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GENERATION AND COMPARISON OF DIFFERENT FORMS OF ATTENUATION RELATIONSHIPS FOR THE WESTERN ANATOLIA, TURKEY

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ABSTRACT *The western Anatolia is one of the good examples of fast intra-continental extensional tectonics with active extensional stress rate about 3-4 cm/year. Increasing lithospheric thinning causes increasing geothermal activities in the region and active tectonics has generated seismic activity with destructive earthquakes. Moderate sized earthquakes in the region are actually the dominant source of seismic hazard, because of their larger amplitudes at longer periods in deep basin structures of western Anatolia graben system. Due to extensive exposure and vulnerability to the effects of earthquakes, seismic hazard assessment is very important issue in the region. In this study we described predictive peak ground acceleration and 5%-damped spectral acceleration attenuation relationships for western Anatolia by regressing strong-motion data (e.g. Joyner and Boore 1981; Ambraseys et al. 1996; Boore et al. 1997). In order to do so, we use strong motion records from the stations which are located in the region and operated by the General Directorate of Disaster Affairs' Earthquake Research Department (ERD) and additionally the data from WASRE network (Akyol et al., 2006). Comparison of obtained attenuation relationships with the ones generated for tectonically different regions have shown that ground motion attenuation relationships in a specific region can not be simply modified for use in engineering analysis for the other regions. On the other hand, comparison of obtained attenuation relationships with the ones generated for tectonically similar regions have shown that our model estimation is lower. This result is consistent with reported low velocities and high attenuation values of crustal structures in the region.*

INTRODUCTION

A fundamental requirement for seismic hazard studies is the determination of predictive attenuation relationships for the ground motion (Kramer 1996). Attenuation relationships are commonly used to describe Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), Spectral Acceleration (SA) and Spectral Velocity (SV) to describe how the amplitude of seismic waves decrease with distance, period and earthquake magnitude. A number of such relationships have been developed for many regions of the world (e.g. Ambraseys *et al.* 1996; Boore *et al*., 1997), mainly by regressing strong-motion data. These studies have shown that the ground motion levels can differ significantly in different tectonic regimes.

By using strong-motion data from all Turkey, some researchers had worked on generation of attenuation relationships: Gülkan and Kalkan (2002) had derived empirical attenuation relationships, regarding with site conditions and fault types, for PGA and SA, by using a total number of 93 records from 47 horizontal components of 19 events. By using 221 recordings of 122 events, Ulusay *et al.* (2006) had generated PGA attenuation relationship and than prepared iso-acceleration map of Turkey based on this relationship. Empirical attenuation models for PGA and SA were developed by Özbey *et al.* (2004), a database consisting of 195 recordings from the Marmara Region.

In this study we describe predictive relationships for the ground motion by regressing strong-motion data only from western Anatolia not for all Turkey, since we believe that such kind of relationships should be generated for each tectonic province, separately. Two-stage nonlinear regression analysis was applied to a database of the maximum horizontal component peak acceleration values of 202 recordings from 82 earthquakes to obtain different forms of PGA attenuation relationships and also 5%-damped SA attenuation relationships for the region.

METHOD

A lot of researchers have used many different forms of the relation (*references here in*). Joyner and Boore (1981) had used following form of the equation:

$$\log y = a_1 + a_2(M-6) + a_3(M-6)^2 - b_1 r - \log r + c_k S_k + \varepsilon \tag{1}$$

where;

M: Moment magnitude

a_i: Coefficients for magnitude dependence

b_i: Coefficients for distance dependence

r: $(d^2+h^2)^{1/2}$

d: The closest horizontal distance to the vertical projection of the rupture (Boore *et al.* 1997)

h: "fictitious" depth measure (Boore *et al.* 1997)

c_k: Site condition coefficients

S_k: Site class definition which is equal to 1 for soft soil, 0 for rock sites

ε = residuals

In this equation, $\varepsilon = \sigma P$. σ is the standard deviation of the residuals. The value of P is based on the assumption that the prediction errors are normally distributed and P=0.84 confidence level for $\pm 1\sigma$ values. In equation 1, the form chosen for the regression is the equivalent of:

$$y = \frac{k}{r} e^{-qr} \tag{2}$$

Where k is a function of M and q is a constant. This corresponds to simple point-source geometric spreading with constant-Q anelastic attenuation. In fact, this form would apply only to a harmonic component of the ground motion, not to peak acceleration. However, Joyner and Boore (1981) suggested that its application to peak parameters is an appropriate approximation since coefficients determined empirically.

