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# Evaluation of Site Effects in Ankara Region during the December 1997 and March 1998 Bala Earthquakes

M. K. Koçkar[1]

## ABSTRACT

Local site conditions can significantly affect the amplitude and frequency of ground shaking during earthquakes. Recordings of recent major earthquakes have demonstrated that near-surface local site conditions can generate prominent amplification of ground shaking and can be compared with the amplification predicted by numerical simulation. This study analyzes the ground motion data from the Bala earthquake series in the southern part of Ankara considering the effect of soil conditions on ground shaking. Initially, shear wave velocity profiles of the strong ground motion stations were evaluated to define site classifications for each station in and around Ankara. Strong motion data collected during the Bala earthquake series ($M_w$ range 5.7 to 4.8) were used to develop event-specific attenuation relationships for peak ground acceleration and spectral acceleration at various periods and different site conditions. Site amplification factors were derived from the regression results from the event-specific attenuation relationships for the Bala earthquake series. Finally, the response spectra from the recording stations were used to develop site amplification factors for each site class to understand the variability of the site response in localized geographic regions.

## Introduction

Bala earthquake series that have occurred in December 20-27, 2007 ($M_w$= 5.7, 5.6, 5.2, 4.8 and March 15, 2008 ($M_w$= 5.2) in the Ankara region have generated prominent interest in the earthquake engineering community because the Ankara region is considered to be quiet in terms of less frequent seismic activity, and rarely moderate earthquakes ($M_w > 5$) have occurred in the inner part of the Central Anatolia. However this perception is disproved by these Bala earthquake series that took place in the southeastern part of Ankara. Another significant interest is that, although Bala earthquakes are moderate; they were felt strongly in the Capital City, Ankara which is situated about 50 km northwest of the epicenter. Hence, the impact of local site conditions might have influenced strong ground motions during the Bala earthquakes. Due to these reasons, even though Ankara may be considered to be situated distant to these seismic activities, the influence of the local sediment conditions under earthquake triggered motions, which significantly plays an important part in contributing seismic damage needs to be investigated (Koçkar and Akgün, 2012).

As previously mentioned, because it is considered that seismic activity and larger magnitude events are less frequent, limited number of strong motion stations have been installed around the Ankara region. In general, the stations have generally been installed particularly along the major Fault Zones where large earthquakes have occurred or within expected active areas with a

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[1] Dr., Earthquake Eng. Implementation & Research Center., Faculty Member, Ankara, Turkey, mkockar@gazi.edu.tr

distance of about 80-100 km away from the Ankara. Therefore, the scarcity of strong motion data for seismic events have make the attenuation of the earthquake ground motions difficult to characterize, and thus difficult to identify the hazard estimation in this region.

The distribution of seismic damage caused by ground shaking commonly reflects areal differences in local sediment conditions. Hence, in understanding the variation in ground shaking, quantitative soil parameters that can be used to predict variations of ground motion amplification due to differences in soil conditions are needed. These evaluations of local site conditions are reflected in seismic code provisions. Recent seismic code provisions, such as the International Building Code, IBC (International Code Council, ICC, 2009), adopt site classification systems that use the average shear-wave velocity to a depth of 30 m ($V_{s30}$) as the sole parameter for quantifying seismic sediment characteristics (Dobry et al., 2000). Alternatively, some site classification systems utilize shear wave velocity ($V_s$) data along with the stratigraphy information to classify soil profiles, such as the Turkish Seismic Code (TSC, 1998). Hence, characterizing the shear wave velocities at strong motion stations and the impact of these soil conditions on the recorded motions is significant for evaluating site effects. In this study, in situ characterization of shear wave velocities was performed at strong motion stations using non-invasive seismic testing methods involving Rayleigh-type surface waves. The $V_s$ results collected and conducted in this study are used to determine site classifications for the strong motion stations.

These recorded strong motion data, that have been obtained from Gazi University-DEMAR and AFAD (National Strong-Motion Observation Network) network database for the Bala earthquake series represent invaluable information to evaluate ground motion characteristics and site effects during moderate earthquakes. The recorded strong motions data from the Bala earthquakes are used to evaluate the effect of soil conditions on ground shaking. Event-specific attenuation relations were developed for peak ground acceleration and spectral acceleration at various periods within different site conditions to evaluate the variation of ground shaking across site classes. Finally, the response spectra from recording stations were used to develop site amplification factors for each site class to understand the variability of the site response in localized geographic regions.

