Applying Machine Learning to Enhance Seismic Scenario Simulation Technology for Urban Disasters in Taiwan

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INTORDUCTION

Earthquakes are disasters that are sudden, highly uncertain, and have immediate destructive effects. When a large number of buildings are damaged, it can trigger a chain reaction and further expand the scale of the earthquake disaster. In recent years, the government has actively promoted the reinforcement of old buildings and the establishment of databases for building assessment and on-site investigation. The main purpose of this study is to develop machine learning technology to assist in building earthquake impact assessment. This study collaborated with the research team of National Taipei University of Technology and used the Preliminary Seismic Evaluation of RC Building (PSERCB database) (Sung et al. 2017) as training data for deep learning, in order to understand the important features of building disaster causes and risk analysis. In this study, machine learning deep learning algorithms were developed to quickly estimate the seismic capacity of buildings. Combined with multidimensional seismic impact three-dimensional models, high-risk areas of urban building damage can be quickly assessed based on actual seismic characteristics. The relevant results can provide disaster prevention and relief units with references for enhancing earthquake response and auxiliary decision-making.

Machine learning techniques are applied to various aspects of civil engineering, such as health monitoring of buildings, safety assessment, and prediction of disasters. The goal is to improve building safety, prevent hazards and accelerate government decision-making to prevent disasters. In previous studies, Harirchian et al. (2021) and Souza et al. (2021) used Artificial Neural Network (ANN) in artificial intelligence as a machine learning model to calculate the risk classification of existing buildings. By repeatedly training the model, the accuracy of the training model is improved. The final system is built on a mobile application to effectively and quickly assess building safety. Wu et al. (2019) and Yang et al. (2020) applied image processing techniques in artificial intelligence to monitor photos and conducted research on the health monitoring and diagnosis of structural cracks and corrosion. The Deep Convolution Neural Network (DCNN) was used as the artificial intelligence model in the study. The model's feature lies in its application of convolutional operations, which can effectively extract features from photos. The trained model can identify whether monitoring images have cracks based on the convolutional data.

DATABASE SYSTEM

This study is based on earthquake scenario simulation and consists of four research processes: (a) integration of three-dimensional building models, (b) seismic resistance information of buildings, (c) artificial intelligence analysis techniques, and (d) visualization platform display. The research framework is shown in Figure 1.

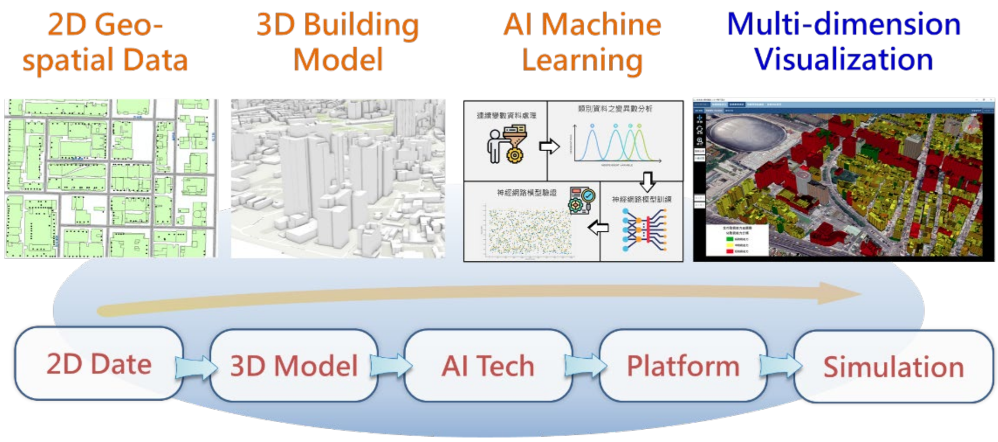

Figure 1. Research method process.

- Building Seismic Performance Model

When constructing a seismic attribute model for buildings, the first step is to confirm the outline of the building polygon. The three-dimensional building model is obtained from the National Land Surveying and Mapping Center, Ministry of the Interior (NLSC). Then, combined with the housing tax data from the Ministry of Finance Financial Information Center, the building exposure model is used for data integration. Direct intersection and different buffer distance settings are used to preliminarily combine the model with the tax data, and establish it as basic building information. The relevant information includes building number, number of floors, housing use, coordinate location, building permit year, structural form, and seismic design level information.