Ambraseys *et al.* (1996) had used following form of the equation:

$$\log y = a_1 + a_2(M-6) + a_3(M-6)^2 - b_1 r - b_2 \log r + c_k S_k + \varepsilon \qquad (3)$$

where; M: M_s and S_k: Site class definition for three different site classes.

Equation 3 includes both anelastic attenuation coefficient (b_1) and geometrical spreading coefficient (b_2) for distance dependence. But they had accepted the values of b_1 equal to zero since they obtained positive b_1 value, while generating strong-motion attenuation relationship for Europe.

Özbey *et al.* (2004) had used following form of the equation:

$$\log y = a_1 + a_2(M-6) + a_3(M-6)^2 - b_2 \log r + c_k S_k + \varepsilon \qquad (4)$$

where; M: M_w and S_k: Site class definition for three different site classes.

Boore *et al.* (1997) have used the same form; although, they described site condition parameter by using near-surface velocity. They have used, only the term of "$b_2$logr" is being used as distance dependence term and suggested that this term represents geometrical spreading for a simple point source (b_1r-logr). Doing so, however, led to values of b_1 greater than zero. This result shows that the motions attenuate less rapidly than 1/r, at least at distances within 100km, perhaps because of the effect of critical-angle reflections from layers within and at the base of the crust (Boore *et al.* 1997).

We fit strong motion data by multiple nonlinear regressions analysis by using three different forms of PGA attenuation relationships described above. Obtained results for equation forms 1, 3, and 4 are given below, respectively;

$$\log y = 0.2851 + 0.5970\,(M-6) - 0.0020\,r - \log r + 0.0437 + 0.3547P$$

$$\log y = 0.0010 + 0.5511\,(M-6) - 0.0055\,r - 0.5447 \log r + 0.0829 + 0.3800P$$

$$\log y = 0.7110 + 0.5844\,(M-6) - 1.3264 \log r + 0.0342 + 0.3493P$$

The coefficient of the second degree term of the magnitude is not significant at the 90% level and the term is omitted for PGA values. Depth parameter, h, is equal to 11.2 km for the equations. Since, our data set has not got enough stations located on hard rock and stiff soil sites; we could obtain separate site condition coefficient only for soft soil sites. In order to do so, we assumed that site condition coefficient is equal to 1 for soft soil, 0 for rock and stiff soil sites. For the regression analysis, earthquake size was characterized by moment magnitude, and the distance parameter (d) is the closest horizontal distance to the vertical projection of the rupture (Boore *et al.* 1997). Finally by choosing the form described in equation 4 (Boore *et al.* 1997; Özbey *et al.* 2004), we obtained not only PGA but also 5%-damped SA attenuation relationships for the region and compared them with different attenuation relationships generated for tectonically similar or different regimes.

CONCLUSIONS and DISCUSSIONS

Two-stage nonlinear regression analysis was applied to the maximum horizontal component PGA and 5%-damped SA values of 202 recordings for 82 earthquakes, to obtain empirical attenuation relationships for western Anatolia. Moment magnitude range of the earthquakes, in the data set, is between 4.5 and 6.2 while the distance range is between 1 and 206 km.

Predicted 5%-damped SA values show that soil amplifications are significant in the region, especially for the period values larger than 0.3-second. Comparison of obtained attenuation relationships with the ones generated by different researchers for tectonically similar regions have shown that our model estimation is lower (Akyol and Karagöz, *submitted to Turkish J. Earth Sci*.). This result is consistent with crustal structure in western Anatolia. The low crustal velocities in the region were associated with high crustal temperatures, high degree of fracture and presence of fluids at high pressure in the crust by Akyol *et al.* (2006). Studies of the attenuation of regionally recorded coda waves (Akıncı *et al*. 1994) and Lg waves (Akıncı *et al.* 1995) indicate that crustal seismic wave attenuation is high. Tomographic studies of Lg coda Q indicate that attenuation values in western Anatolia are among the highest in all of Eurasia (Mindevalli and Mitchell 1989; Cong and Mitchell 1999). Obtained results have shown that ground motion attenuation relationships in one region can not be simply modified for use in engineering analysis for the other regions.

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