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Full Length Research Paper

Seismic microzonation studies in Sisli, Istanbul, Turkey

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Main purpose of this study is to provide an application of seismic microzonation at small scales. For the study area, the probabilistic seismic hazard analysis was determined by using Poisson probabilistic approaches. The hazard gives the probability that a given level of acceleration will be exceeded (%15) in a given time period (50 years). By using deterministic seismic hazard analysis, the magnitudes were estimated by the three rapture (with three different fault, 108, 119 and 174 km) model of North Anatolian Fault Zone in Marmara Region. By using both mode of analysis (deterministic and probabilistic), magnitude of design earthquake was taken as 7.6. From these design earthquakes, accelerations were estimated for several distances (from 25 to 50 km) by several attenuation relations. In the second phase of the study, soil amplification factors and site characteristic periods were determined and estimated by seismic refraction measurements and Standard Penetration Test (SPT test data for the area of Sisli where, the important part of Istanbul city is located. Also microtremor and earthquake data were evaluated to compare the obtained characteristic site period data. Furthermore Vs30 values are compared by MASW techniques. Finally a seismic microzonation map are prepared integrated use of all geophysical and geotechnical data. According to Eurocode soil classification, study area is mainly formed B type soils. A little part of study area is located C and A type soils. Characteristic site periods obtained by seismic methods is agreement with strong (earthquake) and weak (ambient noise) motion spectral values at some part of study area.

Key words: Microzonation, geophysical and geotechnical analyses, soil amplification, Istanbul, Turkey.

INTRODUCTION

Seismic microzonation is evaluation and assessment of different inputs from different fields of earthquake engineering and engineering seismology. In most general terms, seismic microzonation is the process of estimating the response of soil layers under earthquake excitations and thus the variation of earthquake characteristics on the ground surface (Ansal and Slejko, 2001). However, it is also very important to select appropriate ground motion parameters for microzonation that correlate with the observed structural damage as well as which could be implemented in engineering design of the man made structures (Finn, 1991). It can be considered as the preliminary phase of earthquake risk mitigation studies.

Large numbers of seismic microzonation studies were conducted in all earthquake prone areas of the World (Marcellini et al., 1982, 1998; Astroza and Monge, 1991; Lasterico and Monge, 1972; Faccioli et al., 1991; Chavez-Garcia and Cuenca, 1998; Lungu et al., 2000; Faccioli and Pessina, 2001; Fäh et al., 1997, 2001). However, few of these studies are well documented in the literature. An attempt will be made in this section to review the available literature briefly and give more detailed explanation about four studies conducted in Benevetto, Italy (Marcellini et al., 1991, 1995a, 1995b) Barcelona, Spain (Cid et al., 2001; Jimenez, et al., 2000), Thessaloniki, Greece (Lachet et al., 1996; Raptakis et al., 1998b) Dinar, Turkey (Ansal et al., 2001).

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Abbreviations: VS, Shear-wave velocity; **SASW,** spectral analysis of surface waves; **SPT,** standard penetration test; **CPT,** cone penetration test.

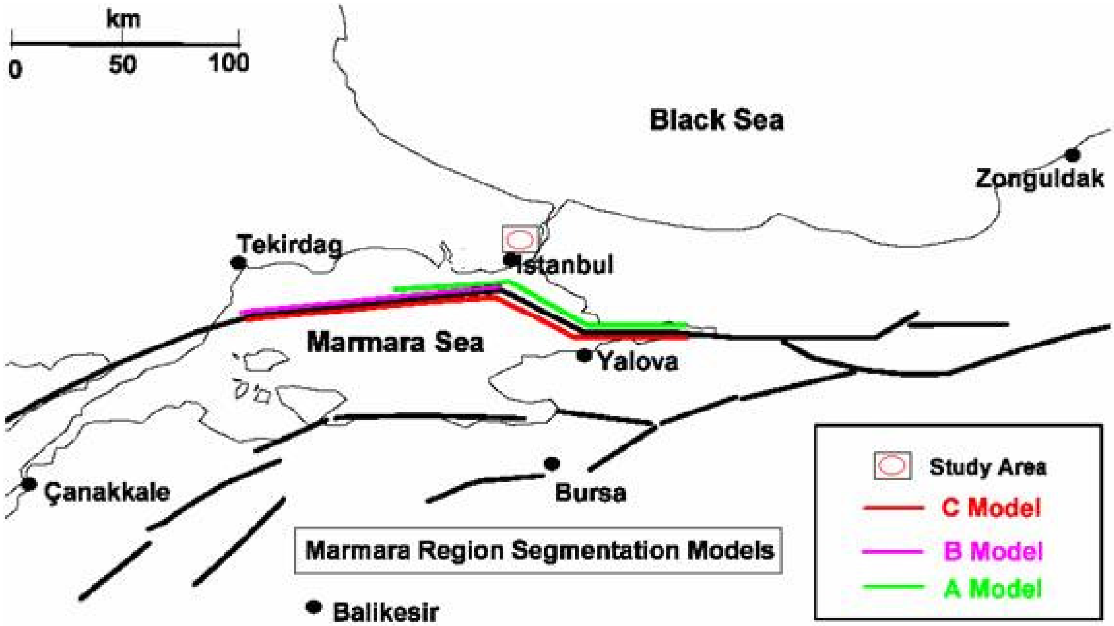

Figure 1a. For Marmara Region, it was assumed three models (A, B and C) for seismic hazard. Model A: approximately 119 km rapture length; Model B: approximately 108 km rapture length; Model C: approximately 174 km rapture length (map is redrawn form JICA-IBB Report, 2002).

EARTHQUAKE HAZARD ASSESSMENT OF THE REGION

Deterministic and probabilistic seismic hazard analysis was used to evaluate the seismic hazard of Region. Potential earthquake source area was considered the North Anatolian Fault in Marmara Sea.

Deterministic seismic hazard analysis

Required input for deterministic hazard analysis is a designation of active faults or earthquake sources in the region. For Marmara Region (Figure 1a), it was assumed three models (A, B, and C) for seismic hazard (JICA-IBB Report, 2002). Model A: approximately 119 km rapture length; Model B: approximately 108 km rapture length; Model C: approximately 174 km rapture length. In Marmara sea where is potential seismogenetic zone of our study are (Figure 1a), there are three active rapture model with different rapture length For this reason, magnitudes were estimated for these models (that is, A, B and C models) as shown Tables 1a and b.

Probabilistic seismic hazard analysis of region

In Table 1c, earthquakes were given in our area about 100 km radius. Earthquakes bigger than 4.5 magnitudes that occurred between 1905 and 2000 years were used. In Aftershocks was eliminated for statistical analysis (Table 1c). Figure 1b also shows the histogram of earthquake events per year versus magnitude (including aftershocks). Gutenberg-Richter recurrence relationships was determined as

$$\text{Log}(N) = 3.0 - 0.71\,M \qquad (1)$$

Earthquake occurrence probability by using Poison distribution were given in Table 2a by using

$$Rm = 1 - e^{-(N(M).D)}$$

Here Rm = Risk value (%); D, duration; N (M) for M magnitude (1) equation value.

In Table 2a, earthquake occurrence probability for region is given. For example, occurrence probability for 50 years of magnitude 6.0 is estimated as 91.6%. Design earthquake magnitude is selected as 7.6 by the integrated use of probabilistic and deterministic seismic hazard analysis. Attenuation relationship was defined by two attenuation models. From a set of attenuation relationships, the design acceleration values of the city were calculated as 0.46 g (for Joyner and Boore (1981) model) and 0.51 g Campbell (1997) model with exceeding probability of 15% in 50 years (bold numbers in Table 2b) by using the shortest epicentral distance 25 km to project area. Finally, hazard curve for region was estimated (in Figure 2) by Joyner and Bore (1981). Estimated acceleration values for 7.6 magnitude and several epicentral distances are given in Table 2b.

Table 1a. Equations for rapture length and magnitude estimations.

Researcher	M (magnitude)	Magnitude type
Abraseys and Zatopek (1968)	M = (0,881 LOG(L))+5,62	Ms
Douglas and Ryall (1975)	M = (LOG(L)+4,673)/0,9	Ms
Ezen (1981)	M = (LOG(L)+2,19)/0,577	Ms
Matsuda (1975)	M = (LOG(L)+2,9)/0,6	Ms
Patwardan et al. (1975)	M = (LOG(L) 1,1)+5,13	Ms
Toksöz et al. (1979)	M = (LOG(L)+3,62)/0,78	Ms
Wells and Coppersmith (1994)	M = 5,16+(1,12 LOG(L))	Mw
Wells and Coppersmith (1994)	M = 5,08+(1,16 LOG(L))	Mw

Table 1b. Model A: approximately 120 km rapture length; Model B: approximately 109 km rapture length; Model C: approximately 174 km rapture length. For these models, Rapture length and magnitude estimations.

Researcher	M (magnitude) ranges for A Model	M (magnitude) ranges for B Model	M (magnitude) ranges for C Model
Abraseys and Zatopek (1968)	7.4	7.4	7.6
Douglas and Ryall (1975)	7.5	7.5	7.7
Ezen (1981)	7.4	7.3	7.7
Matsuda (1975)	8.3	8.2	8.6
Patwardan et al (1980)	7.4	7.4	7.6
Toksöz et al (1979)	7.3	7.2	7.5
Wells and Coppersmith (1994)	7.5	7.4	7.7
Wells and Coppersmith (1994)	7.5	7.4	7.7

Table 1c. Earthquakes in our area about 100 km radius (Data was obtained by KOERI database by using Kalafat et al. (2007)).