## Site Characterization of Strong Motion Stations

As mentioned before, at the southeast of Ankara, the Bala earthquake series have occurred with moment magnitude of 5.7 and 5.6 in December 20 and 26, 2007, respectively (Figure 1; ERD-Earthquake Department of AFAD, 2007). Apart from one station that is located at a distance of less than 65 km (ERD), unfortunately ten and twelve strong motion stations at distances greater than 150 km of the faults recorded these earthquakes, respectively. Therefore, the magnitude of 5.7 earthquake event has been excluded from this study because of the limited strong motion data at distances less than 100 km. However, five strong motion stations of Gazi-DEMAR recorded the magnitude of 5.6 earthquake event. Afterwards, two moderate earthquakes occurred with moment magnitude of 5.2 (ERD, 2007) and 4.8 (Gazi-DEMAR, 2007) in December 27, 2007 (Figure 1), respectively. Fortunately, a total of eight and nine strong motion stations, respectively from DEMAR and ERD within 100 km of the fault have also recorded these earthquake events. The last earthquake event occurred with a moment magnitude of 5.2 in March 15, 2008 and seven strong motion stations within 100 km of the fault have recorded this earthquake event (Figure 1; Gazi-DEMAR, 2008). It should be noted that the shear wave velocity profiles used for this study were not readily available at most of the strong motion stations of AFAD-ERD (2007) in the Ankara region due to various reasons (i.e., temporary stations, location change). In addition, the $V_s$ profiles were measured at strong motion stations of Gazi-DEMAR before this study (Can et al., 2013). The spatial distributions of all these stations are given in Figure 1.

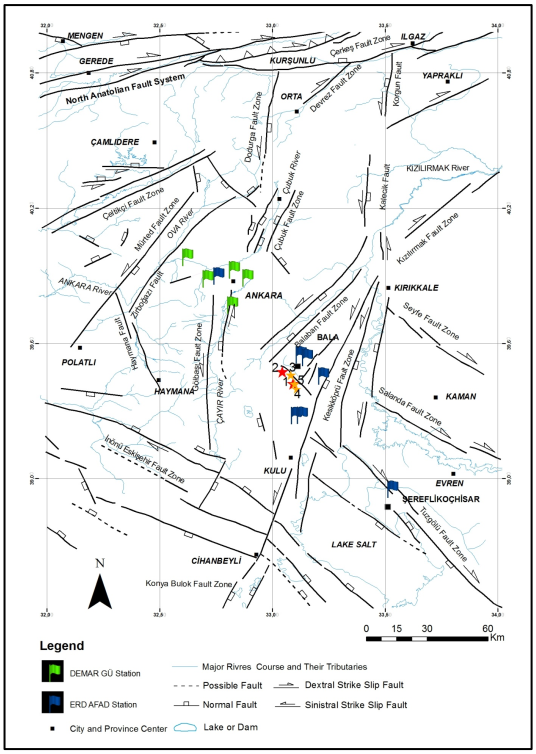


Figure 1: Location of strong motion stations in the study area. Stars with numbers display the Bala earthquake series that have occurred in the Ankara region (1-20.12.2007, $M_w$: 5.7; 2-26.12.2007, $M_w$: 5.6; 3-27.12.2007, $M_w$: 5.2; 4-27.12.2007, $M_w$: 4.8; 5-15.03.2008, $M_w$: 5.2).

### *Seismic testing methods*

In situ characterization of the $V_s$ profiles was performed at five of the Gazi-DEPAR strong motion stations along with the seven of the AFAD-ERD strong motion stations in the Ankara region using seismic testing methods on the basis of the dispersive nature of the Rayleigh-type surface waves. The Multichannel Analysis of Surface Wave Method (MASW) and the Microtremor Array Method (MAM), which gave comparable results, were used in this study as active and passive surface wave methods, respectively, in order to obtain a $V_s$ profile of the subsurface in the vicinity of the strong motion stations. A combined usage of the active and passive surface wave methods was adopted in order to meet the requirements of preserving high resolution at shallower depths while also extending the $V_s$ measurements to greater depths.

