An overview of earthquake ground response analysis: A case study of Gaziantep City, Turkey

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Abstract: The study presents a review of the ground response analysis in current use for engineering-based studies and a case study. A literature review on ground response to wave propagation reveals that ground movements 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, distant and the dynamic properties of the propagation media. Based on the overview made of the previous works dealing with the analysis of ground response, Gaziantep City located at the place where Mediterranean and Southeastern Anatolia meet is described as a case study. The City of Gaziantep, with a population of over 1,000,000, is an industrial centre in Turkey and located in the near-field of the Strands of the Dead Sea Fault Zone (DSFZ). Furthermore, different attenuation relationships for the City of Gaziantep are also investigated for a scenario earthquake of Mw=7.5 on the nearby DSFZ.

Résumé: Cette étude offre un compte rendu de l'analyse de la réaction du sol utilisée actuellement en ingénierie. L'état de l'art de la réponse du sol aux ondes tectoniques révèle que les mouvements du sol qui se développent dans une couche de dépôt pendant un séisme peuvent être dus dans de nombreux cas aux propriétés mécaniques des sources, à la magnitude, à la géologie locale, à la topographie des sols, à la distance et aux propriétés dynamiques des milieux de propagation. Bâtie sur une vue d'ensemble inspirée de travaux antérieurs sur l'analyse de la réaction des sols, la ville de Gaziantep, située à l'endroit où la Méditerranée et les « anatolia » du Sud-Est se rencontrent, est décrite comme cas d'étude. En effet Gaziantep, avec sa population de plus d'un million d'habitants, est un centre industriel turque et est située près de la zone de la faille de la Mer Morte. De plus differentes loi d'atténuations pour Gaziantep ont été echerchées pour un séisme de magnitude 7.5 autour de la faille.

Keywords: Seismic response.

INTRODUCTION

The earthquake is one of the most destructive natural phenomena on the earth. An earthquake includes shaking and vibration at the surface of the earth resulting from the underground movement along a fault plane. The ground vibration resulting from earthquake is due to the upward transmission of the stress waves from rock to the softer soil layers (Kramer 1996). The influence of relatively shallow (about 100 - 200 m depth) earth materials on the propagation of body waves (P and S waves) during an earthquake is termed 'ground response' (Tsai 1969), which is usually used;

- to predict ground surface motion for development of design response spectra
- to evaluate dynamic stress and strains for evaluation of liquefaction hazards
- to determine the earthquake-induced forces that can lead to earth and earth-retaining structures (Kramer 1996).

Over the years, a number of techniques have been developed for ground response analysis. Selection of the best method for ground response analysis depends on the profile of the soil deposit (Kramer 1996). The most widely used method for the analysis is one-dimensional wave propagation analysis because of its simplicity, availability and its conservative results (Schnabel et al. 1972). The methods for estimating the one dimensional ground response to dynamic stresses produced by earthquakes, blasting, and wind loading or machine vibratory can be mainly grouped into three categories; linear, equivalent-linear and non-linear methods (Stewart et al. 2001). The parameters that need to be defined in order to estimate the ground response during an earthquake are mainly dependent on the earthquake magnitude, local geology, surface topography, faulting mechanism, the length of the propagation path between the source and site, and the dynamic properties of the soil medium through which the seismic waves travel from the focus (Abrahamson & Shedlock 1997).

To generate more understanding of the ground motion and parameters needed to make estimates on earthquake risk and hazard assessments, Gaziantep City has been selected as a case study. As can be seen from the Figure 1, Gaziantep Basin where Gaziantep City is located at 37.08 N 37.36 E and 855 m elevation is situated in southern Turkey to the south of the suture zone that formed during the collision of the Arabian and Anatolian plates in late Cretaceous (Maastrichtian) and Miocene times (Coşkun & Coşkun 2000). The City of Gaziantep is located between the lands of the Mediterranean and Mesopotamia and had been often chosen to be the settlement and transition place of mankind. Today, its population (over 1,000,000), industrial importance and tourism potential make the city metropolitan. Gaziantep City is the most developed city of the GAP (South Eastern Anatolian Project) region in industry and commerce as an export gate by its tens of hundreds different products exported to more than 100 countries. The project called Southeastern Anatolian Project (GAP: Turkish acronym) is a multi-sectoral and regional development project including the construction of 19 hydraulic power plants, 22 dams, 26.5 km long irrigation tunnels 7.5m in diameter on an area extending 74,000 km^2, one tenth of the country (Çetin et al. 2000).