Magnitudes	4.5 ≤ M 5.0	5.0 ≤ M < 5.5	5.0 ≤ M < 5.5	6.0 ≤ M < 6.5	7.0 ≤ M < 75
Numbers	31	12	7	1	1

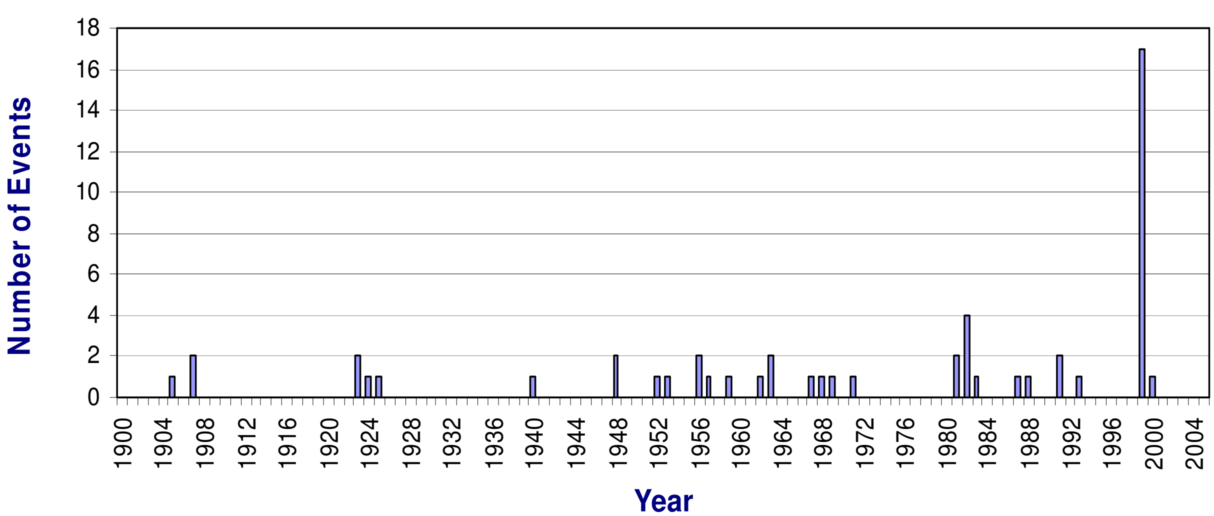

Figure 1b. Histogram of earthquake events per year versus magnitude for study area (Data was obtained by KOERI database by using Kalafat et al. (2007).

Table 2a. Earthquake occurrence probability for region.

Magnitude	For D = 10 (Years) Probability (%)	For D = 50 (Years) Probability (%)	For D = 75 (Years) Probability (%)	For D = 100 (Years) Probability (%)
5	92.4	100	100	100
5.5	67.7	99.6	100	100
6	39	91.6	97.5	99.3
6.5	19.4	66.1	80.3	88.5
7	9	37.7	50.8	61.2
7.5	4.1	18.7	26.7	33.9

Table 2b. Estimated acceleration values for 7.6 magnitude and several epicentral distances.

M (magnitude)	∆, Epicentral Distance (km)	H, Focal depth (km)	Esteva (1970)	Donovan (1973)	Donavan(1973)	Donavan(1973)	McGuier (1984)	Shah et al (1973)	Oliviera (1974)	Joyner ve Boore (1981)	Campbell (1981)	Campbell (1981)	Fukishima et al. (1988)	Campbel (1997)	Average
7.6	25	15	0.19	0.36	0.24	0.25	0.35	0.47	0.19	0.46	0.20	0.20	0.30	0.52	0.31
7.6	30	15	0.16	0.32	0.21	0.23	0.31	0.41	0.16	0.37	0.18	0.18	0.27	0.45	0.27
7.6	35	15	0.14	0.28	0.19	0.21	0.28	0.37	0.14	0.31	0.16	0.16	0.25	0.41	0.24
7.6	40	15	0.12	0.25	0.17	0.19	0.26	0.33	0.12	0.26	0.15	0.14	0.23	0.38	0.22
7.6	45	15	0.10	0.23	0.15	0.17	0.24	0.29	0.10	0.23	0.13	0.13	0.21	0.35	0.19
7.6	50	15	0.09	0.21	0.14	0.16	0.22	0.26	0.09	0.20	0.12	0.12	0.19	0.32	0.18
7.6	45	15	0.10	0.23	0.15	0.17	0.24	0.29	0.10	0.23	0.13	0.13	0.21	0.35	0.19
7.6	50	15	0.09	0.21	0.14	0.16	0.22	0.26	0.09	0.20	0.12	0.12	0.19	0.32	0.18

Table 3a. S wave velocity for 30 m and relevant relative soil amplification (A) (Midorikawa, 1987).

Midorikawa (1987)	$A = 68Vs30^{-0.6}$ (Vs30 < 1100 m/sn) A = 1 (Vs30 > 1100 m/sn)
(Vs, 30= 30/ ($\Sigma_{i=1, N}$ (hi/Vsi)) where Vsi is Shear wave velocity and h is thickness of soil	

GEOPHYSICAL AND GEOTECHNICAL DATA AND SOIL AMPLIFICATIONS

Geophysical analysis of soil amplifications

Shear-wave velocity (Vs) is an important parameter for evaluating dynamic behavior of soil for engineering and microzonation purposes. Vs averaged over the top 30 m of soil are referred to as Vs30. Both the NEHRP Provisions and the Uniform Building Code use Vs30 to classify sites according to type of soil for earthquake engineering design.

As it is known, shear wave velocity is an index property to evaluate the soil amplifications. In Table 3a, it was given the shear wave and soil amplification relations according to Midorikawa (1984). Study area is divided in to two sub-regions: A and B regions as shown in Figure 3. To estimate the soil amplifications for two zones, seismic refraction measurements were taken to obtain the shear wave velocities. Figures 4a and b show Vs30 values on map for A and B Regions. Figures 5a and b shows characteristic site period values on map for A and B regions. Finally, figures 6a and b shows soil amplification values on map for A and B regions according to

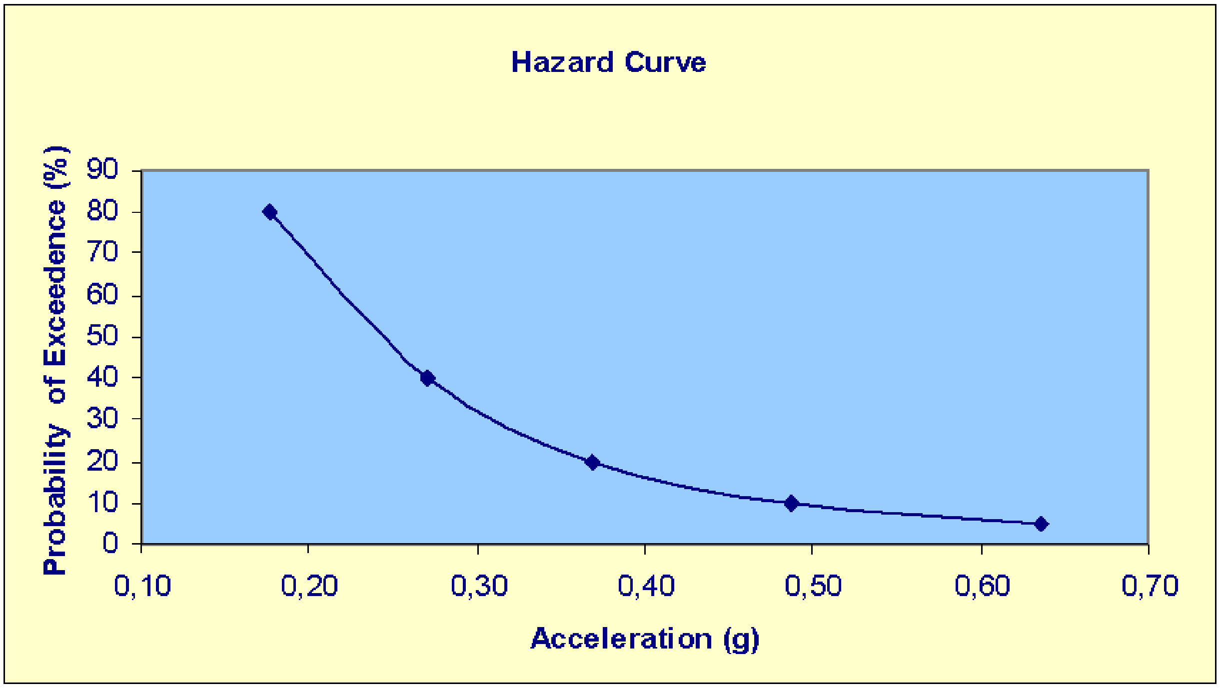

Figure 2. Hazard Curve for region by using Joyner and Bore (1981) attenuation model.

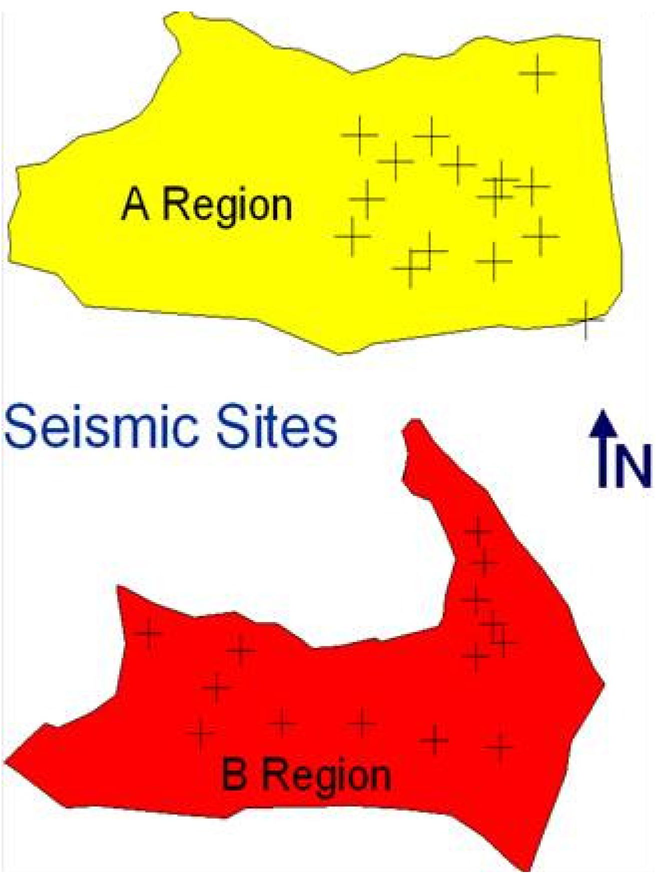

Figure 3. Seismic sites for the region.

Midorikawa (1984) relation.

Comparisons on characteristic site period values obtained by seismic refraction with microtremor and earthquake data

The microtremor experiment also was carried out in Mecidiyekoy site of Sisli area and aimed at recording ambient noise. A measurement of one station was deployed in Sisli. Data was recorded by using Guralp CMG-6TD sensors (flat velocity response between 0.033 and 50 Hz as standard). At each site the signal was recorded with a sample rate of 100 Hz for at least 15 min. All measurements were synchronized by means of a GPS reference time. H/V spectral ratios were calculated from all of the data to obtain fundamental frequency of site (Figure 7). Comparisons of H/V ratios of data set show that fundamental frequency agreement nears to 9 Hz. This fundamental frequency data (that means 0.11s) is agreement with characteristic site period map (Figure 5b).

