International Journal of the Physical Sciences Vol. 6(5), pp. 1169-1195, 4 March, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS11.090
ISSN 1992 - 1950 ©2011 Academic Journals

Full Length Research Paper

Geophysical analysis of the soils for civil (Geotechnical) engineering and urban planning purposes: Some case histories from Turkey

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Accepted 28 February, 2011

The aim of this study is to review the geophysical investigations in civil engineering and urban planning by some case histories in Turkey. Geophysics deals with a wide array of earth phenomena, including the temperature distribution of the earth's interior (the source, configuration and variations of the geomagnetic field) and the large-scale features of the terrestrial crust, such as rifts, continental sutures and mid-oceanic ridges. From the geophysical point of view, civil engineering and urban planning includes several geophysical topics used to investigate the physical properties, the physical techniques for regional and local land use planning or micro-zonation, the natural disaster risk estimation studies, etc. In this study, the geophysical approach, regarding civil engineering and urban planning against the natural or artificial disaster risk in macro (human/nature) and micro (society/earth) scales, is given. Geophysical methods provide solutions to a wide range of geotechnical problems: Slope stability, soil liquefaction and amplification studies, site investigations and testing, water works, subways, etc. In this study, an evaluation of the geophysical methods applied to geotechnical problems related to the soils is presented. Soils consist of the products of physical and chemical weathering of the rocks of the earth's crust. As a part of the engineering design, the aim of a site/soil investigation is to provide the basic data to evaluate the interaction of the natural environment with the proposed structure. As it is known, using physical measurements in geophysics, it is studied as the natural and artificially generated physical fields of the earth.

Key words: Geotechnical engineering, geophysics, earthquake engineering, soils, soil dynamics.

INTRODUCTION

In both archeological and modern periods, that is, in the context of hiding/preserving (ancient times), and in the context of balancing the situation under static and dynamic effects (present times) of "man-made structure" and related materials, there is a soil-structure interaction. This interaction, on the one hand, is the indicators of developments of natural sciences in the context of physical and chemical evolution/development of soils. On the other hand, it also indicates the developments of human sciences in the context of the evolution of the man-made structure from ancient time to present time. In other words, soil, with the structure and related materials, is a media for ancient and modern times. Hence, this media has both "scientific and social meanings". This study was prepared to emphasize the importance of properties of soils that is common to both geotechnical (local) and urban planning (regional) studies. There are several types of physical properties and analysis (in the laboratory and in the field) used to evaluate the soil structure and related materials buried in the soil. Structures, which are a result of the human's cultural and social behaviors, can be investigated by two ways as

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figurative and non-figurative properties. Formal properties are physical-chemical properties such as weight, length, chemical composition of materials, etc. Non-figurative properties of structures are positions of structures in time and spatial domain. Structures (in other words buildings) of the present time must be in equilibrium with soils against static and dynamic forces. Causes of the instability of equilibrium are related to the interaction between the static/dynamic forces of soils and structures. Static forces cause problems of bearing capacity, settlements and slope stability, related to the soil properties. On the other hand, dynamic forces cause liquefaction and amplification problems in the soils. All of these disturb the equilibrium in soils and structures.

Geophysics in civil (geotechnical) engineering and urban planning studies is not only a invesitigation tool, but also an analysis (or test) tool. This paper is related to the "analysis" aspects of geophysics.

In this study, several cases of histories in Turkey about the importance of "soil" in the context of geotechnical and urban planning studies are presented (Alpaslan and Özçep, 2008; Ozcep et al., 2009a, b, c; Karabulut et al., 2009).

CIVIL ENGINEERING, URBAN PLANNING AND GEOPHYSICAL STUDIES

A city is a relatively large and permanent settlement, particularly a large urban settlement (Goodal, 1987; Kuper anad Kuper, 1996). On the other hand, a civil engineering structure is usually defined as any large, man-made artificial object that is permanently fixed to the earth's surface or its orbit, as a result of construction.

The primary need, generated not only from the earthquake preparedness, but from all kinds of disasters (floods, landslides, etc) originated by the earth's structure and movements, is a change of mentality and/or urban growth policy. Another necessary change, at the urban planning level, is the balanced and proper distribution of urban facilities within the city.

The urban geophysics has been developing since the early 1980's to solve the various environmental problems occurring in the urban areas. In historical context, for example, the earthquake disaster that appeared in the 1964 Niigata earthquake was one of the early examples of the urban geosciences (Rau, 1994). Several soil problems (liquefaction and settlements), induced by earthquake for the city has received strong attention to find the mitigations of the earthquake hazards. The earthquake hazard in the urban areas should be studied from the viewpoint of the interaction between the response of the ground and human engineering and social activities. The role of urban studies in earthquake disasters should be a prediction of the hazardous areas and the proposal of anti-disaster plans fitting well to geophysical/geotechnical conditions of the urban area.

The analysis of seismic and/or static soil effects can be performed by various methods: experimental, analytical, numerical methods, vibratory or propagative approaches. For example, soil dynamic response to earthquake motion is mainly influenced by surface layers thickness, geometry, shear moduli, as well as, the wave type, source location and directivity (Bard and Bouchon, 1985; Bard et al., 2002; Paolucci, 1999; Semblat, 2000a, b).

The estimation of earthquake motions at the site of a structure is the most important phase of the design of a civil engineering structure. The 1985 Mexico City and many recent earthquakes clearly illustrate the importance of local soil properties on the earthquake response of structures (Ovando-Shellley, 2007; Computers and Structures, 1998). For the realization of a seismic microzonation study, for urban planning purposes, the soil/rock model is mainly based on geotechnical/geological and geophysical (including seismological) data.

Many earthquakes in the past have left many lessons to be learnt which are very essential to plan infrastructure and even mitigate such calamities in future (Anbazhagan, 2009). The hazards associated with earthquakes are referred to as seismic hazards (Anbazhagan, 2009). The practice of earthquake engineering involves the identification and mitigation of seismic hazards. Microzonation has generally been recognized as the most accepted tool in seismic hazard assessment and risk evaluation and it is defined as the zonation with respect to ground motion characteristics, taking into account source and site conditions (TC4-ISSMGE, 1999).

Seismic microzonation is the generic name for subdividing a region into individual areas, having different potential hazardous earthquake effects, defining their specific seismic behavior for engineering design and land-use planning (Sitharam and Anbazhagan, 2008). The role of geophysical and geotechnical data is becoming very important in microzonation, and in particular, in the planning of the city's urban infrastructure, which can recognize, control and prevent hazards (Bell et al., 1987; Legget, 1987; Hake, 1987; Rau, 1994; Dai et al., 1994, 2001; Van Rooy and Stiff, 2001).

The earthquake damage basically depends on three groups of factors: earthquake source and path characteristics, local geophysical and geotechnical site conditions, structural design and construction features (Ansal and Biro, 2004). Seismic microzonation should address the assessment of the first two groups of factors. In general terms, seismic microzonation is the process of estimating the response of soil layers for earthquake excitations and thus the variation of earthquake characteristics is represented on ground surface (Ansal and Biro, 2004). Seismic microzonation is the initial phase of earthquake risk mitigation and it requires a multidisciplinary approach with major contributions from geology, geophysics (seismology) and geotechnical

engineering (Ansal and Biro, 2004).

The main objective of the site/soil investigation process in civil engineering is to estimate or model the soil/rock media beneath the civil structure and the geotechnical properties of the various materials present at the site (McCann et al., 1997). It is essential that the presence of geological hazards (such as faults, zones of fractured rock, natural cavities, etc.), together with man-made hazards (such as, old mine-shafts and adits), is located and their effect on all aspects of a proposed construction is evaluated (McCann et al., 1997).

Geophysical studies have an important role to play in geotechnical investigations for civil engineering and mine development projects; however, geophysical engineers need to realize that greater care is required in the interpretation and reporting of geophysical results. In particular, geophysicists need to develop an increased sensitivity to alternative interpretations, consistent with a measured data set and their engineering implications.

Conventional site/soil investigation techniques like trial pits and boreholes can be expensive in areas of complex soil structure and behaviour. To solve the structure and behaviour of soils in that areas, the increasing use of geophysical methods can provide additional and supplementary information (McCann et al., 1997).

Soils consist of the products of physical and chemical weathering of the rocks of the earth's crust. As a part of the engineering design, the aim of a site/soil investigation is to provide the basic data to evaluate the interaction of the natural environment with the proposed structure. As it is known, using physical measurements in geophysics, the natural and artificially generated physical fields of the earth are studied. Geophysical methods provide additional information to a wide range of solutions of geotechnical problems: slope stability, pipeline studies, soil liquefaction and amplification studies, site investigations and testing, water works, dams, subways, etc. In this study, an evaluation about the geophysical analysis of soils in civil engineering and urban planning context with some case histories form Turkey is presented.

Soils under static and dynamic loads

Soils include the weathering products of the rocks. As a part of the engineering design, a soil or site investigation is carried out to provide the basic data by aiming the interaction between the proposed construction and natural environment. Soil layers are in interaction with constructions and earthquakes. For example, the earthquake wave affects the soil strength characteristics, while soil strength characteristics also change the frequency, duration and amplitude properties of earthquake waves. Civil engineering structures also interact with soils by transferring their loads into soil layers. In both urban planning and civil engineering context, soils are exposed to the static and dynamic impacts/effects. For this reason, a detailed geophysical and geotechnical analysis or soils is required. Static and dynamic problems related to the soils may be grouped as bearing capacity, settlements analysis, slope stability problems, soil liquefaction and amplification analysis.

Soils are grouped into two main classes as fine grained and coarse grained soils. To withstand the static and dynamic effects of a construction, three engineering characteristics must be known:

1. Earthquake and/or dynamic properties.
2. Soil structure and dynamics.
3. Construction properties.

The static and dynamic behaviors of soil/sites include more complex applications which are carried out by geophysical and geotechnical studies (Table 1). Some important application areas of geophysics in civil engineering and urban planning context are given in Table 2.

CASE HISTORIES

Geotechnical parameter (Soil water content) estimation from geophysical data

For geotechnical engineers, the strength, the stress-deformation behavior and the fluid flow properties of earth materials are of primary concern and they form the conventional framework of the geotechnical discipline (Mitchell, 2004). The solid and liquid phases play an essential role in soil spontaneous electrical phenomena and in the behavior of electrical fields, artificially created in the soil. Engineering properties of geomaterials are very important for civil engineers because almost everything they build (tunnels, bridges, dams and others) are in, on or with soils or rocks. The study area is located in Istanbul (Yesilkoy, Florya and Basinkoy) and Golcuk areas. The geophysical methods of vertical electrical sounding were used for measuring soil electrical properties and were tested in different soil studies. In this area, the electrical resistivity was measured by VES (vertical electrical sounding), and in many points of this location, it was done by field resistivity equipment. For geotechnical purposes, on the soil samples from borings, soil mechanics laboratory procedures were applied and the soil water contents were determined from these samples. Relationships between soil water content and electrical resistivity parameters were obtained by curvilinear models. The ranges of this study's samples were changed from 1 to 50 ohm .m (for resistivity) and 20 to 60% (for water content). For this range, the relation between resistivity (R) and water content (W) of soils was found to be given as $W = 49,21e^{-0,017R}$ (Figure 1a).

An artificial intelligent system (artificial neural networks

Table 1. Main flowchart of engineering studies to investigate the static and dynamic behaviors of soil/sites.

Desk study	Air photos, geologic maps and records, topographic maps, regional geophysical maps (earthquakes, etc.) and data, mining maps, previous soil maps, etc.
Site investigations and tests	
Site investigations	Trial pits, boreholes (Augers, Rotary Boring etc), geophysical investigations, etc.
Site tests	SPT test, CPT test, geophysical tests, plate loading tests, pressiometer tests, etc.
Laboratory tests	Classification tests, strength tests, dynamic tests
Determination and evaluation of engineering parameters and properties	Liquid and plastic limit, shear wave velocity, Poisson's ratio, elasticity modulus, electrical resistivity, design earthquake acceleration, soil characteristic period, cohesion, internal friction angle, spt values, groundwater depth, effective stress, etc.
Main problems of soils caused by static loads	Bearing capacity, settlement, slope stability, retaining walls, etc.
Main problems of soils caused by dynamic loads	Dynamic bearing capacity, dynamic settlements, dynamic slope stability, soil liquefaction, soil amplification
Examination and solutions for design of construction	

Table 2. Some important application areas of geophysics in civil engineering and urban planning context.

Basic geology and hydrology	Aid to sedimantogy and stratigraphy studies
	Aid to geologic maps
	Detection of faults and karstic areas
	Determination of hydrological characteristics
	Estimation of groundwater depth
	Bedrock mapping and failure surface of landslides
Exploration and operating of resources	Contributions of design of shallow marine boring platforms
	Determination of coal veins for mining equipments
Civil, mining and earthquake engineering	Aid to geomechanical studies for tunnelling and other mining activities
	Verification of soil improvements
	Estimation and mapping of soil and rock properties
	Estimation of rock rippability
	Pile integrity tests
	Soil liquefaction and amplification analysis
	Obtaining of soil strength characteristics for building and dam foundation
	Exploration for construction materials
	Ground (Earthquake) motion monitoring

and fuzzy logic applications: Mamdani and Sugeno approaches), based on some comparisons about correlation between electrical resistivity and soil-water content, for Istanbul and Golcuk soils in Turkey, was constructed for identifying the water content with electrical resistivity of soils (Ozcep et al., 2010a). By using artificial intelligent approaches, the purpose of this study is to compare the water content of soils obtained from electrical resistivity in order to have better results from the conventional techniques system. The input variables for this system are the electrical resistivity reading and the water content laboratory measurements. The output variable is the water content of soils. In this study, 148 data sets were clustered into 120 training sets and 28 testing sets for constructing the fuzzy system and validating the ability of the system's prediction,

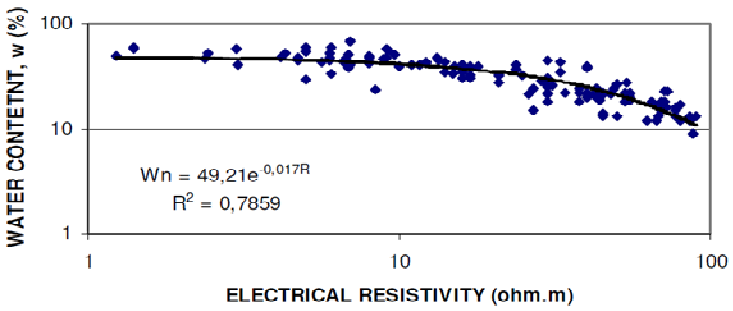


Figure 1a. Relationships between soil electrical resistivity and water content (Ozcep et al., 2009a).

