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Detailed Microzonation Studies around Denizli, Turkey

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Abstract**—**This study has been presented which is a detailed work of seismic microzonation of the city center. For seismic microzonation area of 225 km2 has been selected as the study area. MASW (Multichannel analysis of surface wave) and seismic refraction methods have been used to generate one-dimensional shear wave velocity profile at 250 locations and two-dimensional profile at 60 locations. These shear wave velocities are used to estimate equivalent shear wave velocity in the study area at every 2 and 5 m intervals up to a depth of 60 m. Levels of equivalent shear wave velocity of soil are used the classified of the study area. After the results of the study, it must be considered as components of urban planning and building design of Denizli and the application and use of these results should be required and enforced by municipal authorities.

Keywords**—**Seismic microzonation, liquefaction, land use management.

I. Introduction

GEOPHYSICAL data are collected to delineate Denizli city of Turkey for engineering purposes. A total of 195 geophysical profiles (both methods of Refraction and MASW) were conducted around the city. The aim of the study is to mainly investigate the geological, seismic and geotechnical site characteristics, and to perform site classification of alluvial and terrace deposits at Denizli city. In order to determine the shear wave velocity for a depth of 30 m from the surface, or its generalization to different depths, mostly in-situ seismic methods are utilized to derive the shear-wave velocity as a function of depth. Multichannel Analysis of Surface Wave Method (MASW) were used as active and passive surface wave methods, respectively, in order to obtain a shear wave velocity profile of the subsurface at 195 locations. A combined usage of the active and passive surface wave methods was adopted in order to meet the requirements of preserving high resolution at shallow depths while also extending the Vs measurements to greater depths. The relationships between the geologic units and their shear wave velocity results, vertical variations with respect to the sediment type and Vs with the information collected and average shear wave velocity for the upper 30 m of the soil profile were determined and site classes based on the seismic codes were utilized in this zonation study.

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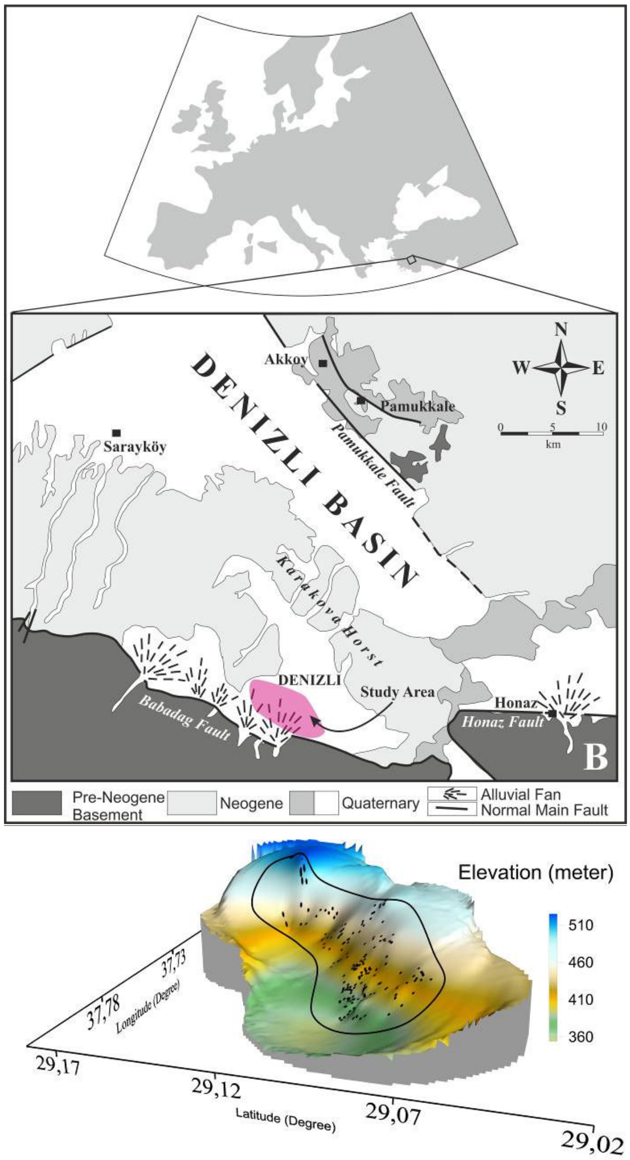