Earthquake data obtained from Earthquake Research Department of State (Bayındırlık İskan Bakanlığı Deprem Araştırma Dairesi) was evaluated to comparisons between site periods near the Mecidiyekoy. Properties of earthquake data were given in Table 3b. Figure 8 shows H/V ratios of all earthquake data. When seismic, micro-tremor and earthquake data are compared; all of them are in agreement with each other.

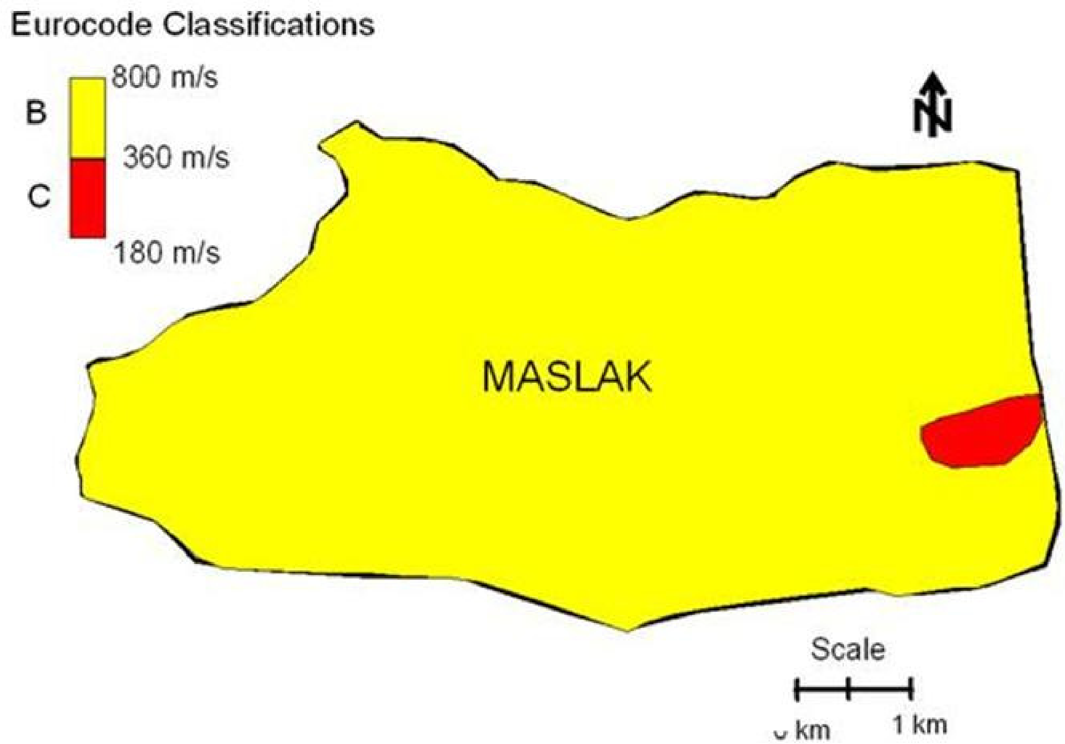

Figure 4a. For A region Vs 30 Map.

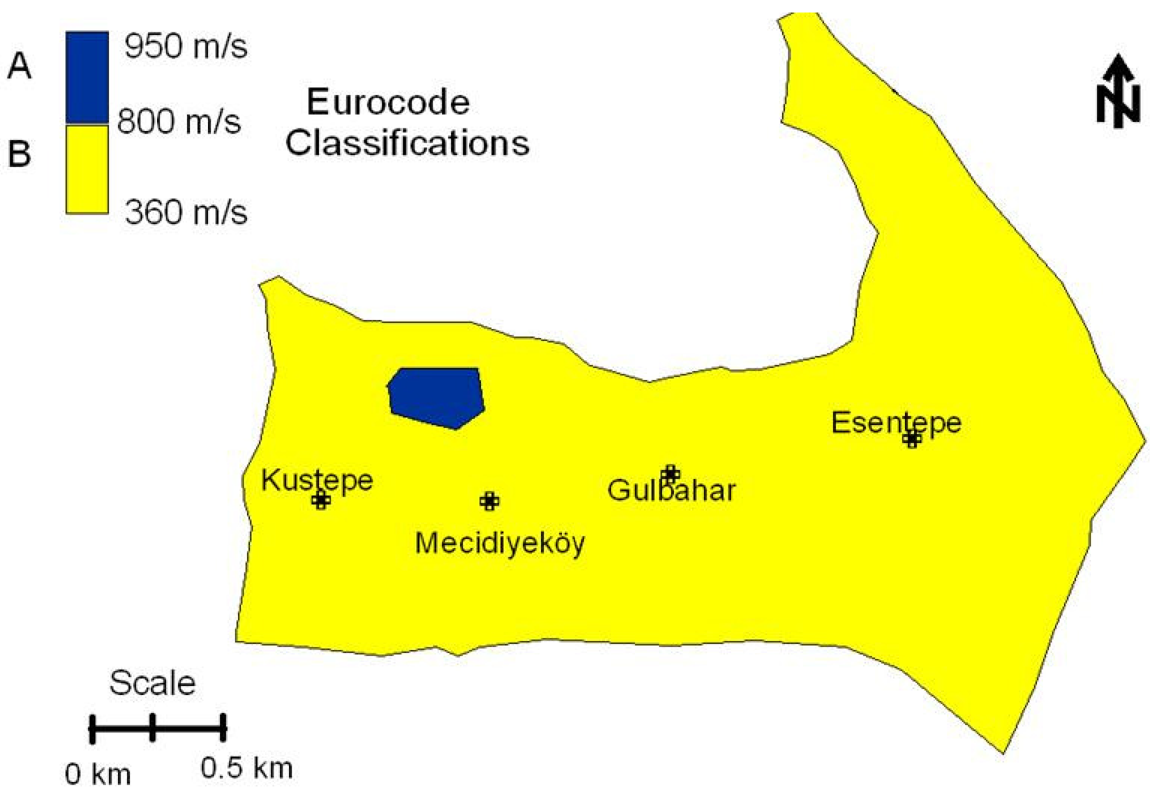

Figure 4b. For a region Vs 30

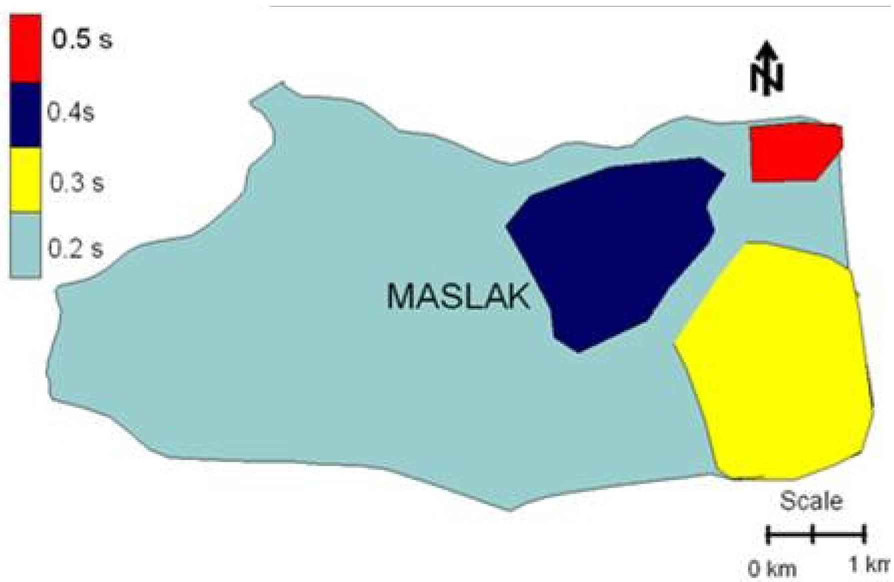

Figure 5a. Characteristic site period map for A region.

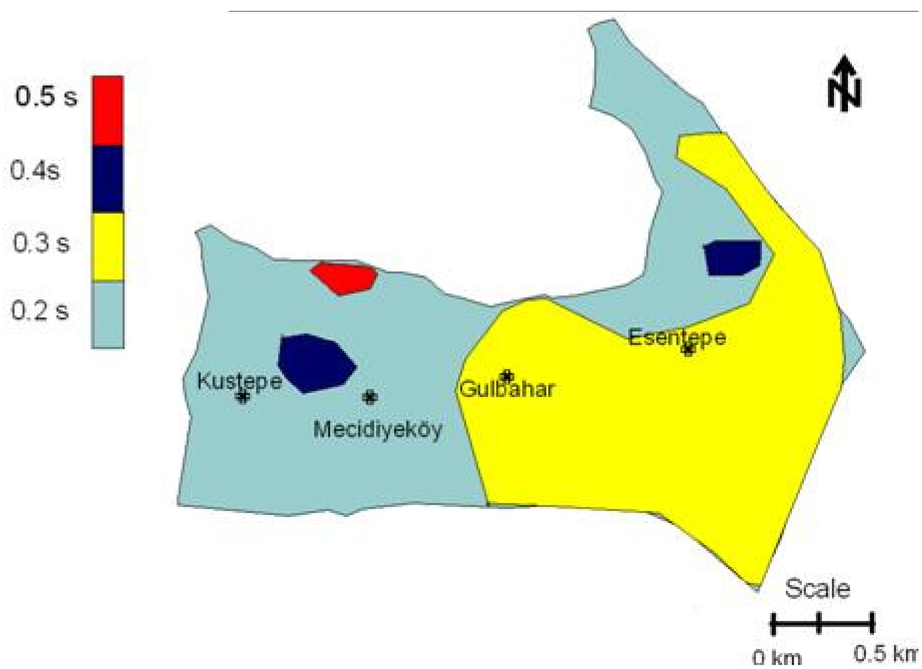

Figure 5b. Characteristic site period map for B region.