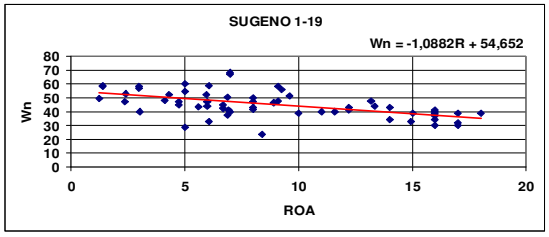


Figure 1ba. ROA values between 0– 19

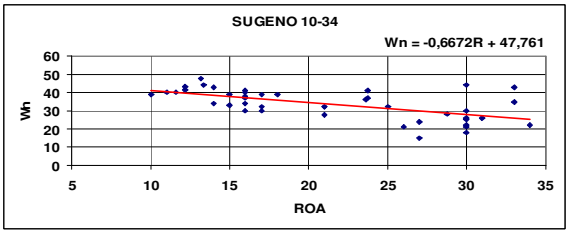


Figure 1bb. ROA values between 10 – 34

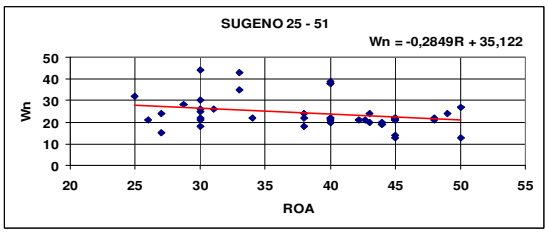


Figure 1bc. ROA values between 25–51

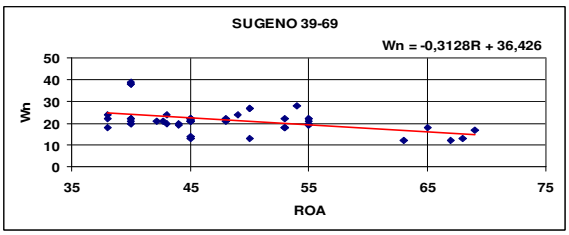


Figure 1bd. ROA values between 39–69

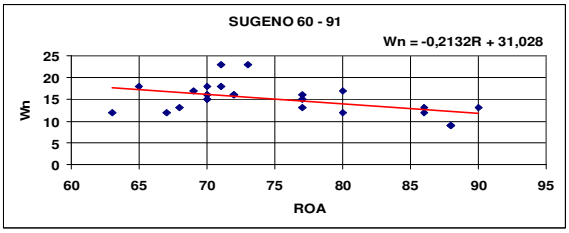


Figure 1be. ROA values between 60 –

Figure 1b. Formation of the sub-set according to the ROA variations.

respectively (Figure 1b and Table 1).

Soil liquefaction safety factors from geophysical and geotechnical data

Liquefaction resistance can be estimated by *in situ* test or laboratory test. Standard penetration (SPT), cone penetration (CPT) and shear wave tests are the most used for the estimation of liquefaction susceptibility. Liquefaction safety factors and liquefaction potential index methods, based on SPT, were developed (Seed and Idriss, 1971; Seed et al., 2001; Iwasaki et al., 1978).

The study area, in which the research was carried out by Ozcep and Zarif (2009), for Yalova city, was characterized by very large quaternary deposits, tertiary

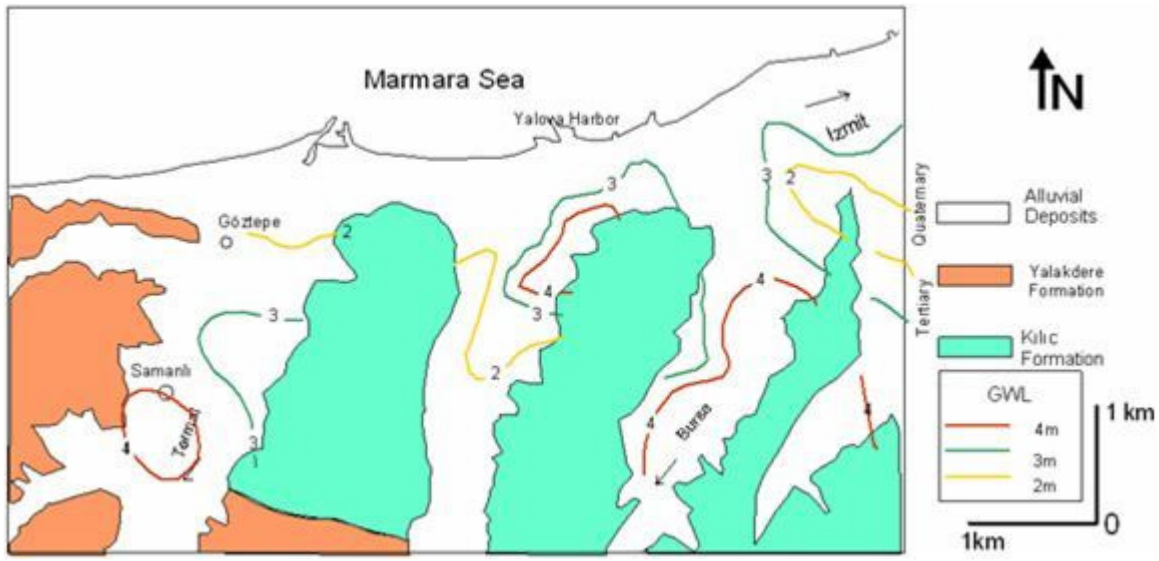


Figure 2a. Depth to groundwater map (from the surface) of Yalova region (Ozcep and Zarif, 2009).

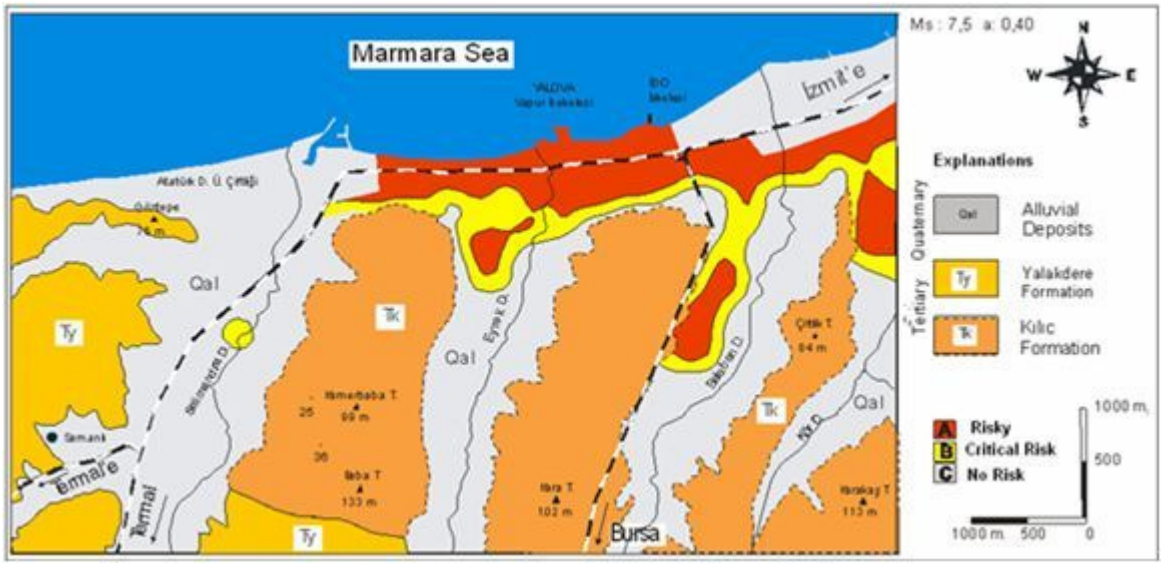


Figure 2b. Variations of liquefaction safety factors (SPT based methods) depending on earthquake magnitude (Ms): 7.5, and acceleration (a): 0.4 g (Ozcep and Zarif, 2009).

yalakdere and kilic formation. Quarternary deposits consist of stratified materials having varied grain sizes, and derived from the various geological units in the vicinity. Probabilistic and deterministic analyses were used to determine the safety factors for several parameters. For the study area, the probabilistic seismic hazard analysis showed very high seismic activity. By using deterministic seismic hazard analysis, the magnitudes were estimated for the three rupture (with four different fault lengths, 109, 120 and 174 km) model of North Anatolian Fault Zone in the Marmara region. By using the analysis (deterministic and probabilistic), estimated magnitudes and accelerations of earthquake were taken alternatively as 6.5, 7.0 and 7.5 for magnitudes and from 0.2 to 0.50 g for accelerations. For several design earthquake parameters, cyclic stress analysis of liquefaction was applied to the field data of both SPT (N) and S wave data, obtained in the Yalova region.

In the first phase of the study of liquefaction, the cyclic stress ratio approach was applied for all data in the analysis of soil liquefaction. Then, FS (factor of safety) values of liquefaction were estimated with this approach (Figure 2a and b).

Geotechnical and geophysical studies for wind energy systems

Wind energy structures are systems related to the conversion of wind energy into useful form by wind power. They are subjected to strong dynamic and static loads. For this reason, an integrated site/soil investigation is required for all phases of the project. In this context, there are several geotechnical/geophysical criteria and requirements such as settlement criteria, stiffness requirements, groundwater and dewatering requirements, excavation criteria, etc. Geotechnical and geophysical studies should include possible degradation of soil and rock due to cyclic loading over expected years of operation, bearing capacity, surcharge soil erosion due to drainage of storm water, differential settlements and consolidation settlements, etc. All soil layers that influence settlement and stiffness of foundation must be investigated. The study area is a seismically active region and is bounded in Bahçe district of Osmaniye city, in Turkey. The geodynamics of the region are controlled by the collision of the Arabian and Eurasian plates. The East Anatolian Fault Zone, which is the major seismogenetic source of the project area, has a length of 550 km, approximately northeast-trending, left lateral strike-slip fault. An (deterministic and probabilistic) earthquake hazard analysis was applied to the region to estimate the ground motion level in engineering bedrock. Several geotechnical/geophysical tests and boreholes were performed in the area to obtain better settlement, stiffness, bearing capacity and degradation properties (Ozcep et al., 2009b).

Determination of soil-structure relation foundation system

Required laboratory studies, over the observations, soil excavations and geophysical applications, have been made about the mentioned foundation soil which has been analyzed regarding the geotechnical perspective and the obtained parameters specified. The planned structures (wind towers) are high towers having rigid bearing systems. Raft foundation will be a proper foundation solution for this project since this kind of foundation will provide safety against differential settlements, and protect the integrity of the bearing system under earthquake loads, dynamic wind load and static loads.

Bearing capacity

Allowable bearing capacity calculations, regarding the related parameters about the soil / rock or structure, have been made separately in different approaches by taking into account land data, laboratory experiment results, drilling core observations and rock quality designation (RQD) values. The rock and soil formations of the environment have been taken into account in the selection of the calculation methods. At the soil / rock locations which are not convenient to provide samples proper for the experiments required for the method (especially in rock tri-axial experiment required for the Bell method), values which have been obtained from the other locations of the same unit or the known technical literature values have been taken into account. Bearing capacity of soils was estimated by Tezcan et al. (2006), using shear wave velocities of the soils

Settlements

It is not expected that the settlements, which exceed the acceptable limits under the load of the soil should occur as a result of the structuring over this soil, of which most parts that the structure foundation will be based on are clay, silt, the settlements value of the medium which has been calculated according to the elasticity module (dynamic) and Poisson ratio values. Special attention should be given not to place the foundation over the excessive splitted, weak durable or decomposed units, except the survey points during the foundation excavation and not to place the foundation over differentiated units. Before the construction and after the excavation, as well as, during and after the construction, it is required to protect the foundation area from the superficial waters and rains, and that adequate discharging system should be designed. Soil settlemets of soils were estimated by Tezcan et al. (2009), using shear wave velocities of the soils.

Liquefaction

There is no ground water danger in a depth of up to 20 m which can negatively affect the foundation structure over the survey area.

Soil class and other parameters

The soil of the survey area is formed of faulted, fractured and layered limestone units of rock. The Vs shear wave velocity (if the thin layer in the surface is ignored) which has been obtained from the geophysical-seismic studies, has been measured between 791 and 834 m/s. According to the Turkish earthquake code, these velocities correspond to soil group (A) and local soil class (Z1), but since these units are fractured and have frequent discontinuity intervals, it is better to classify them as B group Z2 soil class. A little bit more clarification explaining the difference between both classes is given in Tables 3 and 4. Spectrum characteristic periods which

Table 3. Soil groups according to Turkish earthquake design code.

Soil group	Shear wave velocity (m/s)
A	> 700
B	400 - 700

Table 4. Local site class and spectrum characteristic periods (TA, TB) according to Turkish earthquake design code.

Local site class	Soil group according to Table 6 and the topmost layer thickness (h1)	Spectrum characteristic periods (TA, TB)
Z1	Group (A) soils Group (B) soils with h1 ≤ 15 m	Between 0.10 and 0.30 s
Z2	Group (B) soils with h1 > 15 m Group (C) soils with h1 ≤ 15 m	Between 0.15 and 0.40 s

are regarded according to the selected foundation type TA and TB are 0.10 to 0.40 (s), respectively. However, the soil dominant vibration period has been calculated as 0.16 s.

Determination of the fundamental frequency of soils and engineering structures

The microtremor horizontal-to-vertical spectral ratio (H\V) technique is widely used in the urban environment to assess the fundamental frequency response of the soils (Nakamura, 1989; Mucciarelli, 1998). Earthquake damages may increase in case of an earthquake due to an increased structural response of the building. After the August 17, 1999 Izmit earthquake (Mw: 7.4), the building of the School of Engineering at Istanbul University was strengthened and repaired. The microtremor measurements were carried out for analysis of the ratio between the horizontal and vertical components of the spectra, recorded at a station located inside the school buildings, as well as the ratio between the corresponding components of the spectra recorded nonsimultaneously inside the building and at a reference station place in the basements of the School of Engineering. Figure 3aa, 3ab, 3ac, 3ba, 3bb and 3bc show the results of soil and building periods, obtained by microtremor measurement, using H/V spectral ratio appraoch.

