Koc. J. Sci. Eng., 4(2): (2021) 160-170 https://doi.org/10.34088/kojose.952555

Kocaeli University

Kocaeli Journal of Science and Engineering

http://dergipark.org.tr/kojose

Local Geology Effects on Soil Amplification and Predominant Period in Düzce Basin, NW Turkey

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Article Info

Research paper

Received : *June 15, 2021*
Accepted : *August 24, 2021*

Keywords

Local Geology
Soil Amplification
Predominant Period
Düzce Basin

Abstract

Amplification and predominant periods of soils in Düzce Basin were investigated by analysing the data sets of last two major earthquakes and aftershocks of Kocaeli and Düzce earthquakes occurred in 1999 with a magnitude of Mw:7.4 and Mw:7.2, respectively. Two different methods named horizontal/vertical spectral acceleration ratio (HVSAR) and soil-to-rock Response Spectral Acceleration Ratio (RSAR) were used to determine soil amplifications for various periods in Düzce Basin. The data set includes 31 strong gorund motion records from five strong ground motion stations. It was found that the site amplifications at stations are directly related to the local geology underlying the stations. Averaging the residuals between the predicted and observed PGAs resulted in soil amplification from 1.33 to 2.33. The HVSAR method presented soil amplification values between 2.7 and 10 and predominant period values between 0.4 and 0.7 s. Soil amplification values from 1.5 to 14 and predominant periods from 0.5 to 0.8 s were obtained by the RSAR method. High site amplifications and predominant periods mainly depend on the thickness of lithological variances accompanied by low physical and geotechnical properties of alluvial deposits.

1. Introduction

Two major earthquakes struck cities located in the Düzce Basin. The first earthquake occurred on 17 August 1999 (M_w=7.4) (Kocaeli earthquake) and the second one occurred on 12 November 1999 (M_w=7.2) (Düzce earthquake). The epicenter of the first earthquake was located near Golcuk at a depth of 15 km [1] and the epicenter of the second earthquake was located 3.5 km southeast of Düzce at a depth of 12 km [2, 3]. 17 August 1999 (Mw=7.4) earthquake hit the eastern Marmara Region and generated approximately 150 km of surface rupture with dextral offsets exceeding 5 m [4-6]. On 12 November 1999 (M_w=7.2) earthquake, most of the damage occurred in southern Düzce city founded on young alluvial deposits [7] due to soil amplification and poorly constructed buildings [8].

It has been proven that ground motion during an earthquake can be amplified by local conditions [9-10]. In some cases it amplifies the seismic shake in a range of periods that coincide with the periods of vibration of the damaged structures [11]. To this extent [12], the relationship between the amplification caused by surface geology and the extent of damages on buildings can be established. Attenuation relationships for peak ground accelerations (PGAs), and the H/V (Horizontal/Vertical) Spectral Acceleration Ratio (HVSAR) and soil-to-rock Response Spectral Acceleration Ratio (RSAR) methods for strong ground motion records were commonly used to estimate the response of soil-site ground motions [13-18].

The large number of ground motion acceleration recordings after the 17 August 1999 and 12 November 1999 earthquakes provided an opportunity to study attenuation models for the Marmara Region [14], [19-22]. Although the attenuation relationships are used in regional seismic studies, they are not sufficient to explain the damage that occurs in a region after an earthquake. Therefore, site amplification studies are required taking

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into consideration the local geology for analyzing the damage pattern that could be created by a possible earthquake. Some previous studies investigated the site amplification and its effects in northwestern Turkey [16], [23-26]. One of the regional site effect studies defined the site amplification in the Adapazarı Basin [16].

This study investigated the amplification and predominant periods of soil deposits in Düzce Basin, located in east of the Marmara Region, based on the seismologic, geologic, and geotechnical data to evaluate the relationship between the surface and subsurface geology and damage pattern. The study used 26 strong gorund motion records of the main shocks and aftershocks of the 1999 Kocaeli and Düzce earthquakes, as well as an additional five moderate earthquakes which occurred in the year 2000 in the Marmara Region. A total of 31 strong gorund motions recorded at stations located in the Düzce Basin and one station located on a rock site near the Düzce Basin, was evaluated for site amplification and predominant period of the soil deposits (Figure 1). The residuals of peak ground accelarations (PGAs), HVSAR and RSAR methods were used to determine site amplifications and predominant periods of study area stations.

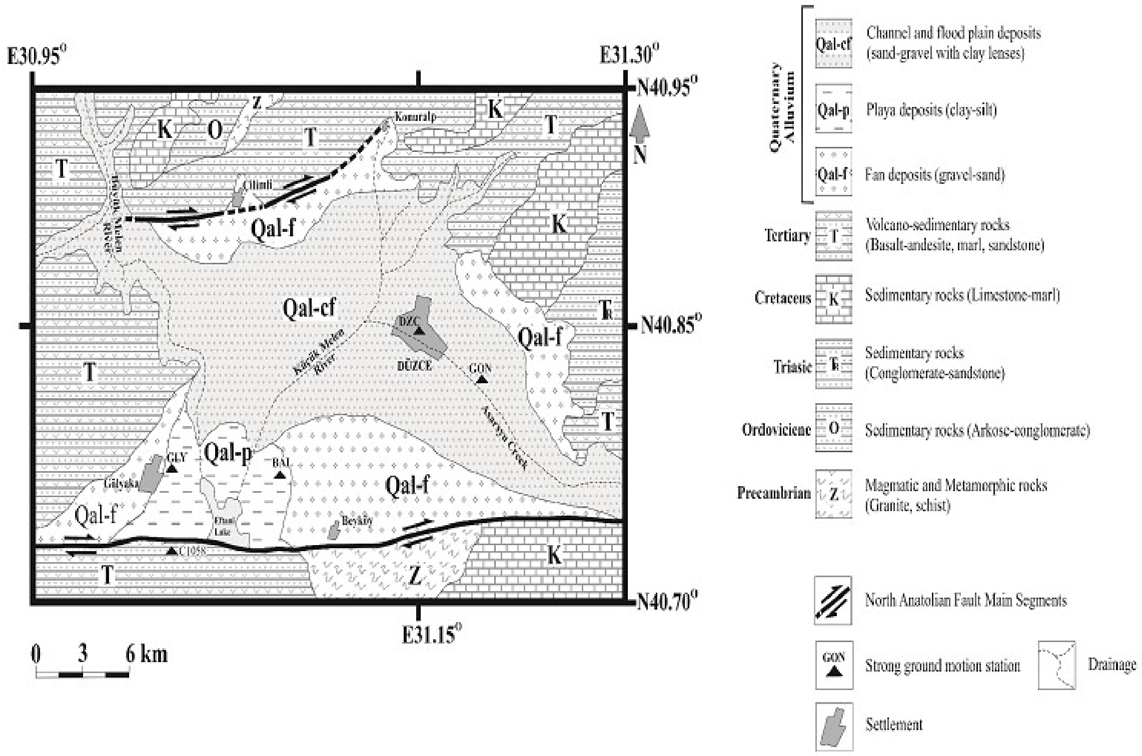

Figure 1. Geology map of the study area.