Comparisons on Vs30 values between seismic refraction studies and MASW and MAM measurements

In the early 1980s, a wave-propagation method to generate the near-surface Vs profile, called spectral analysis of surface waves (SASW), was introduced (Nazarian et al., 1984). SASW uses the spectral analysis of ground roll generated by an impulsive source and recorded by a pair of receivers. This method has been widely and effectively used in many geotechnical engineering projects (Stokoe et al., 1994). The necessity of recording repeated shots into multiple field deployments for a given site increases the time and labor requirements over a multichannel procedure. Multi-channel analysis of surface waves (MASW) tries to overcome the few weaknesses of the SASW method (Park et al., 1999). The multichannel analysis of surface waves (MASW) method deals with surface waves

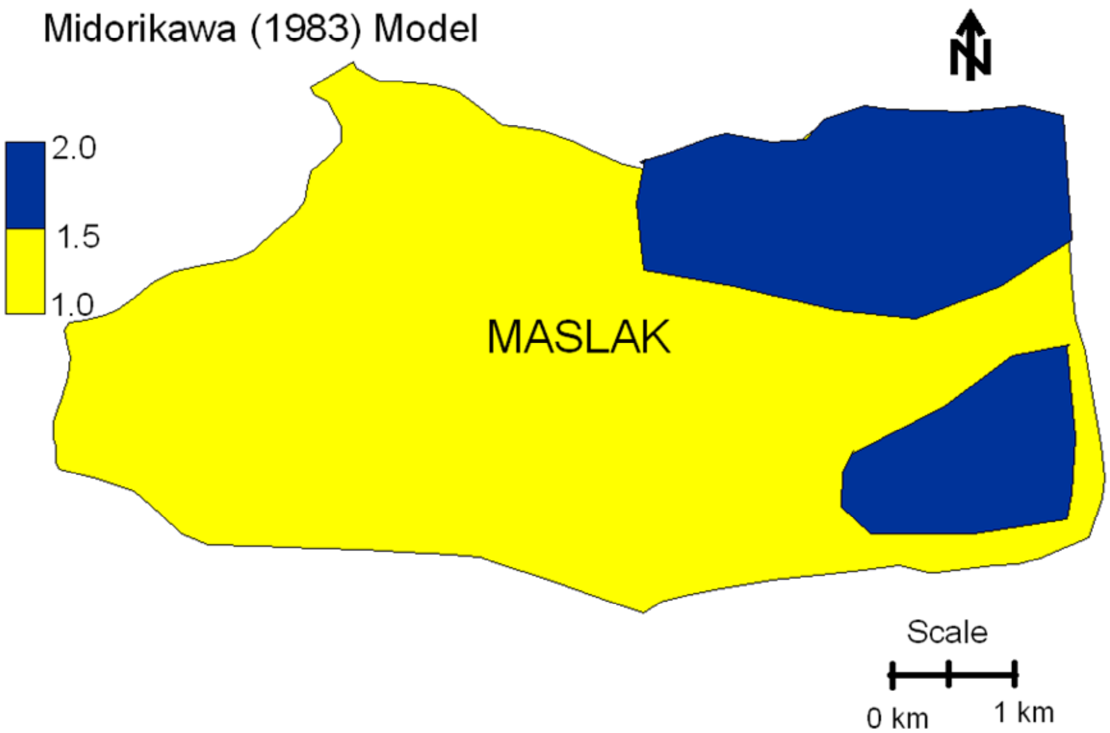

Figure 6a. Soil amplification map for A region according Midorikawa (1984) relation.

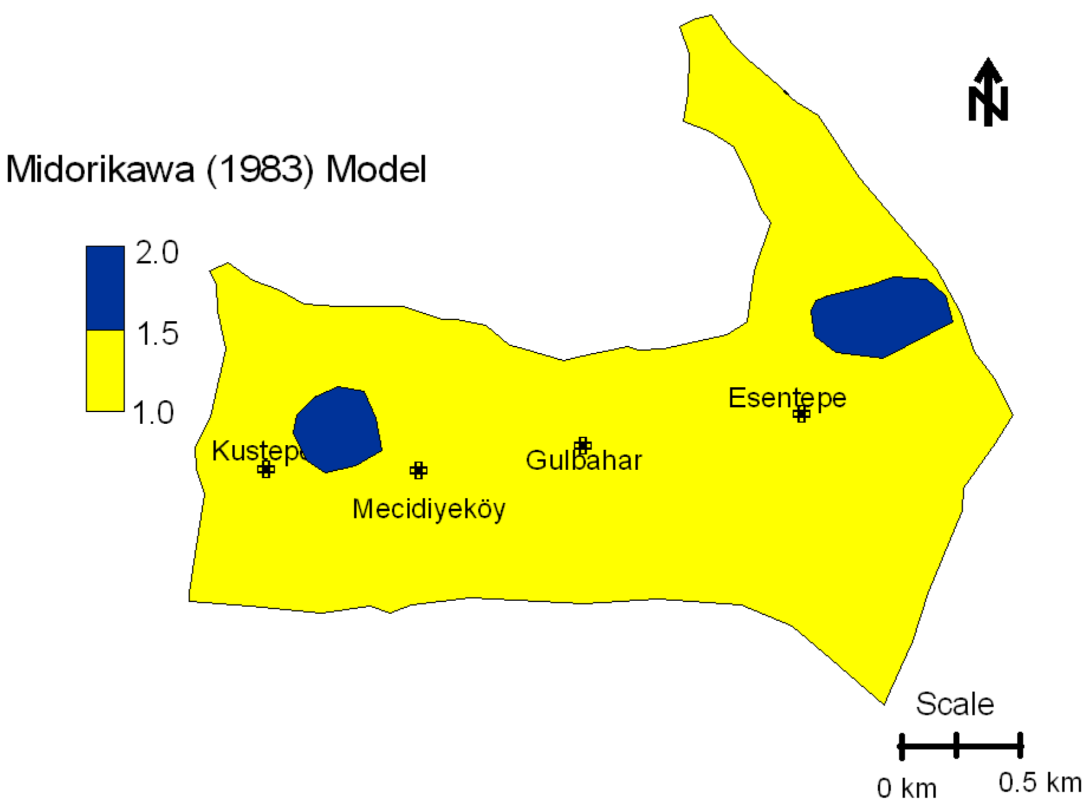

Figure 6b. Soil amplification map for B region according Midorikawa (1984) relation.

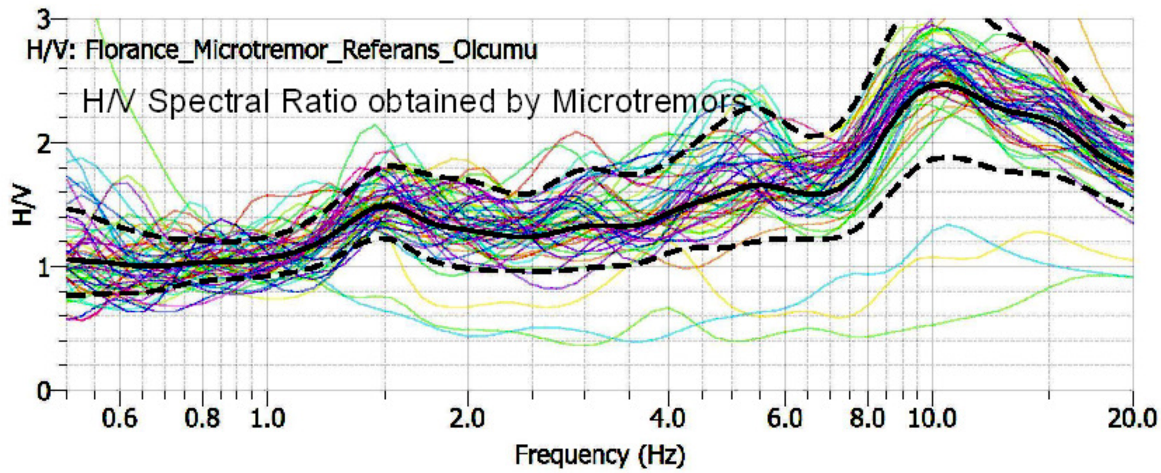

Figure 7. H/V Spectral ratio obtained by microtremors.

Table 3b. Properties of earthquake data to estimate the fundamental period data.

	EQ date (GMT)	EQ epıcenter coord.	EQ magnıtude	EQ depth (km)	Max. values(mG)
1	17.08.1999 00:01	40.76N- 29.97E	7.4 Md	18	(L) 60.6690 (T) 42.6640 (V) 36.2240
2	22.08.1999 14:30	40.740N - 30.680E	5.0 Md	5,4	(L) 1.0680 (T) 1.0990 (V) .6410
3	31.08.1999 08:33	40.780N - 29.960E	4.6 Md	10,9	(L) 1.3120 (T) 1.4650 (V) .7630
4	09.09.1999 01:32	40.710N - 29.140E	4.6 Md	11	(L) 2.7160 (T) 2.2890 (V) 1.9530
5	13.09.1999 11:55	40.770N - 30.100E	5.8 Md	19,6	(L) 14.1300 (T) 15.5940 (V) 9.7050
6	29.09.1999 00:13	40.700N - 29.340E	4.8 Md	12	(L) 3.5400 (T) 3.2350 (V) 1.7700
7	11.12.1999 16:57	40.740N - 31.210E	7.2 Mw	25	(L) 8.9720 (T) 5.2490 (V) 8.2700
8					(L) 2.7770 (T) 3.5400 (V) 2.2580

Table 3c. MASW and MAM results on A and B region.

Region	Measurement point number	Artificial source (MASW)	Natural source (MAM)	Long. (N)	Lat. (E)	Elevation (m)	Geophone interval (m)	Offset (m)	Vs30 (m/s)
A	1	1.dat	2.dat	41.07297	29.01271	135	2	2	773
A	2	3.dat	4.dat	41.07118	29.01007	134	2	2	446-396
A	3	5.dat	6.dat	41.06752	28.98985	123	2	2	573
A	4	7.dat	8.dat	41.06944	28.99099	121	2	2	555
B	5	9.dat	10.dat	41.0078	29.02056	68	2	2	306
B	6	11.dat	12.dat	41.09889	29.02614	43	2	2	254-475
B	7	13.dat	14.dat	41.09978	29.03157	29	2	2	458
B	8	15.dat	16.dat	41.10286	29.02702	97	2	2	648
B	9	17.dat	18.dat	41.10625	29.02077	105	2	2	580

in the lower frequencies (e.g., 1–30 Hz) and uses a much shallower depth range of investigation (e.g., a few to a few tens of meters) (Park et al., 2007).

The shear wave velocities and profile are obtained by multi channel analysis of surface wave in study area. The phase velocity-dispersion curve and shear wave velocity are obtained by inversion distance profile for first 30 meters of soil. The records that are depending on field conditions with different geophone intervals are taken.