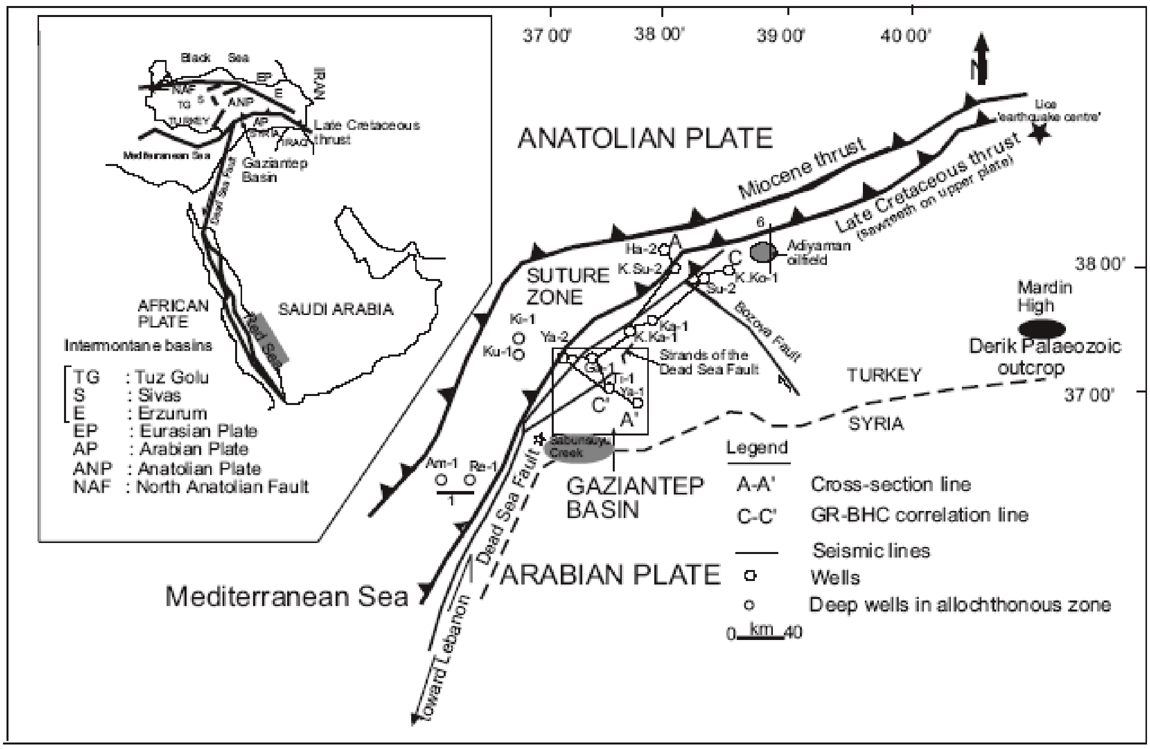

Figure 1. Map showing the different plates influencing the structural evolution of southeast Turkey, and the location of the Strands of the Dead Sea Fault Zone in this area (Coşkun & Coşkun 2000).

Following the 17 August İzmit (Kocaeli) (Mw=7.4), and 12 November Düzce (Mw=7.1) earthquakes on North Anatolian Fault (NAF) in 1999, the earthquake hazard in Turkey has become a great concern. Westaway (2003) has recently noted that the seismicity on the Anatolian Plate (ANP) - African Plate boundary in southern Turkey (see Figure 1), which behaves as a 'geometrical lock', appears correlated with major earthquakes on the NAF. Westaway (2003) has also pointed out that future detailed monitoring of the ANP - African Plate boundary in southern Turkey could provide the basis for an advance warning system of future destructive earthquakes on the NAF. In addition, according to interpretations by Balakani & Moskvina (2004), the most probable largest potential sources in the south west of East Anatolia Fault Zone (EAFZ) and northern part of the DSFZ are capable of producing the strongest future earthquakes. Accordingly, (1) the two earthquakes that occurred in Turkey and the damage suffered by structures in those events, (2) the study of Westaway (2003) on the Kinematics of the Middle East and Eastern Mediterranean, and (3) the study on Seismogenic Zones of Eastern Anatolia and Dead Sea Rift by Balakani & Moskvina (2004) motivated the present study that investigates the ground response analysis procedures and different attenuation relationship applications on Gaziantep City for a scenario earthquake of Mw=7.5 (similar to the hypothesis of Westaway (1994)) on the nearby of Dead Sea Fault Zone (DSFZ) as well as the review made of the previous studies on the analysis of ground response and the seismic data.

