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Full Length Research Paper

Fast and efficient use of geophysical and geotechnical data in urban microzonation studies at small scales: Using Sisli/Istanbul (Turkey) as example

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The main purpose of this study is to provide the combined use of geophysical and geotechnical data in context of microzonation. Earthquake occurrences on the North Anatolian Fault, being usually characterized and well documented in history, a time dependent model can be reasonably used for the probabilistic assessment of the seismic hazard in Istanbul. 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 (30%) in a given time period (30 years). By using deterministic seismic hazard analysis, the magnitudes were estimated by the four rapture (with four different fault length, 108, 119 and 174 km) model of North Anatolian Fault Zone in Marmara Region. By using both analyses (deterministic and probabilistic), magnitude of design earthquake was taken as 7.6. From this design earthquake, accelerations were estimated for several distances (from 15 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 measurements and Standard Penetration Test (SPT test) data for the area of Sisli where the important part of Istanbul city is located. Geotechnical test data from boreholes and laboratory measurements were evaluated with geophysical data. Soil amplification values estimated by empirical relationships in terms of shear wave velocities are in the range of 1.0 and 2.1 values. Shear wave velocity (Vs, 30) values are 381.5 and 915 (m/s). Site characteristic period range is between 0.2 and 0.5 s.

Key words: Microzonation, geophysical and geotechnical analysis, soil amplification, Istanbul (Turkey).

INTRODUCTION

Seismic microzonation can be considered as the preliminary phase of earthquake risk mitigation studies. It requires multi-disciplinary contributions as well as comprehensive understanding of the effects of earthquake that generate ground motions on man made structures (Ansal and Slejko, 2001). 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. However, it is also very important to select appropriate ground motion parameters for microzonation that correlates with the observed structural damage as well as that that could be implemented in engineering design of man-made structures (Finn, 1991). It can be considered as the preliminary phase of earthquake risk mitigation studies. It 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. It has been well recognized that earthquake ground motions are affected by earthquake source conditions, source-to-site transmission path properties and site conditions. The site conditions include rock properties beneath the site to depths of up to about few kilometres, the local site conditions and the topography of the site. Seismic soil

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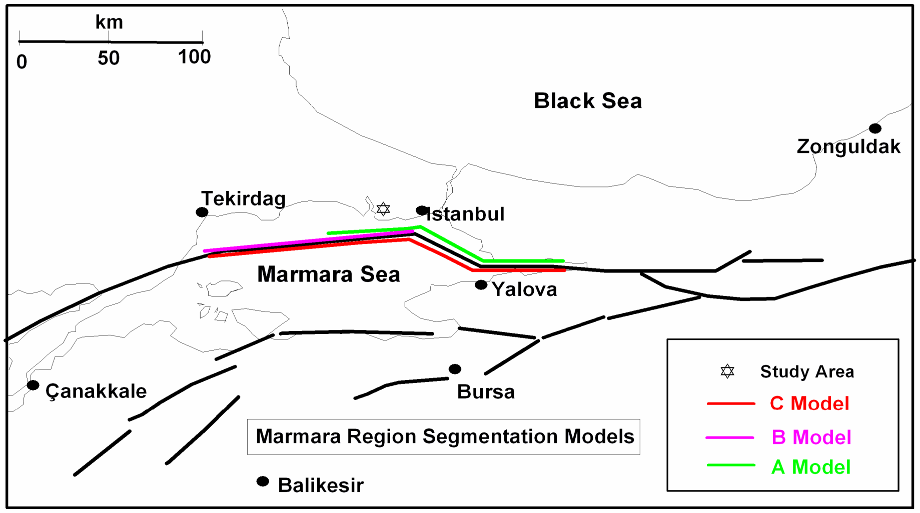

Figure 1. For Marmara region, it was assumed four models (A, B and C) for seismic hazard. Model A: approximately 119 km rapture length; Model B: approximately 108 km rapture length; Model C: approximately 174 km rapture length (map is redrawn form JICA-IBB Report, 2002).

response analysis is required through geophysical and geotechnical investigations in order to assess the mechanical and geometric parameters of system. Near surface geophysical investigations are especially important for definition of the dynamic soil properties at site (that is, shear wave velocity and damping ratio). One approach to estimate the earthquake characteristics on the ground surface is to use an empirical relationship in terms of shear wave velocities. Peak spectral amplifications based on shear wave velocity can be calculated using the relationships given by several researchers (such as Midorikava, 1987; Borcherdt et al., 1991; Joyner and Fumal, 1984). Peak spectral amplifications calculated based on these relationships can be evaluated, and microzonation maps with respect to peak amplifications can also prepared.