Passive source (MAM, Microtremor Array Method)

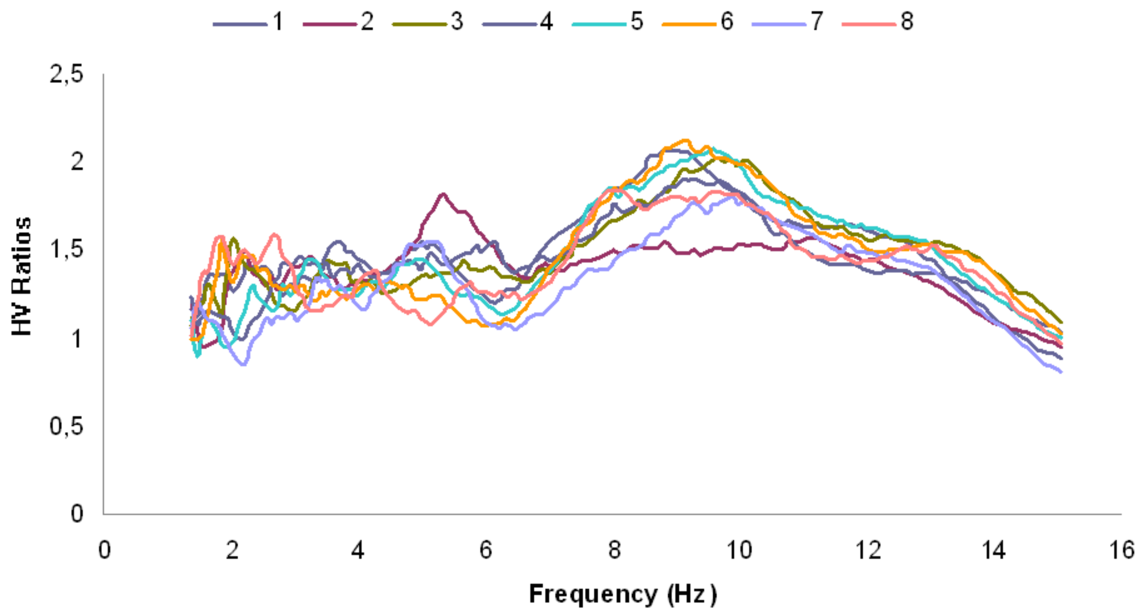

Figure 8. H/V ratios of earthquake data (for detail see Table 3b).

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1	17.08.1999 00:01	40.76N- 29.97E	7.4 Md	18	(L) 60.6690 (T) 42.6640 (V) 36.2240
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3	31.08.1999 08:33	40.780N - 29.960E	4.6 Md	10,9	(L) 1.3120 (T) 1.4650 (V) .7630
4	09.09.1999 01:32	40.710N - 29.140E	4.6 Md	11	(L) 2.7160 (T) 2.2890 (V) 1.9530
5	13.09.1999 11:55	40.770N - 30.100E	5.8 Md	19,6	(L) 14.1300 (T) 15.5940 (V) 9.7050
6	29.09.1999 00:13	40.700N - 29.340E	4.8 Md	12	(L) 3.5400 (T) 3.2350 (V) 1.7700
7	11.12.1999 16:57	40.740N - 31.210E	7.2 Mw	25	(L) 8.9720 (T) 5.2490 (V) 8.2700
8					(L) 2.7770 (T) 3.5400 (V) 2.2580

when it is compared by active source reaches deeper parts of soils because the lower frequency of natural noises are recorded, different noises that are giving more information from the deep distance. In our study the linear arrays are applied.

After the data are collected from the field, data-processing are carried out, the phase velocities for the different frequency are obtained by using Pickwin program and the end of the process, dispersion curve is obtained.

During the evaluation studies, the seismic refraction data are also used. The initial model that is obtained from these data is used the initial model data. By using both forward and inverse solutions algorithm, S wave velocities are calculated and drown depending on distance. On A and B region, MASW and MAM results are given in Table 3c. Dispersion (Phase Velocity-Frequency) curve was given in Figure 9a to k for some points (shown in Table 3c).

Geotechnical analysis

The first group of *in situ* tests generally conducted to identify the soil stratification and engineering properties of the soil layers are penetration tests (Studer and Ansal, 2004). Two methods that have been widely used are the Standard Penetration Test (SPT) and Cone Penetration Test (CPT). SPT is generally used to investigate cohesionless or relatively stiff soil deposits, whereas CPT is used to identify soil properties in soft soil deposits (Lunne et al., 1997; Studer and Ansal, 2004).

The variability of the Standard Penetration Test equipment and procedures used has significant effects on the obtained blow counts (Seed et al., 1985; Skempton, 1986). The energy delivered to the split-spoon sampler, is strongly influenced by many factors such as: type of hammer release equipment, expertise of the operator, size of the cathead, diameter of the rope, number of

Table 3c. MASW and MAM results on A and B region.

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B	5	9.dat	10.dat	41.0078	29.02056	68	2	2	306
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B	7	13.dat	14.dat	41.09978	29.03157	29	2	2	458
B	8	15.dat	16.dat	41.10286	29.02702	97	2	2	648
B	9	17.dat	18.dat	41.10625	29.02077	105	2	2	580

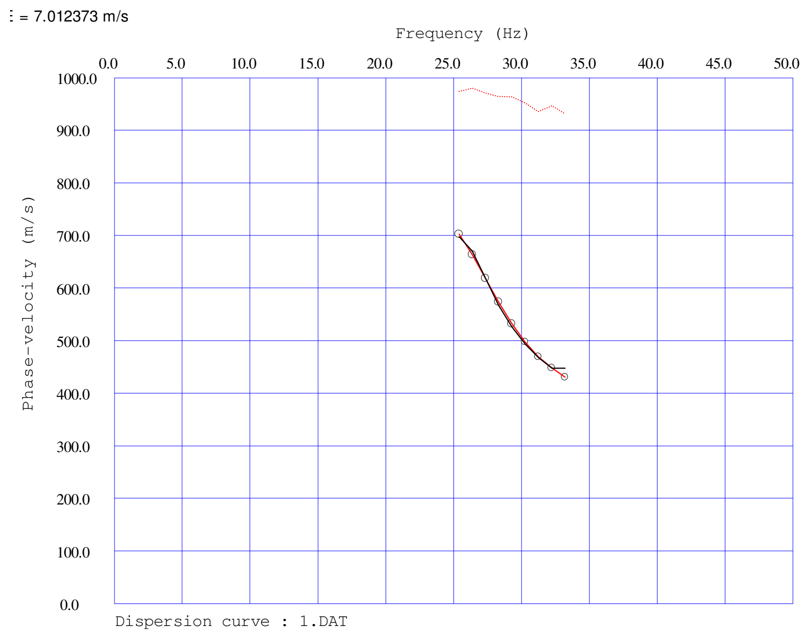

Figure 9a. Dispersion (phase velocity-frequency) Curve for 1.dat.

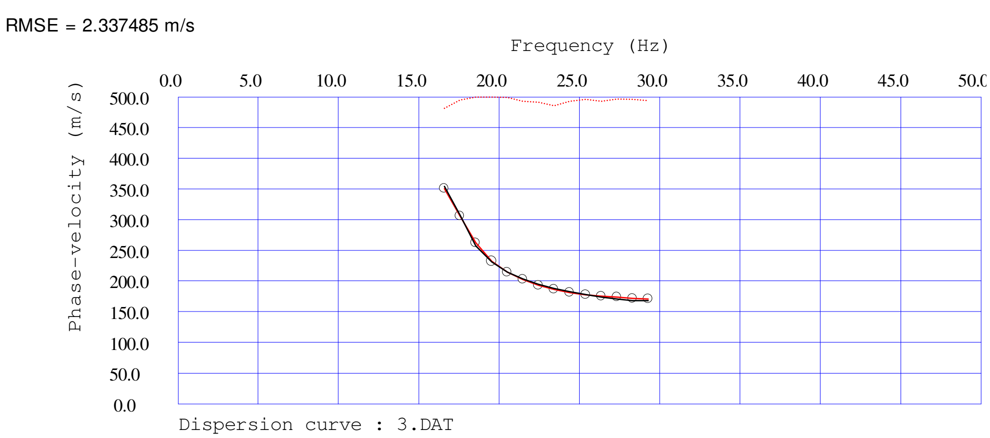

Figure 9b. Dispersion (phase velocity-frequency) curve for 3.dat.

RMSE = 5.685512 m/s

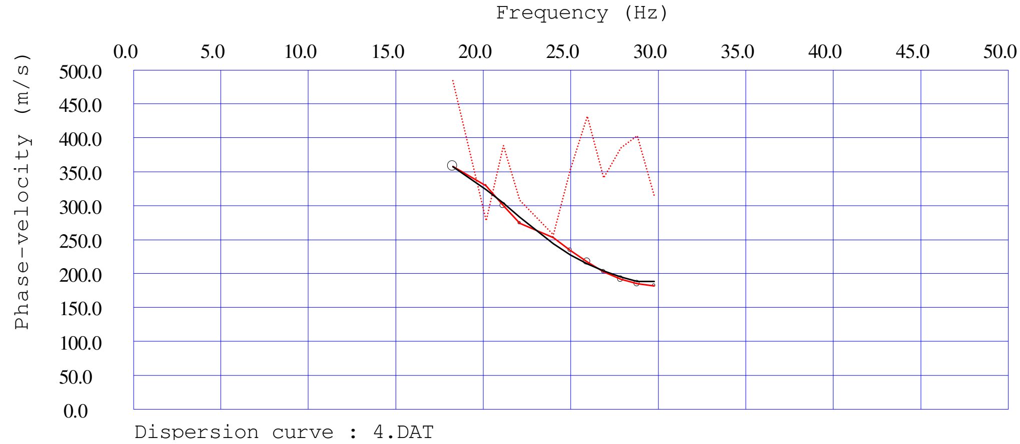

Figure 9c. Dispersion (phase velocity-frequency) curve for 4.dat.