22 surface wave measurements were taken at 11 different strong motion stations to study the seismic response of different lithologies in the Ankara region. In situ measurements were generally recorded in a linear array configuration with twelve 4.5 Hz natural frequency vertical

geophones with 1.5 m spacing for MASW and 10 m spacing for MAM methods. In active MASW surface wave measurements, the primary source was generated by using a trailer mounted 26,5 kg drop weight. This source was developed at the Gazi University-DEMAR to generate surface waves with sufficient energy and the appropriate frequency content for MASW profiling to depths of 30-50 m (Can et al., 2013). The source is designed to be highly mobile, for rapid deployment, and to be safe for testing in urban environments. For passive surface wave measurements, the optimum record length of 10 minutes was selected as a standard for each of the measurements (Hayashi, 2008). In the MAM survey, the sampling time interval was selected as 2 ms. The SPAC (Spatial Autocorrelation) analysis (Okada, 2003) was utilized to construct the dispersion curve. A one-dimensional inversion using a non-linear least square technique has been applied to the phase velocity curves and a one dimensional S-wave velocity structure down to a depth greater than 30 m was obtained.

A blind way technique was implemented over the area and the main aim was to get an average shear wave velocity ($V_{s30}$) at the strong motion stations. Therefore, the geophone type, geophone distance and offset length were selected to characterize the layers at least up to a depth of 30 m. This gave a chance to compare the results of two surface wave surveys, namely MASW and MAM based on different sources. Hence, the $V_s$ profiles were developed and used in the site classification. These profiles obtained from a combination of the active and passive surface wave methods give an indication of the lateral variability in the vicinity of the strong motion stations.

### *Site classification*

Shear wave velocity profiles were developed from the combined usage of the active and passive surface wave methods for the twelve strong motion stations that have been tabulated previously in Figure 1. Then, these $V_s$ profiles of the near-surface geologic units have been used to characterize site classes according to the recent site classification systems which are used to distinguish between different site conditions at strong motion stations. The site classification systems discussed herein are the IBC 2009 and the TSC (1998) systems. The site classes specified by IBC 2009 distinguish soil profiles into five main categories from soft soil to hard rock based solely on $V_{s30}$. The TSC site classification system defines site classes based on an assessment of the stratigraphy information of the surficial soil layer along with the $V_s$ data. The surface layer is assigned to a soil group based on its $V_s$, and then the site class is assigned based on the soil group and the top layer thickness. While the TSC classification system has the advantage of considering some measure of soil depth, it only considers the properties and depth of the surface layer. Thus, it neglects the deeper soils that lie below the top soil layer.

The IBC 2009 and the TSC site classifications for the strong motion stations that recorded the Bala earthquake series are tabulated in Table 1, along with $V_{s30}$ results and surface geology. It should be noted that in the Ankara region, the geologic map subdivides the surface geology into three main units: (1) Pre-Upper Miocene to Lower Pliocene basement rocks (referred as a rock in the text), (2) Upper Pliocene to Pleistocene fluvial deposits (Plio-Pleistocene fluvial), (3) Quaternary terrace and alluvial deposits (Akyürek et al., 1997).

Regarding the IBC results based on surface geology, the $V_{s30}$ data at the strong motion stations indicate that all sites from both the Quaternary and Plio-Pleistocene deposits fall into site class D, despite the fact that the average $V_{s30}$ values for these units are statistically different (Koçkar et al., 2010). In fact, there is no natural boundary between the Quaternary and Plio-Pleistocene deposits as threshold site class values because the variation in $V_{s30}$ in the Quaternary deposits is influenced by the presence of stiffer deposits within the upper 30 meters of the site. Additionally, rock units cross IBC site class boundaries (between site classes B and C for the basement rocks), establishing direct relationships between geologic unit and site class difficult. Because the IBC code-based site classes do not adequately distinguish these geologic units as a unique rock site (i.e., very dense soil and soft rock or firm rock), it is important to maintain the geologic description along with the site class when developing information for ground motion studies.

Table 1: Site classifications for strong motion stations in Ankara region.