SOIL PROPERTIES AND GEOLOGY

Different geological and geotechnical characteristics can affect the amplitude, frequency content and duration of the ground motion during an earthquake. Deep soft sediments, for example, have strongly influence the amplitude of ground motions which can cause liquefaction, landslides or structural failures (Romero & Rix 2001). Because of the importance of the determination of soil properties, engineers have developed various site classification systems based on surface geology (Stewart et al. 2001), average shear wave velocity of upper 30 m (Martin 1994), geotechnical data (Rodrigez-Marek et al. 2001), and the depth to bedrock (Field 2000) to categorize the soil sites. The surface geology classification system for example is usually carried out according to geological age or texture as shown in Table 1. Alternatively, on the basis of changes in ground response with density and shear wave velocity variations, Borcherdt (1994) recommended the average shear wave velocity of upper 30 m as a classification method. The similar system was accepted by the United States Geological Survey National Earthquake Hazard Reduction Program (NEHRP). Geotechnical engineers have recently proposed geotechnical information based site classification systems including sediment stiffness, depth and material type to estimate the response spectra for the soil sites (Stewart et al., 2001, Rodriguez-Marek et al. 2001). Furthermore, a classification system based on the depth to bedrock is also available in the literature (i.e., Field 2000).

Table 1. Criteria for surface geology classifications (Stewart et al. 2001).

Age	**Depositional Environment**	**Sediment Texture**
Holocene	Fan alluvium	Coarse
Pleistocene	Valley alluvium	Fine
	Lacustrine/marine	Mixed
	Aeolian	
	Artificial fill	
Tertiary		
Mesozoic+Igneous		

Following the studies investigating the surface geology (e.g., Rigo de Righi & Cortesini 1964) and the subsurface tectonics (e.g. Robertson 2000) it is widely believed that the stratigraphy of the Gaziantep Basin is mainly formed by the Arabian-Anatolian plate collisions in late Cretaceous and Miocene time (Coşkun & Coşkun, 2000). As can be seen from the Figure 2 showing a general stratigraphic column of the Gaziantep Basin, basalt deposits varying between 0-150 meters may be dominantly occurring in some areas of the Gaziantep Region. This extrusive and basic igneous rock having vesicular and amygdaloidal texture is reddish, dark grey and dark brown coloured and very thick layered place to place. Some of the vesicles are filled with calcite. Because of its significance for the design of slopes, foundations, and underground excavations in the City, geotechnical properties of basalt in this region have been studied by a few authors. For example, Çanakcı et al. (2002) presented a series of experiments on the geotechnical properties of Basalt occurring in Gaziantep. The tests they carried out on the core specimens having the diameter of 54 mm and 110 mm length were density, uniaxial compression, Brazilian indirect tensile, water absorption and Schmidt hammer rebound. The tests performed revealed that the average dry density of the samples are 2.73 g/cm^3, the uniaxial compressive strength of the specimens vary between 33.8 MN/m^2 and 157.7 MN/m^2, tensile strength of the specimens vary between 8.5 MPa and 16.9 MPa, the ultrasonic pulse velocities change between 5466.7 m/s and 4042.9 m/s.

As can be seen from the Figure 2 showing Gaziantep geology, limestone deposits can also be seen dominantly in some areas of the region. As foundation material, limestone, which are the most commonly occurring relatively highly soluble rocks to suffer chemical solution, differs from other rocks in that voids may be found at almost any depth within the rock mass. They may result directly from solution weathering near the surface and along discontinuities, or as specific cave systems at depths related to present or past ground water levels. Some of the characteristics of limestone that need to be taken into account by engineers were summarized in Fookes & Hawkins (1988)'s review paper. During the dissolution of calcium carbonate in water it dissociates at the rock water interface (reaction 1); then the carbonate anions react with water (reaction 2). In a closed system the water quickly becomes a saturated concentration, and thus dissolutions (the forward reaction) and precipitation (the reverse reaction) seems to be possible.

$$CaCO_3 \text{ (solid calcium carbonate)} \longrightarrow Ca^{+2} \text{ (calcium cation)} + (CO_3)^{-2} \text{ (carbonate anion)} \quad (1)$$

$$(CO_3)^{-2} \text{ (carbonate anion)} + H_2O \text{ (water)} \longrightarrow H(CO_3)^{-} \text{ (hydrogen carbonate ion)} + OH^{-} \text{ (hydroxyl ion)} \quad (2)$$

Limestone solution following a chemical process is controlled by a number of factors in an open system, such as, availability of water, temperature, availability of carbon dioxide. It is widely known that, in a nature environment, when water passes through the limestone discontinuities it eventually emerges into caves (Fookes & Hawkins 1988).

Figure 3 shows a typical view of a cave occurred by this process in the Gaziantep City, which seems to be one of the most problematic issues in the city of Gaziantep. It has been therefore widely studying by Çanakcı and co-workers of Gaziantep University. On the other hand, despite the fact that the dynamic properties of the propagation media is another crucial factor for evaluating the response of earth to dynamic stress produced by earthquakes, it has been surprisingly discerned that the dynamic properties of the earth materials in Gaziantep Basin have not been studied widely by the scientists.