Microzonation studies using shear wave velocity: Büyükçekmece (Istanbul) region

Safety against earthquake hazards has two aspects. First, the structural safety against potentially destructive dynamic forces and secondly, safety of a site itself related with the phenomena such as amplification, landsliding and liquefaction (TC4-ISSMGE, 1999). The importance of site safety from earthquake hazards has received increasing attention in recent years among engineers, scientists and city planners in seismically active regions in the world. For each kind of phenomenon such as local ground response, slope instability and liquefaction, three grades of approach to microzonation are described. The study area is located in Büyükçekmece (Istanbul). For microzonation purposes, the shear wave velocity has been obtained by seismic refraction measurements close to the borehole sites. Shear wave velocity of soil layers is a useful property for evaluating site amplification and liquefaction. For the study area, relative amplifications have been calculated by the approaches of Midorikawa (1987), Joyner and Fumal (1984) and Borcherdt et al. (1991). At the same time, liquefaction resistances of soil deposits were determined both by the shear wave velocity and SPT (N) values by the cyclic stress approach of Youd et al. (2001). The second part of Youd et al. (2001) procedure requires the determination of the cyclic stress ratio of earthquake. The accelerations of project earthquake were accepted as 0.4 and 0.5 g, according to the Marmara Sea fault models. For the investigated area, liquefaction safety factor (FS) and liquefaction potantial (PL) have been determined. Also, by using the shear wave velocities, soil classification maps (NEHRP), site charectristic period map, amplification maps and liquefacition safety maps, have been prepared (Ceyhan et al., 2004; Karabulut et al., 2006). According to the soil classification map, soils are categorized as C and D in the study area. On the other hand, according to the site characteristic period map, period values are between 0.3 and 0.6 s. Relative amplifications are between 1.4 and 3.6 values in this area. Liquefaction safety factors and

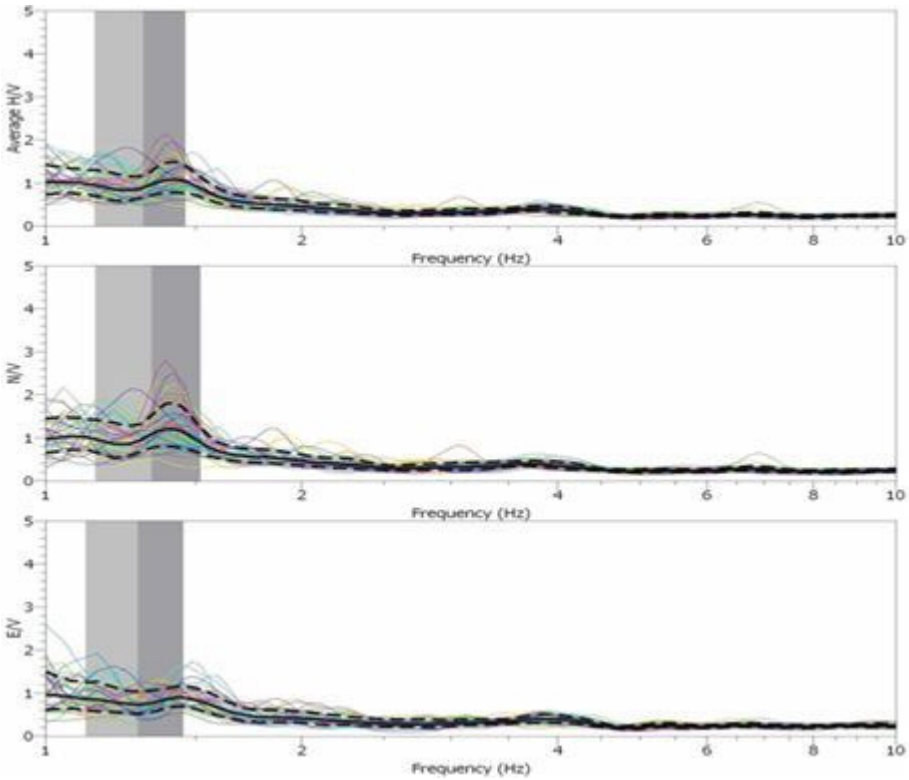


Figure 3aa. Horizontal/vertical spectral ratio on basement floor (H/V), north/vertical (N/V) and east/vertical (E/V) from top to bottom, respectively (X: 1 to 10 Hz, Y: 0 to 5) (Karabulut et al., 2009). Solid line, dashed line and other colored lines show respectively “average spectrum”, “minimum and maximum envelop of spectrum” and “all spectrum”.

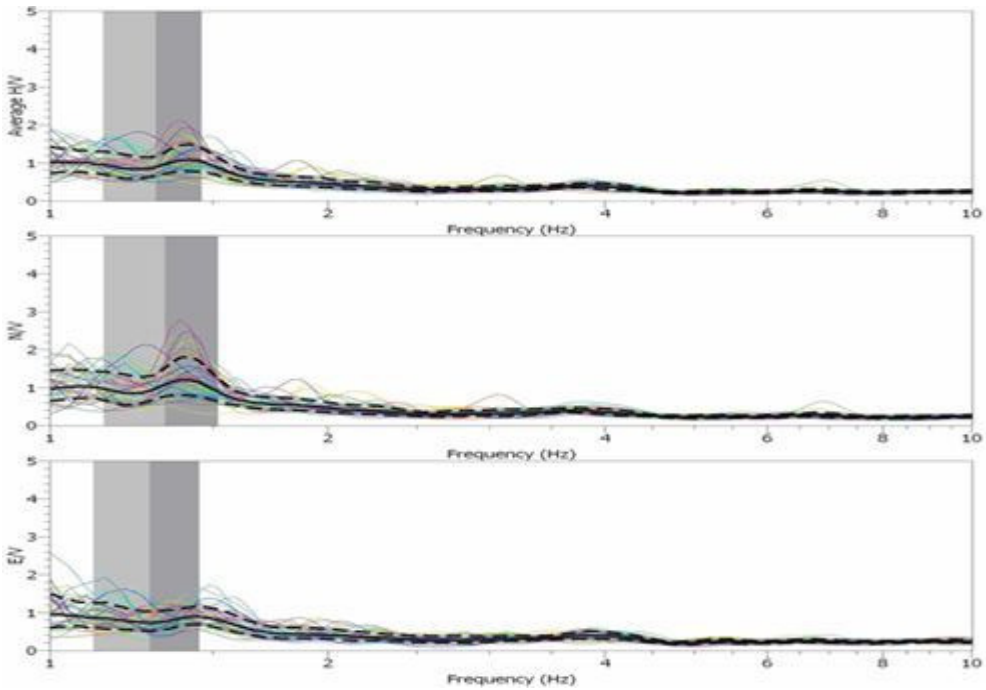


Figure 3ab. Horizontal/vertical spectral ratio on first floor (H/V), north/vertical (N/V) and east/vertical (E/V) from top to bottom, respectively (X: 1 to 10 Hz, Y: 0 to 5) (Karabulut et al., 2009).

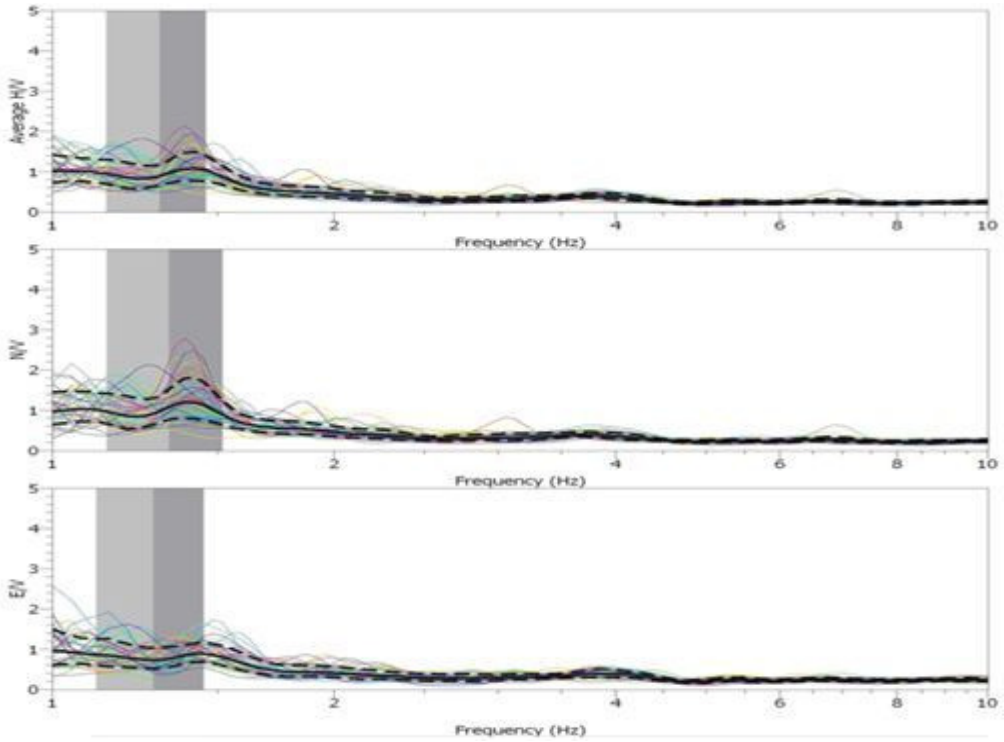


Figure 3ac. Horizontal/Vertical spectral ratio on top floor (H/V), North/Vertical (N/V) and East/Vertical (E/V) from top to bottom, respectively (X: 1-10 Hz, Y: 0-5) (Karabulut et al, 2009).

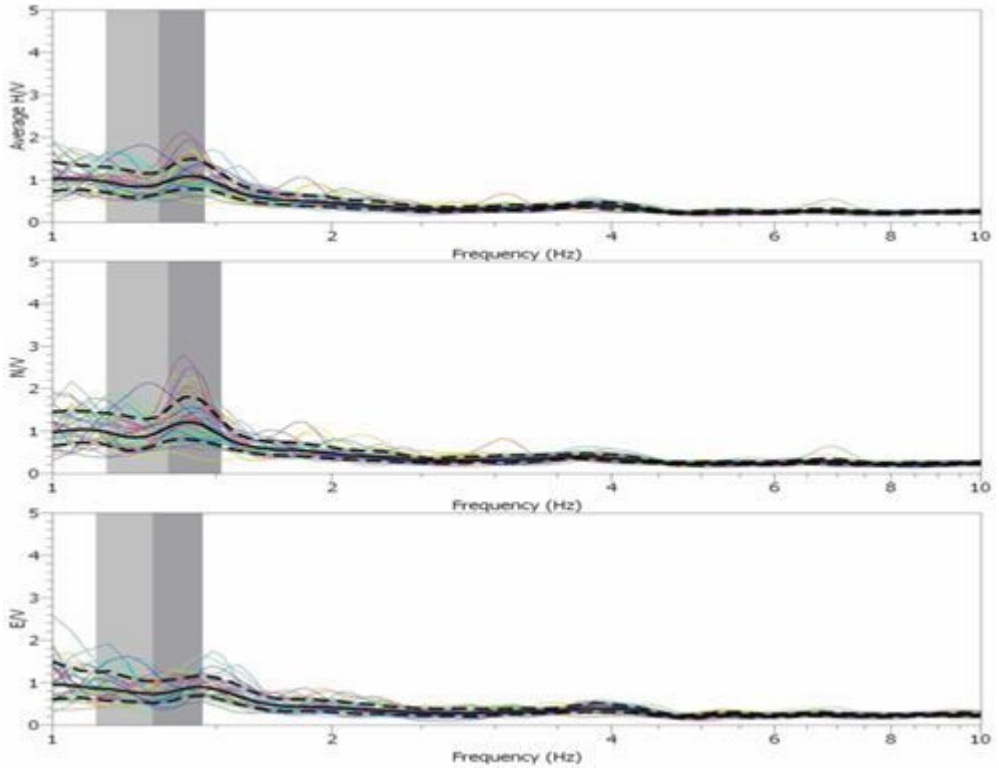


Figure 3ba. Spectrum of the components for all floors. Basement (X: 1-10 Hz, Y: 0-500) (Karabulut et al., 2009).

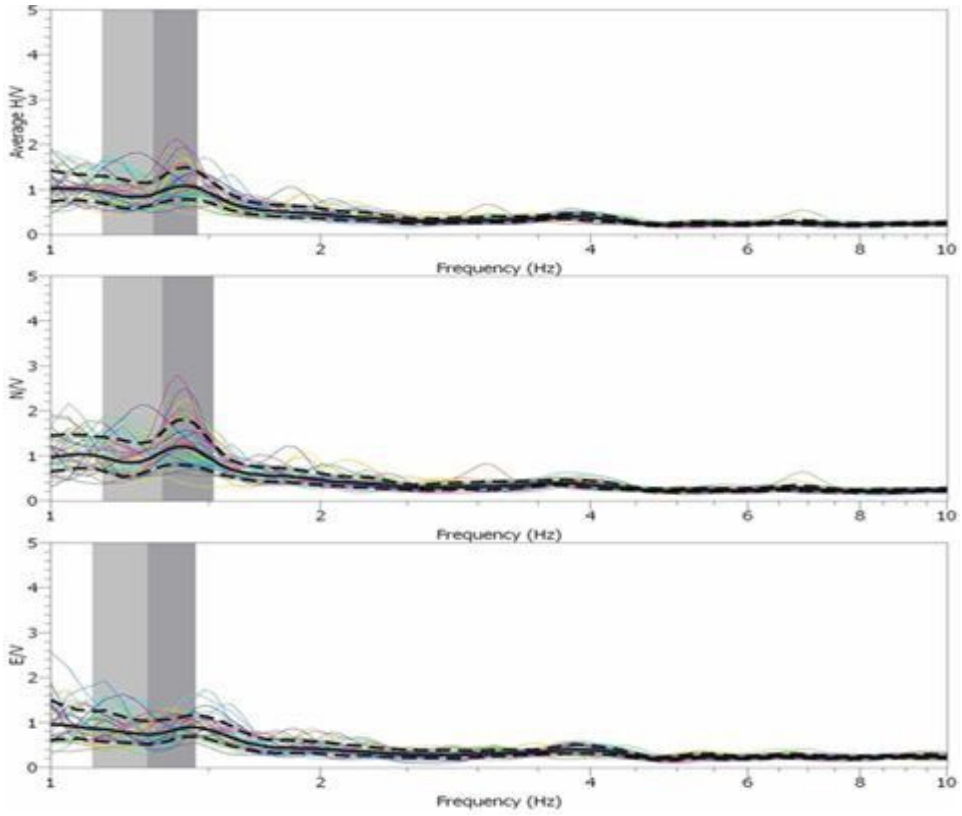


Figure 3bb. Spectrum of the components for all floors. First floor (X: 1-10 Hz, Y: 0-500) (Karabulut et al., 2009).

