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The development of attenuation relationship for Northwest Anatolia region

Développement d'une relation d'atténuation pour la région Nord-Ouest d'Anatolie

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ABSTRACT: Ground-motion attenuation relationships with using the 1999 Kocaeli earthquake data were developed for the Northwest Anatolia region affected by the 1999 Kocaeli and Düzce earthquakes. Soil properties of the investigated stations and strong ground motion data were taken from the Strong Ground Motion Database of Turkey (TR-NSMN) and Pacific Earthquake Engineering Research Center- Enhancement of Next Generation Attenuation Relationships for Western US (PEER-NGA-West2) database. SeismoSignal software was used in the evaluation of the acceleration records measured in the stations. In this research peak ground acceleration is greater than 1 gal, moment magnitude (M_W) is greater than 4.0 and Joyner-Boore distance (R_{JB}) is1-344 kilometers. Attenuation relationships obtained from different types of ground were derived from the model generated by Boore et al. (1997) for shallow earthquakes in North America. In this study attenuation relation equations were developed by applying non-linear regression analysis; with Statistical Package for the Social Sciences (SPSS) Statistics 20.0 software for B-C and D class soil according to National Earthquake Hazards Reduction Program (**N**EHRP) classification system.

RÉSUMÉ: Des relations d'atténuation des mouvements sismiques en utilisant les données du séisme de Kocaeli 1999 ont été développées pour la région Nord-West d'Anatolie qui a été affectée par les séismes de Kocaeli et Düzce. Les propriétés du sol des stations étudiées et les mouvements sismiques forts ont été pris des bases de données de Turquie (TR-NSMN) et du Centre de recherche en génie parasismique Pacifique- Amélioration des relations d'atténuation de nouvelle génération pour l'ouest des États-Unis (PEER-NGA-West2). Le logiciel SeismoSignal a été utilisé pour obtenir les enregistrements d'accélération mesurés dans les stations. Dans cette recherche, l'accélération maximale du sol est supérieure à 1 cm/s^2. La magnitude du moment (M_W) est supérieure à 4.0 et la distance Joyner-Boore (RJB) est 1-344 km. Les relations d'atténuation obtenues à partir de différents types de sol ont été obtenues du modèle généré par Boore et al. (1997) pour des séismes peu profonds en Amérique du Nord. Dans cette étude, des équations de relation d'atténuation ont été développées en appliquant une analyse de régression non linéaire, avec Logiciel de statistiques pour les sciences sociales (SPSS) Statistics 20.0 pour les sols des classes B-C et D conformément au système de classification du programme de réduction des risques liés aux séismes (NEHRP).

Keywords: Attenuation relationships; Nonlinearity; Soil; Rock; Liquefaction

1 INTRODUCTION

Horizontal acceleration is one of the major factors on the damage caused by large earthquakes, which are defined as strong ground-motion. Seismic waves during earhquakes are effected significantly from the local site conditions while spreading upward. The strong ground motion parameters can have different values depending on these conditions.

The acceleration records measured in earthquakes, which may be regarded as one of the most important strong ground motion parameters, contain important engineering information. The estimation of peak ground acceleration should be done by using statistical regression techniques for regions where measurement are not possible due to lack of strong motion stations. In this approach, ground motion equations were developed by the relationships between evaluation the acceleration values of earthquakes from different sources and different site conditions. Ground-motion equations define peak ground acceleration in terms of size, location-source distance, site conditions and faulting mechanism.

During 1999 Kocaeli and Düzce earthquakes, a large number of buildings in Adapazarı city and some structures located on Marmara See and Sapanca Lake shore lines affected by ground displacement by induced liquefaction and bearing capacity failure of soils. During mainshock and aftershock, ground motion data from the stations located on the North Anatolian Fault Zone (NAFZ) were obtained to study the effect of liquefaction on attenuation relationship. Addition 33 main records from large earthquakes were added to NAF data. To develop an attenuation relationship, common equation proposed by Boore et al. (1997) was used by applying non-linear regression analysis with SPSS and nonlinear site amplification effect was applied from Boore and Atkinson (2008).

In this research the attenuation relationship was also studied for liquefaction with the 43 strong motion records obtained liquefied sites in 9 large earthquakes in world. This study is useful to determine the threshold level of acceleration and R_{JB} distance to initiate liquefaction in loose saturated sand based on magnitude level.

2 STRONG MOTION DATABASE USED IN THIS STUDY

A total of 402 strong motion data was used in this study. The acceleration records of August 17, 1999 Kocaeli earthquake (M_W=7.4), November 12, 1999 Düzce earthquake (M_W=7.1) and their aftershocks until the end of 2006. After 2006, there has been no significant earthquake event ($M_W \geq 4.0$) in this researched area.