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) and Dinar, Turkey (Ansal et al., 2001).

Earthquake hazard assessment of the region

Seismic hazard analysis is the computation of probabilities of occurrence per unit time of certain levels of ground shaking caused by earthquakes. This analysis is often summarized with a seismic hazard curve, which shows annual probability of exceedence versus ground motion amplitude. Deterministic and probabilistic seismic hazard analysis was used to evaluate the seismic hazard of the 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 1), three models were assumed (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 potential seismogenetic zone of our study are (Figure 1), there are three active rapture models with different rapture lengths. For this reason, magnitudes were estimated for these models (that is, A, B and C models) as shown in Table 1 a and b.

Probabilistic seismic hazard analysis of region

The westward motion of Turkey relative to Eurasia is related to the collision between Arabia and Eurasia in the Caucasus and Eastern Turkey, which is thought to have started about 12 million years ago in the Mid-Miocene. The thickened crust in Eastern Turkey provides the gravitational potential energy, or buoyancy force, driving Turkey westwards; most of this motion being

Table 1a. Model A: approximately 119 km rapture length; Model B: approximately 108 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 1b. 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

accommodated along the North and East Anatolian strike slips fault systems (Ketin, 1948; McKenzie, 1972, 1978;Sengor, 1979; Oral, 1994; Oral et al., 1995; Taymaz, 2000). The neotectonic related geodynamic evolution of the Mediterranean started during and after the collision of Africa with Arabia. In Northern Anatolia, total consumption of the Tethian Ocean between the Sakarya continent and the Taurides created a compressional system which affects the region since Late Cretaceous. The N-S shortening deformation continued until the late Eastern Anatolia was transferred to the N-S compression toward the west from ate Miocene onward. In this escape regime, the North and East Anatolian strike-slip fault systems have played important roles.

The N-S shortening deformation regime was replaced by an N-S extensional system in the western part of the Anatolian plate as a result of the escape tectonism. In this period, the crust reached an excessive degree of thickening, which was generated from the Upper Mantle. Marmara Region is located in North-west Turkey and connects the Aegean Sea with the Black Sea. The Sea of Marmara includes a series of tectonically active basins at the western end of the right-lateral North Anatolian Fault (Taymaz, 2000). It is 275 km long and 80 km wide with a broad shallow shelf to the south and a series of deep (up to 1250 m) sub-basins to the North (Taymaz, 2000). The most frequent and destructive earthquakes occurred in Turkey. Historical records show that the Anatolian Peninsula has experienced many major shocks that have damaged and destroyed urban centers. The Marmara Sea earthquake on 10 September, 1509 destroyed Istanbul and was one of the largest earthquakes in the last 5 centuries. In the 20th century the most devastating earthquakes were: the magnitude 8 Erzican-Refahiye earthquake of 26 December 1939; the magnitude 7.1 earthquake on 13 March 1992 near Erzincan which ruptured the same segment of the North Anatolian fault that broke in 1939 (500 dead, 2,000 injured, 60,000 homeless); the Golcuk earthquake of 17 August 1999 (with a magnitude of Mw = 7.6 that caused more than 15,000 dead and 40,000 injured people and economic losses of about 16 billion USD (7% of GDP). The combined toll of these earthquakes, concentrated on the North Anatolian fault zone, over the century is 58.000 deaths, 116.000 injuries and excessive building damages and monetary losses (Sayin, 2002). Some important earthquakes in Marmara region are given in Table 2a.

In Table 2b, earthquakes were given in our area as about 150 km radius. Gutenberg-Richter recurrence relationships were determined as:

$$\mathrm{Log}\,(N) = 2.55 - 0.58M \quad (1)$$

Table 2a. Some important earthquakes in Marmara region (Sayin et al., 2002).