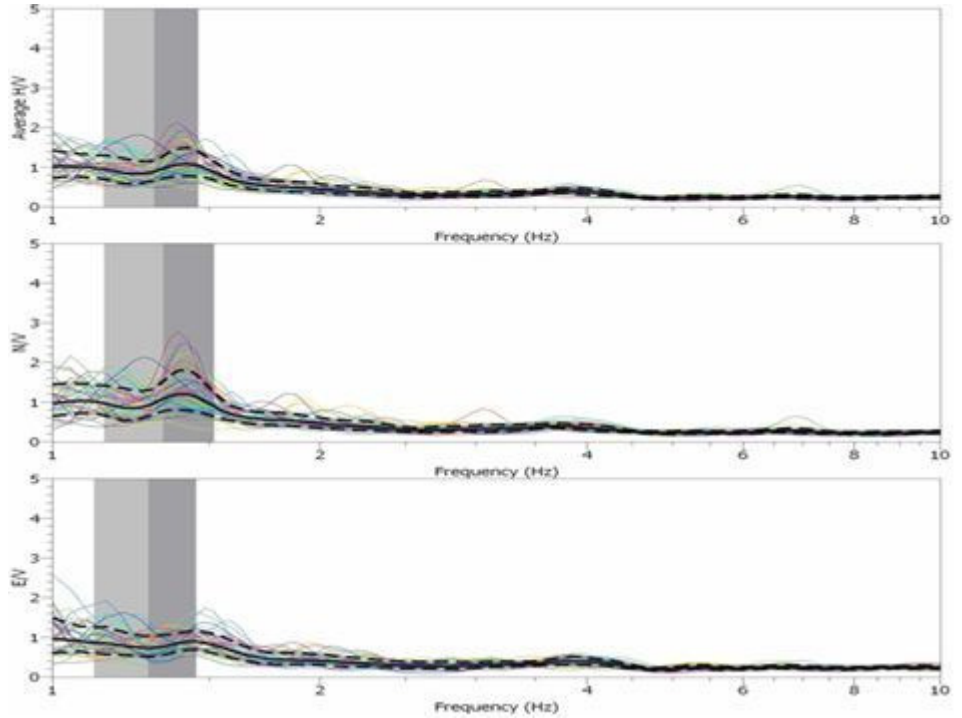


Figure 3bc. Spectrum of the components for all floors. Top floor (X: 1- 10 Hz, Y: 0-1000) from top to bottom, respectively (Karabulut et al., 2009).

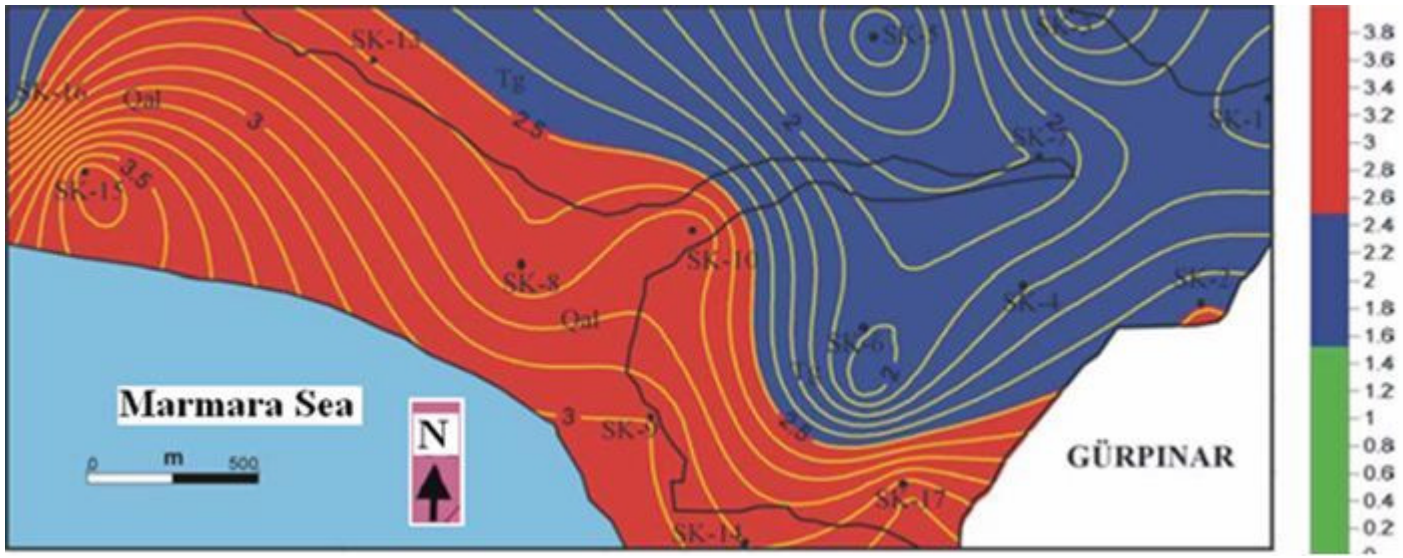


Figure 4a. Acording to Borcherdt et al. (1991) appraoch, soil amplification map of the region (Ceyhan et al., 2004; Karabulut et al., 2006).

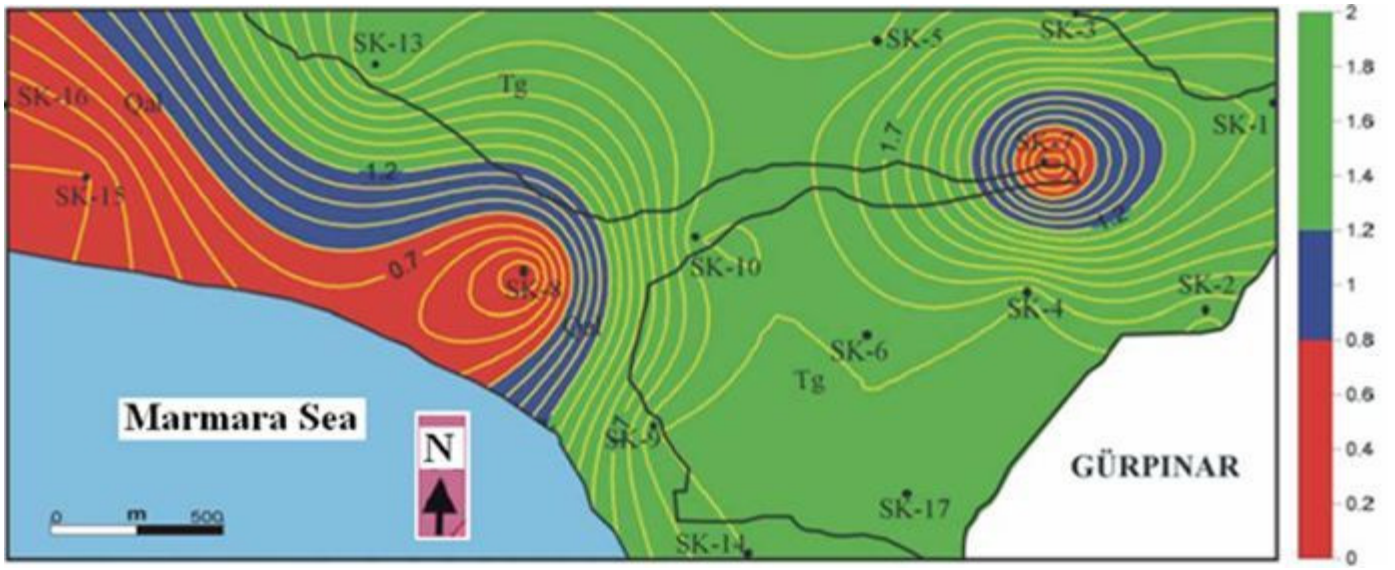


Figure 4b. Variations of soil liquefaction SF for 0.5 g in the region (Ceyhan et al., 2004; Karabulut et al., 2006).

liquefaction potential parameters in some sites (SK15, SK16, SK7 and SK8) are respectively smaller than 0.8 and greater than 15%. Figure 4a shows, according to Borcherdt et al. (1991) appraoch, the soil amplification map of the region, while Figure 4b shows the variations of soil liquefaction safety factor for 0.5 g in the region.

Integrated use of geophysical and geotechnical data in microzonation studies

A small scale microzonation study was undertaken in Sisli (Istanbul) region. The main purpose of this study is to provide the combined use of geophysical and geotechnical data in the context of microzonation. Due to earthquake occurrences on the North Anatolian Fault, 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 probobalistic seismic hazard analysis was determined by using Poisson and Gumbel probalistic approaches. The hazard gives the probality that a given level of acceleration will exceed 20% in a given time period of 30 years, by Joyner and

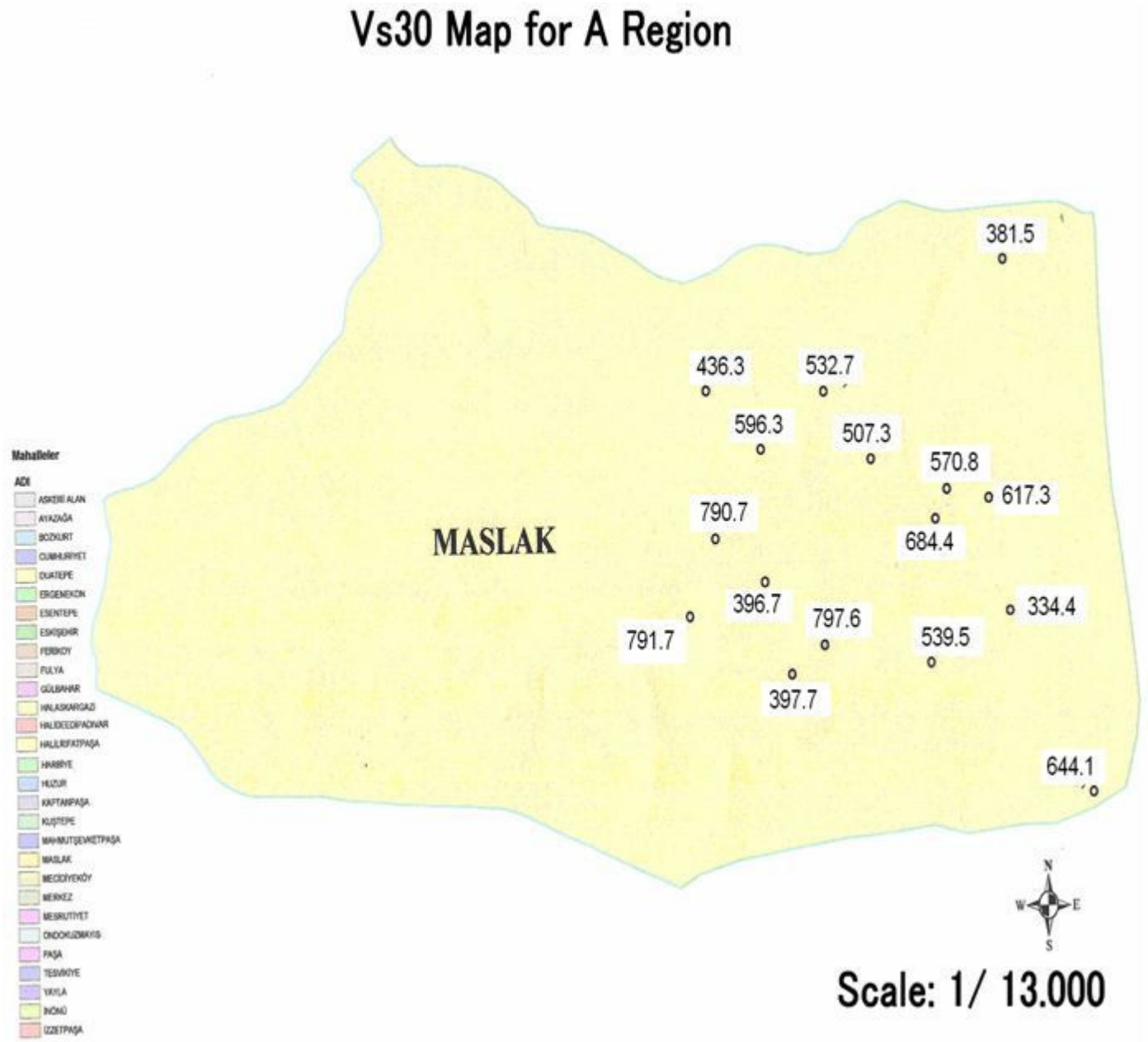


Figure 5a. V_s 30 values on the map for a region (Ozcep et al., 2006a, 2007).

Bore's (1981) approach. By using the deterministic seismic hazard analysis, the maginitudes were estimated by the four rapture (with four different fault length: 108, 119, 37 and 174 km) model of North Anatolian Fault Zone in Marmara region, while by using both analyses (deterministic and probobalistic), the magnitude of the 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 SPT test data for the area of Sisli, which is an important part of Istanbul city (Ozcep et al., 2006a, 2007a, b). From shear and compresional wave velocities, several soil properties were determined and presented in table form. Geotechnical test data from boreholes and laboratory measurements were evaluated with geophysical data. Soil amplification values estimated by empirical relationships and shear wave velocities are in range of 1.0 and 2.1 values. However, shear wave velocity (Vs, 30) values are 381.5 and 915 (m/s), while site characteristic period range is between 0.2 and 0.5 s (Figure 5a and b).

