Comprehensive Journal of Science
Volume (10), Issue (38), (Dec, 2025)
ISSN: 3014-6266

مجلة العلوم الشاملة
المجلد (10) ملحق العدد 38 ديسمبر 2025
ردمد: 3014-6266

Artificial Intelligence Applications in Post-Earthquake Structural Damage Simulation

First Author: Najat Marami ،Department of Environmental Engineering، Faculty of Natural Resources Engineering، University of Zawia/Zawia/Libya
Second Author: Zahra Al-Hanashi ، Department of Civil Engineering، Faculty of Engineering، Subrata University /Sabratha/Libya
Thrid Author: Sumia Alghlam، Department of Civil Engineering ، Faculty of Engineering، Alzintan University/ Alzintan/Libya

تاريخ الاستلام:2025/12/8 –تاريخ المراجعة: 2025/12/12 – تاريخ القبول: 2025/12/19 – تاريخ للنشر : 2026 /1/17

Abstract:
Earthquakes can pose one of greatest challenge to the designers of buildings and other civil engineering structures. These serious risks threaten human safety and infrastructure, with traditional post-earthquake damage assessments being slow, costly, and sometimes hazardous. This paper summarizes recently developed methods and theories in the developing direction for applications of artificial intelligence in civil engineering, including in simulating and predicting structural damage following seismic events. AI enables rapid and accurate assessment of building damage by collected a lot of data from global earthquake networks and, using methods such as leveraging machine learning (ML), deep learning (DL), artificial neural networks (ANNs), convolutional neural networks (CNNs) and long short-term memory (LSTM). AI-based approaches offer significant improvements in prediction accuracy, accelerate post-earthquake response, and early warning integration. By these strategies seismic disaster mitigation can be during a pre-earthquake, and be executed at the time of an earthquake and post-earthquake. The research problem is defined in the following main question: Can we, through the use of artificial Intelligence, predict earthquakes, mitigate disaster risks, avoid human losses, and protect buildings and facilities from collapses that cause loss of life and property? This research aims to study the seismic behavior predicted by artificial intelligence applications for concrete structures as a result of repeated seismic wave loads imposed on them and to know their ability to resist the effects of these waves, represented by shear, torsional, bending and moments forces. This study also aims to evaluate the limits contained in some international codes and compare them with the values predicted by artificial intelligence applications. These codes include the American code ACI-14, the second European code EC-2, and the Egyptian code ECP-2017.

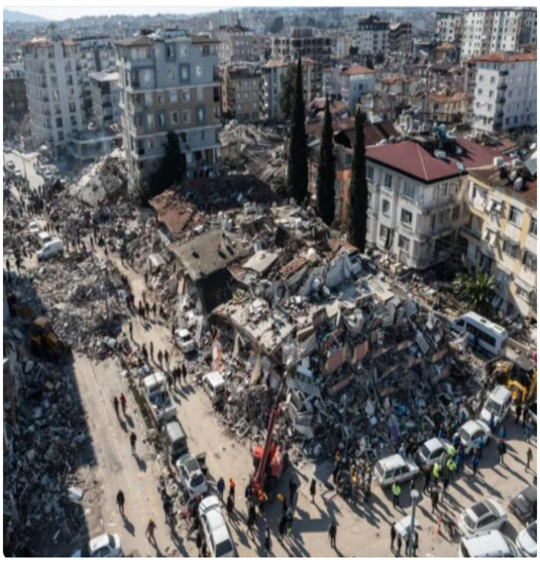
Keywords: Artificial intelligence; Earthquakes Engineering; Deep learning; Seismic behaivour predicted risk; ANN; CNNs; LSTM.

1. Introduction:

Among the last two decades the risk of seismic waves has been rising and the number of earthquakes become more effective, this make researchers thinking about using technology of artificial intelligence applications to predict earthquakes, mitigate disaster risks, Figure 1 shows some of the damage caused by the strongest and most violent earthquakes in the world. The AI can contribute to enhancing our understanding of seismic events' impact on structures and facilitating more efficient in the aftermath of an earthquake.The need for more sophisticated modeling and evaluation systems of building structures is becoming increasingly important to increase the resistance of multi-storey building structures to avoid the risks of results earthquakes, in this situation using of the different AI techniques, machine learning (ML), pattern recognition (PR), and deep learning (DL) was more effective in the felid of earthquake and structural engineering, AI-driven approaches offer the potential for faster, more accurate, and safer evaluations, leveraging advanced computational capabilities to analyze vast amounts of data from various sources, including satellite imagery, sensor networks, and structural models.From another hand using post-earthquake images were analyzed and classify building damage levels automatically by using Convolutional Neural Networks (CNNs). From here the importance becomes clear conventional civil engineering approaches must be connected with artificial intelligence to create more efficient earthquake mitigation system