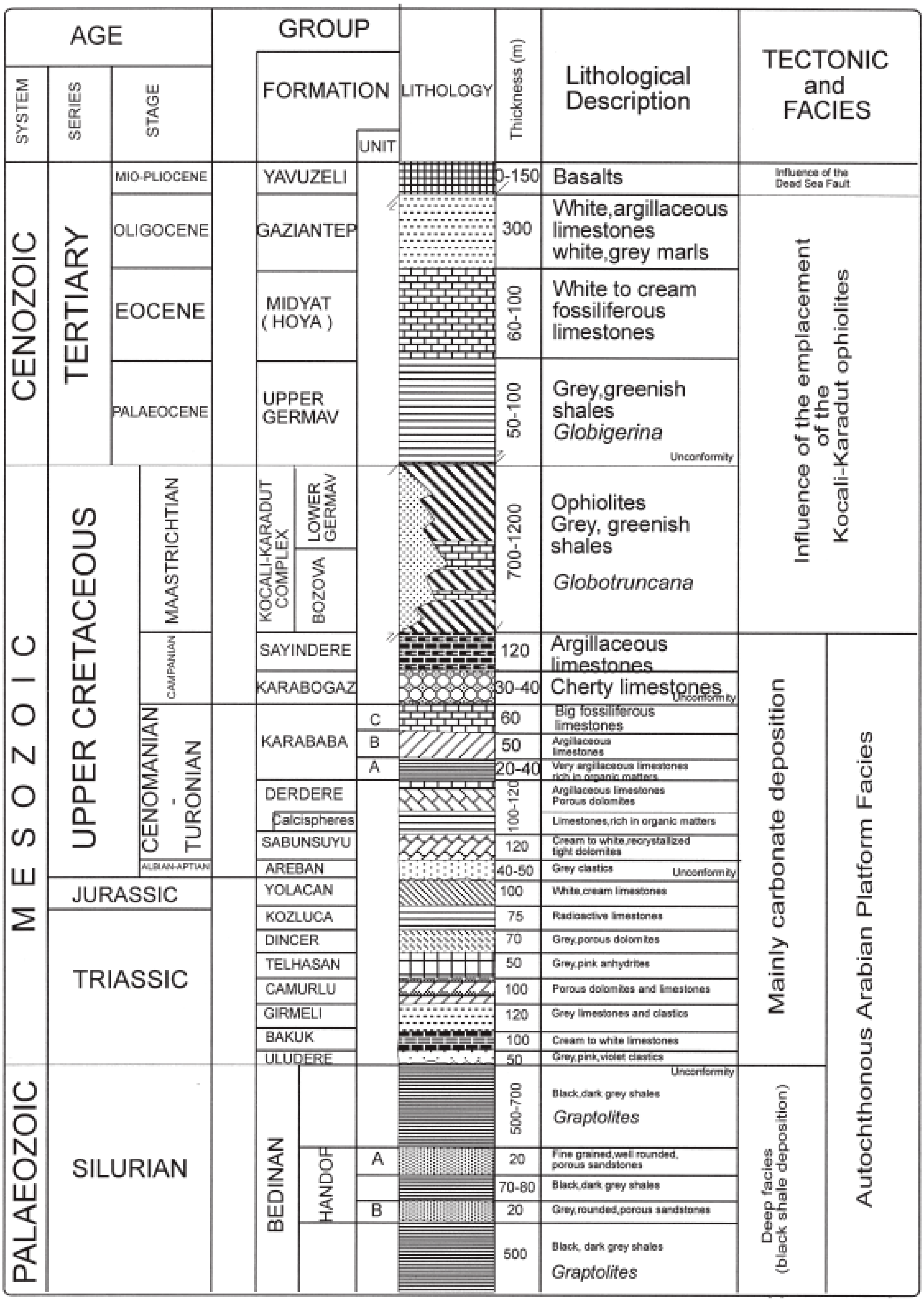

Figure 2. General stratigraphic column of the Gaziantep area (Coşkun & Coşkun 2000)

FAULT MECHANISM

Estimation of ground motions and the development of design criteria require seismic source characteristics as well as the geological conditions of the site. Following some arguments described in their paper, Coşkun & Coşkun (2000) concluded that the fault influencing the structural evolution of the Gaziantep Basin is the Dead Sea Fault Zone (DSFZ). DSFZ, which is an active left lateral fault zone extending for more than 1000 km (e.g., Garfunkel et al. 1981, Gursoy et al., 2003, Altunel et al. 2005), bounding the Arabian and African Plates and it continues northward past

Israel, Jordan, Lebanon, Syria and Turkey, while its southern end meets the Arabian-African boundary in the Red Sea slipping (Westaway 1994). It then steps to the right, west of Gaziantep before merging with the Anatolian Plate-African Plate boundary to form the East Anatolia Fault Zone (EAFZ). Although in most kinematic models this fault zone is considered to meet the East Anatolia Fault Zone (EAFZ) at a triple junction sited close to Kahramanmaras City (see Figure 4) (Tatar et al. 2004), it is difficult to establish the linkage geometry to the EAFZ and to the boundary between the Anatolian and African plates (Yurtmen et al. 2002, Charovicz et al. 2005). It seems therefore that a greater understanding of ‘geometric lock’ as termed by Westaway (2003) requires a study on the northern DSFZ in Turkey.