Year	Location	Magnitude
1912	Sarköy – Mürefte	Ms = 7.3
1935	Marmara Adasi	Ms = 6.3
1953	Yenice – Gönen	Ms = 7.4
1957	Abant	Ms = 6.9
1963	Cinarcik	Ms = 6.3
1964	Manyas	Ms = 6.8
1967	Adapazari-Mudurnusuyu	Ms = 7.0
1975	Çanakkale	Ms = 6.7
1999	Gölcük	Mw = 7.6

Table 2b. Earthquakes in our area about 150 km radius (Data 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	6.5 ≤ M < 7.0	7.0 ≤ M < 7.5
Numbers	51	17	8	2	1	3

Table 3a. 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	98.6	100.0	100.0	100.0
5.5	88.8	100.0	100.0	100.0
6	67.2	99.6	100.0	100.0
6.5	43.4	94.2	98.6	99.7
7	25.2	76.6	88.7	94.5
7.5	13.8	52.4	67.2	77.4

Earthquake occurrence probability was given in Table 3a by using:

$$Rm = 1- ^{(N(M).D)} \qquad (2)$$

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

In Table 3a, earthquake occurrence probability for region is given. For example, occurrence probability for 10 years of magnitude, 7.5 is estimated as 13.8%. 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 was calculated as 0.46 g (for Joyner and Boore (1981) model) and 0.52 g (Campbell (1997) model) with exceeding probability of 30% in 30 years (bold numbers in Table 3b). This was done by using the shortest epicentral distance of 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 were given in Table 3b.

GEOPHYSICAL AND GEOTECHNICAL DATA AND SOIL AMPLIFICATIONS

Geophysical analysis of soil amplifications

As it is known, shear wave velocity is an index property to evaluate the soil amplifications. In Table 4, it was given the shear wave and soil amplification relations according to Midorikawa (1984).

Study area is divided in to two zones: A and B zones as shown in Figure 3. To estimate the soil amplifications for two zones, seismic measurements were taken to obtain the shear wave velocities. Figures 4a and b show V_s30 values on map for A and B regions. Figures 5a and b show characteristic site period values on map for A and B regions. Finally, Figures 6a and b show soil amplification values on map for A and B region according to Midorikawa (1984) relation.

Table 3b. Estimated acceleration values for 7.6 magnitude and several epicentral distances.

M (magnitude)	Δ, 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	0,2	0.2	0.3	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	0.1	0.23	0.15	0.17	0.24	0.29	0.1	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	0.2	0,12	0.12	0.19	0.32	0.18

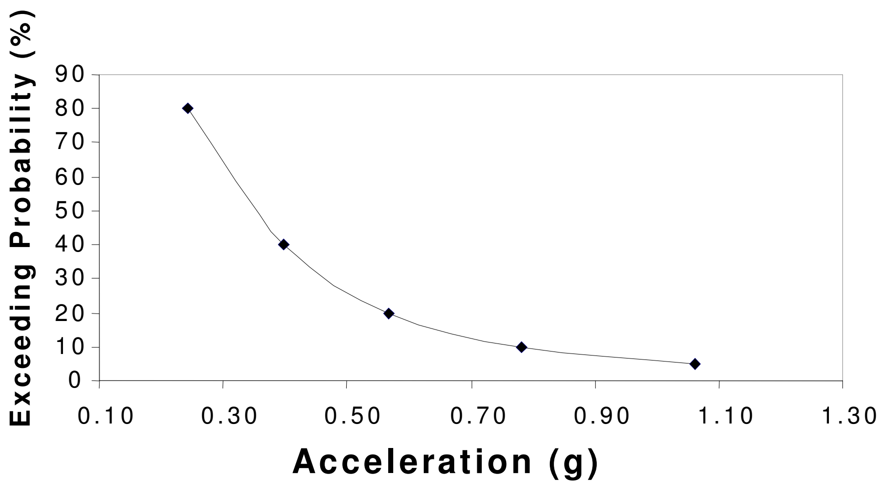

Figure 2. Hazard curve for region by using Joyner and Bore (1981) attenuation model.

Table 4. Shear wave velocity for 30 m and relevant relative soil amplification (A) (Midorikawa, 1987).