The safe and adequate performance of numerous reinforced concrete structures exposed to severe earthquakes in various regions of the world has made it possible to design such structures to be 100% capable of withstanding earthquakes of significant strength and intensity. The extent to which these earthquake-resistant designs rely on values derived from the results of the aforementioned neural networks in artificial intelligence applications has been demonstrated. Although earthquake engineering is a separate science from structural engineering and building structural analysis, there is a slight overlap between the two, which has been taken into account when developing neural networks capable of predicting the intensity and magnitude of seismic waves and ground movements that occur randomly in all directions.


9.5M Earthquake inChile (1960-6000Died)   9.1M Earthquake inIndonesia(2004-22000Died)




7.8M Earthquake in Turkey(2023-53000 Died)   7.9M Earthquake in Nepal (2015-9000Died)

Fig.1 Pictures showing earthquake damage in different parts of the world

2. Structural Design Requirements for Concrete Buildings Exposed to Earthquakes According to International Codes:

The ACI code provide minimum requirements for a cast-in-place or precast concrete structure capable of sustaining a series of oscillations into the inelastic range of response without critical deterioration in strength. The integrity of the structure in the inelastic range of response should be maintained to cast-in-place concrete structures to respond in the nonlinear range when subjected to design-level ground motions, with decreased stiffness and increased energy dissipation but without critical strength decay.which permit precast construction with alternative yielding mechanisms. The combination of reduced stiffness and increased energy dissipation tends to reduce the response accelerations and lateral inertia forces relative to values that would occur were the structure to remain linearly elastic and
lightly damped. The use of design forces representing earthquake effects such as those in ASCE/SEI 7 requires that the seismic-force-resisting system retain a substantial portion of its strength into the inelastic range under displacement reversals.
The American code design No. 203 of 2014 [1], as well as the Egyptian Code for Concrete Design No. 203 of 2017 [12], it was proposed that earthquake loads be taken into account in the equation for calculating the maximum design load in the following manner:

$$U= 1.4 D + 1.8 E =0.75 (1.4D + 1.7L + 1.8E) \quad (1)$$

To examine tensile and torsional stresses, the equation becomes:

$$U= 0.9 D+1.4 E \quad (2)$$

Where:
E : Earthquake load
D: Dead load
L: Live load
Based to the Egyptian Code for Concrete Design No. 203 of 2017, the equation becomes as follows:

$$U=0.8(1.4 D+ 1.6L+ 1.6S) \quad (3)$$

3. Artificial Intelligence Nonlinear Simulation:

Chen Wang, Junxian Zhao, and Tak Ming Chan demonstrate the limitations of traditional design methods, which often fail to take into account the extensive experience of flexible structures during earthquakes in providing optimal earthquake-resistant designs within design criteria that meet the required level of resistance to seismic waves of various types and strengths. They turn to nonlinear numerical simulation with artificial intelligence tools to automatically achieve optimal earthquake-resistant designs, taking into account the complex nonlinear structural response under the influence of strong seismic waves [7].
The flexibility of a building structure, including all its components—foundations, columns, beams, and slabs—when in optimal condition, such that they align with seismic waves without causing significant fractures or cracks that would cause the building to collapse. This is what was assumed in the database of AI models developed and trained to obtain optimal design results that are safer, more stable, and of greater value than the ideal design parameters included in international codes such as the American Code, the European Code, and the Egyptian Code. Impressive results and optimal design values were predicted by the AI, with the error rate not exceeding 1% when the artificial neural network (ANN) was trained across many samples, totaling 1,200 samples [6].

4. AI Applications in Seismic Design and Damage Assessment:

There is a body of research that has addressed the use of artificial intelligence in the field of earthquake engineering by creation of an ideal earthquake-resistant design. These designs demonstrated the limitations and failure of traditional design methods in resisting seismic waves that affect the ductility of structural structures during earthquakes [6].
Recent advances in artificial intelligence, particularly convolutional neural networks (CNNs) and deep learning-based image classification models, have significantly enhanced the precision and automation of post-earthquake damage mapping by enabling the rapid identification of collapsed structures, debris, and affected transportation networks from heterogeneous data sources, allocating limited resources, and planning reconstruction strategies in affected regions [7].