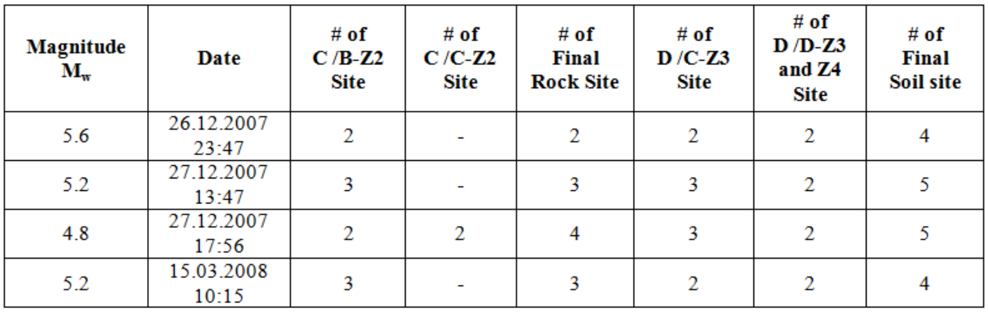
| **Station** | **Owner** | **Surface Geology** | **$V_{s30}$ (m/s)** | **IBC-2009 Site Class** | **TSC Site Class** | **Final Site Classification Assigned (IBC/TSC)** |
|---|---|---|---|---|---|---|
| Gazi Uni. Gölbaşı Campus | Gazi-DEMAR | 1 | 528 | $S_C$ Site | B-Z2 | Soft Rock/ Weathered Rock |
| Eryaman-Güzelkent | Gazi-DEMAR | 2 | 255 | $S_D$ Site | D-Z3 | Stiff Soil/ Soft Soil |
| Gazi U. Beşevler Campus | Gazi-DEMAR | 3 | 195 | $S_D$ Site | D-Z4 | Stiff Soil/ Soft Soil |
| Çankaya | Gazi-DEMAR | 1 | 728 | $S_C$ Site | B-Z2 | Soft Rock/ Weathered Rock |
| Ümitköy | Gazi-DEMAR | 2 | 300 | $S_D$ Site | C-Z3 | Stiff Soil/ Stiff Soil |
| Bala-Sırapınar Village_ Qdr | AFAD-ERD | 2 | 356 | $S_D$ Site | C-Z3 | Stiff Soil/ Stiff Soil |
| Center of Earthquake Research Department. (ERD)- Lodumlu | AFAD-ERD | 2 | 291 | $S_D$ Site | C-Z3 | Stiff Soil/ Stiff Soil |
| Bala-Old Gavernorship Building | AFAD-ERD | 1 | 590 | $S_C$ Site | B-Z2 | Soft Rock/ Weathered Rock |
| Bala-Sofular Village, Feed Mill | AFAD-ERD | 1 | 373 | $S_C$ Site | C-Z2 | Very Dense Soil/ Weathered Rock |
| Bala Sofular Village, Feed Mill_Qdr | AFAD-ERD | 1 | 392 | $S_C$ Site | C-Z2 | Very Dense Soil/ Weathered Rock |
| Bala-District Police Headquarters | AFAD-ERD | 1 | 626 | $S_C$ Site | B-Z2 | Soft Rock/ Weathered Rock |
| Şereflikoçhisar County-Municipality | AFAD-ERD | 2 | 325 | $S_D$ Site | C-Z3 | Stiff Soil/ Stiff Soil |

The $V_s$ and thickness of the surface layer is used by the TSC to define site classes (Table 1). The surface layer is defined based on the location of a significant velocity contrast or, where supporting borehole information is available. Results at the strong motion stations indicate that Quaternary site contains soft soil at the surface (Soil Type D) and is classified as TSC Z3 and Z4 based on the thickness of the soft soil. The Plio-Pleistocene sites are classified as site class Z3. Interestingly, the IBC classifications for the Plio-Pleistocene sites are site class D, which is a softer class than TSC Z3. Thus, the TSC system generally assigns the Plio-Pleistocene deposits to a stiffer site class (Z3) than the IBC system (D). Although the IBC system averages velocities over the entire 30 m and includes stiffer soil below the surface layer, the $V_{s30}$ values for the Plio-Pleistocene sites are still within the site class D range (180 - 360 m/s) (Koçkar et al., 2010). Another important comment regarding the TSC site classes is that the Plio-Pleistocene sites tend to have larger $V_{s30}$ values than Quaternary sites with the similar TSC site class. Comparing the IBC and TSC site class, it is clear that using the TSC system results in more of the basin being defined as the softest site class because only the surface layer is taken into account in the site classification system. Therefore, the IBC and TSC site classes were considered together for assigning the final site category at the strong motion stations.