2. Geological Setting

The geologic setting includes the geological, geomorphological, and tectonic features of the Düzce Basin and its surroundings. Düzce Basin, as a graben-like basin, was formed by the tectonic activities of the North Anatolian Fault (NAF). The basin is bounded in the south by the active Gölyaka-Eftani-Beyköy Fault (GEBF) and in the north by the Çilimli-Konuralp Fault (ÇKF). ÇKF is relatively less active than GEBF. These faults are parts of the southern and northern segments of the NAF and are the main features that shape the morphology of the region. The slopes of the southern elevations facing the Düzce Plain are steeper than the slopes of the northern elevations. Düzce Plain, located in the central part of the basin, presents a low-inclined topography towards the southwest (towards Eftani Lake). The drainage network developed depending on the morphology of the basin has NE-SW and E-W flows. The hydrological and morphological features in the basin are the result of intense tectonic activity that controls the basin structure and the general slope of the plain.

The basement rocks of the region consist of Precambrian magmatic and metamorphic rocks (Z) (Figure 1). Schists and granitic rocks are the basement rocks on which a thick sedimentary sequence is found. The sequence begins with Ordovician arkose and conglomerate sedimentary rocks (O). Triassic sandstone and conglomerate (TR) alternations are exposed on the Ordovician rocks in the east of the basin. Cretaceous limestone-marl alternations (K) are widely observed on Triassic rocks in the region. Tertiary volcano-sedimentary rocks (T) with flysch character were deposited on Cretaceous rocks. Volcano-sedimentary unit consisting of interbedded basalt-andesite, marl and sandstone lithologies. The dominant lithologies in the southwestern part of the region are basalts and andesites. The youngest unit is the alluvium deposited in the basin. The thickness and lithological variation of the alluvium depend on the tectonic environment, which directly affects the morphology and basin geometry. Alluvial fan deposits (Qal-f) on the northern and southern mountain slopes, channel, and flood plain deposits (Qal-cf) and lacustrine-playa deposits (Qal-p). Alluvial fan deposits consist of gravel-sand, channel and flood plain deposits consist of clay-lensed sand-gravel and lake-playa deposits consist of clay-silt deposits.

Tectonic activities that control the morphology and geometry of the basin caused deposition of thick alluvial sediments. The bedrock topography of the plain is inclined toward the southwest, as is the surface topography. Accordingly, the alluvium thickness reaches up to between 215 m and 255 m around the city of Düzce and the northern border of Lake Eftani. While the alluvium thickness toward the west border of the basin is around 100 m, it is around 50 m toward the east and north borders of the basin [27]. The bedrock inclination is an indication of the active tectonism in south. Therefore, there is a sudden increase in the thickness of the alluvial deposits from the south border of the basin to north of Lake Eftani.

3. Geology of the Station Sites

The geotechnical properties of the station sites located on the alluvial deposits of the Düzce Plain were obtained from the shallow geotechnical investigation borings. The data for the thickness and geological properties for deeper levels of the deposits were obtained from the studies of [27-28]. The geologic and geotechnical properties of the study area rocks were determined by the field observations and laboratory tests. Ref [29] standard was used to categorize the ground (soil and rock layers) of the study area stations based on the geotechnical properties. A summary of the geotechnical properties of each station is shown in Figure 2 and the detailed geologic and geotechnical properties of each station are explained below.

