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Fuzzy logic-based attenuation relationships of strong motion earthquake records

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ABSTRACT

Fuzzy logic techniques have been widely used in civil and earthquake engineering applications in the past four decades. However, no thorough research studies were conducted to use them for deriving attenuation relationships for peak ground accelerations (PGA). This paper is an attempt to fill this gap by employing a fuzzy approach with fuzzy sets for earthquake magnitude and distance from source with the objective of proposing new ground motion attenuation models. Recent earthquake records from USA and Taiwan with magnitudes 5 or greater were used; and consisted of horizontal peak ground acceleration recorded on three different site conditions: rock, soil and soft soil. The use of Fuzzy models to quantify ground motion records, which are typically characterized by a high level of uncertainty, leads to a rational analytical tool capable of predicting accurate results. Testing of the fuzzy model with an independent data set confirmed its accuracy in predicting PGA values.

1. Introduction

Earthquakes can inflict severe loss of life and property, especially when they occur in densely populated metropolitan areas (Po-Shen & Chyi-Tyi 2008). Recent earthquakes, such as Northridge (1994), Kocaeli and Düzce (1999), and Chile (2007) have alerted the community that much research studies still need to be conducted to avoid the damage caused by strong motion records. According to Sharma (2000), the estimation of peak ground acceleration in terms of magnitude, source-to-site distance, tectonic environment and source type using attenuation relationships has been a major research topic in seismic hazard estimation studies. However, prediction of ground motion characteristics far from the source for a particular region is of much importance and needs to be accurately simulated.

Earlier studies to derive ground motion models were conducted by Aptikaev and Kopnichev (1980), Campbell, 1985, Youngs, Day, and Stevens (1988), Youngs, Chiou, Silva, and Humphrey (1997), Crouse (1991), Spudich, Fletcher, and Hellweg (1997, 1999) and Ambrasseys & Douglas, 2003. A comprehensive summary of ground motion models was prepared by Douglas (2004). Lately, next generation attenuation relationships for different soil types were proposed through a research effort conducted at the Pacific Earthquake Engineering Research Center (PEER) by Abrahamson and Silva (2008), Boore and Atkinson (2008), Campbell and Bozorgnia (2008), Chiou and Youngs (2008) and Idriss (2008). These studies represent the current state of the art in ground motion modeling for shallow crustal earthquakes. Validation of these models for a series of recent California earthquake records was performed by Kaklamanos and Baise (2011). Application of these models in China was performed by Zhang, Hu, Jiang, and Xie (2012). Currently there is an on-going project conducted at PEER to develop next generation attenuation relationships for central and eastern North America. Most of these models have empirical nature and are developed based on a set of strong motion recordings from extensional tectonic environments. Because of this, their application out of the region they were developed in is limited, so that accurate seismic hazard assessment cannot be achieved. Fuzzy logic, however, offers significant advantages over this kind of approaches due to its ability to naturally represent qualitative aspect of inspection data and apply flexible inference rules (Sun, Sung, & Yong, 2002).

Fuzzy logic techniques have been previously used in earthquake engineering to evaluate seismic hazard (Lamarre & Dong, 1986), to quantify damage due to earthquake loads (Souflis & Grivas, 1986), to develop optimum systems for seismic design of reinforced concrete buildings (Yamada, Kawamura, & Tani, 2002), to evaluate structural repair methods due to seismic loads (Furuta, 1993), to

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quantify the uncertainties in structural models and the subsequent response due to ground motions (Wadia-Fascetti & Smith, 1996), and to develop hybrid control systems of structures (Subramaniam, Reinhorn, Riley, & Nagarajaiah, 1996). Recently it was used to develop earthquake response spectra models (Wadia-Fascetti & Gunes, 2000), to minimize accelerations of friction pendulum base isolators (Kim & Roschke, 2006), to improve structural vibrations caused by earthquakes (Nomura, Furuta, & Hirokane, 2007), and to control seismic vibrations of small-scale buildings (Kim, Langari, & Hurlebus 2010). However, no thorough research studies were conducted to use them for deriving attenuation relationships. The objective of this study is, therefore, to develop new attenuation relationships of ground motions using fuzzy logic techniques. The data used in the study includes records from earthquakes of moment magnitude greater than 5, and site conditions characterized as soft soil, soil, and rock with closest distance less than 150 km. The fuzzy model in this study is established with inputs of earthquake magnitude and epicentral distance whereas the output is the horizontal component of peak ground accelerations (PGA).

2. A review on expert system applications

Expert systems have been applied in a variety of fields. According to Durkin (1990), expert systems have been developed in such diverse areas as science, medicine, engineering and business, to aid people engaged in these fields in increasing the quality, efficiency, and competitive leverage of their operations.