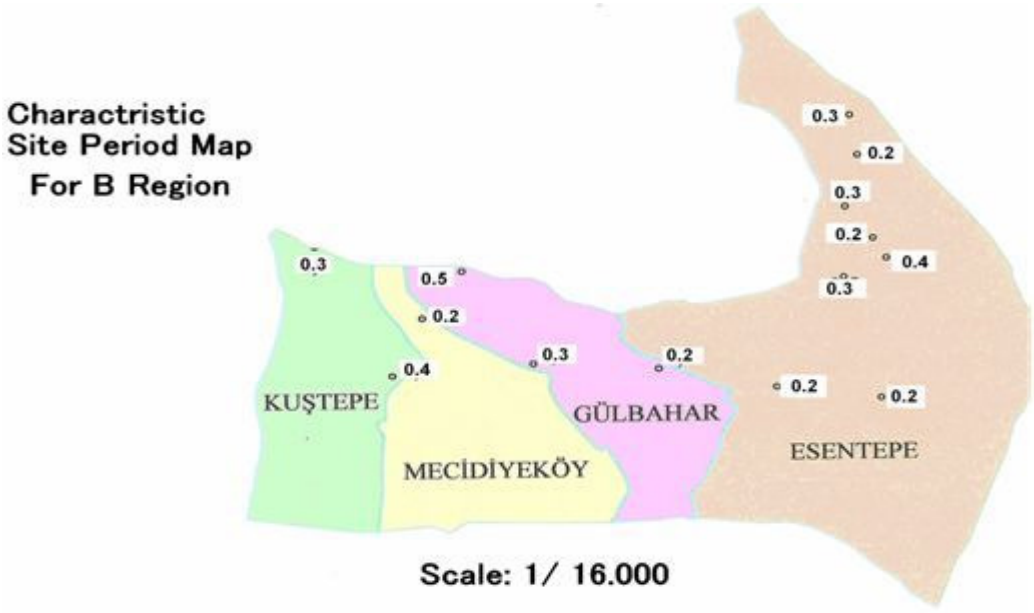


Figure 5b. Characteristic site period values on the map for B region (Ozcep et al., 2006a, 2007).

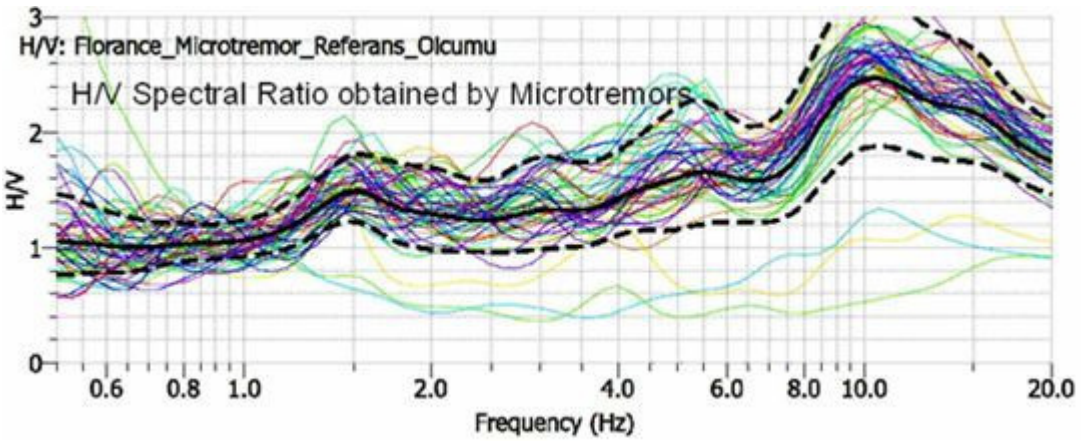


Figure 5c. H/V spectral ratio obtained by microtremors.

Comparasions of the characteristic site period values obtained by seismic refraction with microtremor and earthquake data

The microtremor experiment was also carried out in Mecidiyekoy site of Sisli area and it aimed at recording ambient noise. A measurement of one station was deployed in Sisli. Data were 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 the data to obtain the fundamental frequency of the site (Figure 5c). Comparisons of the data set's H/V ratios show that the fundamental frequency agreement is close to 9 Hz. This fundamental frequency datum (0.11 s) is in agreement with the characteristic site period map.

The earthquake data, obtained from the Earthquake Research Department of State (Bayindirlik İskan Bakanliği Deprem Araştirma Dairesi), were evaluated by comparisons between the site periods close to Mecidiyekoy. Figure 5d shows H/V ratios of all earthquake data. When seismic, microtremor and earthquake data, were compared, all of them were in agreement with each other.

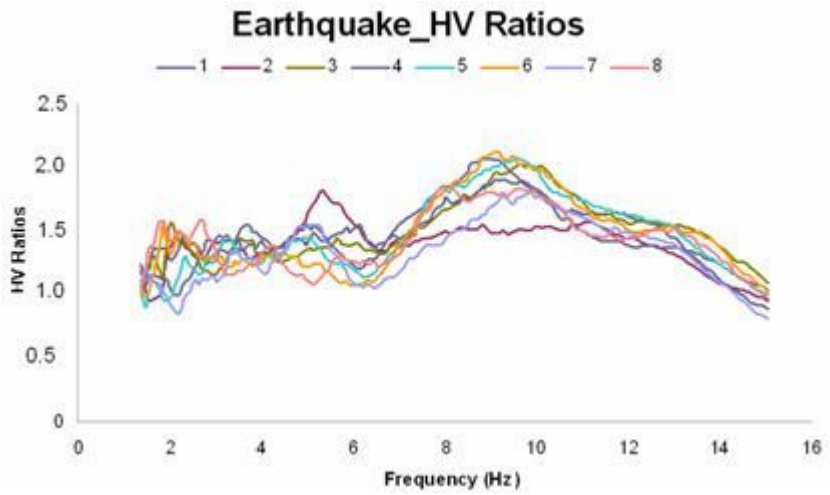


Figure 5d. H/V ratios of earthquake data.

Table 5. Performance evaluations and comparisons of formed models.

	Ann (1 5 1)	Mamdani	Sugeno	Regression
MAEP	17.76	19.99	17.63*	20.85
MES	33.62	43.12	32.59*	50.39
R^2	0.8844*	0.8268	0.8825	0.8454

* The best results.

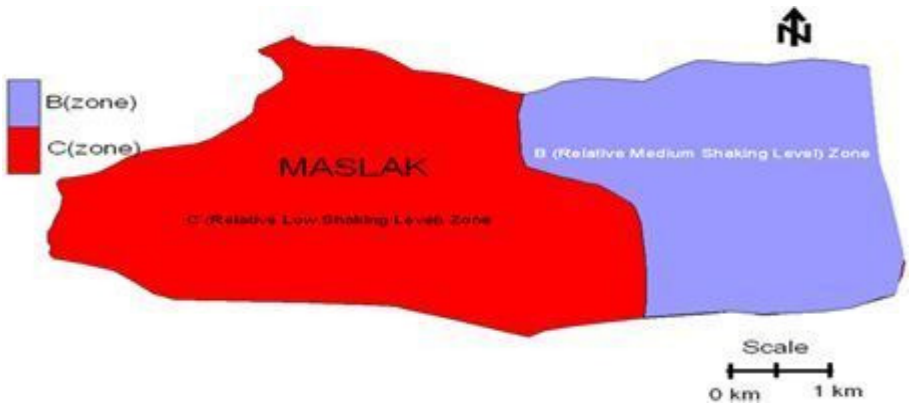


Figure 5e. Seismic microzonation map for A region (Ozcep et al., 2010d).

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

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

During the evaluation studies, the seismic refraction data were also used. The initial model that was obtained from these data was used as the initial model data. By using both forward and inverse solutions algorithm, S wave velocities were calculated and drawn, depending on the distance. In Table 5, MASW and MAM results on A and B region (Ozcep et al., 2010d).

Finally, Figure 5e and f show the proposed microzonation map for A and B regions. In this map, the

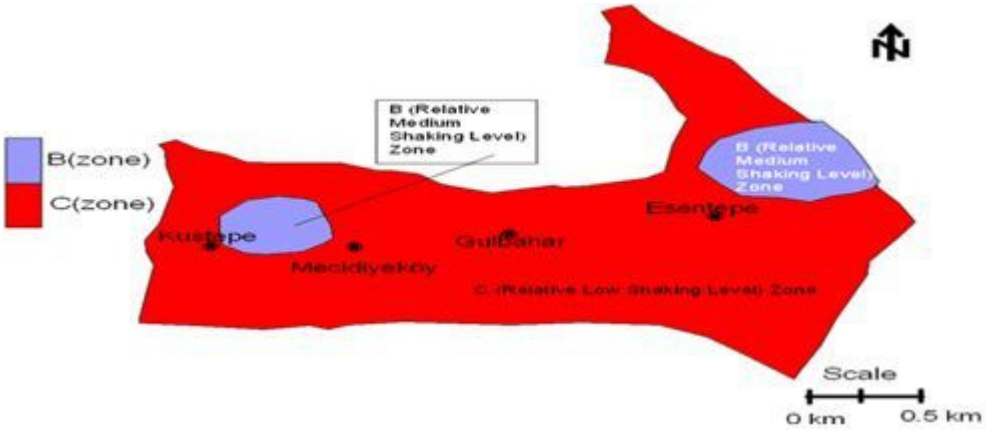


Figure 5f. Seismic microzonation map for B region (Ozcep et al., 2010d).

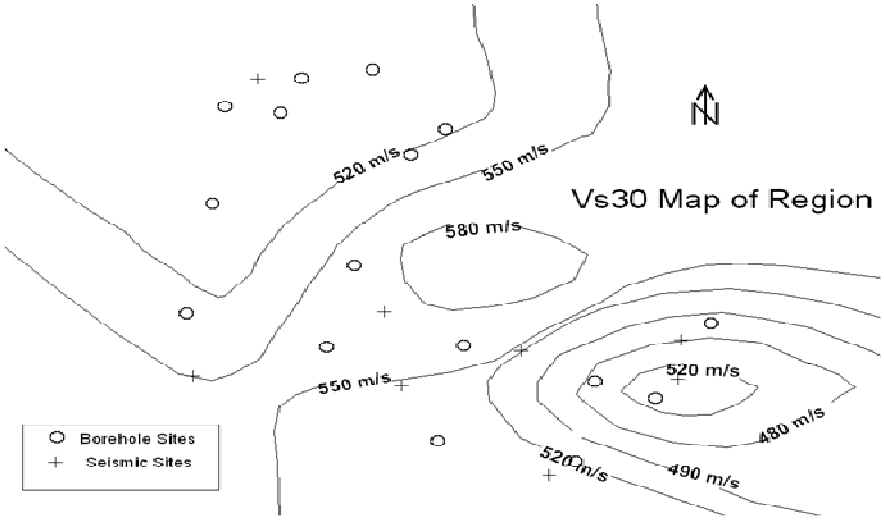


Figure 6a. Soil VS30 (m/s) map of the region (Imre et al., 2006).

criteria of World Institute for Disaster Risk Management (2004) were used. There are two microzonation zones (Figure 5e and f), namely C (relative low shaking level) and B (relative medium shaking level) zones.

Micro-scale seismic-zonation for the new urban areas: Silivri (Istanbul) case

Documents on historical events and modern geophysical data analysis of site effects show that earthquake damage distribution is not uniform and it varies with local soil conditions. In other words, damaging potential of earthquakes can be strongly amplified by local soil conditions. This research focuses on the influence of the Silivri (Istanbul) area. The study area was first divided into cells by a grid system. Then, the soil profiles were classified according to the “Turkish Earthquake Code” from shear wave velocity and used for site response analyses. Soil amplification was evaluated by empirical approaches based on shear wave velocity (Vs, 30). The obtained micro-scale zonation map was based on the relative maximum amplifications. The micro-scale zonation map of the area with respect to ground shaking was established on the average of spectral amplifications obtained from shear wave velocities. Figure 6a, b and c show respectively, soil VS30, soil vibration period and soil amplification maps of the region.

Estimation of the liquefaction-induced ground settlements for Marmaray rail tube tunnel

From the liquefaction analysis, liquefaction-induced ground settlements were estimated by using Ishihara and Yoshimine (1992) approach which was carried out by

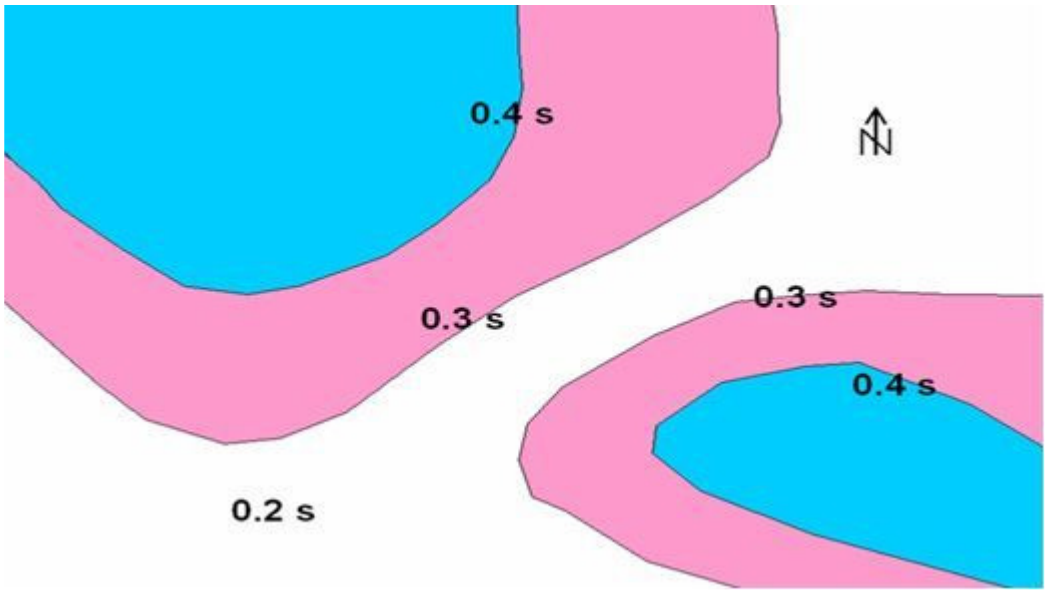


Figure 6b. Soil predominant period (s) map of the region (Imre et al., 2006).



