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Genetic programming-based attenuation relationship: An application of recent earthquakes in turkey

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ABSTRACT

This study investigates an application of genetic programming (GP) for the prediction of peak ground acceleration (PGA) using strong-ground-motion data from Turkey. The input variables in the developed GP model are the average shear-wave velocity, earthquake source to site distance and earthquake magnitude, and the output is the PGA values. The proposed GP model is based on the most reliable database compiled for earthquakes in Turkey. The results show that the consistency between the observed PGA values and the predicted ones by the GP model yields relatively high correlation coefficients ($R^2 = 0.75$). The proposed model is also compared with an existing attenuation relationship and found to be more accurate.

1. Introduction

Determination of the peak horizontal ground acceleration, for designing the earthquake-resistant structures in regions of a major seismic belt, bears paramount significance. The economic and social issues caused by earthquakes can be reduced by seismic hazard assessment. Seismic hazard assessment can be made either deterministically or probabilistically (Erdik et al., 2001). Both of these approaches need attenuation models for ground motions, which are developed by regression analysis of strong motion database. Ground motions that develop in a soil deposit during an earthquake can be attributed in many cases mainly to the source mechanics, magnitude, local geology, surface topography, source to site distance, and the dynamic properties of the propagation media (Kramer, 1996). However, these independent variables could produce uncertainties in construction of database because of oversimplification. In addition, some physical parameters including nonlinear soil behavior, directivity, rupture propagation, basin effects, and stress drop affect the predictive relationships, even more profoundly than the independent variables (Somerville and Graves, 2003). Therefore, it is seen that these uncertainties can affect analytical methods and procedures employed to the derivation of attenuation relationships. The issue raised above prodded a few researchers to decrease errors for the peak ground acceleration (PGA) estimates concerning the computational processes. In this context, the interaction between the independent variables in attenuation relationships and PGA was expected to fit more accurately by considering soft computing techniques.

The interest in the transfer of methods developed in one discipline to the analysis of problems in other disciplines has evidently increased in recent years. This concerns particularly the computer-inspired methods of information processing known as soft computing techniques. For example, a different way of using artificial neural networks (ANN) was employed to model the material behavior from the experimental results. Due to the ability to learn and generalize interactions among many variables, the ANN technique has a potential in the modeling problems (Ghabousi et al., 1991; Ellis et al., 1992). For example, ANN has been widely used for modeling liquefaction (Goh, 1994; Wang and Rahman, 2002; Chen et al., 2002; Hanna et al., 2007; Baziar and Jafarian, 2007). Soft computing techniques have been applied to the derivation of attenuation relationships as well (Sobhaninejad et al., 2007; Güllü and Erçelebi, 2007). Such as, Güllü and Erçelebi (2007) developed an algorithm based on Fletcher–Reeves conjugate gradient back-propagation supervised neural network (NN) (Fletcher and Reeves, 1964) for the prediction of PGA. They stated that their comparisons of correlations by the ANN and the regression method indicated that the ANN approach did better than the regression.

The purpose of this paper is to propose a soft computing technique, genetic programming (GP) approach to minimize the residuals between the measured and predicted PGA values in the attenuation relationships. The attenuation relationships proposed here do not reduce these uncertainties. However, through the use of a GP study, the interaction between the predicted PGA values and the observed ones in the attenuation relationships is expected to be a more sophisticated and reliable than the traditional attenuation relationships in the literature. The main advantage of

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GP is that it can provide a pattern from a set of fitness cases without being explicitly programmed for them. As a set of functions and terminals are defined, a target fitness function is selected, and a finite set of fitness cases are provided. GP can find a solution in the search space defined by the terminals and functions provided (Koza, 1992; Liu, 2001).

Turkey is one of the most seismically active countries in the world. Over the course of history, Turkey has been the site of numerous destructive earthquakes. Therefore, this paper is intended to show the application of the GP technique for modeling a new attenuation relationship for Turkey. The input variables used over the developed genetic programming models are average shear-wave velocity, earthquake source to site distance, and earthquake magnitude, which are available from various databases.