In the course of history, the DSFZ region has been the site of numerous destructive earthquakes. Following the long history of studies of the DSFZ detailed in Figure 4, Westaway (1994) said that the DSFZ can be divided into three parts: the Zone’s north-trending northern and southern parts north of ~34.5°N and south of ~33.5°N, and the ~N30°E trending central part. In addition, the DSFZ becomes braided north of 36.5° latitude into three main fault segments comprising the (1) Amanos Fault Zone (AFZ) in the west, which is believed to have formed the main strands of the Africa-Arabian boundary (Yurtmen et al., 2002) (2) East Hatay Fault, and (3) Afrin Fault (Tatar et al. 2004). According to Yurtmen et al. (2002), the most subsequent strike slip has occurred to the east of the Karasu Rift and Amanos Rang, and sidesteps onto faults at the western margin of the Gaziantep Basin. Westaway (1994) listed the earthquakes with M>6.5 that have occurred in the northern part of the DSFZ, which continues northward in to Turkey near Gaziantep, using the data given by Ambraseys & Barazangi (1989). The literature shows that large earthquakes destroying many important cities were recorded on DSFZ. Table 2 shows the seismicity on this zone for c. 800 years.

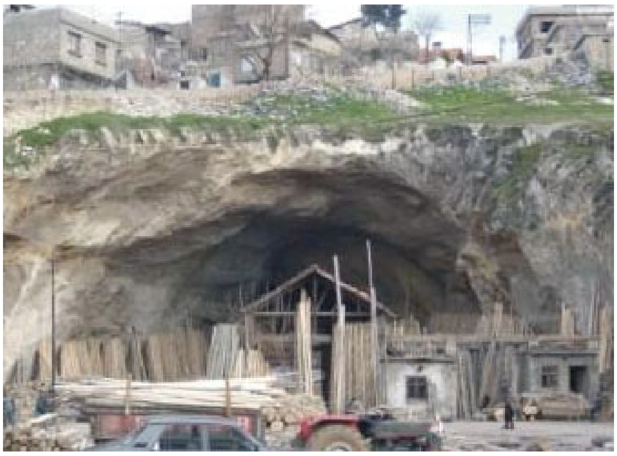

Figure 3. The view of a cave in the City of Gaziantep

Table 2. Seismicity of Northern DSFZ (Westaway 1994)

	Epicentre			
	Latitude	Longitude		M_o†
Date	°N	°E	M*	10^{18} Nm
		Bekaa Valley; Latitude 33°N – 34.5°N		
May 20, 1202	34.1	36.1	7.5	200
Oct. 30, 1759	33.1	35.6	6.6	10
Nov. 25, 1759	33.7	35.9	7.4	140
		Gharb Fault; Latitude 34.5°N – 36.5°N		
Aug. 15, 1157	35.1	36.3	>7.0	>40
June 29, 1170	35.9	36.4	>7.0	>40
Feb. 22, 1404	35.9	36.3	large	~100
April 29, 1407	35.7	36.3	~7.0	40
April 26, 1796	35.7	36.0	6.6	10
April 3, 1872	36.4	36.5	<7.2	<70
		Karasu Fault Zone; Latitude 36.5°N – 37°N		
Aug. 13, 1822	36.7	36.9	>7.4	>140

*M is estimated magnitude

†M_0 is estimated seismic moment.

One of the analysis results suggested by Westaway (1994) has pointed out the large proportion of the expected ~7 mm yr^{-1} left-lateral slip is associated with very large earthquakes, with 'Mw~7.5', which occur at intervals of several hundred years on each fault segment of the DSFZ. The present study, therefore, aims first to review the ground response analysis literature and second to show the influence of a scenario earthquake of Mw=7.5 on the nearby Strands of the Dead Sea Fault on the City of Gaziantep, having a high population and the most important industrial zone in southeast Turkey. Herein, it is also worthy to refer the study of Balakani & Moskvina (2004) to point out the probable locations of future large earthquakes using various sources of seismogenic zones of the EAFZ and the northern part of the DSFZ. In their paper, the recurrence intervals T of maximum possible earthquakes in sources of various sizes in these zones have been estimated, and time sequences of such shocks occurring in preceding centuries have been calculated for each source. The most probable locations of disastrous earthquakes in these zones have been identified for the 21st century.