An expert system was established by Nasir, Khalil, and Sinha (1990) for inventory management. The objective of the study was on the development of a simple, user-friendly tool that can be used effectively by managers to increase the cost-effectiveness of their inventory systems. The study showed that expert system is capable of analyzing input parameters by performing statistical analyses of data bases, generating plots and graphs, implementing a set of rules for the selection of inventory models, and choosing a solution procedure.

Calvin (1991) used expert system application to clinical investigations. The DESIGN EXPERT, a prototype expert system for the design of complex statistical experiments was developed in this study. The system was designed for scientific investigators and statisticians who must design and analyze complex experiments, and it was able to (i) recognize specific types of complex experimental designs, based on the application of inference rules to non-technical information supplied by the user; (ii) encode the obtained and inferred information in a flexible general-purpose internal representation for use by other program modules; (iii) generate analysis of variance tables for the recognized design and an appropriate Biomedical Computer Programs run file for data analysis, using the encoded information.

Jo, Jung, and Yang (1997) established ramp scheduling system, called RACES (Ramp Activity Coordination Expert System), to solve complex and dynamic aircraft parking problems. RACES was developed from the domain knowledge and experience which were acquired from the domain experts. The domain knowledge and experience were taken as important factors in controlling the scheduling procedure for the development of the expert system. RACES was developed to divide the problem into sub-problems and experimental heuristics in the knowledge acquisition process, and independently processes scheduling for the divided sub-problems and shares variables and domains. It then selects or confines the search space with domain filtering techniques by exploiting the characteristics of various constraints and knowledge. The main focus of the study was to produce a user-driven near-optimal solution by means of a trade-off scheduling method using heuristics between the size of aircraft and the best-fit time. The performance evaluation of the system showed that, for 400 daily flights, RACES made parking schedules for aircraft in about 20 s compared with 4–5 h by human experts.

According to Al-Homoud and Al-Masri (1999), an expert system called Cut Slopes and Embankments Expert System (CSEES) was developed for Jordan with the objective of evaluating failure potential of cut slopes and embankments for the planning and design of roads. The expert system was designed to include a classification system for evaluating slope failure potential, and a data bank on landslides in the study area. Fuzzy set theory was used with the modified Monte Carlo simulation technique to obtain Slope Failure Potential Index (SFPI). Factors affecting slope stability, such as geology, topography, geomorphology, precipitation, vegetation, and drainage conditions were incorporated in obtaining the SFPI. The developed expert system was then applied to cut slopes and embankments in Jordan and it was proven to be successful for the areas that suffered landslides in the past.

A study made by Yang, Lim, and Tan (2005) established an expert system called VIBEX (VIBration EXpert) in order to aid plant operators in diagnosing the cause of abnormal vibration for rotating machinery. A decision table based on the cause-symptom matrix as a probabilistic method for diagnosing abnormal vibration was used in the work so as to automatize the diagnosis. Also a decision tree was used as the acquisition of structured knowledge in the form of concepts is introduced to build a knowledge base which is indispensable for vibration expert systems. The proposed system was written in Microsoft Visual Basic and Visual C++ and has been successfully implemented on Microsoft Windows environment.

Hatiboglu et al. (2010) developed a predictive tool by fuzzy logic in order to predict the outcomes of patients with intracranial aneurysm. The researchers recorded World Federation of Neurological Surgeons Scale (WFNSS), Fisher Scale and age at admission and Glasgow Outcome Score (GOS) at discharge from hospitalization for all the patients, and these were divided into appropriate classes to develop fuzzy sets. The outcomes of the patients were then calculated with these sets by fuzzy model. According to the results of study, predicted outcome by fuzzy logic approach correlated with observed outcome scores of the patients ($p > 0.05$), including 95% confidence interval. The study concluded that the outcome of the patient with intracranial aneurysm could be predicted accurately by fuzzy logic based expert system which was rarely used in medicine.

A new adaptive prediction tool termed as Geno-Kalman filtering (GKF) was established by Altunkaynak (2010b) by combining Genetic Algorithm and Kalman filtering in order to predict suspended sediment concentration. The establishment of the expert system involved three steps: relating discharge and suspended sediment concentrations by using dynamic linear model, obtaining an optimum transition matrix relating state variables by Genetic Algorithms (GAs) and calculation of an optimum Kalman gain, and prediction of suspended sediment concentration from discharge measurements by using Kalman filtering. The validation results of the proposed expert system were found to result in less errors and better efficiencies compared to perceptron Kalman filtering. The combined Geno-Kalman Filtering (GKF) technique was again used to develop predictive models for estimation of significant wave height by Altunkaynak and Wang (2012) at stations LZ40, L006, L005 and L001 in Lake Okeechobee, Florida. The results of the study showed that the GKF methodology performed better in predicting significant wave height than those from Artificial Neural Network (ANN) models.

Gudu, Gichoya, Nyongesa, and Muumbo (2012) developed an experiment system named Medical Expert System (MES) for the diagnosis and treatment of Hypertension in Pregnancy (HIP). The