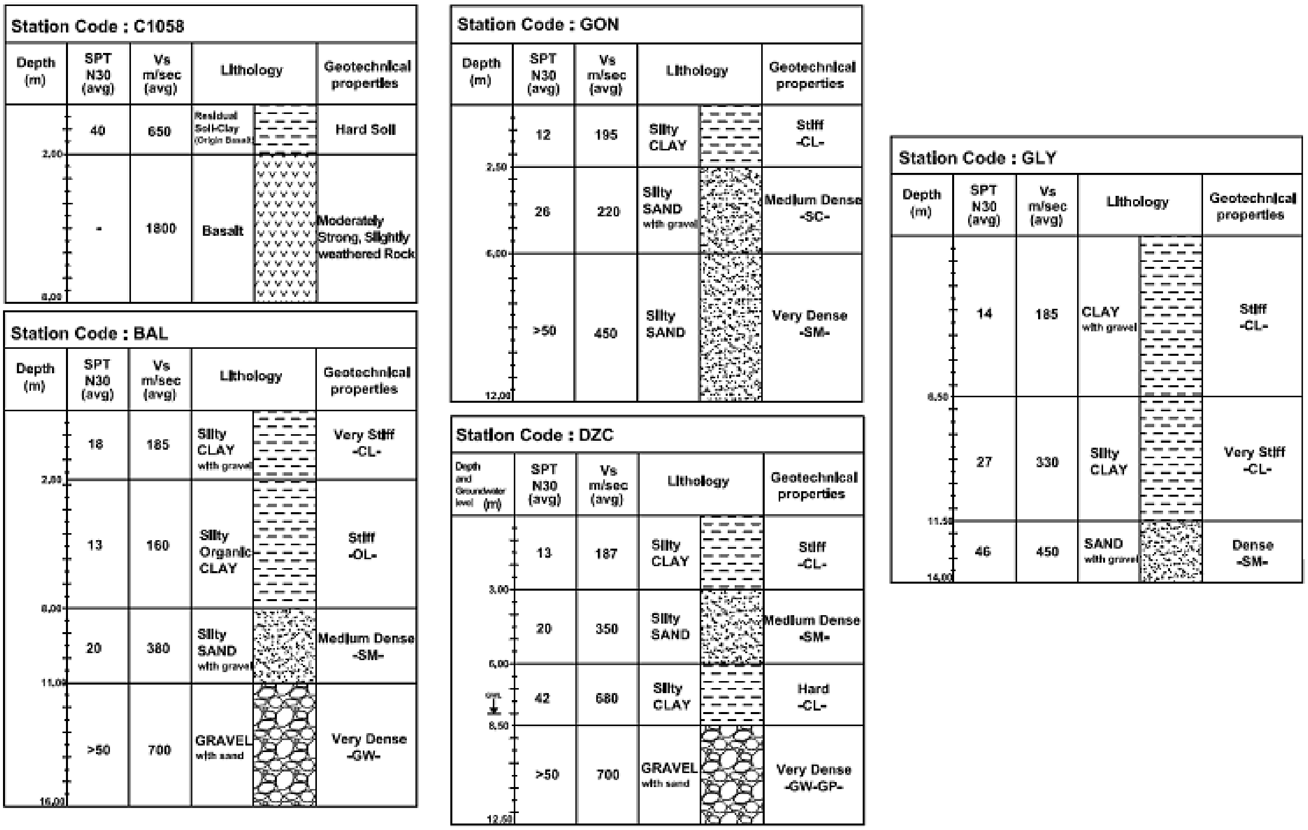

Figure 2. Summary of geotechnical properties of each station.

3.1. Station 1058

This station is located on a basalt level of the Tertiary volcano-sedimentary rocks (T). It is located on a site approximately 520 m south of the GEBF. The basalt level has a two-meter weathered zone below the surface. This zone has gained a residual soil character under the atmospheric conditions. The laboratory tests run for the samples of this zone indicated a hard soil with low plasticity. This zone has a 650 m/s average Vs (Shear Wave

Velocity) based on the geotechnical properties and falls into the "Hard Soil" category according to the [29] standard. At depths below two meters, there is a dark brown, slightly weathered, very wide spaced discontinuity and moderately strong basalt level. The recording device was located on the weathered zone and the slope of the site location is around 25 percent toward the plain.

3.2. Station BAL

This station is located on the lacustrine-playa deposits (Qal-p) to the north of Eftani Lake. The distance between the station and the GEBF is about four km. The thickness of the alluvial deposits is approximately 210 m in this section. According to the 16 m geotechnical boring data, the soil layers downward are very stiff silty clay with gravel (CL) (2.80 m), stiff silty organic clay (OL) (5.20 m), medium dense silty sand with gravel (SM) (3.00 m) and very dense gravel with sand (GW) (in excess of 5.00 m). The Vs values of the layers vary between 160 m/s and 700 m/s based on the seismic refraction measurements [30]. The soil layers below the station yield different geotechnical properties. Especially, the second layer (organic clay) has low geotechnical properties (consitency, unit weight, SPT-N_{30} values, etc.) and Vs value.

3.3. Station GLY

This station is also located on the lacustrine-playa deposits (Qal-p) in the western section of Düzce Plain. The distance between the station and the GEBF is about 2.3 km. The thickness of the alluvial deposits is approximately 120 m in this section. According to the 14 m geotechnical boring data, the soil layers downward are very stiff clay with gravel (CL) (6.80 m), stiff silty clay (CL) (5.00 m) and very dense sand with gravel (SM) (in excess of 2.50 m). The Vs values of the layers vary between 185 m/s and 450 m/s based on the seismic refraction measurements [31]. The soil profile of the station site ground presents homogeneity with depth in general. The soil profile consisted of an 11.50 m clay layer and increasing geotechnical properties with depth. The organic material proportion is quite low in the clay layer. The environment of deposition should be the margin of a lake and flood plain for the clay layer. The sand with gravel layer below the 11.50 m depth should be part of the upper levels of the alluvial fan deposits (Qal-f). The geotechnical properties of the clay layer are low.

3.4. Station GON

This station is located on alluvial deposits (Qal-cf) in the eastern section of Düzce Plain. The distance between the station and the GEBF Fault is about five km. The thickness of the alluvial deposits is approximately 170 m in this section. According to the 12 m geotechnical boring data, the soil layers from the surface are stiff silty clay (CL) (2.50 m), medium dense silty sand with gravel (SC) (3.50 m) and very dense silty sand (SM) (in excess of 6.00 m). The Vs values of the layers vary between 195 m/s and 450 m/s based on the seismic refraction measurements [32]. The soil profile under the station consisted mainly of fine- and coarse-grained sand layers covered by a cap clay layer. The sand layers were deposited in the channel and floodplain of the river with low energy. The geotechnical properties of homogeneous sand layers indicate a consistent increase with depth in general.

3.5. Station DZC

This station is also located in the central part of Düzce Plain with alluvial deposits (Qal-cf). The distance between the station and the GEBF is about 8.5 km. The thickness of the alluvial deposits is approximately 220 m in this section. According to the 12.50 m geotechnical boring data, the soil layers downward are stiff silty clay (CL) (3.00 m), medium dense silty sand (SM) (3.00 m), hard silty clay (CL) (2.50 m) and very dense gravel with sand (GW-GP) (in excess of 4.00 m). The V_s values of the layers vary between 187 m/s and 700 m/s based on the seismic refraction measurements [33]. The soil profile of the ground at the station site presents heterogeneity with depth in general, due to soil layers with different soil grains. The gravel layer at the bottom of the soil profile must be the channel deposits of the river, placed with high energy. On the other hand, the clay and sand layers should be deposited in the channel and flood plain during the energy decrease of the river.

4. Data Processing

The data set for this study included acceleration records of 31 strong ground motions recorded at five different stations. These strong ground motion data came from 15 different recordings of earthquakes that occurred between 1999 and 2000 (Figure 3). The strong ground motion stations were operated by three data centers (Table 1); Boğaziçi University Kandilli Observatory Earthquake Research Institute (KOERI), Ministry of Public Works and Settlement Department of Disaster Affairs Earthquake Research Department (ERD) and Columbia University Lamont Doherty Earth Observatory (LDEO). Accelerometers set up in various ground types recorded the strong ground motion data and Table 1 shows the recording types and sampling frequencies of the study area stations.

Table 1. Sensor type and sampling rate of the recordes of the study area stations.