## Event-specific Attenuation Relationships

Data from the Bala Earthquake series were used to develop event-specific attenuation relationships for peak ground acceleration and spectral acceleration at various periods within different site conditions. For each event, the number of recordings from the distances less than 100 km for each site class is shown in Table 2. In this table, C /B-Z2 (IBC/TSC) represents soft rock to weathered rock sites, C /C-Z2 represents very dense soil to weathered rock, and then rock site is the combination of these categories based on IBC and TSC. D /C-Z3 represents stiff soil, D /D-Z3 or Z4 represents stiff soil to soft soil, and then soil site is the combination of these two categories based on IBC and TSC. Table 2 indicates that for the Bala Earthquakes, there is poor sampling of true rock sites (IBC-A or TSC A- or B-Z1). Only two recording stations is close to this category. Hence, similar rock categories are sometimes combined to increase the number of recordings for competent sites, although the general response characteristics of rock and very dense soil sites are different (i.e., Rodriguez-Marek et al., 2001). Additionally, to extend more evenly distributed site categories, IBC stiff soil and TSC soft soil sites are generally combined because they both represent deep soil sites (Rathje et al., 2003).

Table 2: The Bala Earthquake series ($M_w$ range 5.7 to 4.8) analyzed and the number of recordings for each site class based on IBC 2009 and TSC (IBC/TSC).



| **Magnitude $M_w$** | **Date** | **# of C /B-Z2 Site** | **# of C /C-Z2 Site** | **# of Final Rock Site** | **# of D /C-Z3 Site** | **# of D /D-Z3 and Z4 Site** | **# of Final Soil site** |
|---|---|---|---|---|---|---|---|
| 5.6 | 26.12.2007<br>23:47 | 2 | - | 2 | 2 | 2 | 4 |
| 5.2 | 27.12.2007<br>13:47 | 3 | - | 3 | 3 | 2 | 5 |
| 4.8 | 27.12.2007<br>17:56 | 2 | 2 | 4 | 3 | 2 | 5 |
| 5.2 | 15.03.2008<br>10:15 | 3 | - | 3 | 2 | 2 | 4 |

Considering the distance range, strong motion data from the Bala Earthquake series are not evenly distributed with the distance for all site classes. No data fall in the distance range of 0-10 km for any of the earthquakes. Apart from the magnitude of the 5.6 event, most of strong motion data fall within a distance range of 10 to 80 km. For the magnitude of the 5.6 event, the minimum distance recorded was 40 km. In addition, the number and distribution of the recordings across site classes were not always adequate. For instance, there are limited data for C sites and D/ D-Z4 soft soil sites for all earthquake events. For this reason, appropriate categories from the different rock and soil sites are also combined as a rock (B/C Site) and soil class (D Site) based on IBC and TSC (Table 5).

The functional form of the event-specific attenuation relationship used in this study is:

$$\ln Y = c_1 + c_2 \ . \ln\left(\sqrt{R^2 + c_3{}^2}\right) + \sigma \qquad (1)$$

where, InY is the natural logarithm of the spectral acceleration at selected periods, T; R is the closest distance to the fault rupture plane in km, σ is an error term that was evaluated by using the ordinary least square method and $c_1$, $c_2$ and $c_3$ are regression coefficients. This functional form was previously used in the attenuation relationships of Rathje (2004). Equation 1 was fit to PGA and Sa at periods of 0.3, 1.0, and 2.0 seconds using the data obtained from strong motion stations within 100 km of the fault. Then, a regression analysis was performed only for the rock and soil sites to obtain event specific attenuation relationships for acceleration response spectral values at selected periods. The regression coefficients for site classes and each event are shown in Table 3.

Table 3: The regression coefficients for event-specific attenuation relationships for the Bala Earthquake series ($M_w$ range 5.6 to 4.8).