Figure 6c. Soil amplification map of the region (Imre et al., 2006).

Imre et al. (2006). “Marmaray Rail Tube Tunnel and Commuter Rail Mass Transit System Project” provides an upgrading of the commuter rail system in Istanbul, connecting Halkali on the European side with Gebze on the Asian side with an uninterrupted, modern, high capacity commuter rail system. Railway tracks in both sides of Istanbul strait will be connected to each other through a railway tunnel connection under the Istanbul strait. The line goes underground at Yedikule, continues through the Yenikapi and Sirkeci new underground stations, passes under the Istanbul strait, connects to the Üsküdar new underground station and emerges at Sögütlüçesme. This project is one of the major transportation infrastructure projects in the world at present. The entire upgraded and new railway system will be approximately 76 km long. In this study, by using CPT data, and acceleration and magnitude data (obtained by seismic hazard analysis of Marmara region), the settlement analysis was carried out for Marmaray project. As it is known, liquefaction is a soil activity of saturated

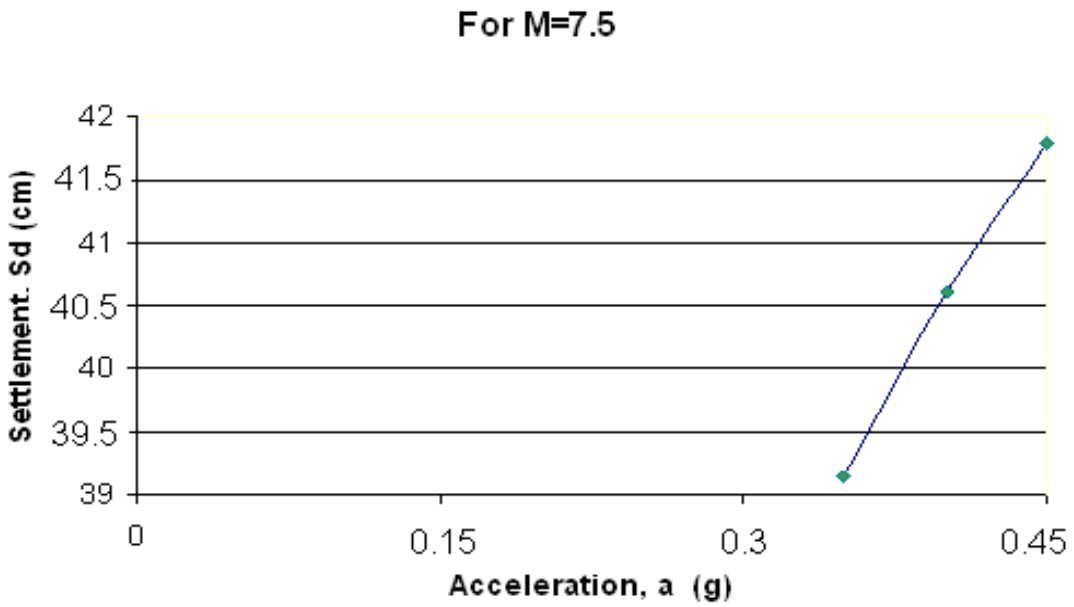


Figure 7a. Variation of liquefaction-induced ground settlements with acceleration by using BH4 borehole data for magnitude 7.5 (Yuksel and Ozcep, 2008).

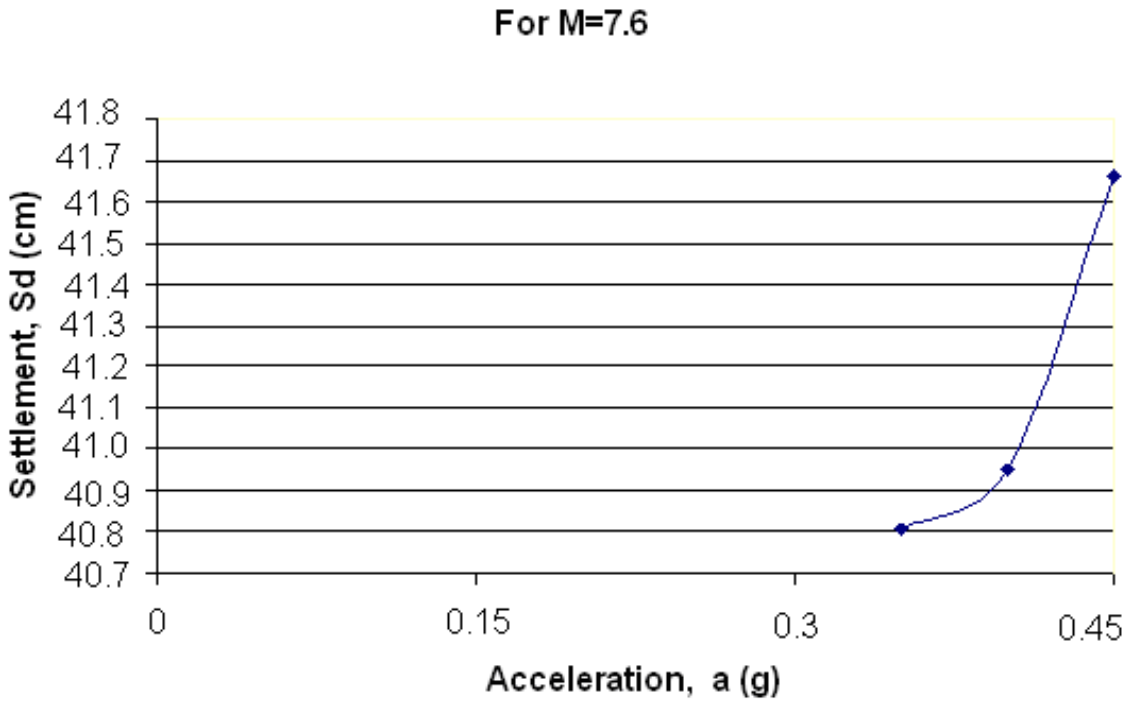


Figure 7b. Variation of liquefaction-induced ground settlements with acceleration by using BH4 borehole data for magnitude 7.6 (Yuksel and Ozcep, 2008).

sandy soils under earthquake/dynamic effects. In the first phase of the study, cyclic stress ratio approach was applied to all data for analysis of soil liquefaction (Yuksel and Ozcep, 2008). In the second phase of the study, by using Ishihara and Yoshimine (1992) approach, possible soil settlements for a number of design earthquakes (for several acceleration and magnitude values) were estimated (Figure 7a, b and c).

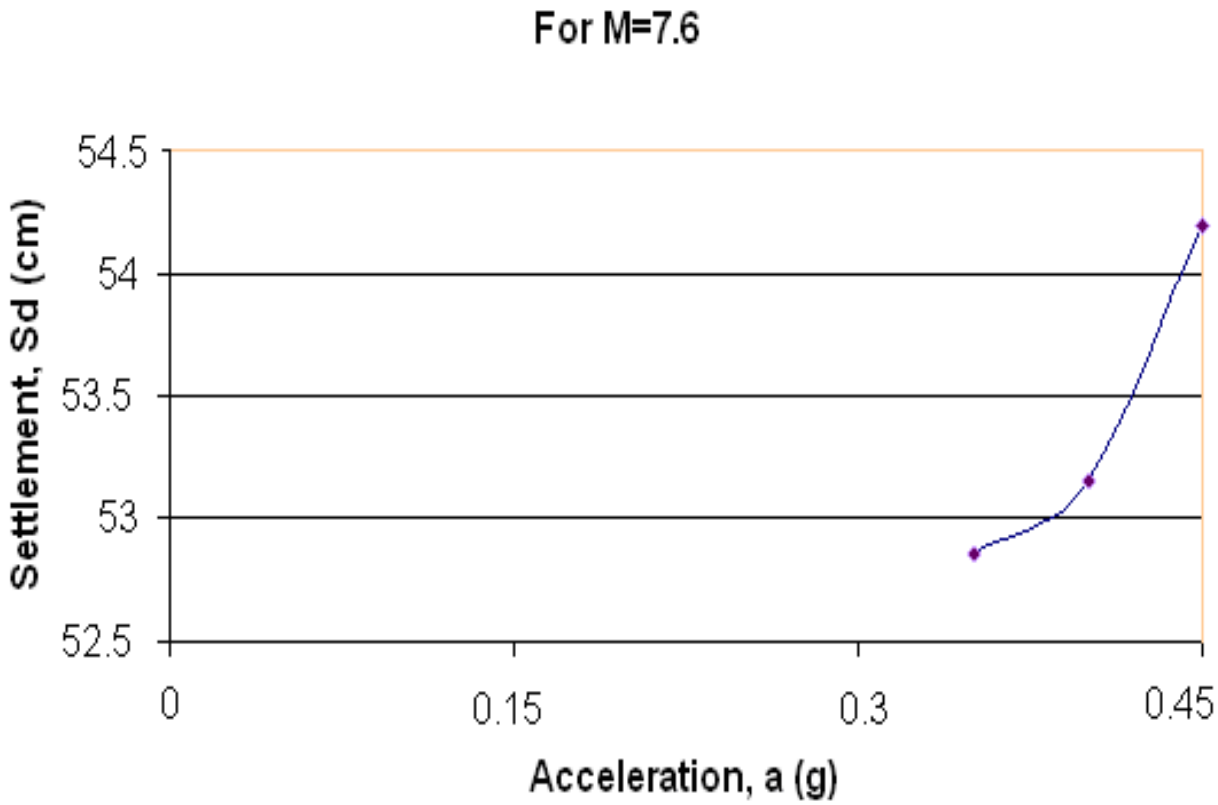


Figure 7c. Variation of liquefaction-induced ground settlements with acceleration by using BH5 borehole data for magnitude 7.5 (Yuksel and Ozcep, 2008).

Variation of soil bearing capacity with dynamic loads (Earthquake acceleration): Some examples from Istanbul

The static bearing capacity of soils has been extensively studied and reported in the literature. However, soils can be subjected to dynamic loads that may be in vertical or horizontal directions. Seismic bearing capacity and settlements of foundations were studied by Richards et al. (1993). Earthquake damages are controlled basically by three interacting factor groups: (1) Earthquake source and path characteristics, (2) local geophysical and geotechnical site conditions, and (3) structural design and construction features. Variation of soil bearing capacity with dynamic loads (that is, acceleration) is one of the most important factors of the structural design buildings that affected dynamic loads. In the study (Ozcep et al., 2006b), the authors's aim is to investigate the variation of soil bearing capacity with dynamic loads (that is, acceleration) in some sites of Istanbul city (namely, Avcilar and Bahçelievler). For this aim, some geophysical and geotechnical (boring and laboratory) data were obtained and all of these data were used to solve these problems. Figures 8a and b show variation of soil bearing capacity with dynamic loads (earthquake acceleration) in some sites of Istanbul.

An application of the new alternative in urban geophysics: Multi-channel analysis of surface waves (MASW) method

In the early 1980s, a wave-propagation method used to generate the near-surface *vs* profile, called spectral analysis of surface waves (SASW), was introduced (Nazarian and Stokoe, 1984; Nazarian, 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. Multichannel 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 in lower frequencies (for example, 1 to 30 Hz) and uses a much shallower depth range of investigation (for example, few ranges to a few tens of meters) (Park et al., 2007).

Geophysical studies are increasingly being applied to geotechnical investigations as they can identify soil properties and soil boundaries. Another advantage is that

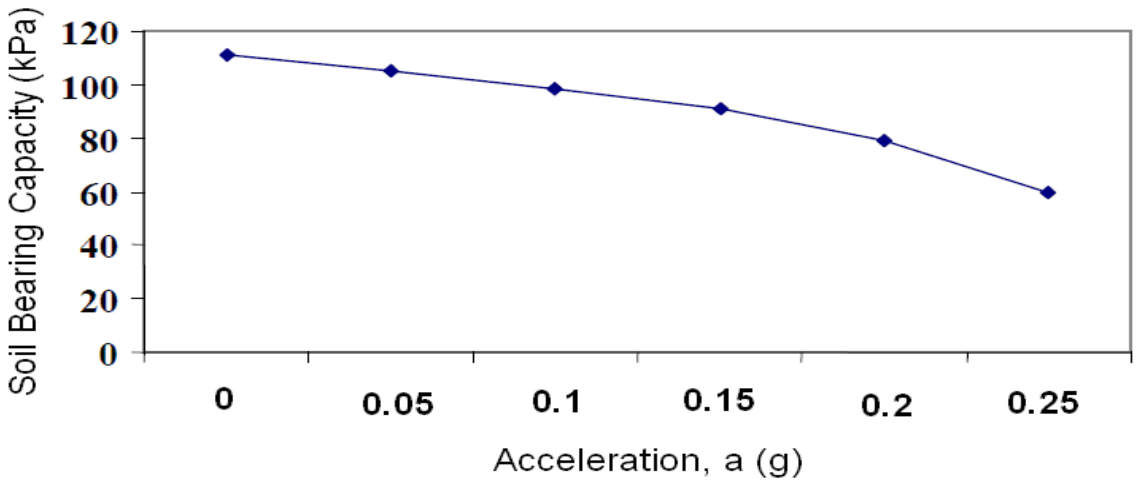


Figure 8a. Variation of soil bearing capacity with dynamic loads (Earthquake acceleration) in Avcilar (Istanbul) (Ozcep et al., 2006b).