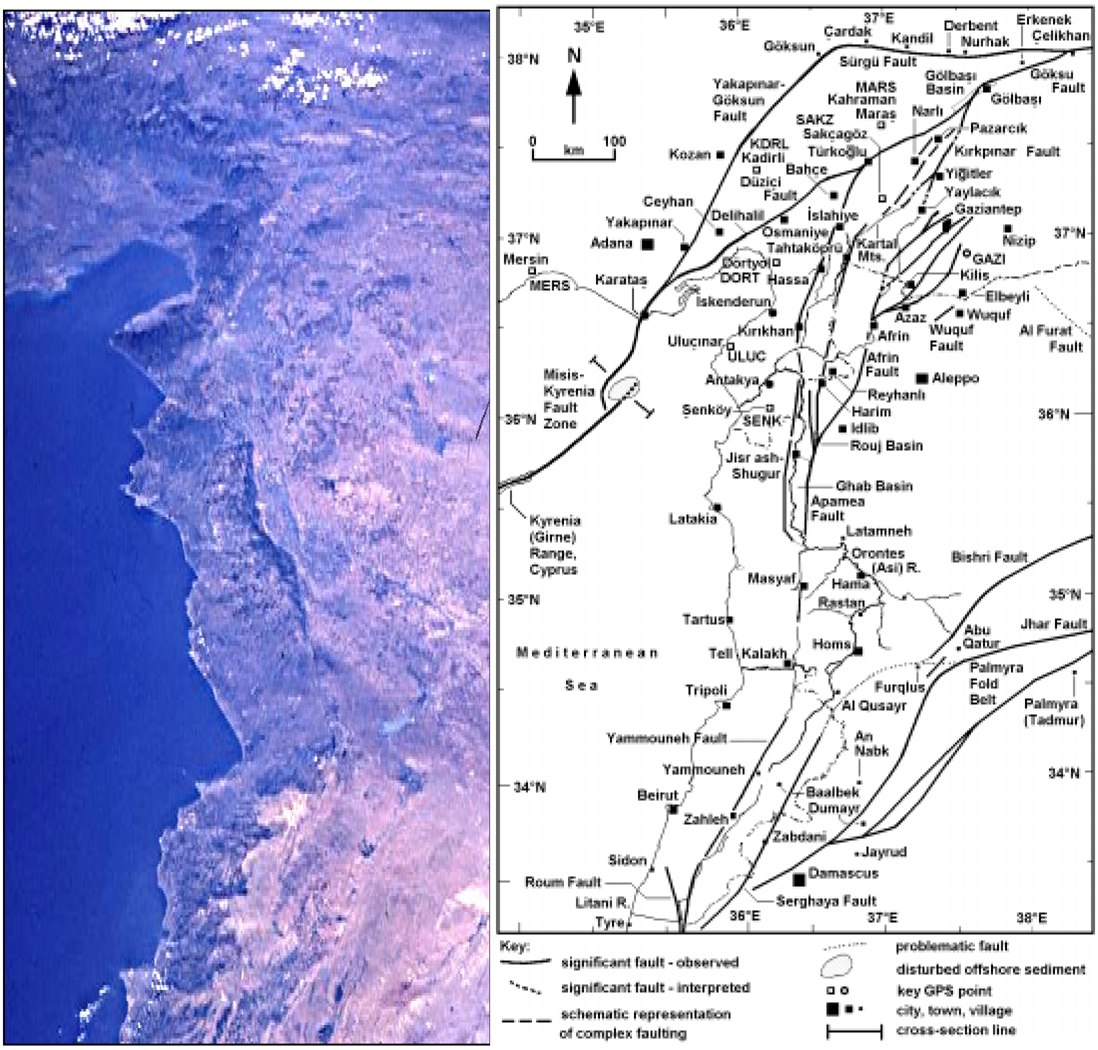

Figure 4. **a).** Satellite image of the DSFZ area (NASA, 2005), **b).** Map of significant segments of the ANP-AP and ANP-African Plate boundaries (Westaway 2003).

ATTENUATION RELATIONSHIPS

Estimates of expected ground motion at a given distance from an earthquake are fundamental inputs to earthquake hazard assessment that can be performed either (a) deterministically, which involves (1) the determination of the scenario earthquake (2) identification of appropriate site response quantification (3) identification of proper attenuation relationships, or (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 determined empirically or theoretically, 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 (PGA), 5 percent damped spectral acceleration (Sa), peak ground velocity (PGV) (Kramer 1996, Abrahamson & Shedlock 1997). A number of attenuation relation studies could be found in the literature. Many reviews of attenuation relationship studies were published providing the results and problems associated with such relationships as well as a good summary of the methods (i.e., Idriss 1978, Joyner &