Midorikawa (1987)	$A = 68 Vs30^{-0,6}$ ($Vs30 < 1100$ m/s) $A = 1$ ($Vs30 > 1100$ m/sn)
($Vs30 = 30/ (\Sigma_{i=1, N} (hi/Vsi))$ where Vsi is Shear wave velocity and h is thickness of soil	

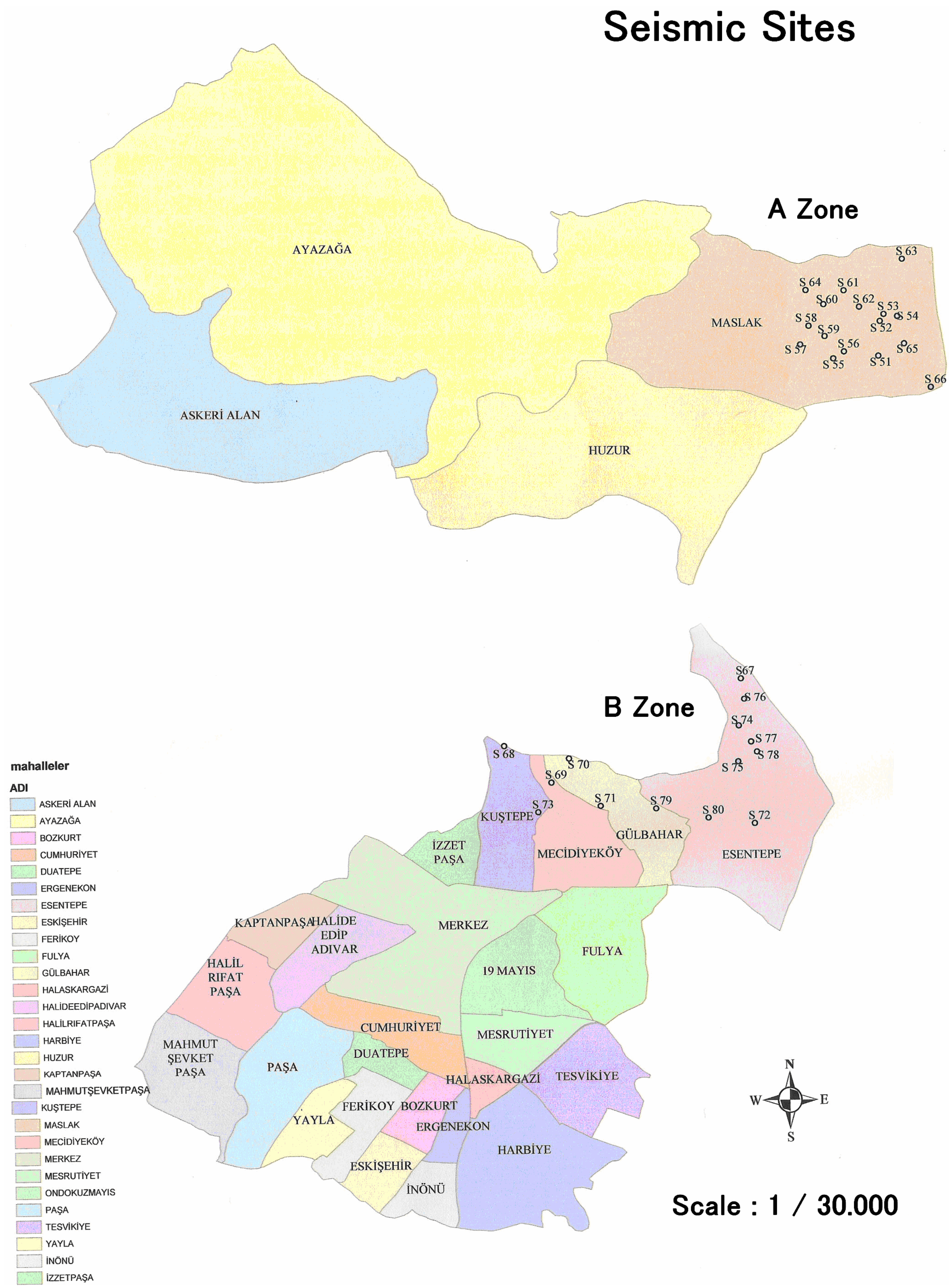

Figure 3. Seismic sites for the region.

