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Aseismic ability estimation of school building using predictive data mining models

Wei-Ko Kao, Hung-Ming Chen *, Jui-Sheng Chou

Department of Construction Engineering, National Taiwan University of Science and Technology, 43, Sec. 4, Keelung Rd., Taipei 106, Taiwan, ROC

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ABSTRACT

The aseismic ability of buildings is generally analyzed using a nonlinear model. Numerical models are constructed based on the structural configuration and material property of buildings by simulating their stress responses and behaviors to obtain their aseismic ability. This method is complex and time-consuming and should be conducted by professionals. Hence, the aseismic ability of buildings cannot be determined rapidly on a large scale. Additionally, rapidly sequencing and screening the aseismic ability of a large number school buildings to make maintenance and management decisions is extremely difficult. This work adopts predictive data-mining models to determine the relationship between basic design parameters of school buildings and their aseismic ability, and then proposes a best model for predicting the aseismic ability of school buildings. Only basic geometric information of school buildings is needed to estimate quickly their aseismic ability. This prediction model must be able to handle the heavy load of evaluating the aseismic ability of school buildings. The proposed model will help maintenance managers conduct detailed assessments and sequencing of reinforcement work through nonlinear analysis. The proposed model can serve as a reference for disaster prevention in disaster plans and staff rescue during rescue work.

1. Introduction

When impacted by a large seismic force, the stress behavior generated by a damaged building is generally nonlinear. Nonlinear structural analysis is the most common and reliable method for assessing the aseismic ability of buildings or the capacity of a building to withstand destruction or collapse during a strong earthquake. The most suitable nonlinear analytical methods for assessing the aseismic ability of buildings have been developed by countries based on their geological situation, geographic environment, and other factors.

Take the United States as an example. Its standard for the aseismic ability of reinforced-concrete buildings, the seismic evaluation and retrofit of concrete buildings (ATC-40) (1996), uses a capacity spectrum method for determining aseismic ability. This method uses the two curves of the demand and capacity spectrums to obtain identify building performance points. The demand spectrum is obtained based on earthquake intensity, the soil profile, the seismic region coefficient, and other factors. The capacity spectrum describes the relationship between force and strain when buildings are impacted by seismic force. The capacity spectrum of a building is obtained via pushover analysis; that is, simulating the nonlinear behavior of a structure subjected to a lateral force.

The procedure consists of the following steps: (1) the incremental external force is applied to the structural model as recommended by the standard; (2) the structure is pushed over in one direction; (3) one structural analysis is conducted for each increment; (4) the incremental stress and strain of each structural member is calculated, and then added to the last analytical result to obtain the response of each structural member at this stress stage; (5) whether the structural member is damaged is determined, i.e., whether cracks yield or reach ultimate strength; (6) the behavior of each structural member is updated based on the extent of destruction, such as changes in the stiffness or the damaged structural member is removed from the structural model; and, (7) analysis is repeated until the structure is unstable and collapses.

However, this assessment method is time-consuming and requires structural experts who address a complex environment. Applying this method to a large number of structures is difficult. To date, only hundreds out of 20,000 school buildings in Taiwan have complete nonlinear analysis data. When a devastating earthquake occurs, there is not enough time to determine which areas might lose contact through complex nonlinear analysis. If a simple and rapid method for obtaining reliable data on the aseismic ability of buildings were available, one could determine immediately which buildings would be seriously damaged in a disaster, and this knowledge would serve as a reference for disaster rescue and decision-making, even when contact with schools is lost. Additionally, a rapid and reliable method for assessing the aseismic ability of buildings can also serve as the basis for budget allocation and prioritizing building reinforcement. Decision-makers must have adequate information for decision-making. If such information can be adjusted in real time

* Corresponding author. Tel.: +886 2 2737 6585; fax: +886 2 2737 6606.
E-mail address: hungming@mail.ntust.edu.tw (H.-M. Chen).

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based on decision-maker needs, the cost effectiveness of decisions can be improved.

Data-mining methods were developed in response to the development of database systems and data warehousing systems, the rapid growth in data volume, and the increasingly complexity of data. Hence, extracting useful knowledge from a collection of statistics has become increasingly difficult. Modern of data-mining techniques include statistics, on-line analytical processing (OLAP), information retrieval, machine learning, and pattern recognition. Prediction models, clustering models, and data patterns can be generated from such methods. As mentioned, assessing the aseismic ability of buildings is time-consuming and must be conducted by professionals. Thus, a model that can predict aseismic ability using data-mining technology based on existing assessment examples would be faster than nonlinear analysis of buildings and have satisfactory accuracy.

As buildings have various forms without a fixed pattern, and their design, layout, and dimensions cannot be classified and quantified, converting building information to fixed and quantifiable attributes is almost impossible. However, few studies have attempted to construct a model for predicting the unique attributes of an entire building, such as its aseismic ability, lifespan, and maintenance costs. This work focuses on typical school buildings that follow certain design rules and have fixed design patterns. The design and geometric configuration of buildings can be expressed by several quantitative characteristics, which are utilized to train and build a model for predicting building features.