| **26.12.2007_23:47_Mw=5.6** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **PGA** | | **Sa (T=0.3)** | | **Sa (T=1.0)** | | **Sa (T=2.0)** | |
| | **Rock (B/C Site)** | **Soil (D Site)** | **Rock (B/C Site)** | **Soil (D Site)** | **Rock (B/C Site)** | **Soil (D Site)** | **Rock (B/C Site)** | **Soil (D Site)** |
| $c_1$ | -0.952 | -1.124 | -0.782 | -0.413 | -0.233 | 0.411 | -0.655 | -0.377 |
| $c_2$ | -0.787 | -0.656 | -1.028 | -1.172 | -1.432 | -1.246 | -1.146 | -0.626 |
| $c_3$ | 5.000 | | 5.000 | | 5.000 | | 5.000 | |
| $\sigma$ | 0.525 | 0.614 | 0.642 | 0.594 | 0.613 | 0.520 | 0.796 | 0.657 |
| **27.12.2007_13:47_Mw=5.2** | | | | | | | | |
| | **PGA** | | **Sa (T=0.3)** | | **Sa (T=1.0)** | | **Sa (T=2.0)** | |
| | **Rock (B/C Site)** | **Soil (D Site)** | **Rock (B/C Site)** | **Soil (D Site)** | **Rock (B/C Site)** | **Soil (D Site)** | **Rock (B/C Site)** | **Soil (D Site)** |
| $c_1$ | -1.943 | -1.574 | -1.526 | -1.782 | -1.353 | -0.431 | -0.314 | 0.746 |
| $c_2$ | -0.475 | -0.587 | -0.552 | -0.239 | -0.642 | -0.609 | -1.262 | -1.124 |
| $c_3$ | 5.000 | | 5.000 | | 5.000 | | 5.000 | |
| $\sigma$ | 0.475 | 0.520 | 0.480 | 0.592 | 0.430 | 0.382 | 0.588 | 0.402 |
| **27.12.2007_17:56_Mw=4.8** | | | | | | | | |
| | **PGA** | | **Sa (T=0.3)** | | **Sa (T=1.0)** | | **Sa (T=2.0)** | |
| | **Rock (B/C Site)** | **Soil (D Site)** | **Rock (B/C Site)** | **Soil (D Site)** | **Rock (B/C Site)** | **Soil (D Site)** | **Rock (B/C Site)** | **Soil (D Site)** |
| $c_1$ | -1.820 | -1.625 | -0.342 | 0.249 | 0.567 | 0.618 | 0.815 | 1.184 |
| $c_2$ | -0.687 | -0.656 | -1.423 | -1.581 | -1.917 | -0.290 | -2.052 | -1.672 |
| $c_3$ | 5.000 | | 5.000 | | 5.000 | | 5.000 | |
| $\sigma$ | 0.480 | 0.384 | 0.465 | 0.429 | 0.486 | 0.512 | 0.615 | 0.523 |
| **15.03.2008_10:15_Mw=5.2** | | | | | | | | |
| | **PGA** | | **Sa (T=0.3)** | | **Sa (T=1.0)** | | **Sa (T=2.0)** | |
| | **Rock (B/C Site)** | **Soil (D Site)** | **Rock (B/C Site)** | **Soil (D Site)** | **Rock (B/C Site)** | **Soil (D Site)** | **Rock (B/C Site)** | **Soil (D Site)** |
| $c_1$ | -1.643 | -1.815 | 0.415 | 0.971 | 1.376 | 0.654 | 0.187 | 0.377 |
| $c_2$ | -0.702 | -0.583 | -1.905 | -2.225 | -2.487 | -1.723 | -1.655 | -0.819 |
| $c_3$ | 5.000 | | 5.000 | | 5.000 | | 5.000 | |
| $\sigma$ | 0.675 | 0.794 | 0.635 | 0.714 | 0.705 | 0.572 | 0.512 | 0.674 |

Note that some of the coefficients in Equation 1 were constrained to render reasonable relationships. Initial analyses resulted in large values of $c_3$, which does not agree with attenuation relationships in the literature. The coefficient $c_3$ was held constant across site conditions to avoid the coupling of uncertainty in the coefficient $c_3$ with the uncertainty in amplification factors (Abrahamson and Silva, 1997; Rodriguez-Marek et al., 2001, Rathje, 2004 and Rathje et al., 2005). In this regression study, the $c_3$ parameter was calculated for each ground motion parameter using the data from all site categories, in an effort to overcome the relatively small number of strong motions in each site category. Subsequently, $c_1$ and $c_2$ were estimated for each site category using the constrained value of $c_3$. This constraint was also necessary due to the poor sampling of the rock sites across all distances in the Bala Earthquake events.