19 major earthquakes that have focal depths of 4.90-18.50 kilometers ranges were evaluated in this study (Figure 1). The magnitudes of earthquakes mainly between 4.0 to 5.0 except 6 earthquakes which are greater than 5.0 magnitude. In addition these data, 33 mainshock records of 7 major earthquakes worldwide with 5.5 km to 17.9 km focal depths and high magnitudes were used too in the regression analysis.

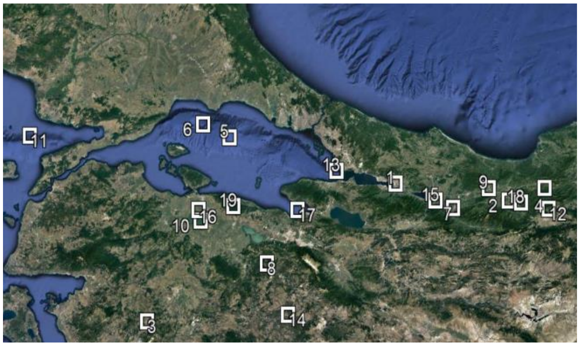

Figure 1. Locations of 19 major earthquakes used in this study (Google Earth)

Atotal of 402 records were evaluated. 1 of them was in group A representing hard rock V_{S30}>1500 m/s, 38 of them were in group B representing rock in the range of 760<V_{S30}≤1500 m/s, 188 of them were in group C representing very stiff soil or soft rock in the range of 360<V_{S30}≤760 m/s, 173 of them in group D representing stiff soil in the range of $180<V_{S30}\leq360$ m/s and 2 of them in group E representing soft soil in the range of $V_{S30}<180$ m/s. Due to a lack of data on soil class A and E, this study represents the B-C and D soil classes.

Acceleration records used in this study focused on R_{JB}=10-200 km, which is defined as the nearest horizontal distance to the surface projection of the fault rupture and the magnitudes ranged between M_W=4.0-7.6. The soil types at the strong motion stations are stiff clay, dense soils and weathered rock average shear wave velocities are mostly in the range of 200 m/s$<V_{S30}<$700 m/s.

The relationship between acceleration and magnitude are given in Figure 2 for the B, C soil classes and D soil class in Figure 3.

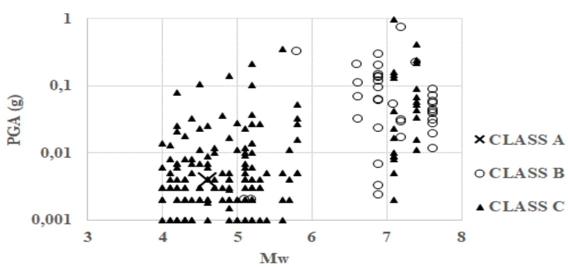

Figure 2. Acceleration-magnitude relationship for B-C soil classes

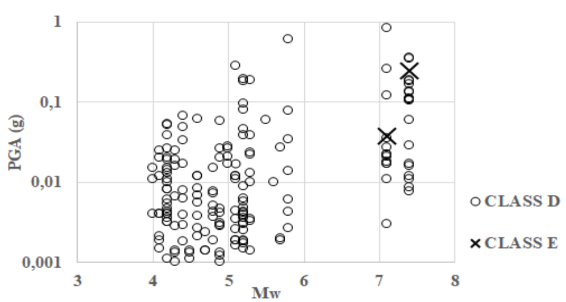

Figure 3. Acceleration-magnitude relationship for D soil class

In order to avoid the effects of different soil conditions in the study, V_{S30} value was kept constant. The relationships between R_{jb}-PGA depending on the records taken from SKR station located on weathered rock, wereobtained for M_W=4.0-5.0-7.0 values (Figure 4).

62 acceleration records, which were in the content data catalog and measured at SKR station, were evaluated. The magnitude has more effect than the fault rupture distance at the same soil condition.

3 DEVELOPMENT OF ATTENUATION RELATIONSHIP

In this study, to develop the attenuation relationship, common equation proposed by Boore et al. (1997) were used (Eq 1).

$$lnY = b_1 + b_2(M-6) + b_3(M-6)^2 + b_5 lnr + b_v ln\frac{V_S}{V_A}; \qquad r = \sqrt{\left(R_{jb}^2 + h^2\right)} \quad (1)$$

Y is ground-motion parameter (g), M is moment magnitude, V_S is average shear-wave velocity (m/s), h is fictitious depth which is determined by the regression, $r_{jb}$is distance (km), b_1, b_2, b_3, b_5, b_v, V_A are coefficients that are determined by the regression. In this equation, V_A is taking as a reference velocity (=760 m/s corresponding to NEHRP B/C boundary site conditions). M, V_S and r_{jb} values are known from dataset, nonlinesar part F_{NL} for site amplification added to the equation. According to these approaches, that used equation in this study is presented below.