RMSE = 2.404762 m/s

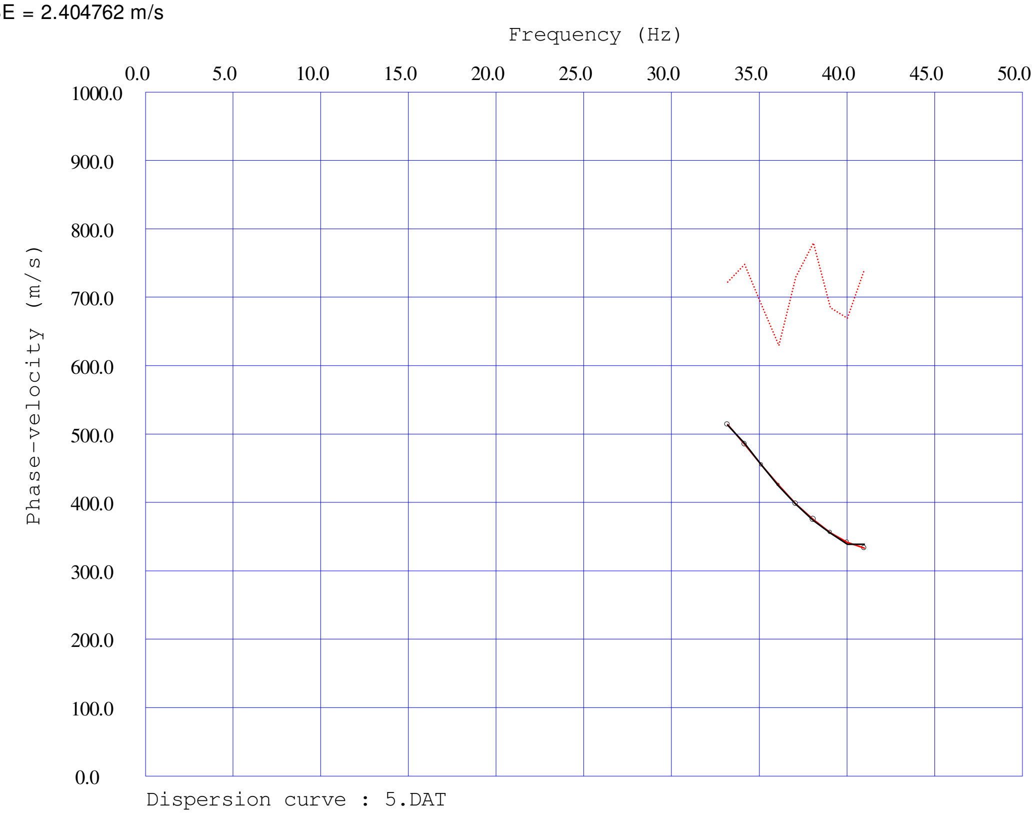

Figure 9d. Dispersion (phase velocity-frequency) curve for 5.dat.

wraps of the rope around the cathead, hammer type, borehole diameter, rod length, rod diameter, tightness of the rod joints, verticality of the rod string, and type of sampler. Therefore it is very important to have sufficient information to estimate the energy ratio correction for SPT blow counts before using these results for assessing the properties of soil layers (Studer and Ansal, 2004).

Empirical relations have been proposed to correlate the penetration test results between CPT and SPT (Robertson et al., 1983) as well as with the shear-wave velocities (Ohta and Goto, 1978; İyisan, 1996; Mayne and Rix, 1995). The standard penetration test (SPT) is an in situ dynamic penetration test designed to provide information on the geotechnical engineering properties of soil. The test procedure is described in the British Standard BS EN ISO 22476-3 and ASTM D1586. In this study, we

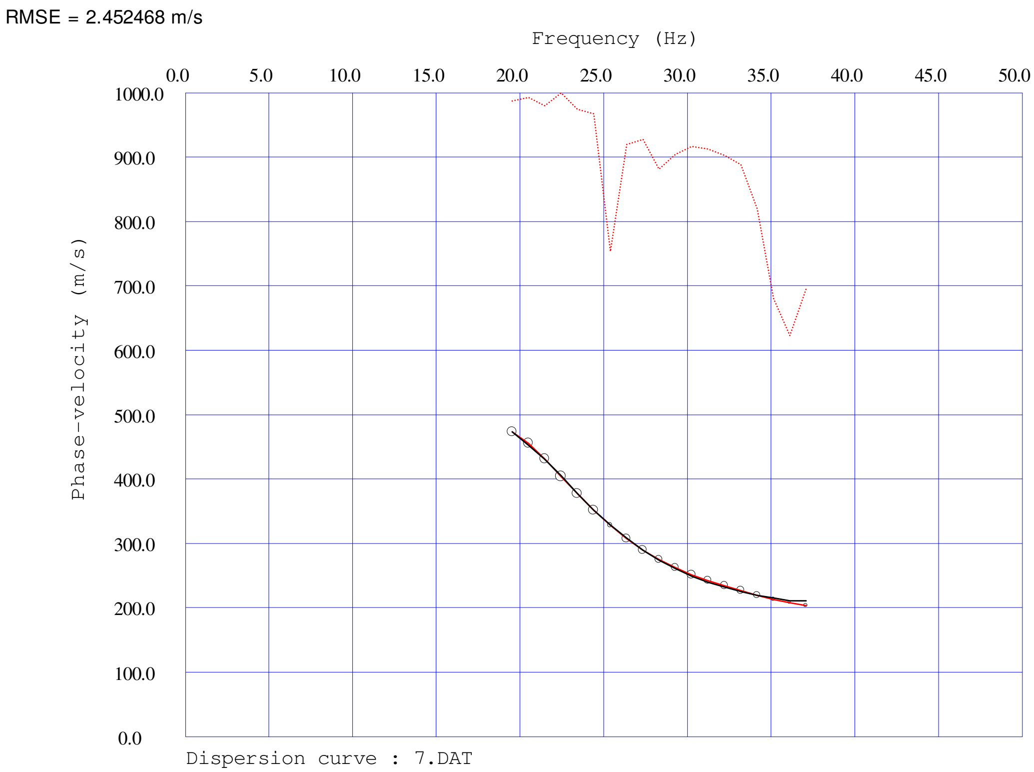

Figure 9e. Dispersion (phase velocity-frequency) curve for 7.dat.

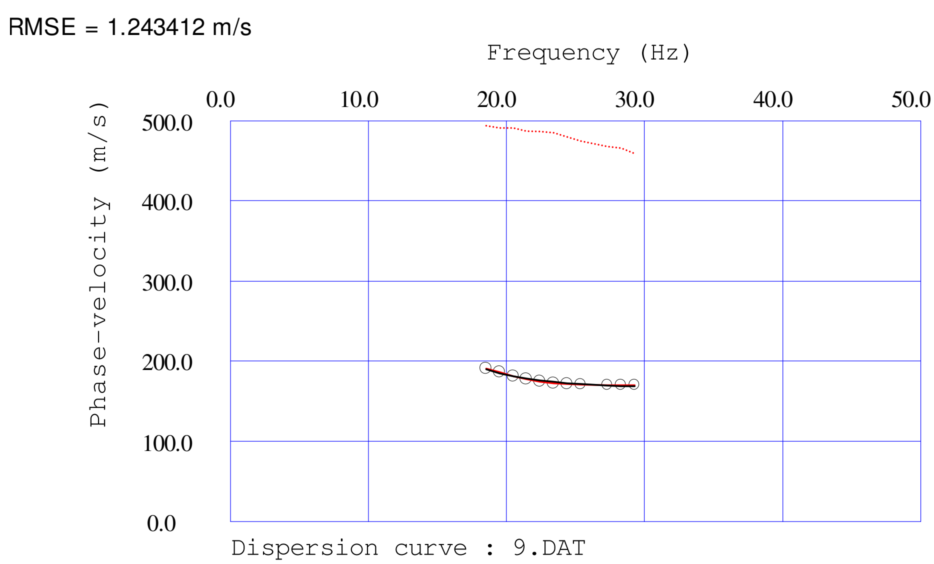

Figure 9f. Dispersion (phase velocity-frequency) curve for 9.dat

have obtained and evaluated the borehole geotechnical data. SPT (N) values were converted into equivalent shear wave velocity values following relation given by Iyisan (1996)

$$Vs = 51.5(SPT)^{0,516}$$

for A and B regions (Table 4a and b).

Microzonation map of the regions

As Studer and Ansal (2004) point out, ground shaking is a term used to describe the vibration of the ground during

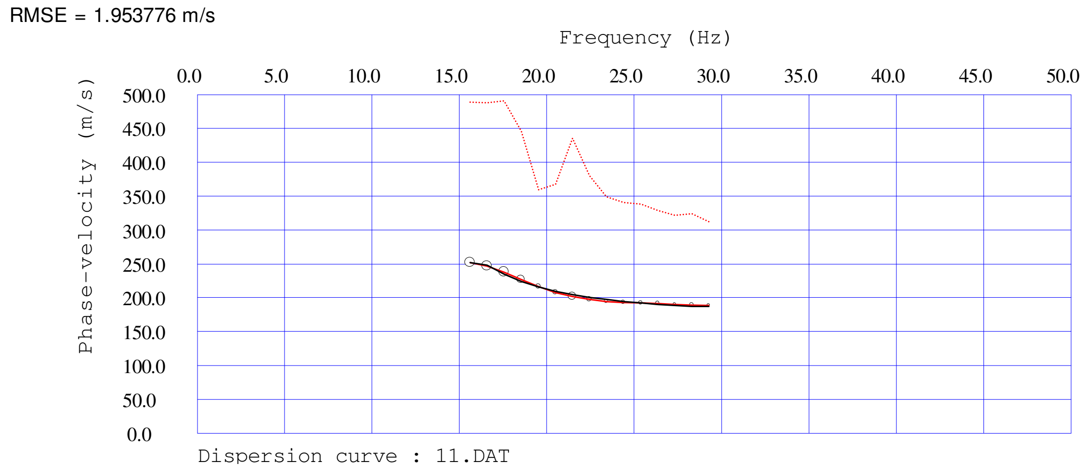

Figure 9g. Dispersion (phase velocity-frequency) curve for 11.dat.

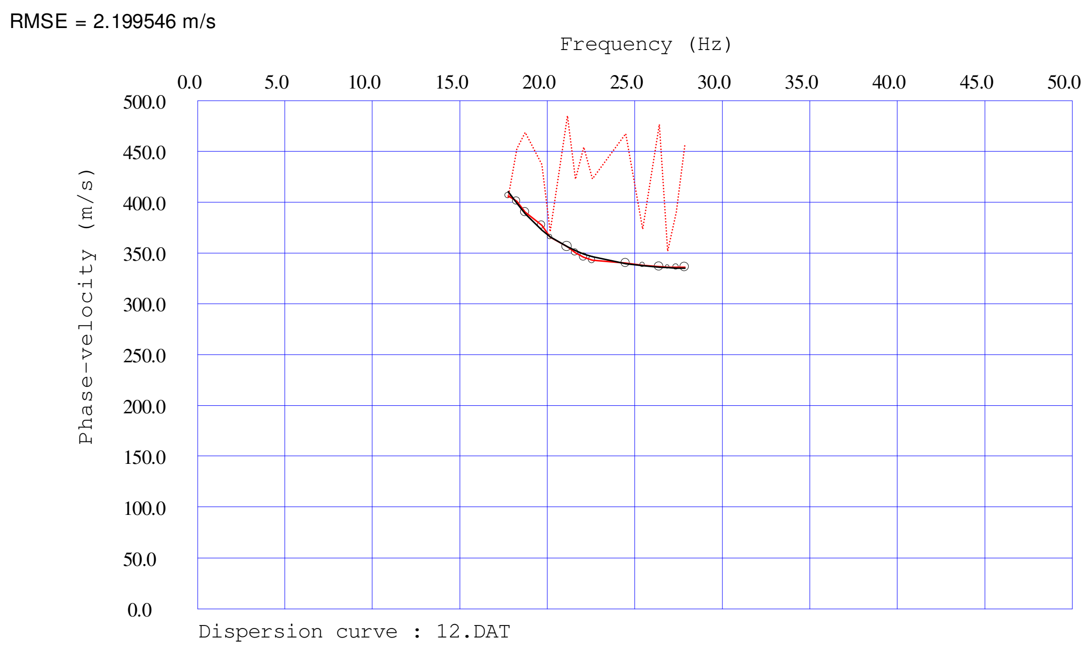

Figure 9h. Dispersion (phase velocity-frequency) curve for 12.dat.

an earthquake. Ground shaking is caused by body and surface seismic waves. As a generalization, the severity of ground shaking increases as magnitude increases and decreases as distance from the causative fault increases.