## Site Amplification Factors

The event specific attenuation relationships were then used to develop site dependent amplification factors with respect to a baseline site condition. As a standard practice, rock site is used as the baseline site condition (Idriss, 1991, Abrahamson and Silva, 1997). The site-dependent amplification factors are a function of the soil conditions (i.e., site class) and intensity of rock motion ($PGA_{ROCK}$). During the evaluation of the amplification ratios, the most important issue is the development of the event-specific attenuation relationships for the baseline site condition (i.e., rock) because this is the basis of the developed amplification ratios. As mentioned before, the poor sampling of rock data resulted in rock motions that did not give reasonable amplification factors. Hence, the constrained regression results for Rock Site were used, along with the regression results for Soil Site, to develop amplification factors for PGA and spectral acceleration at T=0.3, 1.0, and 2.0 s.

Spectral amplification factors developed for each Bala events are shown in Figure 2. In this figure, the amplification factors proposed by IBC (2009) for the intensity of rock motion are also tabulated. The Bala Earthquake series show some variability in the amplification factors. For PGA, the regression results indicate similar amplifications for all Bala events. Apart from the $M_w$= 4.8 event, almost similar results were found for spectral acceleration at T=0.3 s. At shorter periods, the amplification factors of Bala earthquakes tend to be relatively smaller than those proposed by the IBC (2009). Interestingly, the smallest event amplification of $M_w$= 4.8 is higher than the larger events. At longer periods (T=1.0 and 2.0 s), the larger event amplifications of $M_w$= 5.6 and $M_w$= 5.2 (27.12.2007_13:47) are higher than the other events. However, the variability of the $M_w$= 5.2 (27.12.2007_13:47) and $M_w$= 4.8 events are greater compared to the other events. For instance, at longer periods, $M_w$= 5.2 (27.12.2007_13:47) event amplification value is almost similar to the amplification value of $M_w$= 5.6; $M_w$= 4.8 event amplification value is higher than the larger events of $M_w$= 5.2 (15.03.2008_10:15). Of all of the events, the well-recorded and evenly distributed $M_w$=5.2 (27.12.2007_13:47) and 4.8 events provide consistent amplification factors at selected periods. Additionally, these events show larger amplification factors at longer periods (T=2.0 s) comparing the amplification factors proposed by IBC (2009).

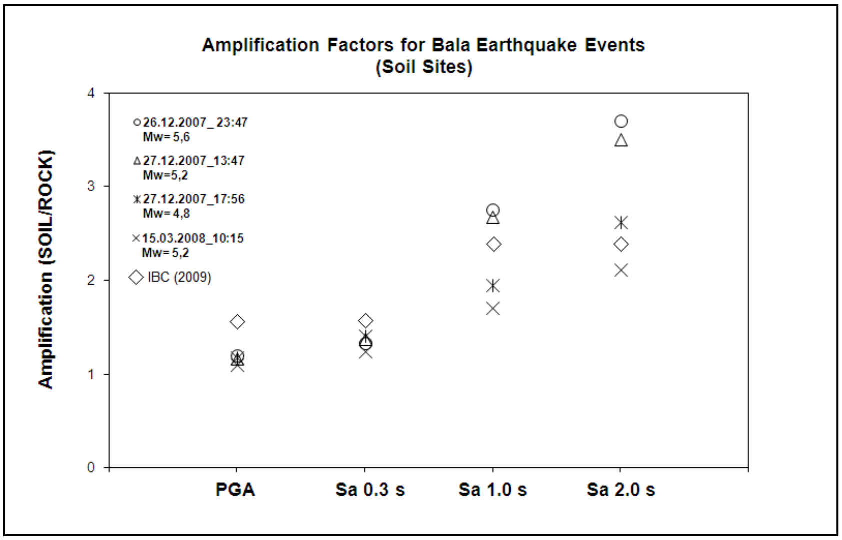


Figure 2: The amplification factors for PGA and $S_a$ at periods of 0.3, 1.0, and 2.0 s. from the Bala Earthquake events.

## Conclusions

The data from the December 1997 and March 1998 Bala earthquakes were analyzed and used to develop event specific attenuation relationships for PGA and spectral accelerations at periods T = 0.3, 1.0, and 2.0 s. The event specific attenuation relationships were developed for each earthquake event using data recorded at distances less than 100 km. Despite the fact that the data set is relatively small and a number of data is clustered in the 10 to 80 km distance range, the data seems to be generally well distributed between rock and soil sites. Amplification factors obtained from the event specific attenuation relationships indicate that the Bala earthquake events displayed similar amplification factors at shorter periods, but these events generally revealed large amplification factors at larger periods. Soil response nonlinearity would also tend to increase the response at larger periods as a consequence of the softening of the site.