$$lnPGA = b_1 + b_2(M-6) + b_3(M-6)^2 + b_5 lnr + b_v ln\frac{V_S}{V_{ref}} + F_{NL} \quad (2)$$

F_{NL}represents the nonlinearcomponent of site amplification, which depends on V_{S30} and the amplitude of shaking onreference rock (taken as V_{S30}= 760 m/sec). Nonlinear site amplification effect was applied from Boore and Atkinson 2008-BA08

To carefully evaluate the magnitude and distance scaling, only Sakarya (SKR) station records were used in order to avoid the effects of different soil conditions. This station was used due to it being the nearest researched area and is known well for its soil conditions. As a result, magnitude-dependent distance slope does not occure in the used data set and distance term is not correlated with the magnitude term.

The coefficients in the equation were calculated by means of non-linear regression analysis. Nonlinear regression analysis on the database was carried out with the software SPSS 20.0. Since the soft soil recordings are affected by soil conditions, the data were divided into two soil classes. Statistical calculations were made for three classes including the group B, C and D. The final equations for B-C and D soils presented below respectively Eq 3 and Eq 4 (Erken at al., 2018).

$$lnPGA = 1.835 + 1.034(M_W - 6) - 0.252(M_W - 6)^2 - 1.397\ ln\sqrt{(R_{JB}^2 + 9.718^2)} - 0.069ln\frac{V_{S30}}{760} + F_{NL} \quad (3)$$

$$lnPGA = 2.135 + 1.008(M_W - 6) - 0.163(M_W - 6)^2 - 1.380ln\sqrt{(R_{JB}^2 + 10.510^2)} - 0.133ln\frac{V_{S30}}{760} + F_{NL} \quad (4)$$

Equation 3 was applied at 1-200 km ranges for magnitude of M_W=7.0-5.0-4.0 and by keeping V_{S30}= 760 m/s constant (Figure 4). Furthermore, the model which was obtained by non-linear regression analysis was applied from 1 to 200 km, for magnitude M_W =4.0-5.0-7.0 and by keeping V_{S30} =280 m/s constant (Figure 5). It is found in the obtained results that the measurement values and the calculated values are compatible with each other.

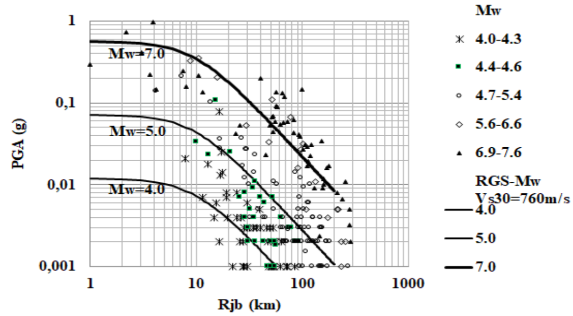

Figure 4.Acceleration-distance distribution of recordings and values calculated for V_{S30}=760 m/s- and different distances by equation which obtained regression analysis result belonging to B-C soil classes

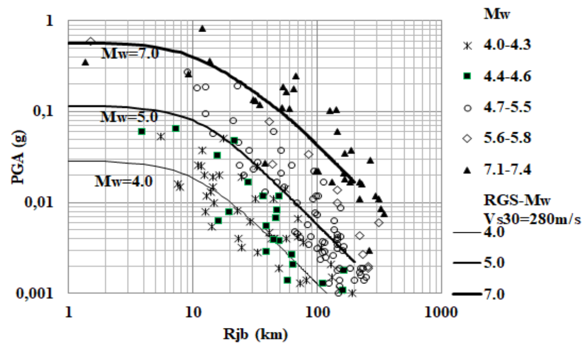

Figure 5.Acceleration-distance distribution of recordings and values calculated for V_{S30}=280 m/s- and different distances by equation which obtained regression analysis result belonging to D soil class

4 THE RELATION BETWEEN LIQUEFACTION AND ATTENUATION RELATIONSHIP

The relationship between PGA and R_{JB} is obtained from used earthquakes in this study, is applied for V_{S30}=200m/s and Mw=6.0, 7.0, 9.0 (Erken at al., 2018). The relationship based on the PGA data obtained from1995 Kobe Japan, 1999 Chi-Chi Taiwan, 2004 Niigata Japan, 2010 Darfield New Zealand, 2011 Christchurch and 2011 Tohoku Japan earthquakes where liquefaction occurred are presented in Figure 6. Soil data and measured acceleration values at the strong motion stations were considered in this study. As shown in Figure 6, liquefaction occurs when the acceleration is greater than PGA>0.1g and the distance is within the 30 km (surface projection of rupture to the site –the Joyner Boore distance) for the M_W=7.0. If the distance is longer than 30 km, sandy soil cannot liquefy even though the magnitude is 6.0. If the moment magnitude increases up to 9.0, liquefaction occurred within 125 km disttance.