Preparation of microzonation map carried out Studer and Ansal (2004) methodology. This methodology is given the following paragraphs. Graphical representation of three different zones defined according to the criteria given below. It should be kept in mind that these zones represent the relative shaking hazard in relation to the whole investigated area. Definition of three zones with respect to average spectral accelerations determined from site response analysis.

The following steps should be performed at each grid point *i*:

1. Calculate the output response spectra at engineering bedrock, for both input motions by using spectral acceleration attenuation relationship by Boore et al. (1997).
2. Calculate the geometric mean of the two output response spectra. This leads to a "mean output response spectrum". Take the average (arithmetic mean) of the mean output response spectrum for the spectral range 0.2 to 1.0s (Table 5). This average value is called Si and will represent the plateau in the output acceleration response spectra for grid point *i*.

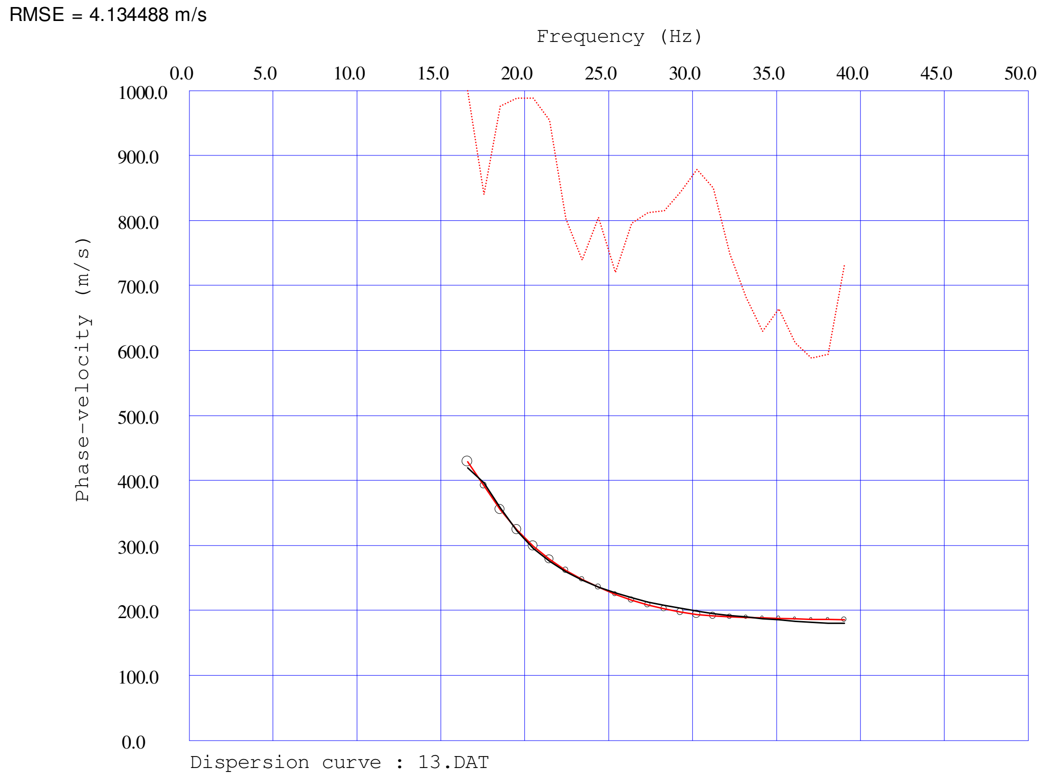

Figure 9i. Dispersion (phase velocity-frequency) curve for 13.dat.

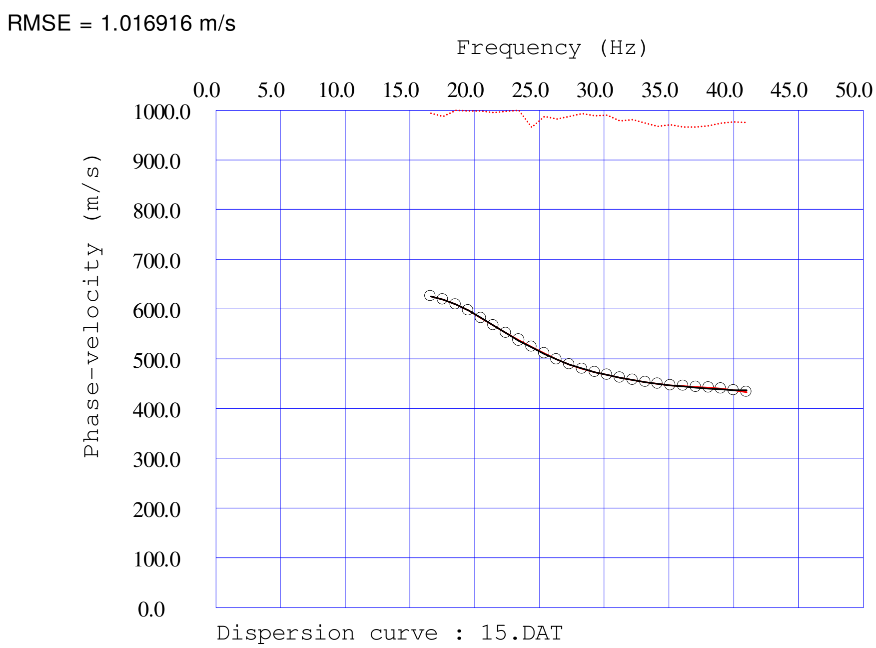

Figure 9j. Dispersion (phase velocity-frequency) curve for 15.dat.

After calculating the above defined average values Si at each grid point, three ground shaking zones are defined as follows:

1. Calculate the 33 and 67% percentiles of all average values Si for the whole investigated area. These percentiles are called S (33) and S (67%).

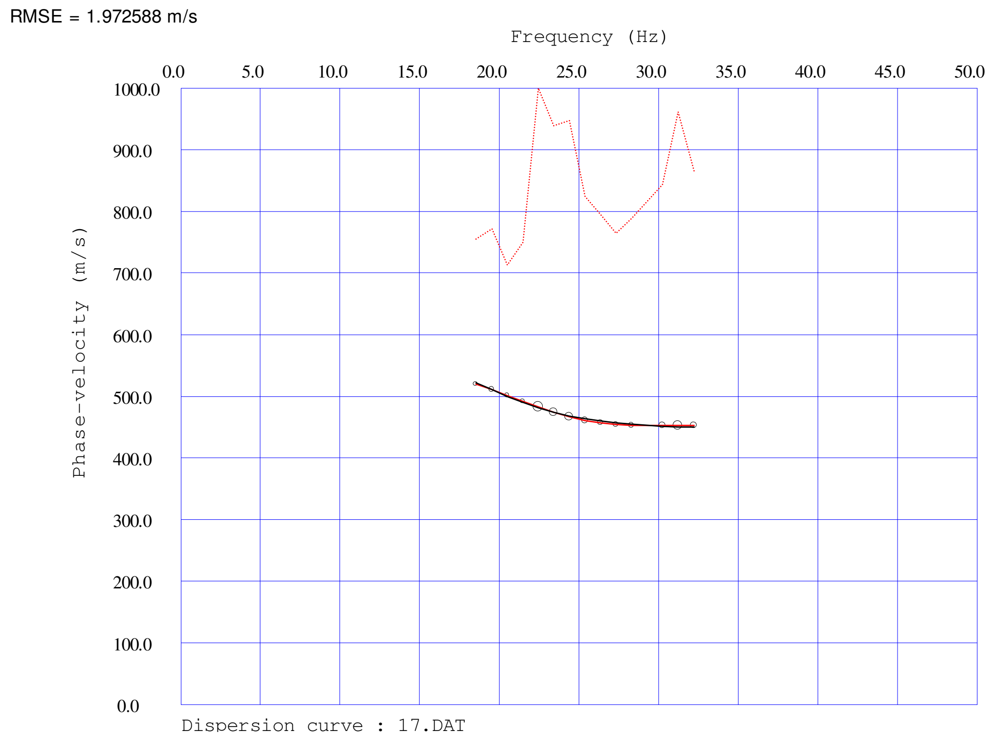

Figure 9k. Dispersion (phase velocity-frequency) curve for 17.dat.

Table 4a. Soil amplification values obtained by equivalent shear wave velocity (Vs30) for A region.

Boring point	Equivalent shear wave for 30 m Vs 30 (m/s)	Relative soil amplification Midorikawa
1	420	1.8
2	422	1.8
3	373	1.9
4	396	1.9
5	392	1.9
6	370	2
7	420	1.8
8	420	1.8
9	292	2.3
10	271	2.4
11	423	1.8
12	327	2.1
13	412	1.8

2. A zone is assigned at each grid *i* depending on the value of Si at the corresponding grid.

A three zone differentiation (A/B/C) as described above is justified only if S (67%) > 1.3 S (33%). If this is not the case, it is recommended to define in an analogous way only two zones AGS and CGS, where zone AGS represent values Si above 50% percentile and CGS values Si below 50% percentile.

The final mapping with respect to ground shaking can be accomplished by comparing the average spectral accelerations obtained by site response analyses with the peak spectral amplifications calculated using equivalent shear wave velocity (Table 3a and Figure 6a and b) based on by Midorikawa (1987).

There are basically two possibilities in making the

Table 4b. Soil Amplification values obtained by equivalent shear wave velocity (Vs30) for B Region.

Boring point	Equivalent shear wave for 30 MetersVs 30 (m/s)	Relative soil amplification Midorikawa
1	339	2.1
2	392	1.9
3	477	1.7
4	358	2
5	477	1.7
6	477	1.7
7	477	1.7
8	368	2
9	477	1.7
10	477	1.7
11	477	1.7
12	477	1.7
13	444	1.8
14	477	1.7
15	477	1.7
16	405	1.9
17	355	2
18	477	1.7
19	477	1.7

Table 5. The average (arithmetic mean) of the mean output response spectrum for the spectral range 0.2 to 1.0 s. Where Rjb, is closest horizontal distance from the station to a point in km.