This study showed that significant seismic events that might take place in and around Ankara might affect the highly populated city center of Ankara and its surroundings. Although, Bala earthquakes are moderate, they were felt strongly in the Capital City, Ankara which is about 50 km northwest of the epicenter. Hence, the impact of local site conditions might have influenced the strong ground motions which tend to increase the response at larger periods as for the Bala earthquakes. Due to these reasons, even though Ankara may be considered to be situated distant to these seismic activities, the influence of the local soft sediment conditions under earthquake triggered motions plays a significantly important part in contributing seismic damage. Hence, the strong motion data from these earthquakes and the impact of their soil conditions are significant because they provide invaluable information regarding ground shaking and site effects during moderate earthquakes.

## References

Abrahamson NA, Silva WJ. Empirical Response Spectral Attenuation Relationships for Shallow Crustal Earthquakes.*Seis. Res. Letters* 2007; Vol. **68**(1): 94-127.

Akyürek B, Duru M, Sütçü YF, Papak İ, Şaroğlu F, Pehlivan N, Gönenç O, Granit S, Yaşar T. *The surrounding geology of the city of Ankara and natural resources project*. MTA compilation no. 9961, 1997. In Turkish.

Can H, Koçkar MK, Felek G. Evaluation of the Site Characterization of the Weak and Strong Motion Stations Installed in Ankara and it's Surroundings by Gazi University, DEMAR. Gazi University, Scientific Research Project 2013; BAP-06/2011-22; 19 p.

Dobry R, Borcherdt RD, Crouse CB, Idriss IM, Joyner WB, Martin GR, et al. New site coefficients and site classification system used in recent building seismic code provisions. Earthquake Spectra 2000; **16**(1):41–67

Gazi University, Earthquake Engineering Implementation and Research Center (GAZİ-DEMAR 2007 and 2008), Ankara. http://deprem.gazi.edu.tr/

Hayashi, K. *Development of surface-wave method and its application to site investigations*, PhD Thesis, Kyoto University 2008; 278 p.

Idriss IM. *Procedures for Selecting Earthquake Ground Motions at Rock Sites*, a report to the National Institute of Standards and Technology, University of California at Davis, September 2010 (Revised March 1993).

International Code Council, ICC. *International Building Code. Structural and fire- and life-safety provisions (seismic, wind, accessibility, egress, occupancy and roof codes),* 2009. Whittier, CA.

Koçkar MK, Akgün H, Rathje EM. Evaluation of site conditions for the Ankara basin of Turkey based on seismic site characterization of near-surface geologic materials. *Soil Dynamics and Earthquake Engineering* 2010; **30**: 8–20.

Koçkar MK, Akgün H. Evaluation of site effects of the Ankara Basin, Turkey. *Journal of Appl. Geophys*. 2012; **83**,120–134.

Ministry of Public Works and Settlement. *Turkish Seismic Code, specification for structures to be built in disaster areas*, Ankara, Turkey, 1998.

Okada H. *The microtremor survey method*, Geophysical Monograph Series no. 12. Published by Society of Exploration Geophysicists (SEG), Tulsa, 2003.

Pampal S, Özmen B, Başkaya G., Gel AC, İnan E. *Development of weak and strong motion station in and around the Ankara*. Gazi University, Scientific Research Project 2007; BAP-00/2007-01.

Rathje EM, Stokoe KH, Rosenblad BL. Strong Motion Station Characterization and Site Effects During the 1999 Earthquakes in Turkey. *Earthquake Spectra*, Earthquake Engineering Research Institute 2003; **19**(3): 653-676.

Rathje E.M. *Evaluation of Site Effects During the 1999 Chi-Chi Earthquake and its Aftershocks*. Final Project Report to United States Geological Survey Earthquake Hazard Reduction Program 2004; USGS- Award No. 03HQGR0040; 16 p.

Rathje EM, Koçkar MK, Özbey MC. Observed Site Effects During the 1999 Chi-Chi Earthquake and its Aftershocks, *Seismological Research Letters* 2005; **76** (2): 238.

Republic of Turkey Prime Ministry Disaster & Emergency Management Authority, Earthquake Department (AFAD-ERD 2007). Ankara. http://kyh.deprem.gov.tr/ftpt.htm

Rodriguez-Marek A, Bray JD, Abrahamson NA. An empirical geotechnical seismic site response procedure, *Earthquake Spectra*2001; **17**:65–87.