Station Code	Lat. (°)	Long.(°)	Operator	Type of Recorders	Sampling Rate (Hz.)
BAL	40.780	31.102	KOERI	GSR-12	200
C1058	40.755	31.014	LDEO	TERRA-TEK	100
DZC	40.843	31.151	ERD	SMA-1	200
GON	40.817	31.210	KOERI	GSR-12	200
GLY	40.786	31.009	ERD	K2-ALTUS	200

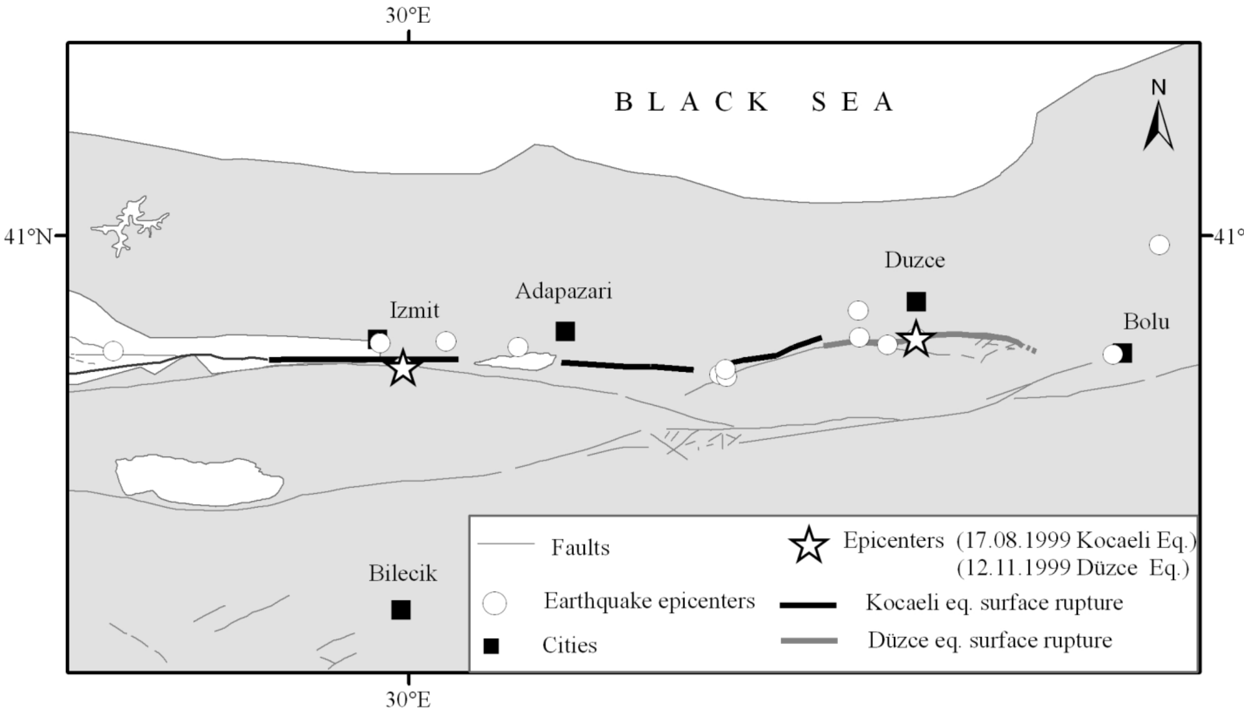

Figure 3. Locations of 15 earthquakes used for the soil amplification of the sites.

The data set is restricted to earthquakes with M_w greater than or equal to 4.7 (Table 2). Focal depths of the earthquakes are between 6 and 22 km. The earthquake size is characterized by the moment magnitude (M_w) as described by [34]. M_w corresponds to a well-defined physical property of the source. Thus, all types of magnitudes were converted to the moment magnitudes with an empirical equation Eq. (1) proposed by [15] for the Marmara Region:

$$M_d = 0.778M_w + 1.525 \quad (1)$$

Table 2. Sensor type and sampling rate of the records of the study area stations.

Event Index	Date	hr:min:sec	Lat. (°)	Long. (°)	M_w	Depth (km)
1	17.08.1999	00:01:39	40.75	29.86	7.4	17
2	22.08.1999	14:30:58	40.64	30.77	5.1	10
3	31.08.1999	08:10:49	40.71	29.95	4.7	10
4	13.09.1999	11:55:28	40.71	30.05	5.8	13
5	29.09.1999	00:13:05	40.74	29.35	5.0	10
6	07.11.1999	16:54:41	40.69	30.73	5.2	10
7	11.11.1999	14:41:25	40.74	30.27	6.0	22
8	12.11.1999	16:57:19	40.76	31.16	7.2	10
9	12.11.1999	17:17:56	40.78	31.12	5.6	10
10	13.11.1999	00:54:55	40.77	31.05	4.7	10
11	19.11.1999	19:59:07	40.81	30.97	5.1	6
12	16.11.1999	17:51:18	40.72	31.61	5.0	10
13	14.02.2000	06:56:34	41.02	31.76	5.1	10
14	06.06.2000	02:41:49	40.69	32.99	5.6	10
15	23.08.2000	13:41:28	40.68	30.72	5.4	15

All of the raw strong ground motion data were obtained from different databases supplied by the following organizations: European Strong-Motion Data (ISESD); the Pacific Earthquake Research Center (PEER); Consortium of Organizations for Strong Motion Observation Systems (COSMOS) and the United States Geological Survey (USGS). The raw data always contain some errors, so these errors should be corrected prior to conducting the site amplification analyses. Thus, a software application developed by [35] as "The Basic Strong-Motion Accelerogram Processing Software" was used to carry out the data corrections for all of the raw data of time-history records. Firstly, a baseline correction was applied. A Fast Fourier Transform (FFT) is calculated for all recording to ensure that the selected frequency is the dominant signal band. A more or less constant amplitude of the FFT spectrum at frequencies lower than f_c (corner frequency) or at frequencies beyond f_{max} (maximum frequency) is generally an indicator to understand low or high frequency noise, respectively [36-16]. This situation proves the necessity of band-pass filter usage to eliminate low-and high-frequency noise. Therefore, the signal parts considered to be noises and the reliable parts of the signal were filtered with a Butterworth filter of order 2. The Butterworth filter is one of the ideal filters that has a very sharp transition from passband to stopband. The filter intervals defined for all of the records are mainly in the range of 0.12-20 Hz.