4.1 Artificial Neural Network (ANN).

Early studies primarily focused on Artificial Neural Networks (ANNs) to predict and classify building damage based on seismic parameters such as ground acceleration, displacement, and frequency response.
(ANNs) used as smart models to analyze data and classify post-earthquake satellite images as shown in figure 2. It identifies the location and extent of earthquake damage, as well as areas that were not affected. A model is created based on inputs from satellite images divided into layers, with each layer representing a type of data, such as infrared, visible light, or reflection from the Earth's surface. Some researchers used ENVI software, which specializes in processing satellite images, to transform the data into the desired format for use in the neural network as shown in figure 3. Collapsed buildings, cracked buildings, damaged roads, factories destroyed, water networks and rivers, and intact lands are identified, and these are considered as Classes from which a is ultimately obtained content the last information placed as a result of the impact of seismic waves, GIS applcation worke to add including the road network and hospitals, to quickly guide rescue teams, and population to create a practical rescue plan.

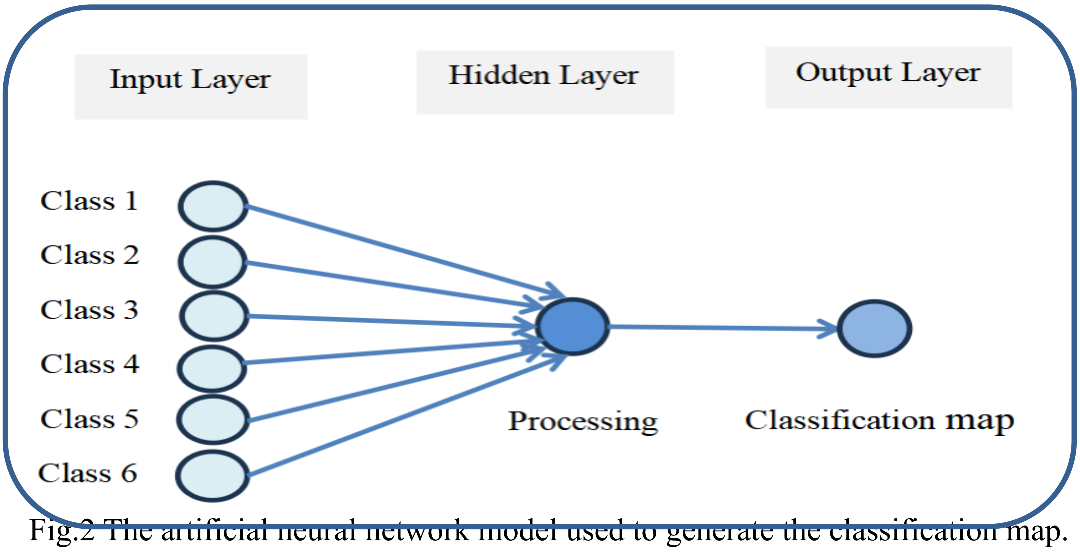


Fig.2 The artificial neural network model used to generate the classification map.

Satellite Images

↓

ENVI Software
- Analyze images
- Layer separation (infrared, visible light, etc.)
- Damage classification (collapsed buildings, damaged roads, intact areas)

↓

Classification Map

↓

GIS Software

- Map integration with road data
- Adding hospital and population locations
- Route and needs analysis