2. Tectonic setting and seismicity of Turkey

Studies on seismotectonic and fault mechanisms mostly describe major structures that govern the neotectonics of Turkey are the Aegean–Cyprean Arc, the East Anatolian Fault, and the North Anatolian Fault Zone (Fig. 1). Turkey lies among the Mediterranean part of the Alpine–Himalayan orogenic system, which extends from Italy to Burma (Erdik et al., 1985). This system, which is identified with high mountain ranges, constitutes one of the most seismically active continental regions of the world with a long and well-documented history of earthquakes (Erdik et al., 2001). The Alpine orogeny is the result of the compressional motion between Africa and Europe; however, the Himalayan orogeny is produced as a result of the India–Asia collision. The seismicity distribution among the Alpine–Himalayan system is not homogenous, and concentrates mostly along the plate margins. The African, Arabian, and Eurasian plates are involved in the tectonics of the Mediterranean region (McKenzie, 1970); however, the eastern Mediterranean is more complicated. The reason of the local increase in seismic activity in the region may be because of the rapidly moving smaller plates (Erdik et al., 1985). The reader is referred to the plate tectonics models for details of this region (i.e., McKenzie, 1972; Dewey and Sengör, 1979; Dewey et al., 1986; Barka, 1992; Westaway, 2003).

3. Attenuation relationships

The social and economic effects of an earthquake that is one of the most expensive and deadly natural events can be reduced by a comprehensive assessment of seismic risk and hazard. Estimates of expected ground motion at a given distance from an earthquake are fundamental inputs to earthquake hazard assessment. It can be performed (a) deterministically, which involves (i) the determination of the scenario earthquake, (ii) identification of appropriate site response quantification, (iii) identification of proper attenuation relationships, and (b) probabilistically, which accounts for all possible earthquake scenarios that could affect the site and results in hazard represented by ground-motion parameters at reference ground conditions (Erdik et al., 2004). These estimates are generally mathematical equations called attenuation relationships, which may be divided to empirical ground-motion relations (Atkinson and Boore, 2003; Campbell and Bozorgnia, 2003) and physically based models (Atkinson and Boore, 2006; Zafarani et al., 2008), expressing ground motion as a function of source parameters (magnitude and mechanism), propagation path, fault distance, and local site effects (site class). The most common ground-motion parameters are vertical and horizontal peak ground acceleration, 5% damped spectral acceleration (Sa), and peak ground velocity (PGV) (Kramer, 1996; Abrahamson and Shedlock, 1997). A number of attenuation relation studies can be found in the literature. Many reviews of attenuation relationship studies have been published providing the results and problems associated with such relationships as well as a good summary of the methods (i.e., Idriss, 1978; Joyner and Boore, 1988). Douglas (2001) has, for example, recently presented a comprehensive review of published strong-ground-motion relationships for peak ground acceleration and spectral ordinates from 1969 to 2000.

Although attenuation relationships for earthquakes in one region cannot be simply used for engineering analyses in another region, Erdik et al. (2004) indicates that the empirical response spectra of the ground motion at several locations in Turkey can be predicted, within engineering tolerances, by the Western United States based attenuation relationships (i.e., Boore et al., 1997; Sadigh et al., 1997). In addition to these international relationships, a number of domestic attenuation relationships predicting

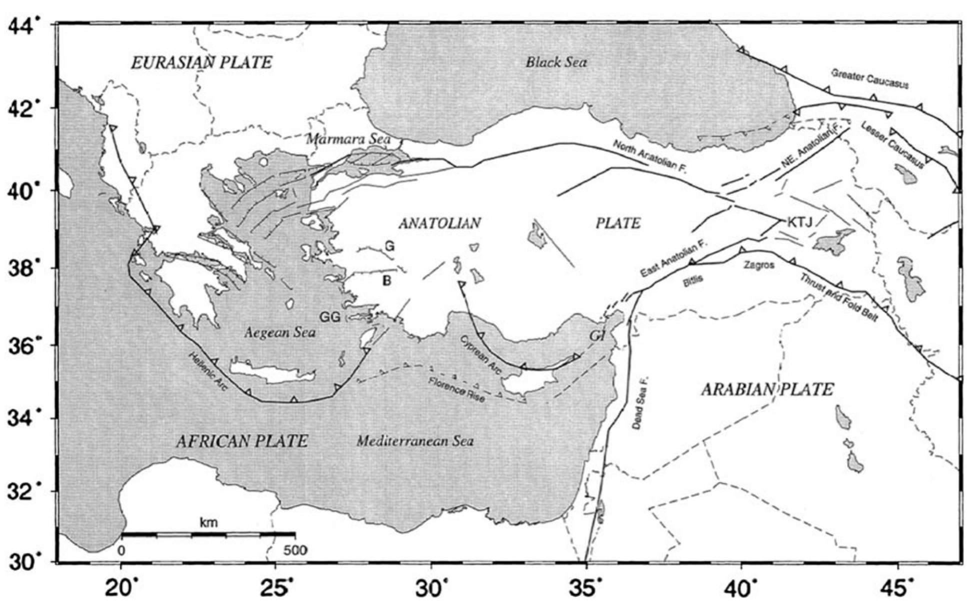

Fig. 1. Map showing kinematics of Eastern Mediterranean (Reilinger et al., 1997).