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. Therefore, the present study attempts to predict free-field horizontal components of the peak horizontal acceleration (PGA) and 5 percent damped acceleration response spectra (Sa) using the Boore et al. (1997), Sadigh et al. (1997), and Gülkan & Kalkan (2004) (just for PGA) attenuation relationships for a scenario earthquake of Mw=7.5 on the Northern Dead Sea Fault Zone (DSFZ) (Figures 5 and 6). In their paper, Boore et al. (1997) firstly summarized the works on estimating horizontal response spectra and peak acceleration for shallow earthquakes in Western North America. The set of data restricted to shallow earthquakes (above a depth of 20 km) with moment magnitude greater than 5.0 were combined with the 1989 Loma Prieta, 1992 Petrolia and 1992 Lander Earthquakes, which were collected by the California Division of Mines and Geology's Strong-Motion Instrumentation Program and the United States Geological Survey's National Strong-Motion Program. And then, they developed a ground-motion estimation equation shown in Equation 1. The attenuation relationship (Equation 2) presented by Sadigh et al. (1997) are based on strong motion data mainly earthquakes in California, which are crustal earthquakes. The relationships presented in their study are for different faulting earthquakes (strike-slip and reverse) and different soil types combined with the magnitude 4 to 8 and distance up to 100 km. In the present study, an attenuation relationship of horizontal response spectral accelerations for rocks sites developed by Gülkan & Kalkan (2004) has also been used. Following the study of Boore et al. (1997), Gülkan & Kalkan have recently derived the attenuation relationships for Turkey using the database compiled for earthquakes with moment magnitudes in the range 5 to 7.5 and distance up to 150 km, a total of 19 earthquakes between 1976-1999.

$$\ln Y = b_1+b_2(M-6) +b_3(M-6)^2+b_5\ln r+b_v\ln(V_s/V_A) \quad (1)$$

$$\ln Y = C_1+C_2M+C_3(8.5-M)^{2.5} +C_4\ln(r_{rup}+\exp (C_5+C_6M))+C_7\ln(r_{rup}+2) \quad (2)$$

In the equations above, Y is the ground motion parameter in g, M is moment magnitude, r and r_{rup} are distance in km, V_S is the average shear-wave velocity to 30 m and the coefficients to be determined are b_1, b_{2A}, b_3, b_5, b_v, C_1, C_2, C_3, C_4, C_5, C_6, C_7, V_A.

The attenuation of peak ground acceleration (PGA) obtained using different attenuation relationships for Mw=7.5 on the left lateral strike slip fault are compared in Figure 5. In addition, a comparison on the response spectral values for the scenario earthquake at a distant of 60 km is presented in Figure 6 as well. Using the attenuation models developed by three different studies has showed that the differences in the curves are judged to be reasonable mainly because of the different regression models and different databases in each method. The coefficients in the equations for predicting ground motion were determined using the local characteristics in the City of Gaziantep (i.e., strike-slip earthquake, 60 km nominal distant, rock site, 20 km depth, magnitude of 7.5). Plots of the peak ground acceleration versus distance for Mw=7.5 (Figure 5) have showed that the two sets of curves obtained from Boore et al. (1997) and Gülkan & Kalkan (2004) are similar at almost all distances, but the curve of Sadigh et al. (1997) is higher than the others up to 90 km. As can be seen from the Figure 5, peak accelerations for the curves obtained by Boore et al. (1997) and Gulkan & Kalkan (2004) are 0.4 g and 0.3 g respectively. Whereas, the peak acceleration in the curve obtained from Sadigh et al. (1997) is 0.7 g. The response spectra for a magnitude 7.5 event at a 60 km are compared in Figure 6. The plots of the spectral acceleration versus period have showed the all two attenuation relationships obtained from Boore et al. (1997) and Sadigh et al. (1997) to have a more similar trend in smaller periods. Evidently, Boore et al. and Sadigh et al. models seem to be reasonable consistent.