- PSERCB Database

By conducting big data analysis and artificial intelligence algorithms, the seismic capacity of buildings that have not yet been evaluated can be estimated quickly. This study obtained the preliminary assessment results of the seismic capacity of buildings from the PSERCB database. The analysis mainly focuses on the walls and columns on the first floor, calculating the ultimate strength and ductility of each structural material. It also considers the sequence in which each structural material bears horizontal forces under earthquake action, as well as the distribution and contribution of forces and ductility among the structural materials. The study uses tax data and relevant data from the preliminary seismic assessment database of buildings as input parameters for estimation (Figure 2). It calculates the yield ground acceleration of the structure and the seismic force reduction coefficient for earthquakes with a return period of 475 years and 2500 years. Based on seismic design specifications, it estimates the ground acceleration Ac_1 corresponding to the earthquake with a return period of 475 years (ductility reaching allowable ductility capacity) and the near-collapse ground acceleration Ac_2 corresponding to the earthquake with a return period of 2500 years (ductility reaching ductility capacity but not collapsing). When evaluating the seismic capacity of a building, the following parameters need to be input:

- Structure types: Reinforced concrete, reinforced brick, steel structure, brick structure, and wood structure.
- Usage categories: apartments, residential complexes, mixed-use residential and commercial buildings, offices, and other types of buildings.
- Near-fault, ground characteristics: The design ground acceleration specified in the regulations varies in different regions, and the standard of seismic resistance also varies depending on the location. It is also necessary to consider the type of ground and the distance from the fault.
- Seismic design: Different architectural design specifications are used in different eras, such as different restrictions on the spacing of reinforcement bars, which will result in inconsistent structural component ductility.

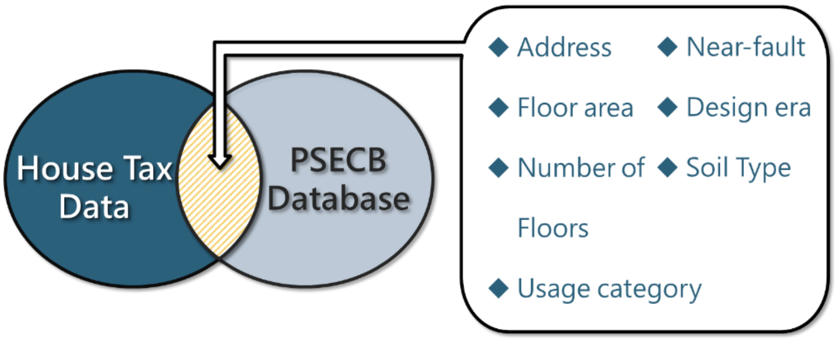

Figure 2. Integration of tax registration data and initial assessment data of buildings.

ESTIMATING THE SEISMIC RESISTANCE OF BUILDINGS USING MACHINE LEARNING TECHNIQUES

In order to effectively improve the efficiency of seismic capacity assessment of buildings, this study uses machine learning technology to assist in estimating the seismic capacity of buildings. Through existing preliminary assessment data of buildings, the seismic capacity of buildings that have not been assessed can be quickly estimated. This estimation method is called "Quick Seismic Estimation of the Building Structures (QSEBS)". It uses limited data that intersects with the building use license and preliminary assessment cases, including: number of floors, floor area, building use classification, construction site type, and construction year. First, a neural network is used to estimate the total area and cross-sectional area of the first-floor columns of the building. Then, the shear force is calculated following the calculation method of the seismic capacity assessment system to obtain the corresponding ground acceleration Ac_1 for a 475-year return period earthquake and the corresponding ground acceleration Ac_2 for a 2500-year return period earthquake. Figure 3 shows the machine learning seismic capacity estimation process developed in this study, and the explanations of each stage are as follows:

(1) Preliminary seismic capacity assessment data is being screened.

(2) Conduct variance analysis to observe the influence of each evaluation item on the target data, and eliminate parameters that have no influence.

(3) Program compilation, reading various data, including numerical data and categorical data, ultimately digitizes all data, completing the pre-processing work before data processing.

(4) Perform neural network program compilation, using a neural network model with multiple hidden layers, using limited data from tax records as input values, and conducting model training.

(5) Compare the predicted values of the neural network model with the actual values, and draw a fitting curve to verify the fitting situation of the neural network.

(6) Confirm the neural network model predicts the value, calculate the shear force according to the seismic capacity evaluation system calculation mode, and indirectly obtain the target values of Ac_1 and Ac_2.

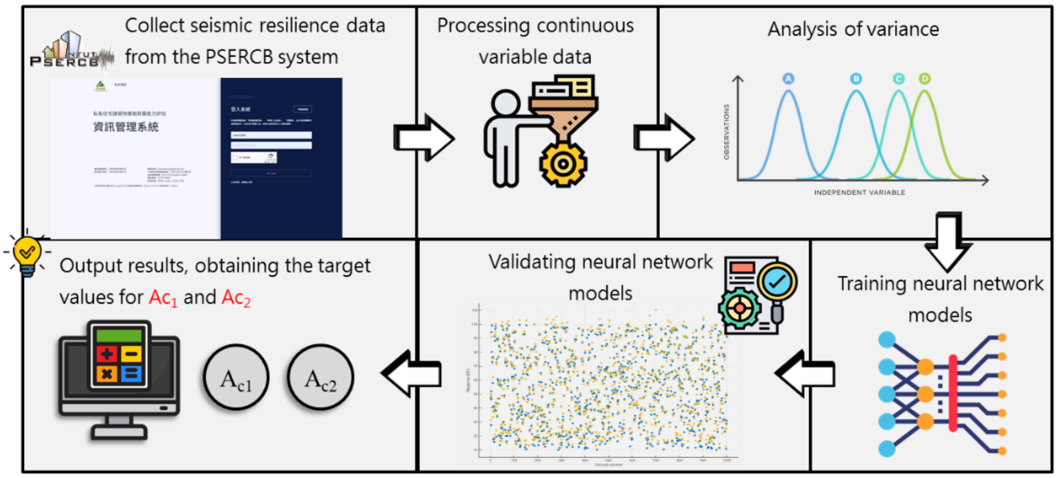

Figure 3. Process of seismic capacity estimation method for machine learning.