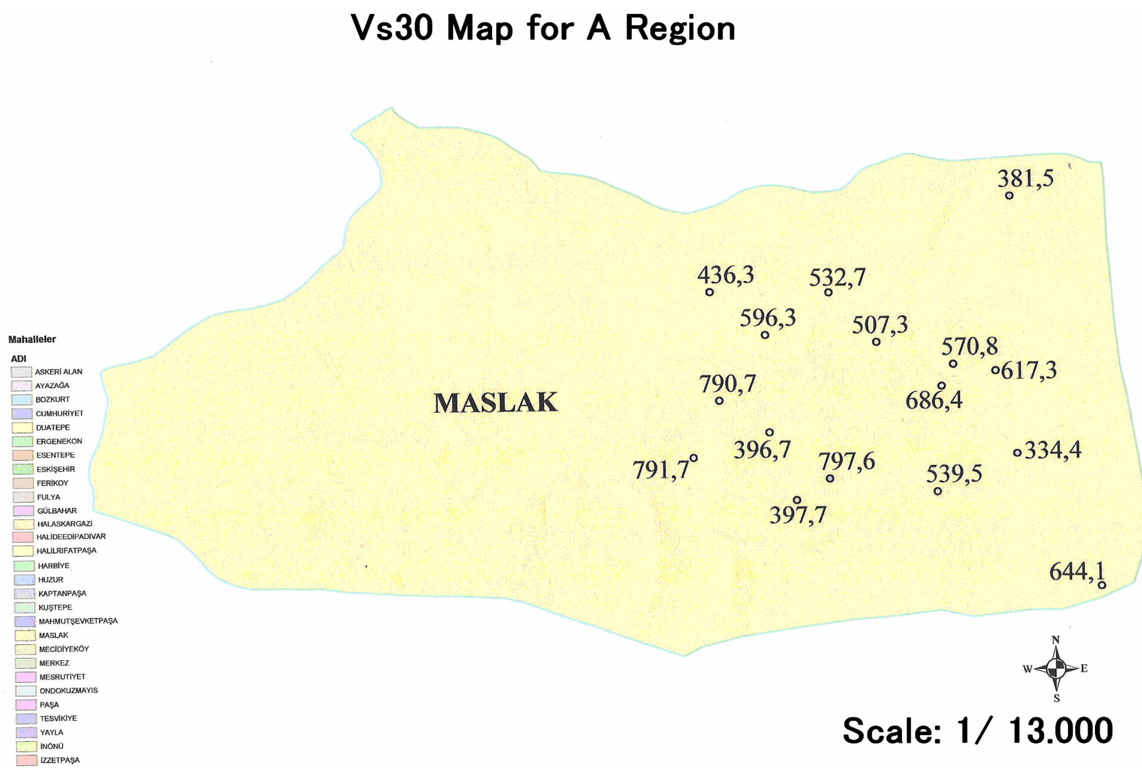

Figure 4a. V_s30 values on the map for region A.

