms of quality, quantity, and diversity. In developing countries, post-earthquake structural data are often poorly documented. This is a serious obstacle in building reliable predictive models. Therefore, the authors consider that strengthening data infrastructure is an important foundation for the widespread adoption of this technology.

Findings from Li et al. (2023) and Eslami et al. (2020) suggest that hybrid models such as CNN-RNN or CNN-LSTM provide better predictive accuracy in analyzing a building's response to earthquakes. These models not only consider visual aspects, but also take into account temporal dynamics, such as changes in deformation over time. This is relevant to dynamic systems theory in earthquake engineering, which states that the response of structures to seismic loads is non-linear and changes in seconds (Chopra, 2017).

One of the research gaps identified is the lack of studies examining the application of deep learning in multi-storey buildings with complex geometries and structural systems, such as outrigger systems, shear wall-core combinations, or steel-concrete hybrid structures. This complexity poses challenges in the process of data labeling, structural behavior modeling, and validation of simulation results. The authors consider that it is necessary to develop a specific structural dataset for complex multi-storey buildings, as a basis for testing more accurate AI models.

Outside of the post-earthquake context, AI can also be leveraged in the planning stage of the design of multi-storey building structures. With data-driven analysis of earthquake history and documented structural performance, AI can provide more efficient and earthquake-resistant design recommendations. This approach supports the principle of performance-based seismic design (PBSD), which emphasizes the resilience of building functions, not just the resilience of its physical structure. Therefore, AI can accelerate the transition to resilience-based building planning.

The application of AI in structural resilience cannot be done partially. Collaboration between structural experts, data scientists, earthquake experts, and policy makers is needed to develop a complete system framework, both from the technical, regulatory, and ethical sides. Findings in the literature show that although algorithms are available, their application in the field still faces bureaucratic constraints, limited human resources, and the absence of standard technical regulations. The author emphasizes the need for national and international collaborative forums in encouraging the systemic implementation of this technology.

This research contributes to providing a comprehensive overview of the potential and challenges of applying deep learning in the context of the resilience of multi-storey buildings to earthquakes. Through the mapping of the literature, it can be seen that this technology has great potential to change the paradigm of structural engineering, from being originally based on manual calculations to an intelligent data-driven predictive approach. However, this technology still requires a supporting ecosystem in the form of data, infrastructure, and regulations.

In closing, the author believes that the future of structural engineering will be greatly influenced by the development of AI, especially in the context of adaptation to climate change and increased risk of natural disasters. This research not only serves as a theoretical study, but also as a trigger for strategic discussions in formulating the policy direction of disaster-resistant infrastructure development. The authors recommend an application for further research agendas, including the development of AI-based building monitoring platforms for high-rise buildings in earthquake-prone areas.

4. CONCLUSION

This study confirms that the application of artificial intelligence technology based on deep learning has great potential in increasing the resilience of multi-storey building structures to earthquakes. Through a literature review of ten main articles, it was found that algorithms such as Convolutional Neural Network (CNN), Long Short-Term Memory (LSTM), and other hybrid models have been widely used in detecting structural damage, monitoring building performance in real-time, and predicting building seismic response. This technology has proven to offer efficiency, accuracy, and predictive capabilities that conventional approaches do not have.

Nevertheless, there are still a number of important challenges that need to be overcome. One of them is the limitation of representative training data, especially for local contexts in developing countries such as Indonesia. In addition, there have not been many studies that have examined the implementation of deep learning in buildings with high architectural and structural complexity. Multidisciplinary collaboration between structural experts, data scientists, and policy makers is also still minimal, so the application of this technology in the field is not optimal. There is also a need for regulations and technical standards that can bridge the gap between technology development and structural engineering practice.

Further Research Recommendations

Based on the results of this study, it is recommended that the next study be focused on developing a more comprehensive structural dataset, especially for high-rise buildings in earthquake-prone areas in Indonesia. In addition, future research needs to explore deep learning models that are more adaptive to local seismic data and the integration of AI systems in IoT-based smart monitoring systems. It is also necessary to take a case study approach on real buildings to test the validity and reliability of AI systems in the context of structural resilience. The development of an AI-based open platform for post-earthquake structural evaluation is also an important agenda in supporting fast, accurate, and efficient disaster mitigation.