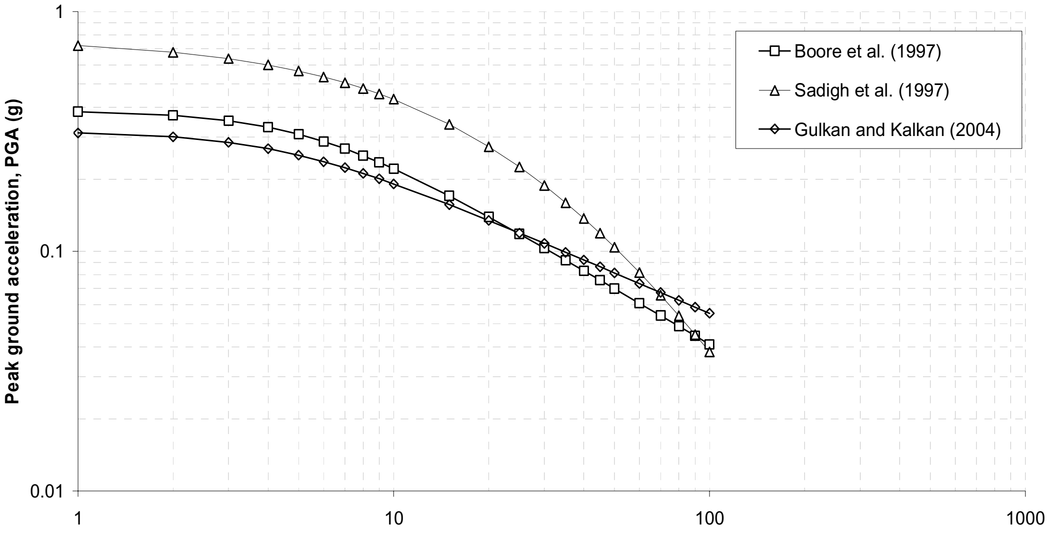

Figure 5. Horizontal peak ground acceleration (PGA) vs. horizontal distance

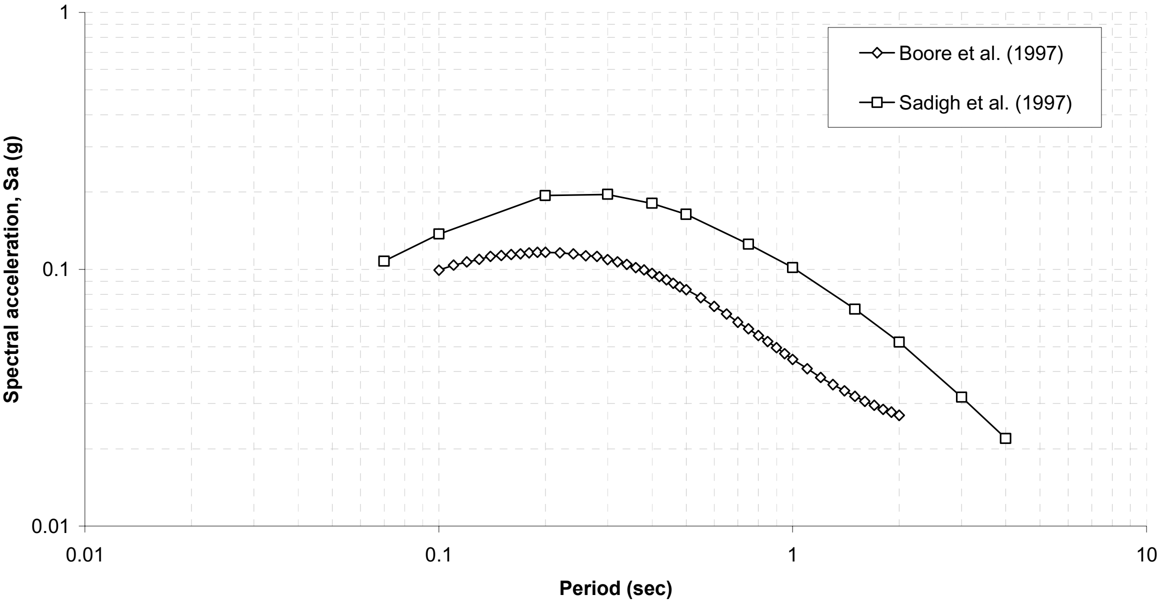

Figure 6. Spectral acceleration (Sa) vs. period

CONCLUSIONS

Following the disastrous İzmit and Düzce earthquakes on the North Anatolian Fault (NAF) in 1999, the earthquake hazard in Turkey, particularly İstanbul in Marmara Region (northwest of Turkey), has become a great concern. However, based on the review made of the previous studies on the analysis of ground response and the seismic data, this study has aimed to point out the northern part of the Dead Sea Fault Zone (DSFZ) in southern Turkey. It has been seen that the left-lateral slip on DSFZ is associated with earthquakes of magnitude ~7.5 occurring at intervals of several hundred years on each fault segment. A possible earthquake could evidently have significant social and economic effects on the cities (Gaziantep, Antakya, Kahramanmaraş in Turkey, and Aleppo in Syria) having a high population and industrial facilities in the region. Investigating on the city of Gaziantep located in Gaziantep Basin has been concluded that the development of attenuation relationships and a seismic hazard analysis in detail are needed for possible earthquakes on Northern Dead Sea Fault Zone, because the ground motion relations for earthquakes in one region cannot be simply applied for engineering based use in another region. Furthermore, it has been also noticed that the Anatolia- Africa Plates boundary in southern Turkey could behave as a 'geometric lock' which may provide an advance warning of future larger earthquakes on NAF by monitoring of moderate sized earthquakes on this region.

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