5. Methods

Determination of soil amplification consisted of four stages: data gathering, data correction, data analysis and interpretation of the results. Raw strong ground motion data gathered in the field were corrected to be used by the amplification methods. The amplification methods were performed using the corrected data. Three different methods were used to define the soil amplifications and predominant periods in the basin. These methods are residuals of peak ground accelerations (PGAs), HVSAR and RSAR methods. The results obtained from these methods were interpreted by considering the geology of the basin and the engineering geological properties of the soils deposited in the basin. Application of each amplification method is explained below in detail.

5.1. Residual of Peak Ground Accelerations (PGAs)

The previous GMPEs [14-16] predicted from a number of records recorded in the NW of Turkey were selected for the purpose of a set of site amplifications and spectral shapes of the ground motions. The GMPEs were then used to predict the differences between the measured and the observed values of strong ground motions, also known as the residual approximation of strong ground motions. For the residual calculations, the horizontal components of PGAs from the earthquake magnitudes of Mw≥ 4.7 were used. The rupture distance were choosen as a surface projection of the rupture area. In order to calculate the residuals of PGAs, the empirical attenuation relationship used in this study was chosen from the coefficients of [15], who had collected a considerable amount of PGA data and derived an attenuation relationship by using basic linear regression empirical approaches [37]. The formulation of PGA for the Marmara region proposed by [15] is given in Eq. (2):

$$\text{Log A} = 0.183684 + 0.534677M_w - \log_{10}(r_{rup} + 0.0183x10^{0.4537M_w}) - 0.001622r_{rup} \quad (2)$$

where A is acceleration in g and r_{rup} is source to site distance as Joyner and Boore distance [38] in km. Site effect terms were not included in the model [15]. This is because some of the stations do not have Vs_{30} measurements (the average shear-wave velocity for the upper 30-m depth in m/s). The behavior of the attenuation curves (Figure 4) of the selected model curve are in good agreement with the model of [14].

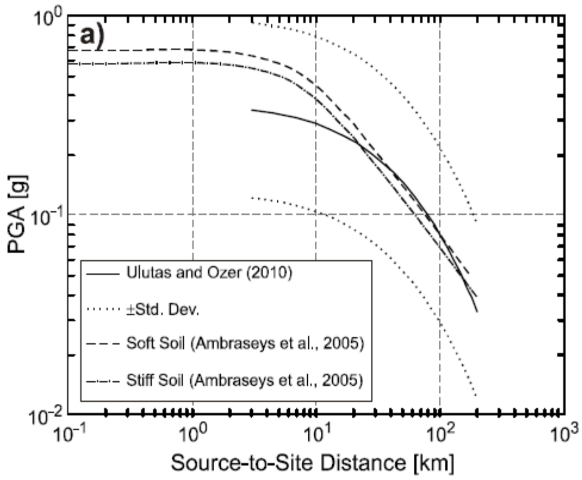

Figure 4. Comparison of the attenuation relationships of [14-16]

In order to assess site amplification, the records of the five stations installed in Düzce Basin were chosen. The site amplifications were determined empirically by averaging the abovementioned residuals between observed and predicted values of PGAs and SAs. Eq. (3) is the formulation for the site amplifications [38]:

$$S = exp\left[\frac{1}{n}\sum_1^d \ln(D_i/\overline{D_i})\right] \quad (3)$$

where D_i the observed PGA value and $\overline{D_i}$ is the predicted PGA value. For the peak ground motion, the observed PGA could be multiplied with the above-mentioned site amplification factor (S) as explained in Eq. (4).

(SxD_i) (4)

For comparing the results from various empirical PGA attenuation relationships, one of the most commonly used relationship was selected [14]. Table 3 presents the calculated site amplification values of the stations by using the residuals of PGA proposed by [14-15]. The amplification results of these two models are consistent with soil conditions of stations.

Table 3. Comparison of site amplifications

Station Code	Site Amplification for PGA[1]	Site Amplification for PGA[2]
BAL	2.22	1.63
C1058	0.31	0.24
DZC	1.33	1.33
GLY	1.5	1.68
GON	1.35	1.06

[1] PGA attenuation model proposed by [15]
[2] PGA attenuation model proposed by [14]

5.2. H/V (Horizontal/Vertical) Spectral Acceleration Ratio (HVSAR)

The second method used for determination of soil amplification and predominant period is the HVSAR method. The technique, originally proposed by [39] and made widely known by [40], consists of estimating the ratio between the Fourier amplitude spectra of the horizontal (H) and vertical (V) components of ground motion at a single station.

The hypothesis of this technique is that for a soft layer overlying a half space, the soft layer will amplify the horizontal component of ground motion, while amplification effects on the vertical component are small enough to be neglected [40]. Comparisons between this technique and other methods for site response estimation were described by [18], [41-43]. It has been found that the HVSAR method is consistent with the general geological conditions of the recording sites [44]. It is accepted that the results of the HVSAR method reflect the predominant period of the sediments. However, the general conclusion is that the technique fails at the amplitude level, especially for high periods [45].

The spectral ratios are calculated by taking the ratio of the Fourier amplitude spectra (FAS) or response spectra (RS) of a soil site record [40-48,18]. The RS is a very useful tool of engineering seismology and earthquake engineering for analyzing the performance of structures during an earthquake. It is an approach to estimate the effects of ground motion on buildings for the various natural periods. The natural period that affects a building is related to damping ratios defined by the structural features of buildings. The vibration created by an earthquake on a building is damped by converting it to friction and heat energy with the interaction of building elements. The degree of damping depends on the type of construction of the building in question. A damping ratio of 5% is generally accepted for the design of reinforced concrete construction [49]. The RS ratios were used for 5% critical damping from the earthquakes (M_w>5.1) recorded in the region. Selected events are in the moment-magnitude range $4.7 \leq M_w \leq 7.4$ and focal depths range 6 to 22 km in this study. The horizontal component used in HVSAR method is the largest peak among the two horizontal components (EW-NS).

The RS clearly demonstrate that the horizontal components of motion have dominant peaks. These peaks are very significant in describing the damage to structures in a city. The HVSAR method facilitates the calculation of the transfer function using the relationship in Eq. (5).

$$R = (A(f)_{horizontal})/(A(f)_{vertical}) \quad (5)$$

The HVSAR of each station is calculated by using the largest earthquakes that have occurred in the region and been recorded by the stations located in the basin. Figure 5 shows the characteristics of H/V spectral ratios versus period for the BAL, GLY, DZC, C1058, and GON stations. The amplification values of the stations ranged from 2.7 to 10. The largest amplification corresponds to a 0.4 s predominant period for the BAL station, a 0.5 s predominant period for the GLY station, a 0.7 s predominant period for the DZC station and a 0.5 s predominant period for the GON station. The C1058 station, set on the bedrock outcrop at the basin margin, yielded a smaller amplification value than other stations, as expected.