5. ACKNOWLEDGMENT

The author expresses his deepest gratitude to the researchers and institutions who have published scientific articles that form the basis for this literature review. Without their contribution in developing knowledge in the field of structural resilience and artificial intelligence, this study would not have been comprehensively comprehensive. The author also expresses appreciation to the university library and international scientific journal database for providing full access to relevant references. In addition, appreciation is

expressed to colleagues who have provided academic input in the process of compiling this article.

6. AUTHORS' NOTE

This article was compiled as part of the author's efforts to explore the use of artificial intelligence technology, especially deep learning, in strengthening the resilience system of multi-storey building structures in earthquake-prone areas. The authors recognize that the literature study approach has limitations in generalizing local contexts and a lack of empirical field data. Therefore, the results of this study are expected to be a theoretical basis for further research that is applicable and experimental. The author has no conflict of interest in the publication of this article, and all views and interpretations in this article are the sole responsibility of the author.

7. REFERENCES

- Alzubaidi, L., Zhang, J., Humaidi, A. J., Al-Dujaili, A., Duan, Y., Al-Shamma, O., ... & Farhan, L. (2021). Review of deep learning: Concepts, CNN architectures, challenges, applications, future directions. *Journal of Big Data*, 8(1), 53. <https://doi.org/10.1186/s40537-021-00444-8>
- Chopra, A. K. (2017). *Dynamics of Structures* (5th ed.). Pearson.
- Duarte, D., & Sánchez, J. (2022). Deep learning techniques for structural health monitoring: A systematic review. *Engineering Structures*, 252, 113600. <https://doi.org/10.1016/j.engstruct.2021.113600>
- Eslami, M., Gandomi, A. H., & Roke, D. A. (2020). Machine learning and structural health monitoring: A review. *Archives of Computational Methods in Engineering*, 27(2), 525–544. <https://doi.org/10.1007/s11831-019-09319-w>
- Khandelwal, K., Ahmad, R., & Sharma, R. (2022). Smart damage detection in structures using deep learning and IoT-enabled sensors. *Structural Control and Health Monitoring*, 29(3), e2870. <https://doi.org/10.1002/stc.2870>
- Kim, J., & Cho, S. (2020). Damage detection of concrete structures using deep learning and digital image correlation. *Sensors*, 20(19), 5577. <https://doi.org/10.3390/s20195577>
- Li, Y., Wang, X., & Zhang, H. (2023). Data-driven seismic performance assessment of high-rise buildings using hybrid AI models. *Journal of Building Engineering*, 68, 106156. <https://doi.org/10.1016/j.jobbe.2023.106156>
- Moeini, R., Khoshnoudian, F., & Bozorgnia, Y. (2021). Seismic performance of tall buildings: Lessons from recent earthquakes. *Soil Dynamics and Earthquake Engineering*, 150, 106972. <https://doi.org/10.1016/j.soildyn.2021.106972>
- Moleong, L. J. (2019). *Qualitative Research Methodology (Revision)*. Bandung: Remaja Rosdakarya.
- Patel, H. V., Shah, H. R., & Shah, K. D. (2021). Challenges and opportunities in earthquake-resilient structures in the era of smart technologies. *Innovative Infrastructure Solutions*, 6(1), 1–10. <https://doi.org/10.1007/s41062-020-00386-4>
- Ridwan, M. (2015). *Research Methodology: For Thesis and Thesis Writing*. Bandung: Alfabeta.
- Zed, M. (2008). *Literature Review: The First Steps of Scientific Research*. Jakarta: Yayasan Obor Indonesia.

Zhou, H., Liu, Z., & Li, Q. (2020). Earthquake risk and structural vulnerability assessment in urban buildings. *Natural Hazards*, 104(1), 455–475. <https://doi.org/10.1007/s11069-020-04133-7>.