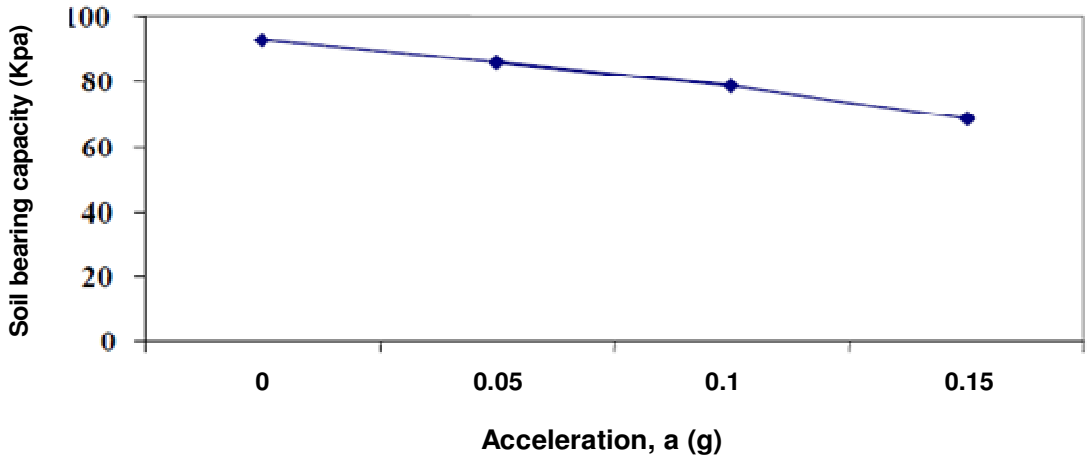


Figure 8b. Variation of soil bearing capacity with dynamic loads (Earthquake acceleration) in Bahcelievler (Istanbul) (Ozcep et al., 2006b).

many of these methods are non-invasive and environment friendly. Spectral analysis of surface waves is a simple and efficient method for determining the shear-wave velocity of soils *in situ* and their variation with depth (Cuellar, 1997). The non-destructive character of the method, together with the possibility of generating long wavelengths by letting a weight drop from a certain height, makes it a very suitable technique to obtain shear wave velocity profiles without requiring the drilling of boreholes (Cuellar, 1997). Soil stiffness is one of the critical material parameters considered during an early stage of most foundation construction. It is related directly to the stability of structural load, especially as it relates to possible earthquake hazard. Soil lacking sufficient stiffness for a given load can experience a significant reduction in strength under earthquake shaking, resulting in liquefaction, which is a condition responsible for tremendous amount of damage from earthquakes around the world. The multichannel analysis of surface waves (MASW) method originated from the traditional seismic exploration approach that employs multiple (twelve or more) receivers placed along a linear survey line. The main advantage is its capability of recognizing different types of seismic waves based on wave propagation characteristics such as velocity and attenuation. The MASW method utilizes this capability to discriminate the fundamental-mode Rayleigh wave against all other types of surface and body waves generated not only from the active seismic source, but also from the ambient site conditions. Dispersive characteristics of seismic waves are pictured from an objective 2-D wavefield transformation. The present paper indicates results from

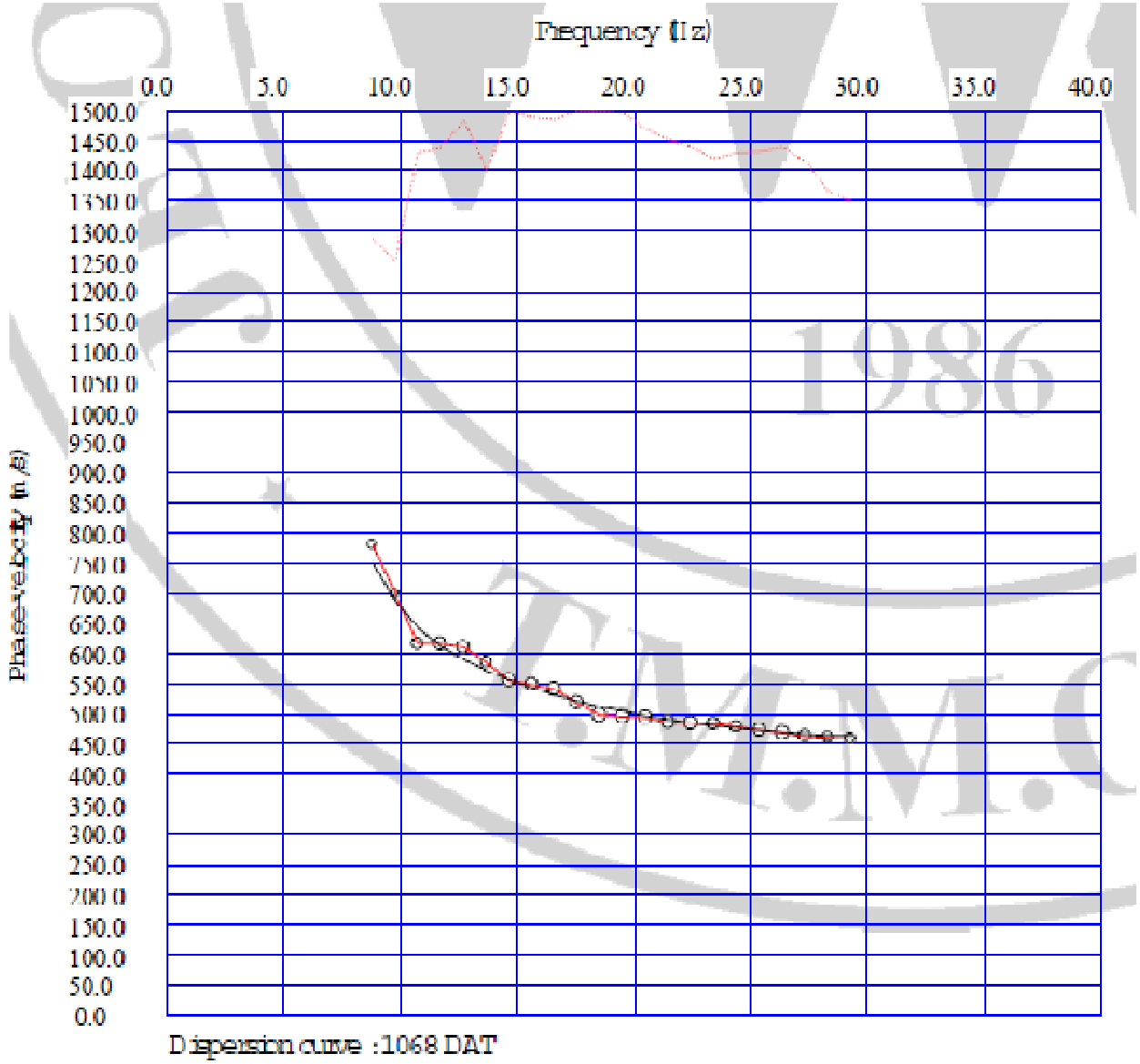


Figure 9a. Dispersion curve of the site in Iznit- Bekirpasa region (Avci and Ozcep, 2006).

MASW survey at different urban sites in Turkey. MASW techniques will prove to be important tools for obtaining shear wave velocity and evaluating liquefaction potential, soil bearing capacity and soil amplification, for future geophysical and geotechnical engineering community.

The first example for MASW is from Izmit-Bekirpasa region. Dispersion curve and vs30 section are given in Figure 9a and b (Avci and Ozcep, 2006).

In the second example, which was carried out by Ozcep et al. (2009c), Adapazari area was selected as the study area, and the shear-wave velocity distribution was obtained by the multichannel analysis of surface waves (MASW) at 100 sites for soil column of the first 50 m. For these sites, soil classifications were mapped according to the Eurocode-8 (Figure 9c).

Seismic slope stabilty analysis: Gurpinar (Istanbul) as a case history

Slope failures triggered by the earthquakes are one of the most important soil problems. In this study, dynamic (earthquake) slope stability analysis was carried out in Gurpinar area. For this aim, *in situ* tests (SPT) were carried out and laboratory samples were obtained from 6 boreholes (their maximum depth was 50.0 m) to determine soil classification and strength characteristics. Moreover, geophysical studies (seismic refraction and MASW) were also carried out in the area to estimate the structure and strength characteristics of the slope to 50.0 m. All the data, obtained in the field and laboratory, were used to construct the mechanical and structural

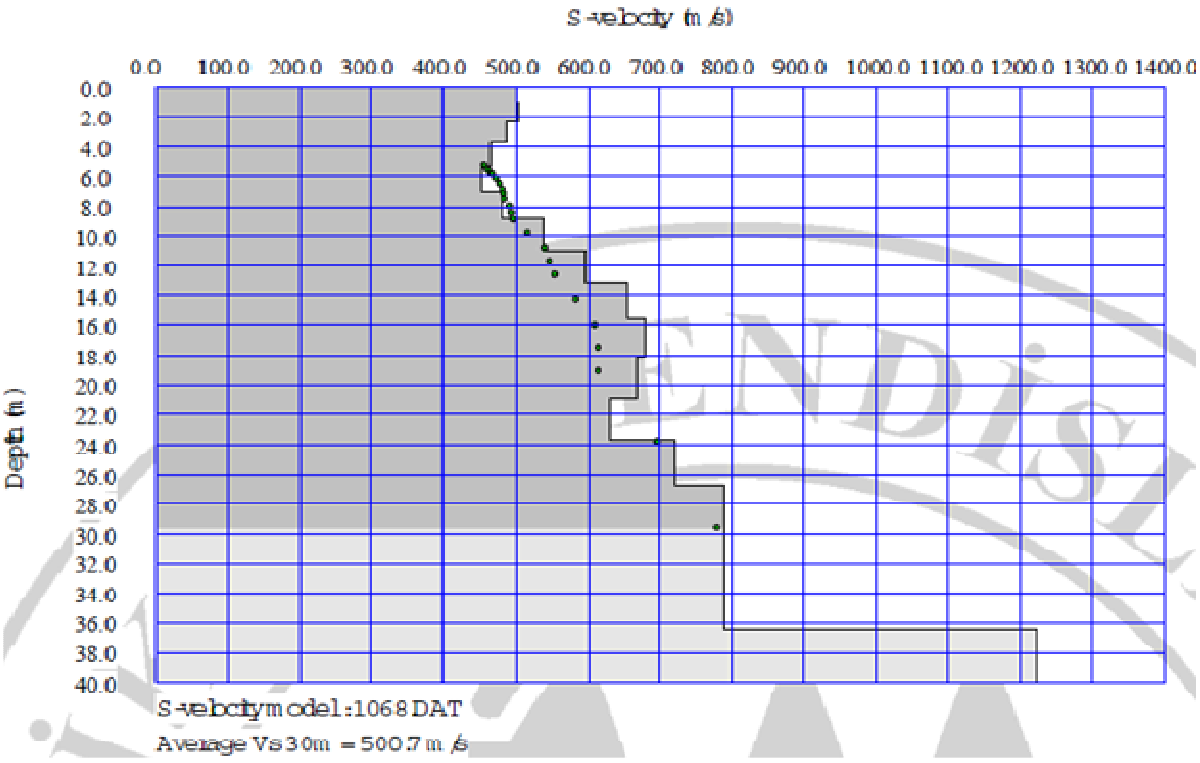


Figure 9b. Vs30 section of the site in Iznit- Bekirpasa region (Avci and Ozcep, 2006).

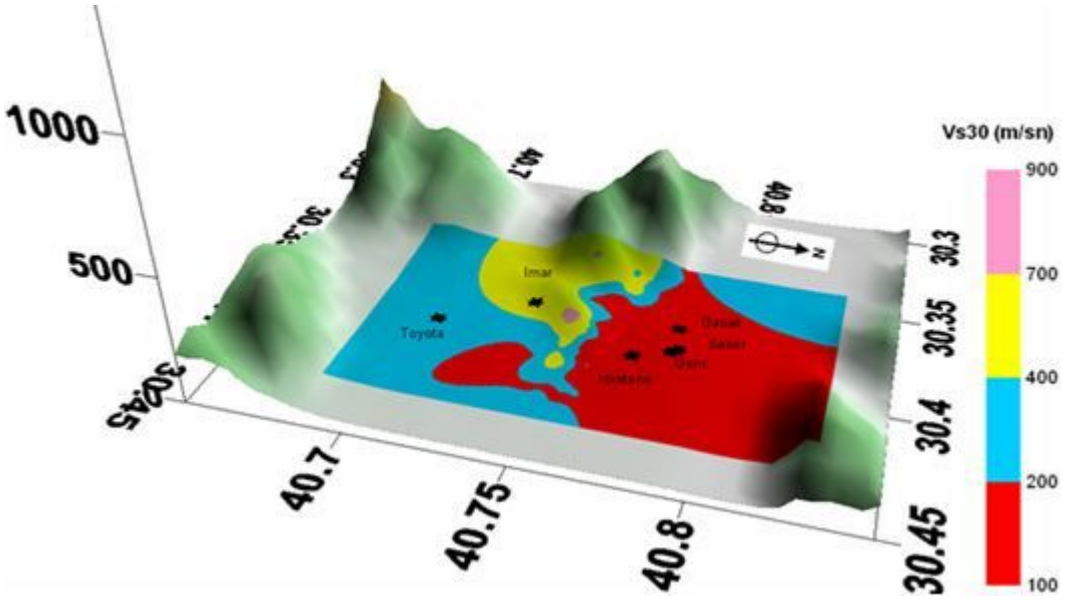


Figure 9c. Vs velocity map obtained by multi-channel analysis of surface waves (MASW) method (Ozcep, 2008; Ozcep et al., 2009c).

(geometrical) behavior of the slope. To solve the slope stability problem, a three soil slope model was considered for the area. In a dynamic state, to estimate the earthquake acceleration, seismic hazard analysis was carried out in the region. At the end of the analysis, while there was no problem in static condition/loads, some slope stability problems appeared with increasing earthquake acceleration.