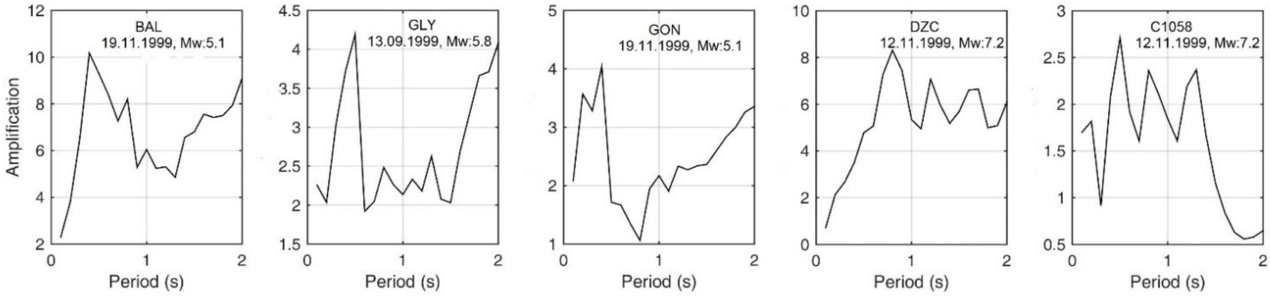

Figure 5. HVSARs on strong ground motion data from the various earthquakes at BAL, GLY, GON, DZC and C1058 stations.

5.3. Soil to Rock Response Spectral Acceleration Ratio (RSAR)

This method considers a "reference" motion to a nearby rock site. The critical assumption in this method is that the surface-rock-site record is equivalent to the input motion at the base of the soil layers [50]. The records of C1058 station were chosen for the soil-to-rock spectral ratios. First, the horizontal components that have the peak acceleration values were selected for the magnitude 5.1, 5.8 and 7.2 events recorded at the BAL, DZC, GLY and GOL stations. Then, the RS values of the 5% critical damping ratios for horizontal components were determined from the selected three events which are the largest earthquakes recorded at the BAL, DZC, GLY and GOL stations. Each horizontal response spectrum of the soil site records was divided into the response spectrum of the C1058 reference station. This method is accepted to be valid if the distance between the two sites is much smaller than their epicentral distance, and therefore the differences in the records are solely due to site effects [51]. Ratios of response spectra were used rather than Fourier spectra [52] because they require less data smoothing than do Fourier spectra. The amplification values of the stations ranged from 1.5 to 14. The largest amplification corresponds to a 0.5 s predominant period for the BAL station, a 0.8 s predominant period for the GLY station, a 0.7 s predominant period for the DZC station and a 0.5 s predominant period for the GON station. Figure 6 displays the response spectral ratios of each station for the selected earthquakes.

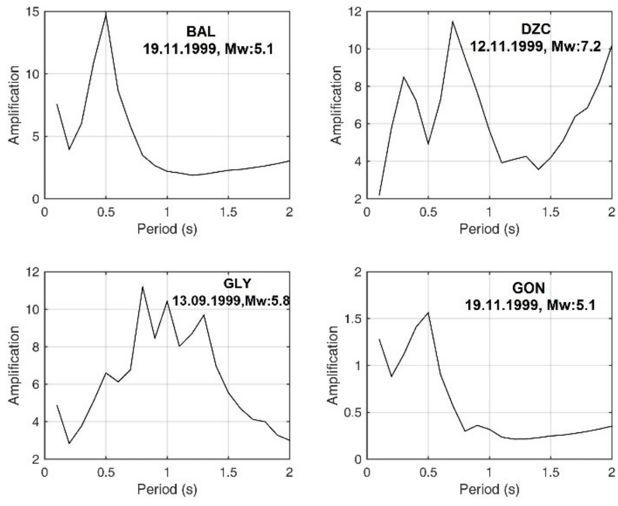

Figure 6. RSARs for various events with respect to the reference station of C1058.

6. Discussion

Site amplification and the predominant periods at five stations located in the Düzce Basin were assessed by the GMPEs, HVSAR and RSAR methods and considering local geology. GMPEs, HVSARs and RSARs with a five percent critical damping of recorded strong ground motions give amplification on soil sites in the basin. Four stations (BAL, GLY, GON, DZC) located in the Düzce Basin and one station (C1058) located on a rock site near the Düzce Basin were evaluated for site amplification and predominant periods of the soil deposits in the basin.

The site amplification varies between 1.33 and 2.22 in GLY, BAL, DZC and GON stations according to the observed and predicted PGA residuals for those stations. As expected, de-amplification with a value of 0.31 was calculated at station C1058, which was installed on rock. The amplification values obtained from the residuals are usually valid for the soils with predominant periods shorter than 3 seconds. Additionally, PGA is not generally a good measure for earthquake risk assessment of medium and high-rise structures (>2 stories) [17]. For this purpose, the HVSAR and RSAR methods were used to determine the soil response related to the soil's predominant frequencies in earthquakes.

The results of the HVSARs were obtained by using the data for moderate and large magnitude earthquakes which have occurred in the Marmara Region. The seismic record of the 19 November 1999 earthquake (M_w=5.1) for the BAL and GON stations, the seismic record of 11 December 1999 earthquake main shock (M_w=7.2) for the DZC station and the seismic record of 13 September 2011 earthquake (M_w=5.8) for the GLY station were used in the HVSAR method.

Although the C1058 station yielded a de-amplification according to the results of calculated residuals from observed and predicted acceleration values, it showed an amplification value of 2.5 at a 0.5 s period in the HVSAR method. However, this amplification value of 2.5 is lesser than the amplification values of the other stations, obtained from the HVSAR and RSAR methods. As expected, periods and amplifications revealed by the HVSAR and RSAR methods for the C1058 station located on rock are lower than those located on alluvium deposits. The two-meter weathered zone of the C1058 station site probably caused the amplification value of 2.5 in the HVSAR method.