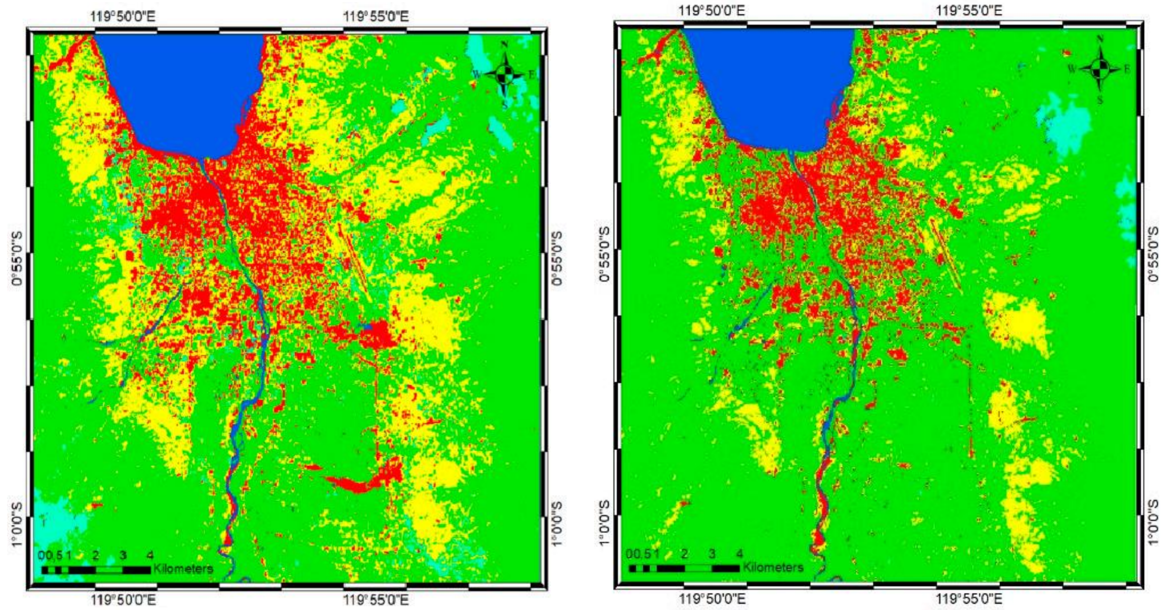
↓

Emergency Response Map

Fig.3 Diagram showing the steps of satellite images and different software (ENVI & GIS) are used to create an Emergency Response Map.

Figure.4 (A) shows the damage predicted using AI applicatThe artificial neural networks method (ANN from the classification results of the ANN and the (Support Vector Machine (SVM method from the Sentinel images were used to map the damage after the severe seismic (waves in Palu, Indonesia. The total damaged area after the earthquake was 11,502,100 square meters, which is much larger than the damage estimated from field data. Method (ANN (

determined the damage area to be much larger than Method(SVM and the actual damage on (the ground. Figure.4 (B)shows the damage from the actual images .



A. Damaged urban area according to field data B. Affected urban area according to AI predictions

Fig.4 shows actual field damage and damage predicted by AI applications.

4.2 Convolutional neural networks (CNNs)

Convolutional neural networks, referred to as CNNs, are used in a variety of deep learning problems and variety of classification and prediction problems, and consider one of the most powerful technologies that are used for a variety of classification and prediction problems. Convolutional neural networks (CNNs) have achieved breakthrough performances in a wide range of applications including image classification, semantic segmentation, and object detection. Convolutional neural networks involve a huge number of neurons. Each neuron has weights and biases associated with them which can be learned over time to fit the data properly.They can be used for classification as well as prediction problems which involve images as input. Alot of researchers theoretical and experimental for results both demonstrate that bounds for CNNs are are more effective than others.

It has become possible to predict post-earthquake damage through some AI applications. Researchers such as Wang et al. [11] have integrated AI technology into some of its advanced applications with optimal design in structural engineering, designing a back-end system for a new AI-powered framework to conduct automated structural damage diagnosis after earthquakes.

The development of Convolutional Neural Networks (CNNs) marked a significant advancement in the analysis of post-disaster earthquake satellite and aerial imagery, enabling highly precise damage detection.

4.3 Long Short-Term Memory LSTM

Some researecers recomended by upon the analysis findings/results, the application of machine learning for structural failure prediction and its effectiveness in reducing earthquake damage can be realized, by an integration of a comprehensive and dynamic database, capable of storing the seismic data gathered by the sensors and also such as temperature sensors, pressure sensors, surface crack meter etc. could greatly improve the quality and reliability of seismic data [8].

This research clearly shows that LSTM architecture in terms of processing data and output accuracy Confirms its effectivenesso. Clearly, LSTM has the potential to be reliable to detect earthquake and structural failure prediction due to its high performance. LSTM architecture by researchers can not only process data gathered by IoT sensors accurately, but also warn people as the output can be integrated with an EEWS alarm, Figure 5. shows Suggested LSTM Architecture for Earthquake and Structural Failure Prediction