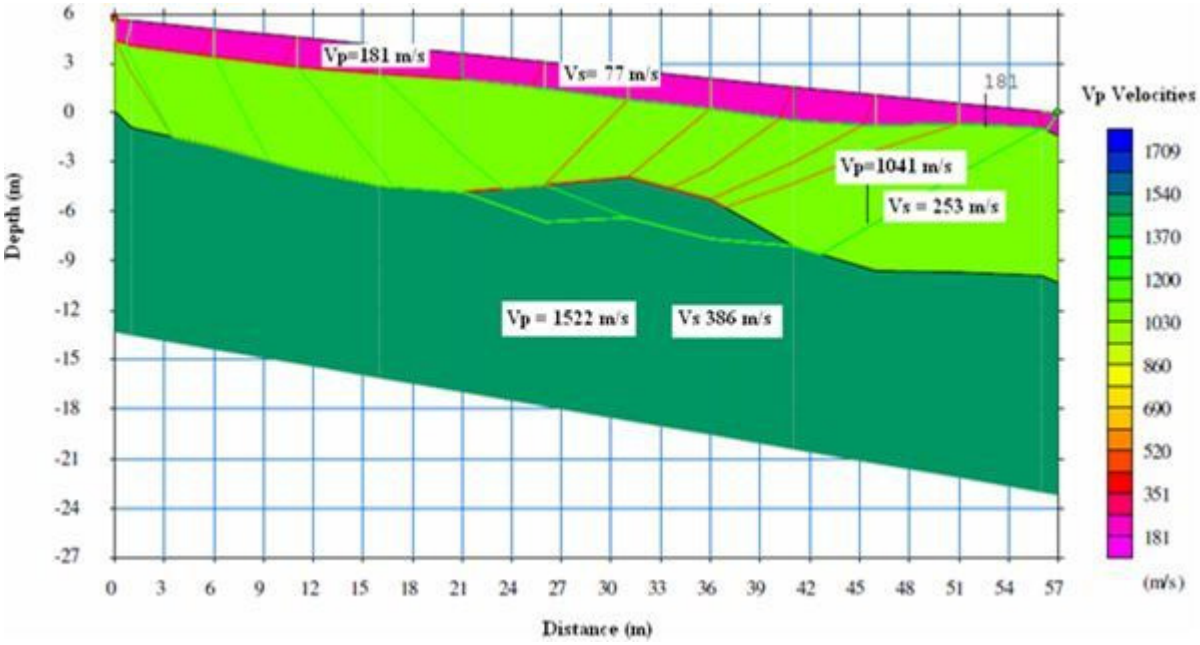


Figure 10a. Geophysical cross-section (obtained from Vp velocities) of the study area (Ozcep et al., 2010b).

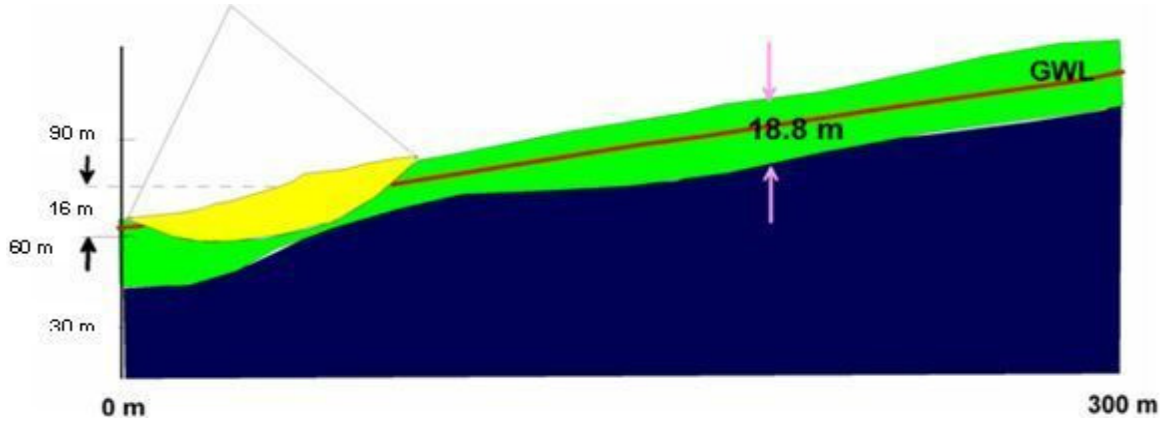


Figure 10b. One of the slope models of the study area (Ozcep et al., 2010b).

In the study, Geometrics Smart Seis SE seismic instrument, geophone and other seismic tools were used. The records that were obtained from the measurement were controlled in the field, after necessary arrangements were made and obtained. The refraction measurement and the dynamic and elastic parameters were modeled and explained by using the computer program named Seis Imager 1D Pickwin / surface wave analysis. Finally, the cross-section (obtained from Vp velocities) was given in Figure 10a,b. In this figure, the slope structure for the first 19.0 m was given with Vp and Vs velocities.

Both static and seismic slope stability analyses were carried out and the safety factor of the slope was obtained. While there was no problem for stability in the static case, seismic safety factors were obtained as 0.8 and 0.9, which were unsafe for stability. However, slope improvement was proposed for the study area.

Soil engineering: A Microsoft Excel® Spreadsheet© program for geotechnical and geophysical analysis of soils (Ozcep et al., 2010c)

Soil engineering is a user-friendly, interactive Microsoft Excel® spreadsheet© program that uses a computer program for the geotechnical and geophysical analysis of soils (Ozcep et al., 2010c). The influence of soil activities on earthquake characteristics and/or structural design is

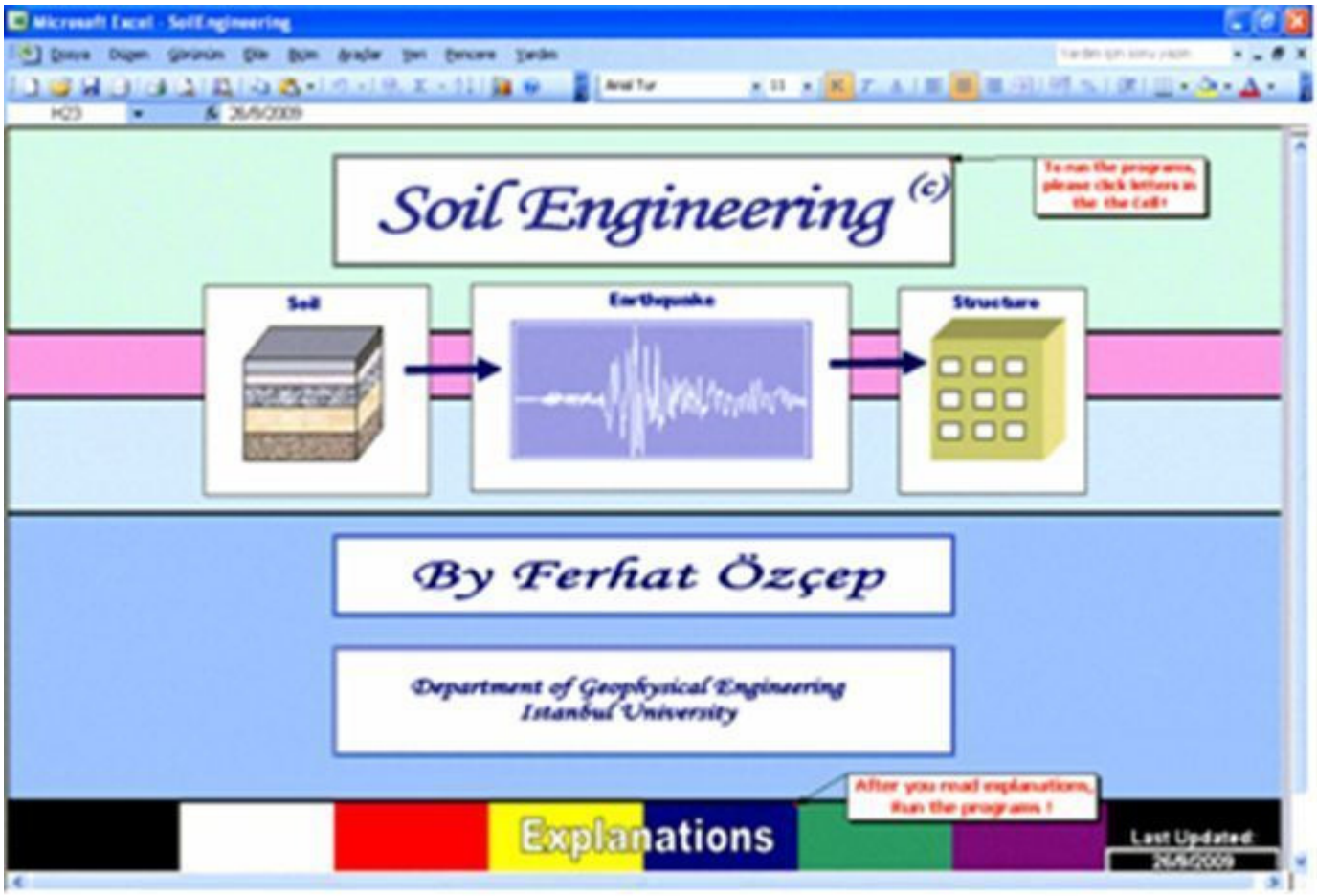


Figure 11a. General view of the soil engineering microsoft Excel® workbook (Ozcep et al., 2010b).

one of the major elements in investigating earthquake forces, and thus the structural response with static and dynamic loads. With its interactive nature, the program provides the user with an opportunity to undertake soil static and dynamic analysis.

Soil engineering, which was prepared as a Microsoft Excel® spreadsheet program, aimed at the geotechnical and geophysical analysis of soils (Figure 11a). It could be executed on Excel 2003 or newer versions under Windows Media. By using this program, it could be easy to analyze the soil static and dynamic problems for scientific and engineering purposes (Figure 11b). In the program, a high quality graphic output could also be obtained for purposes of academic and engineering communities.

RESULTS AND DISCUSSION

There is an interaction between socio-economic conditions and the physical environment, and this is one of the most important factors in the increase/decrease of natural disaster's frequency. Measures to prevent or minimize the effects of disasters, which depend on high technology and scientific achievemets, must reinforce with information and data on socio-economic and geophysical conditions.

As Ansal et al. (2004) pointed out, microzonation studies are useful tools to improve the state of land use management and to better mitigate earthquake risk in the future. On the other hand, at local scale, earthquake-soil-structure interaction is one of the most important issues in design and implementation of the civil engineering structures. However, understanding and analysing the regional and local soil conditions could need the integreted use of geophysical and geotechnical data. This is vital to mankind because of economical and live losts due to the natural hazards.

Geophysical studies provide measurements of physical properties associated with soil and rock media. They are used to non-invasively sample large areas and provide more complete coverage than borings alone. Geophysical techniques can be applied on scales ranging from regional to site-specific, on land or under

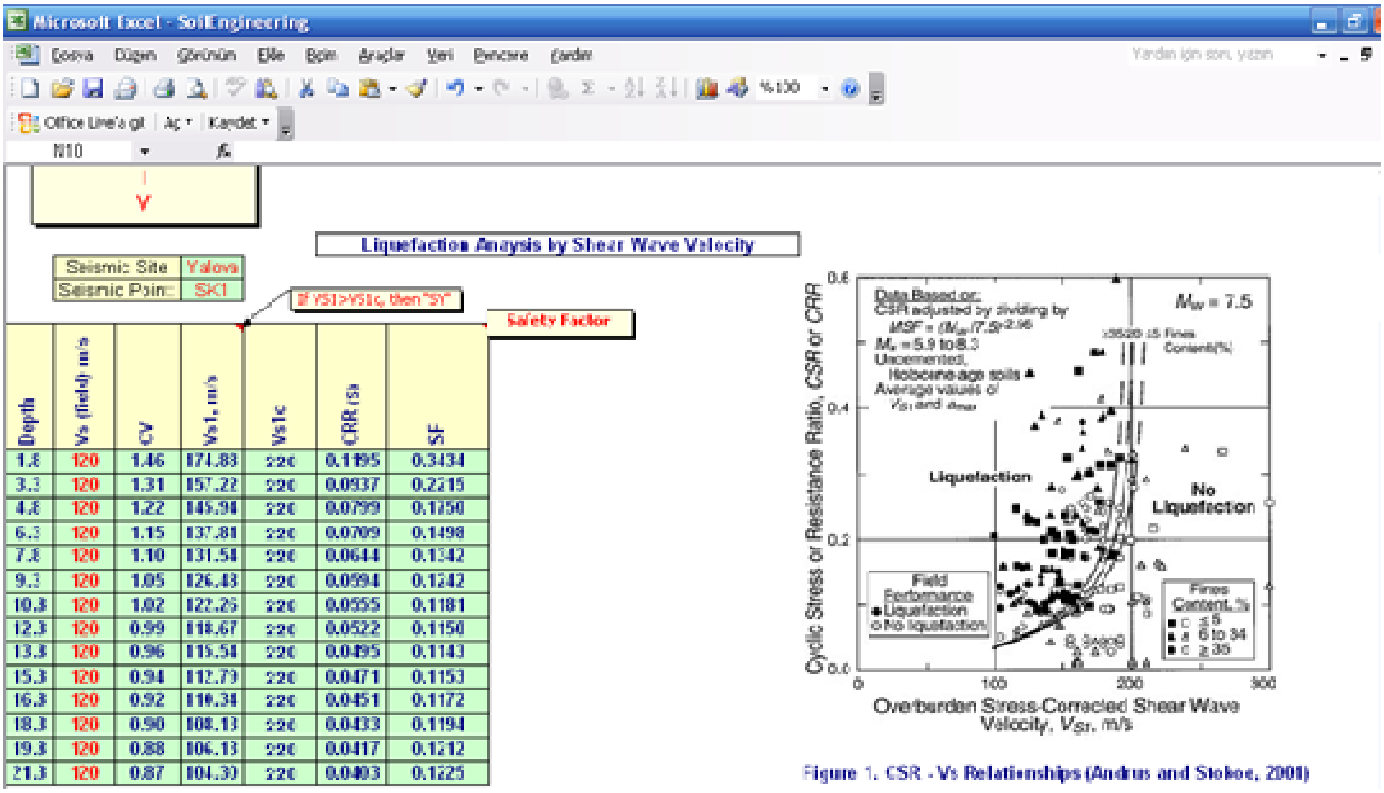


Figure 11b. Output parameters of soil engineering software for liquefaction analysis by shear wave velocity (Ozcep et al., 2010b).

water. Nowadays, these techniques are implemented in order to resolve a diversity of geological, hydrological, environmental and geotechnical problems.

This study presents some examples on geophysical analysis of the soils for civil engineering and urban planning purposes in several cities from Turkey. To the civil engineer and/or city planner, integration of geophysical and geotechnical data provide economic feasibility and technical safety of the project on local and/or regional scale. This contribution is most important in developing contries like Turkey.

ACKNOWLEDMENTS

The author is grateful to Istanbul University. Most parts of this work were supported by the research fund of the Istanbul University (project numbers: yadop-4145, yadop-6708, udp-6530/26031010 and t-1355).

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