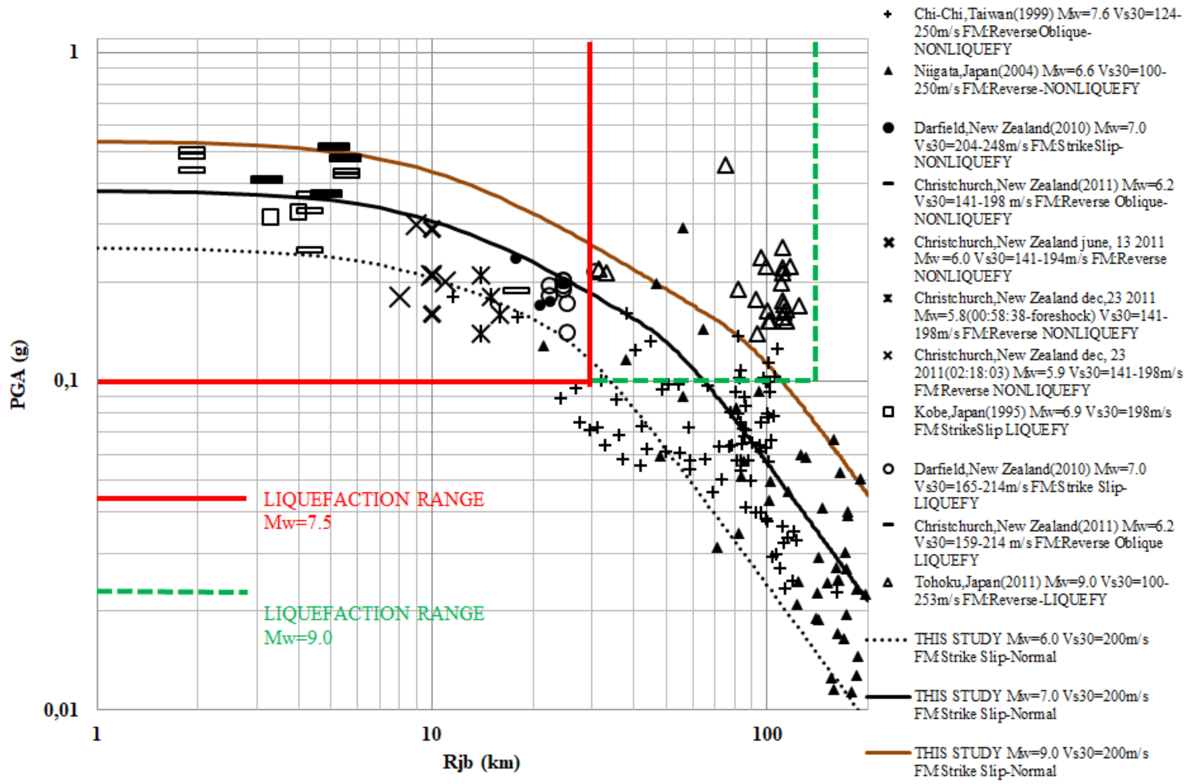

Figure 6.Comparison the measured PGA values from strong motion stations with the regression analysis results for V_{S30}=200 m/s and M_W=6.0-7.0-9.0

5 CONCLUSION

The model developed in this study were considered to be applicable for estimating peak ground acceleration values for earthquakes in which the following conditions apply:

$5.0 \leq M_W \leq 7.0$

$0 \leq R_{jb} \leq 200$ km

B, C, D, E soil classes (NEHRP)

It was found that equations obtained in this study are compatible with $5.0 \leq M_W \leq 7.0$ values models in group B, C and D according to the NEHRP soil classification system and with recorded values. In addition, measured acceleration records of world-wide data on D and E soils which have V_{S30}<250 m/s are compatible with the presented model; including acceleration data obtained liquefaction sites. So it can be said that presented model which was developed for D soil class is also valid for E soil class. Present attenuation relationships verified with earthquakes taken worldwide reveals that acceleration causes liquefaction. When the PGA≥0.1g and the distance is within the 30 km of the area liquefaction occurs for the M_W=7.0 only if the soil condition is loose and the shear wave velocity is less than 200 m/s. The present attenuation is also verified for M_W=9.0 and within the area of PGA ≥0.1g to R_{JB}=125 km.

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