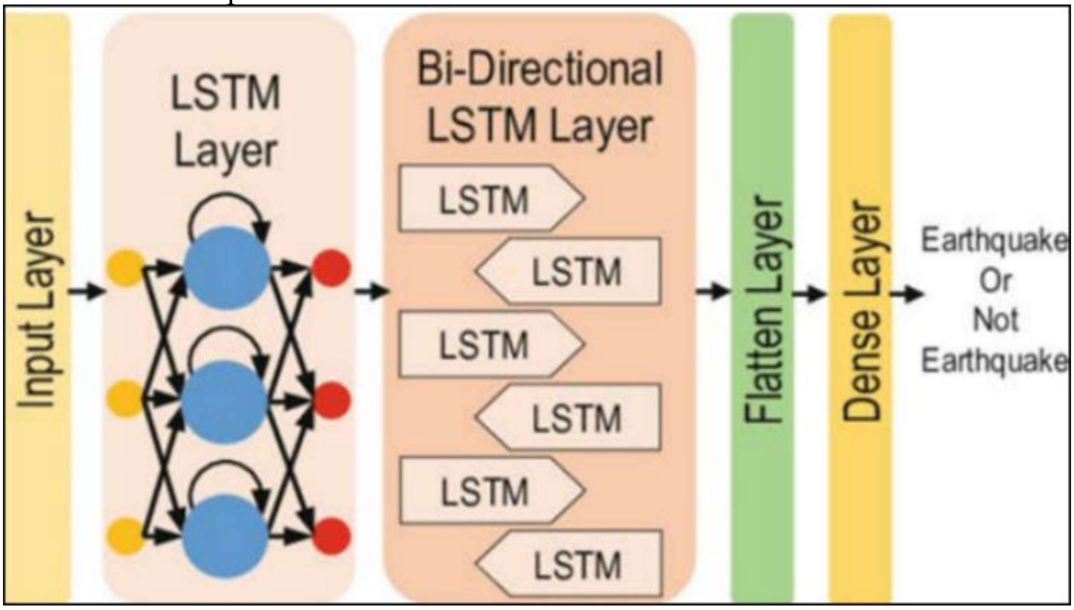


Fig.5 Suggested LSTM Architecture for Earthquake and Structural Failure Prediction

Conclusion:

Based on the results of current experimental and analytical studies on the effectiveness of artificial intelligence as atool in simulating post-earthquake structural damage , the following conclusions can be drawn:

1- Artificial Intelligence represents a significant advancement in simulating post-earthquake structural damage. By enabling fast and accurate prediction of damage levels, it helps reduce losses, speed up rescue operations, and support reconstruction efforts.

2-Future directions include developing more integrated models. Investing in this field is essential for achieving safer and more sustainable buildings.

3-Artificial Neural Networks (ANNs) play a vital role in recognizing complex damage patterns and classifying affected structures based on visual and structural data.

5. Integrating CNN predictions into GIS environments enables decision-makers to visualize and prioritize reconstruction zones more efficiently.

References

[1] ACI Committee 318 (1999), " Building Code Requirements for Reinforced Concrete and Commentary (ACI 318-99)," American Concrete Institute, Detroit, 1999.

[2] Matsuoka, M.; Wakamatsu, K.; Fujimoto, K.; Midorikawa, S. Average shear-wave velocity mapping using Japan engineering geomorphologic classifification map. Struct. Eng. Earthq. Eng. 2006, 23, 57–68. [CrossRef]

[3] Rusydi, M.; Efendi, R. Earthquake hazard analysis use Vs30 data in Palu. J. Phys. Conf. Ser. 2018, 979, 012054. [CrossRef]

[4]Ahmed M. Yousef. Earthquake Resistant Design Structures. 2011, pp - .

[5] Conforti, M.; Pascale, S.; Robustelli, G.; Sdao, F. Evaluation of prediction capability of the artificial neural
networks for mapping landslide susceptibility in the Turbolo River catchment (northern Calabria, Italy).

Catena 2014, 113, 236–250. [CrossRef]
[6] Chen Wang, Junxian Zhao, and Tak-Ming Chan, Artificial intelligence (AI)-assisted simulation-driven earthquake-resistant design framework: Taking a strong back system as an example
[7] Mutiara Syifa, Prima Riza Kadavi and Chang-Wook Lee , An Artificial Intelligence Application for Post-Earthquake Damage Mapping in Palu, Central Sulawesi, Indonesia, 2019, PP .
[8] Pankaj Kumar Sarker, Suchayan Chakraborty Shoumik, Santanu Palit, Abdullah Al Naseeh Chowdhury, Mst Sanjida Alam, Mohammad Delowar Hossain Gazi and Mahabubur Rahman, Machine learning applications in predicting structural failures and earthquake damage
[9] Shan Lin, Jingwei Zhang, Generalization Bounds for Convolutional Neural Networks.

[10] Khosravani, M. R., & Ghaffarian, A. (2018). Artificial neural networks for post-earthquake damage assessment of reinforced concrete buildings. Structural Safety, 70, 65–78.

[11] Yuntao Zhu, Jain Zhong, AI-assisted analytical model of seismic displacement estimation for frictional isolated bridge portfolios under pulse-like ground motions September, 2024.

[12] ECP-203-17. (2017). Egyptian Code for Design and Construction of Reinforced Concrete Structures. Ministry of Housing, Utilities and Urban Communities, Cairo, Egypt.