Figure 4 shows the estimated results statistics, showing the cumulative distribution of Ac_2/IA2500 obtained by PSERCB and QSEBS. From the figure, it can be seen that there is a high consistency in the cumulative probability distribution of both. Buildings with lower seismic capacity (i.e., Ac_2 /IA2500 < 0.35) account for 25.9% of the total samples in PSERCB, while they account for 24.3% when assessed through QSEBS. Comparing the estimation model with different classification methods to correspond to the actual values of PSERCB, the estimation model is similar to the actual trend, indicating that the estimation model has certain reference value.

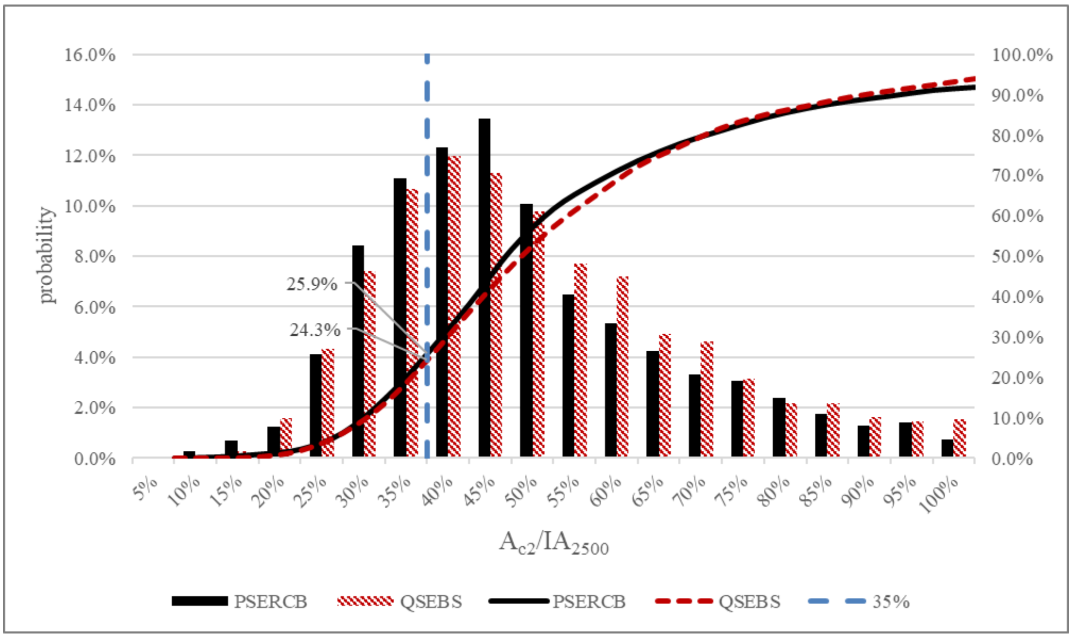

Figure 4. Overall probability distribution of PSERCB and QSEBS.

TECHNICAL APPLICATION CASE

This study develops machine learning-assisted earthquake impact assessment technology, which can quickly estimate the seismic capacity of buildings. In the visualization results exhibition, it further combines the Multi-Dimensional Urban Earthquake Impact Simulation Platform (MDUES) developed by the Hsu et al. 2022 to present three-dimensional urban model visualization scenes. After the earthquake, artificial intelligence building damage impact assessment can be carried out based on actual ground motion characteristic data, and the city model can quickly display high-risk areas in the city. This study takes Taipei city as a demonstration area and considers the seismic impact damage risk of individual buildings under specific earthquake scenarios. The visual analysis of earthquake simulation results is represented by simplified geometric graphics and colors to indicate the degree of damage, allowing buildings to be more identifiable and facilitating decision analysis. Figure 5 shows the spatial distribution of building damage considering earthquake scenarios, from which the expected distribution of the most affected areas can be obtained.

Figure 5. Display of application case results under earthquake scenario.

CONCLUSION

This research develops machine learning-assisted earthquake impact assessment technology. Through collaboration with the research team at National Taipei University of Technology, it utilizes big data on seismic assessment of vulnerable old buildings as training data for deep learning. This enables the rapid determination of the seismic capacity of buildings, combined with the latest multidimensional seismic impact analysis models. After an earthquake, building impacts are assessed based on actual seismic data, identifying high-risk areas for building damage. The results will be presented using three-dimensional visualization techniques. These research findings can provide valuable references for disaster prevention and relief agencies, assisting in improving decision-making capabilities for earthquake response.

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