The critical assumption in the reference site amplification studies is to define the amplification by selecting the optimum rock site motion. Although this assumption is the best possible approximation revealing the site amplification effects on the ground, the selection of the most suitable reference site is difficult in practice, because a reference rock site can have a site response of its own. The amplification values observed at the consecutive periods for the C1058 station suggest that this station reflected its own site response. The reference site was selected according to the geotechnical data and geologic information that was available for the study area. The differences in the amplification results of the stations with the same site classes depend on the rock-soil seismic impedance difference, depth to bedrock, layer thicknesses, lithology variance and geotechnical properties of the soils.

7. Conclusions

It could be concluded from the study that the empirical models using the residuals can provide only a general estimation of the actual amplification of the sites. The residuals obtained from this study are the results of PGAs and do not reflect the dominant frequencies of the soils. The amplification results of the study for soft soils and rock at the site are important to predict the site response of sedimentary deposits if similar earthquakes occur in the near future. Although the results obtained from these methods indicate a general approximation, effects of the seismic impedance between the bedrock and soil layers should be considered in amplification studies. It is possible that the seismic impedance could affect peak amplifications spread in a broader band for the DZC and GLY stations.

The residual method allowed classification of the different soil types based on the amplification results. Also, the HVSAR and RSAR methods allowed determination of the predominant periods of the soil deposits in the basin. Determination of predominant periods is a necessary step to differentiate the fundamental period of engineering structures and the dominant period of soils. It is concluded that the average predominant periods of the stations are between 0.4 and 0.8 s. Moderately to severely damaged or collapsed 5-6 story buildings [53], in Düzce Earthquake, indeed support these predominant frequencies.

Declaration of Ethical Standards

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Polat O., Eyidoğan H., Haessler H., Cisternas H., Philip H., 2002. Analysis and interpretation of the aftershock sequence of the August 17, 1999, İzmit (Turkey) earthquake. Journal Seismology, **6**(3), pp. 287-306.

[2] Bouin M.P., Bouchon M., Karabulut H., Aktar M., 2004. Rupture process of the 1999 November 12 Düzce (Turkey) earthquake deduced from strong motion and Global Positioning System measurements. Geophysical Journal International, 159, pp. 207-211.

[3] Taymaz T., 1999. Seismotectonics of the Marmara region: Source characteristics of 1999 Golcuk-Sapanca-Duzce earthquakes. Proceedings of the International Symposium on the Kocaeli Earthquake. Istanbul, Turkey, 2-5 December, pp. 55-78.

[4] Pucci S., Martini P.M., Pantosti D., 2008. Preliminary slip rate estimates for the Düzce segment of the North Anatolian Fault Zone from offset geomorphic markers. Geomorphology, 97, pp. 538-554.

[5] Pucci S., Martini, P. M., Pantosti, D. 2008. Preliminary slip rate estimates for the Düzce segment of the North Anatolian Fault Zone from offset geomorphic markers. Geomorphology, 97, pp. 538-554.

[6] Utkucu M., Nalban S.S., McCloskey J., Steacy S., Alptekin Ö., 2003 Slip distribution and stress changed associated with the 1999 November 12, Düzce (Turkey), Geophysical Journal International, 153(1), pp. 229-241.

[7] Rathje E. M., Stewart J. P., Baturay M. B., Bray J. D., Bardet J. P., 2006. Strong ground motions and damage patterns from the 1999 Düzce earthquake in Turkey. Journal Earthquake Engineering, **10**(5), pp. 693-724.

[8] Özmen B., 2000 12 Kasım 1999 Düzce Depreminin Konut ve İşyeri Hasarları (Rakamsal Verilerle), Bayındırlık ve İskan Bakanlığı, Afet İşleri Genel Müdürlüğü, Deprem Araştırma Dairesi, Ankara, pp. 155-214.

[9] Aki K., 1993. Local site effects on weak and strong ground motion. Tectonophysics, 218, pp. 93-111.

[10] Bard P., 1999. Microtremor measurements: A tool for site effect estimation. Proceedings of the Second International Symposium on the Effects of Surface Geology on Seismic Motion. Yokohama, Japan, 3, pp. 1251-1279.

[11] Seo K., 1994. On the applicability of microtremors to engineering purpose, Preliminary report of the Joint ESG Research on Microtremors after the 1993 Kushiro-Oki (Hokkaido, Japan) earthquake. Proceedings of 10th European Conference on Earthquake, 4, pp. 2643-2648.

[12] Navarro M., Enomoto T., Sánchez F. J., Matsuda I., Iwatate T., Posadas A., Luzón F., Vidal F., Seo K., 2001. Surface soil effects study using short-period microtremor observations in Almeria City, Southern Spain. Pure Applied Geophysics, 158, pp. 2481-2497.

[13] Rosenblueth E., Archiniega A., 1992. Response spectral ratios. Earthquake Engineering Structural Dynamics, 21, pp. 483–492.

[14] Ambraseys N. N., Douglas J., Sarma S. K., Smith P. M., 2005. Equations for the estimation of strong ground motions from shallow crustal earthquakes using data from Europe and the Middle East: horizontal peak ground acceleration and spectral acceleration. Bulletin Earthquake Engineering, 3, pp. 1-53.

[15] Ulutaş E., Özer, M. F., 2010. Empirical attenuation relationship of peak ground acceleration for Eastern Marmara region in Turkey. Arabian Journal Science Engineering, 35, pp, 187-203.

[16] Ulutaş E., Coruk, Ö., Karakaş A., 2011. A study of residuals for strong ground motions in Adapazarı basin, NW Turkey, by Ground Motion Prediction Equations (GMPEs). Studia Geophysica Geodaetica, 55, pp, 213-240

[17] Douglas J., 2003. Earthquake ground motion estimation using strong motion records: A review of equations for the estimation of peak ground acceleration and response spectral ordinates. Earth-Science Reviews, 61, pp, 43-104.

[18] Field E. H., Jacob K. H., 1995. A comparison and test of various site-response estimation techniques including three that are not reference-site dependent. *Bulletin Seismology Society America,* 85: pp. 1127-1143.

[19] Gülkan P., Kalkan, E., 2002. Attenuation modeling of recent earthquakes in Turkey. Journal Seismology, 6, pp, 397-409.

[20] Ozbey C., Sarı, A., Manuel, L., Erdik, M., Fahjan, Y., 2004. An empirical attenuation relationship for northwestern Turkey ground motion using a random effects approach. Soil Dynamics Earthquake Engineering, 24, pp. 115–125.

[21] Ulusay R., Tuncay E., Sonmez H., Gokceoglu C., 2004. An attenuation relationship based on Turkish strong motion data and iso-acceleration map of Turkey. Engineering Geology, 74, pp. 265-291.