Design Earthquake Magnitude (Mw) = 7.6						
Period (s)	Acceleration (g) for Rjb =25 km	Acceleration (g) for Rjb =30 km	Acceleration (g) for Rjb =35 km	Acceleration (g) for Rjb =40 km	Acceleration (g) for Rjb =45 km	Acceleration (g) for Rjb =50 km
0.00	0.17	0.15	0.13	0.12	0.11	0.10
0.20	0.33	0.28	0.24	0.22	0.19	0.18
1.00	0.18	0.16	0.14	0.12	0.11	0.10
Mean output response spectrum	0.25	0.22	0.19	0.17	0.15	0.14

comparison between the average spectral accelerations obtained by site response analysis (lets call the corresponding zones AS, BS and CS) and peak spectral amplifications obtained from equivalent shear wave velocities (lets call the corresponding zones AV, BV and CV).

In the procedure that can be followed in carrying out this assessment, and since both maps are divided in to three zones, it is also essential to have three zones again in the final map:

- The zone AGS corresponds to overlapping zones of AS and AV or AS and BV or BS and AV.
- The zone BGS corresponds to overlapping zones of AS and CV or CS and AV or BS and BV.
- The zone CGS corresponds to overlapping zones of BS and CV or CS and BV or CS and CV obtained from both approaches.

Finally, Figure 10a and b show the proposed micro-zonation map for A and B region.. In this map, criteria of World Institute for Disaster Risk Management (2004) were used. There are two microzonation zone (as shown Figure 10a and b), namely C (Relative Low Shaking Level) zone and B (Relative Medium Shaking Level) zone.

RESULTS AND DISCUSSIONS

Seismic microzonation requires multi-disciplinary contri-butions as well as comprehensive understanding of the

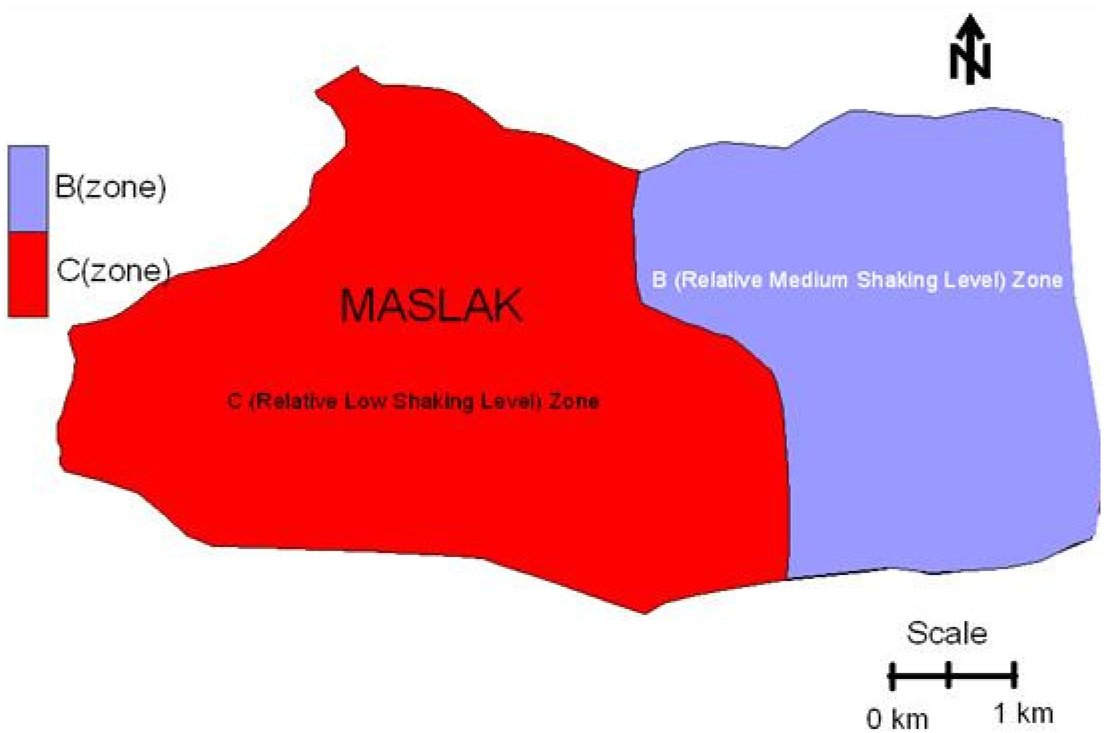

Figure 10a. Seismic microzonation map for A Region.

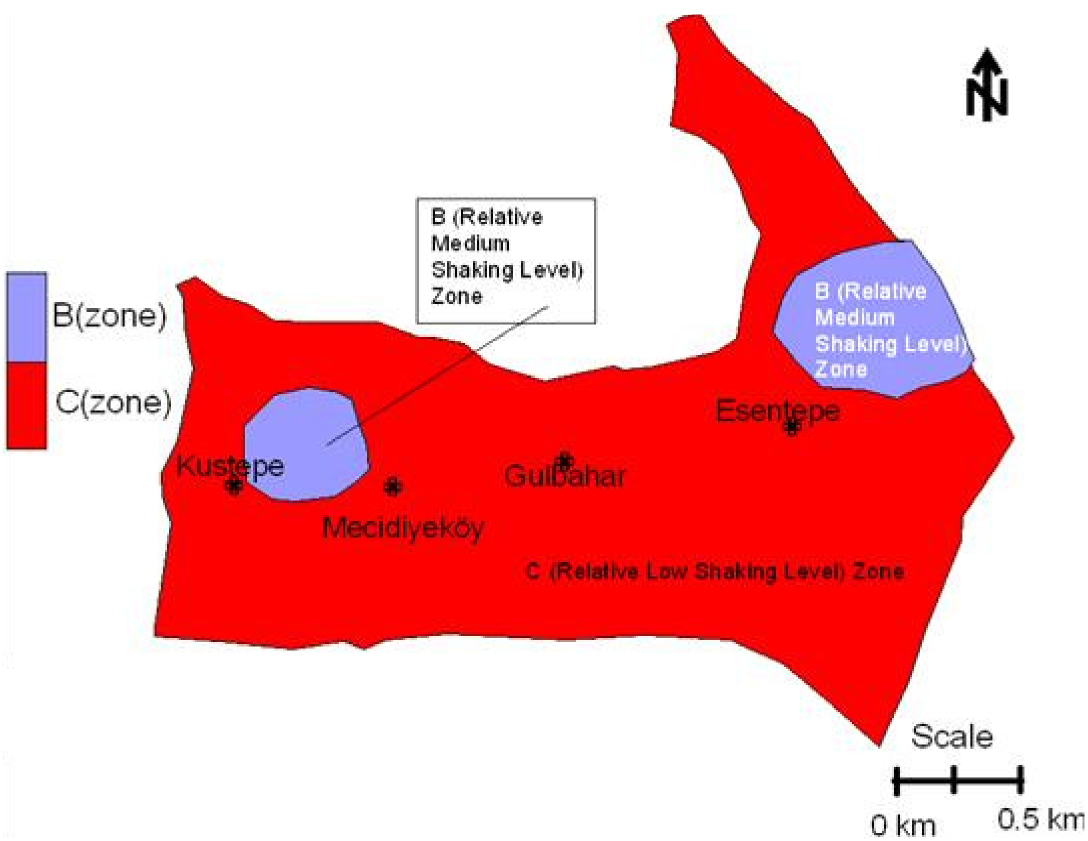

Figure 10b. Seismic microzonation map for B Region.

effects of earthquake generated ground motions on man-made structures. It can be considered as the process for estimating the response of soil layers under earthquake excitations and thus the variation of earthquake ground motion characteristics on the ground surface.

Main aim of this study is to put forward the combined use of geophysical and geotechnical data in integrated form in context of seismic microzonation. For this aim, firstly, seismic hazard analysis of region was carried out by deterministic and probabilistic hazard analysis techniques. In deterministic approach, design earthquake was estimated by using several fault raptures relations. Then, by probabilistic approach, acceleration values were estimated exceeding probability of 15% in 50 years. Acceleration values vary from 0.40 g for the shortest distance (15 km) to 0.18 g for the distance of 50 km. In the second phase of this study, soil amplifications were determined by geophysical and geotechnical data. Geophysical and geotechnical estimations for soil amplifications are in agreement each other. Geophysical estimations of soil amplifications vary from 1.0 to 2.1 values. Vs30 values are between 380 - 918 m/s. Site characteristic period values for the region range from 0.2 to 0.5 s. From geotechnical data, soil amplifications are estimated in range of 1.5 and 2.0.

As a result, geotechnical and geophysical data on soil amplification on sites are controlled/confirmed each other and in agreement each other.

The understanding of geotechnical and geophysical characteristics of soil material is of fundamental interest in earthquake microzonation studies. Shear wave velocity (Vs), one of the most important soil properties for soil response modeling, has been evaluated through seismic profiling (geophysical) and SPT (geotechnical) analysis of sites in the city Sisli/Istanbul. Obtained Shear wave velocity (Vs30) can be used to estimate amplification for the 'design' earthquake. Amplification information can provide the framework for future microzonation studies and be of value in their development.

When microtremor and earthquake data were evaluated to compare the obtained characteristic site period data of seismic measurements, they are changed between 0.1 - 0.25 s. These mean B and A type of soils according Eurocode classifications. When Vs30 values of seismic measurements are compared Vs30 values by MASW techniques, they are in agreement with each others. Finally by integration of use of all geophysical and geotechnical data, obtained seismic microzonation map shows two region (relative low shaking level and relative medium shaking level).

According Eurocode soil classification, study area is mainly formed B type soils. A little part of study area is located C and A type soils. Characteristic site periods obtained by seismic methods is agreement with strong (earthquake) and weak (ambient noise) motion spectral values vicinity study area.

Fast and efficient use of geophysical and geotechnical data in urban microzonation studies is possible to obtain the seismic hazard analysis and soil amplification studies. Geophysical and geotechnical data have physical connection to utilize and get soil information. Microzonation studies in Sisli (Istanbul) are good examples for this aim. Geophysical and geotechnical data can be easily and fast evaluated in this context.

Lastly, Rajendran (2001) point out, the attempts to develop strategies for earthquake damage mitigation are primarily borne out of societal compulsions; but these are also fuelled by the scientific community’s enhanced ability to design and develop programmes to address region-specific issues.

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