School buildings have regular patterns, and most have similar designs such as an I-shape with external corridors and partitions. Hence, complex and varied design, dimensions, and other building data can be transformed into typical properties, such that a prediction model can be constructed based on overall school building features. Such a prediction model can be constructed using heuristic computing technology. Taiwan's National Center for Research on Earthquake Engineering (NCREE) constructed a database of aseismic information for school buildings and collected data for 20,000 school buildings in Taiwan, including data for structure, design (e.g., beam column design), quantity of structure elements, design pattern, number of floors, and distribution of classrooms, in addition to the floor layout, usage of building, and number of occupants. These data are for specific structural features of school buildings. The aseismic ability of roughly 1000 school buildings has been assessed by professionals. Based on this database of school buildings and aseismic ability data obtained through nonlinear analysis, this work builds a novel prediction model for determining the aseismic ability of school buildings using data-mining technology.

Using existing assessments of aseismic ability, a nonlinear numerical analysis model is constructed. After professionals have obtained determine the stress abilities of buildings via stress simulations, aseismic ability can be obtained using the capacity spectrum method. As mentioned, this work builds a prediction model to determine the aseismic ability of school buildings using a data-mining method applied to the aseismic database for school buildings (Fig. 1a). Only basic data from the database are needed to estimate rapidly and automatically the aseismic ability of school buildings (Fig. 1b). Although this prediction model cannot replace a complete evaluation process, its operating efficiency is better than that of nonlinear analytical methods, and can accommodate a large number of buildings when rapid assessment is needed.

2. Related research

Data mining techniques are widely used in various applications, such as forest fire prediction (Alonso-Betanzos et al., 2003), stock trading (Chang, Liu, Lin, Fan, & Celeste, 2009; Lee, 2009), sea-water quality prediction and monitor (Hatzikos, Hatonen, Bassiliades, Vlahavas, & Fournou, 2009). On civil and construction field, there were a lot of researches using data-mining technique. Complex systems in the construction field cannot be simply simulated. Using artificial neural networks (ANNs) is a common method when prediction is required. For instance, Owusu-Ababia (1998) used ANNs and components of pavement, road traffic, and environmental situations to predict pavement destruction. This prediction model can be used for road maintenance. Francisco, Rivero-Angeles, Gomez-Ramirez, and Garrid (2005) used ANNs to predict building shaking during an earthquake or under strong winds. We recommend that future researchers monitor the condition of buildings using this prediction model. Gupta, Kewalramani, and Goel (2006) used ANNs to estimate concrete strength, and built an expert system to deploy this prediction model easily. Baykasoğlu, Öztaş, and Özbay (2009) utilized several prediction methods and multi-objective optimization to choose high-strength concrete parameters. Sarıdemir (2009) used ANNs to predict the compression strength of concrete after adding silica and metakaolin. Bai, Wild, Ware, and Sabir (2003) predicted the workability of concrete combined with fly ash and metakaolin using ANNs and determined the relationship between percentages of components and working performance. Topçu and Saridemir (2008) predicted unit neutral liquidity using ANNs for a mix of rubberized concrete and other materials. Ince (2004) predicted concrete fracture parameters using ANNs.

Although ANNs can generate accurate predictions, ANNs have two major shortcomings. The first is that training the prediction model is time-consuming. Additionally, ANNs are impractical in applications in which the prediction model requires real-time updating. The second shortcoming is that the prediction model obtained is a black box, and determining its meaning is impossible. Hence, the construction field also uses data-mining methods for prediction and estimation. For instance, Fan, AbouRizk, Kim, and Zaïane (2008) predicted the residual value of large machines using the auto regressive tree (ART). Yeh and Lien (2009) predicted the strength of high-performance concrete using a hybrid genetic algorithm (GA) and operation tree. One feature of the operation tree is that the equation of the regression line has great variability and does not need to determine the form of the relational equation before. Pal and Deswal (2008) predicted the strength of a pipeline using a support vector machine and this strength with the prediction model of the general regression neural network (GRNN) method. They found that both methods generated good prediction models. Zhang and Sato (2006) used a support vector machine to regression for systematic identification of a structure. Chou (2009) established a prediction model for traffic planning cost using a generalized linear model (GLM) and built an expert system to assist in the operation of traffic planning.

Among previous studies on prediction using heuristic computing in the construction field, few predicted such building features as aseismic ability, lifespan, and maintenance cost as geometric and design information of buildings is complex and is not easily converted into fixed and quantifiable attributes. This study targets typical school buildings that have a similar line shape with corridors, large windows, and a fixed design pattern. The geometric design information of such buildings can be expressed by quantifiable attributes.

3. School building database

Taiwan's NCREE has constructed a school building aseismic database in response to the needs of aseismic studies of school