[22] Gulkan P., Kalkan E., 2005. Discussion of the paper: An empirical attenuation relationship for northwestern Turkey ground motion using a random effects approach. Soil Dynamics Earthquake Engineering, 25, pp. 889-891.

[23] Bakır S., Sucuoglu H., Yılmaz T., 2002. An overview of local site effects and the associated building damage in Adapazarı during the 17 August 1999 İzmit Earthquake. Bulletin Seismology Society America, 92, pp. 509-526.

[24] Şafak E., Erdik, M., 2000. Recorded main shock and aftershock motions. Earthquake Spectra, 16, pp. 97-112.

[25] Özel O., Sasatani T., 2004. A site effect study of the Adapazarı basin, Turkey, from strong-and weak motion data, Journal Seismology, 8, pp. 559-572.

[26] Özel N., Sasatani, T., Özel, O., 2004. A study of strong ground motions during the largest aftershock (Mw = 5.8) of the 1999 Kocaeli Turkey Earthquake. Tectonophysics, 391, pp. 347-335.

[27] Şimşek O., 1994. Consolidation properties of clays at Düzce Plain and their relationship with geological evolution. Unpublished Ph.D. Thesis, Department of Geology, İstanbul University, 88.

[28] Şimşek O., Dalgıç S., 1997. Consolidation properties of clays at Düzce Plain and their relationship with geological evolution. Geological Bulletin of Turkey, **40**(2), pp. 29-38.

[29] BS 5930., 1999, Code of Practice for Site Investigations: British Standards Institution, London, 207.

[30] Özyapıcı Mühendislik Ltd. Şti., 2008. Konaklı Ballıca Köyü Geoteknik Araştırma Raporu, 38 p.

[31] Akbulut Mühendislik ve Müşavirlik Ltd. Şti., 2008. Gölyaka-İmamlar Mahallesi Geoteknik Araştırma Raporu, 47p.

[32] Özyapıcı Mühendislik Ltd. Şti., 2011. Düzce-Kaynaşlı D100 Otoyolu Geoteknik Araştırma Raporu, 128 p.

[33] Özyapıcı Mühendislik Ltd. Şti., 2010. Düzce Uzunmustafa Mahallesi Geoteknik Araştırma Raporu, 47 p.

[34] Hanks T.C., Kanamori H., 1979. A moment magnitude scale. Journal Geophysical Research, 84, pp. 2348-2350.

[35] Converse A., Brady, A.G., 1992. Basic Strong-Motion Accelerogram Processing Software, Version 1.0: United States Department of the Interior, Geological Survey Open-File Report 92-296A, Washington, D.C.

[36] Zare M., Bard, P. Y., 2002. Strong motion dataset of Turkey: Data processing and site classification. Soil Dynamics Earthquake Engineering, 22, pp. 703-718.

[37] Joyner W.B. Boore D.M., 1981. Peak horizontal acceleration and velocity from strong-motion records including records from the 1979 Imperial Valley, California earthquake. Bulletin Seismology Society America, 71, pp. 2011-2038.

[38] Wu Y.M., Shin T.C., Chang C.H., 2001. Near real-time mapping of peak ground acceleration and peak ground velocity following a strong earthquake. Bulletin Seismology Society America, 91, pp. 1218-1228.

[39] Nogoshi M., Igarashi, T., 1971. On the amplitude characteristics of microtremor (Part 2). Journal Seismological Society Japan, 24, 26-40 (in Japanese with English abstract).

[40] Nakamura Y., 1989. A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. Quarterly Report Railway Technical Research Institute, **30**(1), pp. 25-30.

[41] Bonila L.F., Steidl J.H., Lindley G.T., Tumarkin A. G., Archuleta R.J., 1997. Site amplification in the San Fernando Valley, California: Variability of site-effect estimation using the S-wave, coda and H/V methods, Bulletin Seismology Society America, 87, pp. 710-730.

[42] Huang H.C., Teng, T.L., 1999. An evaluation on H/V ratio vs. spectral ratio for site-response estimation using the 1994 Northridge earthquake sequences. Pure Applied Geophysics, 156, pp. 631-49.

[43] Riepl J., Bard P.Y., Hatzfeld D., Papaioannou C., Nechtschein S., 1998. Detailed evaluation of site-response estimation methods across and along the sedimentary valley of Volvi (EURO-SEISTEST). Bulletin Seismology Society America, 88, pp. 448-502.

[44] Gosar A., 2010. Site effects and soil-structure resonance study in the Kobarid basin (NW Slovenia) using microtremors. Natural Hazards Earth System Science, 10, 761-772.

[45] Sokolov VYu., Loh C.H., Jeanc W.Y., 2007. Application of horizontal-to-vertical (H/V) Fourier spectral ratio for analysis of site effect on rock (NEHRP-class B) sites in Taiwan. Soil Dynamics Earthquake Engineering, 27, pp. 314-323.

[46] Berilgen M.M., 2007. Evaluation of local site effects on earthquake damages of Fatih Mosque: Engineering Geology, 91, pp. 240-253

[47] Fah D., Kind F., Giardini D., 2001. Theoretical investigation of average H/V ratios. Geophysical Journal International, 145, pp. 535-549.

[48] Zhao J.X., Zhang J., 2010. Side-effect of using response spectral amplification ratios for soft soil sites-earthquake source-type dependent amplification ratios. Soil Dynamics Earthquake Engineering, 30, pp. 258-269.

[49] DBYBHY, Deprem Bölgelerinde Yapılacak Binalar Hakkında Yönetmelik, 2007. Resmi Gazete, Yayın Tarihi: 06.03.2007.

[50] Steidl , J. H., Tumarkin, A. G., and Archuleta, R. J., 1996. What is a reference site? Bulletin Seismology Society America, 86, pp. 1733-1748.

[51] Safak E., 2001. Local site effects and dynamic soil behavior. Soil Dynamics Earthquake Engineering, 21, pp. 453-458.

[52] Yamazaki F., Ansary, M.A., 1997. Horizontal-to-vertical spectrum ratio of earthquake ground motion for site characterization: Earthquake Engineering Structural Dynamics, 26, pp. 671-689.

[53] Dönmez C., Pujol, S., 2005. Spatial Distribution of Damage Caused by the 1999 Earthquakes in Turkey. *Earthquake Spectra*, 21, pp. 53-69