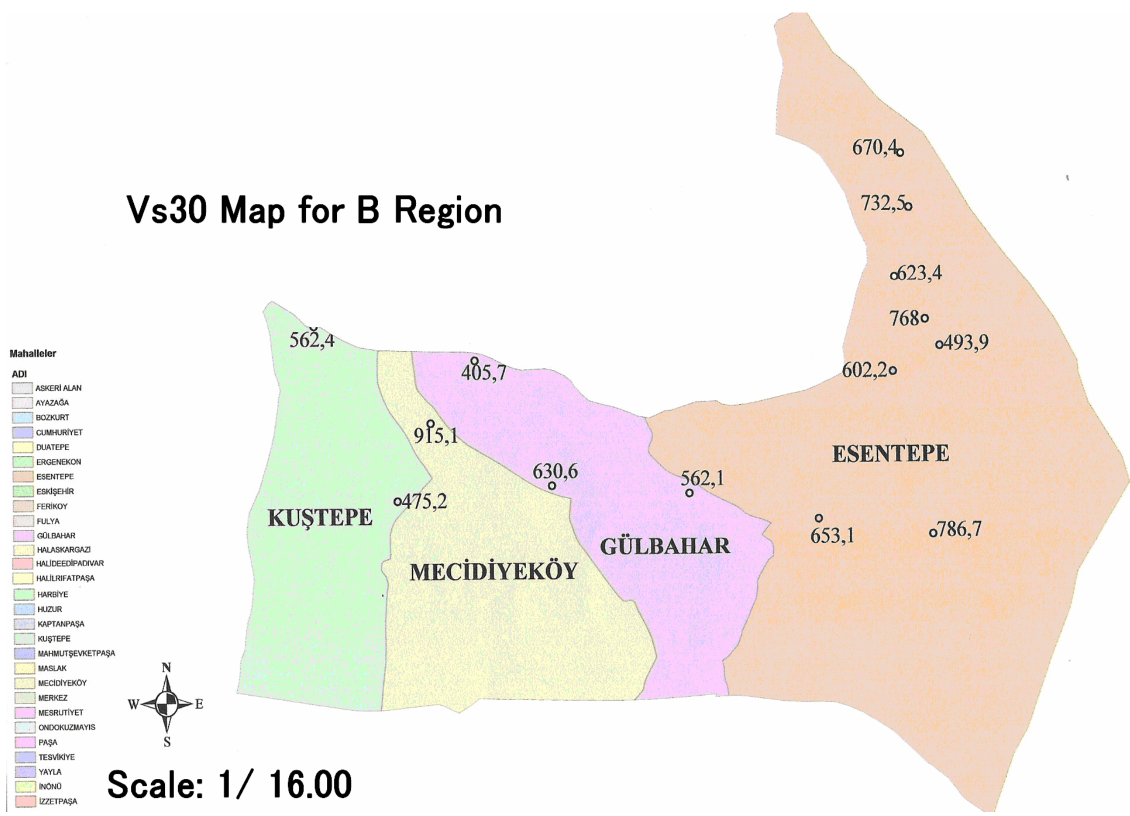

Figure 4b. V_s 30 values on the map for region B.

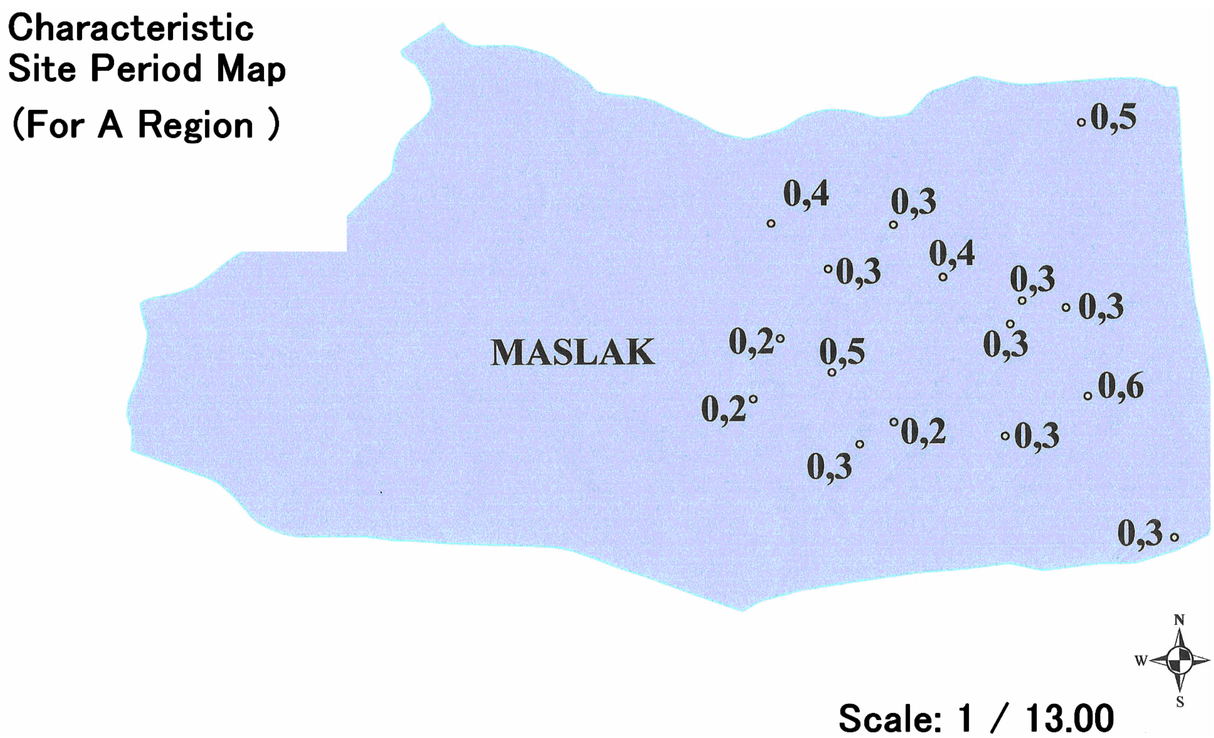

Figure 5a. Characteristic site period values on map for region A.

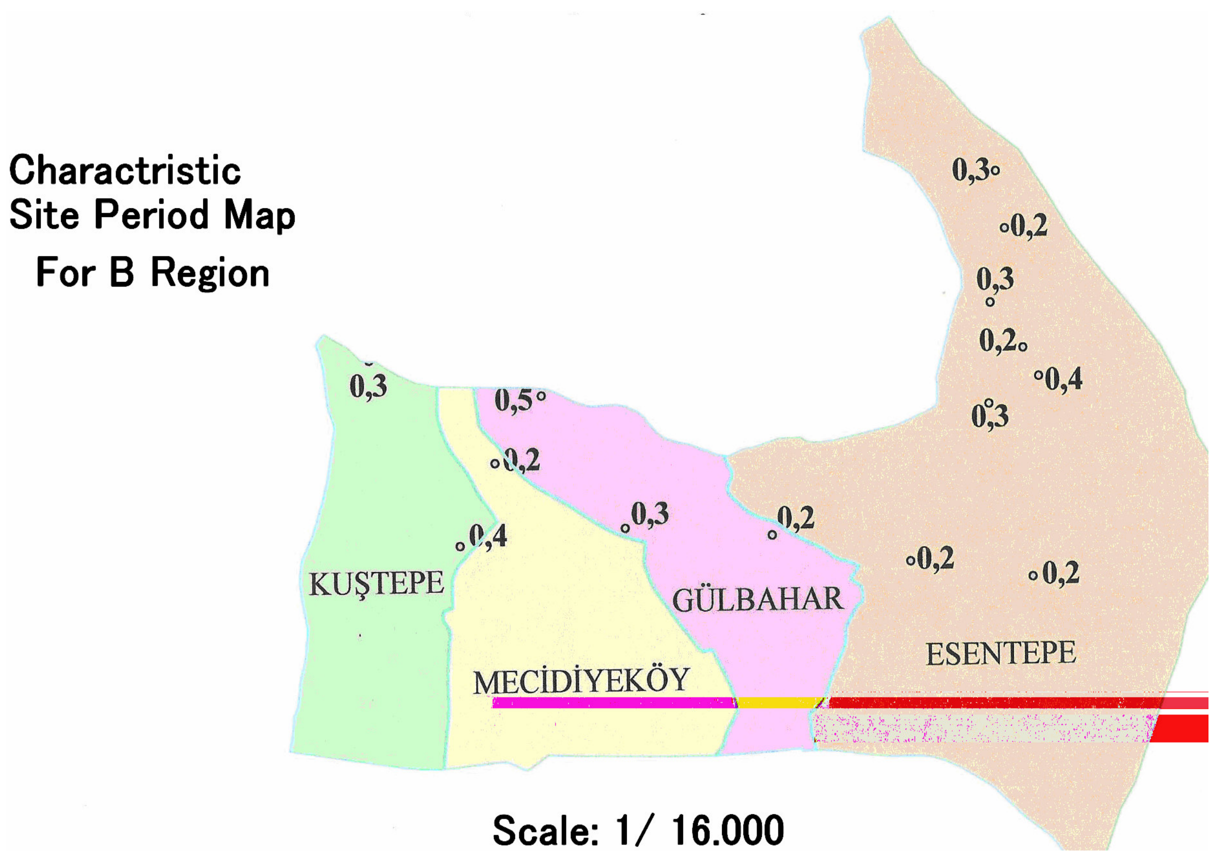

Figure 5b. Characteristic site period values on map for region B.

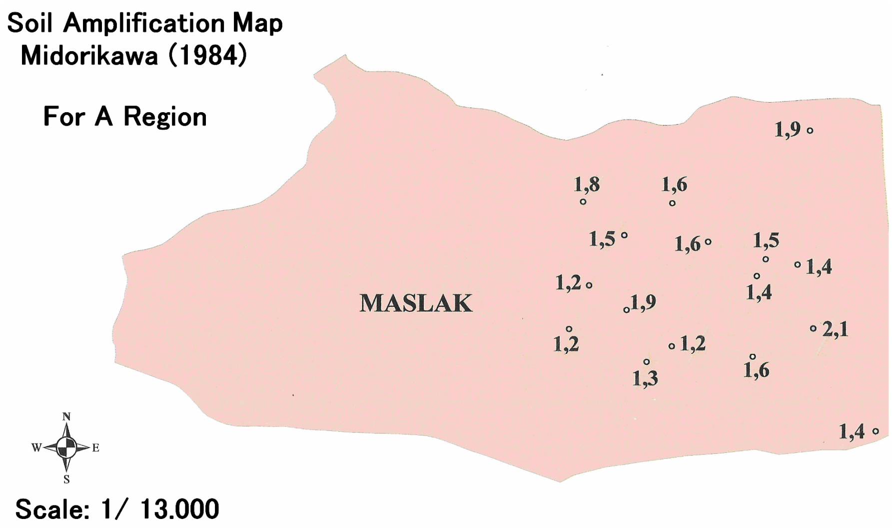

Figure 6a. Soil amplification values on map for region A according Midorikawa (1984) relation

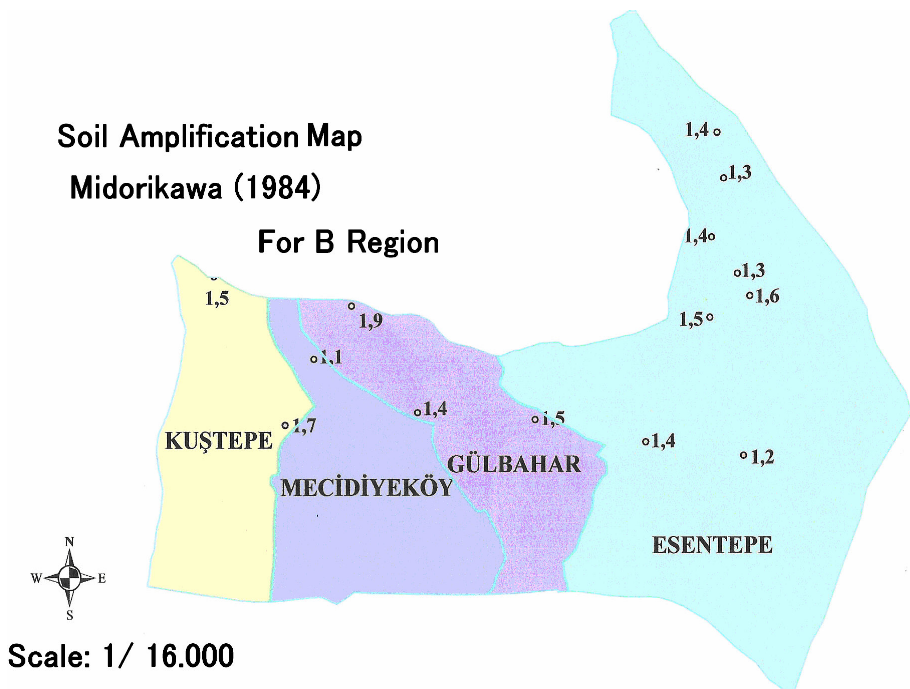

Figure 6b. Soil amplification values on map for region B according Midorikawa (1984) relation.

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 effectson the obtained blow counts (Seed et al., 1985; Skempton,

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

Boring point	Equivalence 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	2.0
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

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

$Vs = 51,5(SPT)^{0,516}$ (3)for A and B regions (Tables 4a and b).

RESULTS AND DISCUSSION

Seismic microzonation requires multi-disciplinary contributions as well as comprehensive understanding of the effects of earthquake that generate 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.

The 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 30% in 30 years. Acceleration values vary from 0.40 g for the shortest distance (15 km) to 0.18 g for the 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 with 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 are from 0.2 s to 0.5 s. From geotechnical data, soil amplifications are estimated in the range of 1.5 and 2.0. As a result, geotechnical and geophysical data on soil amplification on sites confirmed and in agreement with 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 its development.

Fast and efficient use of geophysical and geotechnical data in urban microzonation studies makes it 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 a good

Table 4b. Soil amplification values obtained by equivalence shear wave velocity (Vs30) for region B.

Boring point	Equivalence shear wave for 30 m Vs 30 (m/s)	Relative soil amplification
		Midorikawa
1	339	2,1
2	392	1,9
3	477	1,7
4	358	2,0
5	477	1,7
6	477	1,7
7	477	1,7
8	368	2,0
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

example for this aim. Geophysical and geotechnical data can be easily and fast evaluated in this context.

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

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