Fig. 1 The map of the stud area and profile locations, topography map of Denizli city with profile points

II. Location and Geology of Study Area

Denizli city covers an area of 20 km^2 and geographically located between latitude 37º44'39" and 37°47'40" and longitude 29°03'45" and 29°09'16". Fig. 1 shows the location and simplified geological map of the study area. The profile locations are illustrated on 3D topographic view below. The study area is about 14 km^2 and is mainly of Quaternary sediments.

Denizli city is located at southwestern part of Turkey. Denizli Basin as a whole is bounded in the north by the Cökelezdag Horst and in the south by the Babadag and Honazdag Horsts. In the central part, it is traversed by one of the faults of the Laodikia Fault Zone that also controls the northern margin of the Acipayam Graben. It is a NW–SW elongated basin approximately 50 km long and 25 km wide, and comprises two Quaternary sub-basins, namely the Cürüksu Graben in the north and the Laodikia Graben in the south, separated by a large basin-parallel topographical high along which Late Miocene–Pliocene fluvio-lacustrine deposits are exposed (Fig. 2). The Çürüksu graben is controlled in the north by the Pamukkale Fault Zone and in the south by the Laodikia Fault Zone. The Laodikia Graben is controlled by one of the branches of Laodikia Fault Zone in the north and Babadag Fault in the south. To the east of Denizli town center, north of Honaz and around Kaklık the Denizli Basin has a staircase geometry delimited in the south by the Honaz and Kaklık Faults, around which the main boundary faults of the NE–SW trending Baklan and Acipayam grabens interfere [1].

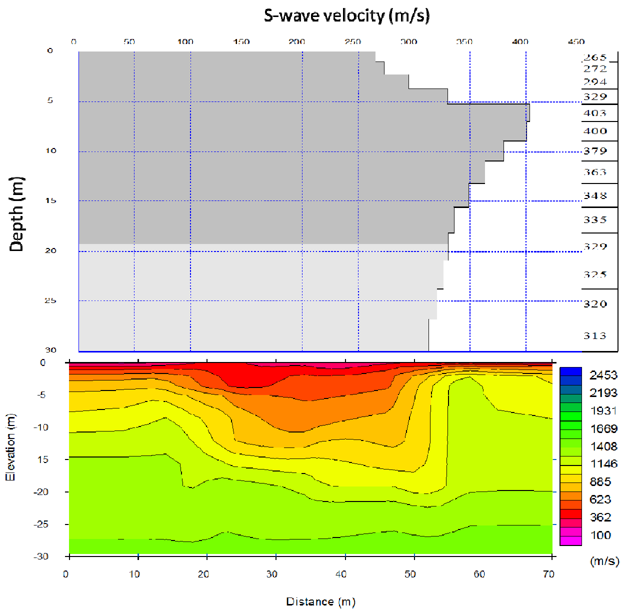

Fig. 2 Profile P wave velocity-depth model and velocity cross-section

III. Surface Wave Survey and Application of the Methodologies

Surface waves are generated by active source which means that seismic energy is intentionally generated at a specific location relative to the geophone spread and the recording begins when the source energy is imparted into the ground. MASW and Spectral Analysis of Surface Wave (SASW) methods are classified as active surface methods [2]-[3].

The choice of equipment (source type, geophone type and number) and testing configuration (geophone interval, spread length and offset distance) is closely linked to the scope of the test and to the technique to be used in the field because of the different frequency interest range of the methods. This study is mainly interested in a depth of 30 m and more, so the related configuration and equipment was chosen for that purpose. In this study, MASW was preferred as the active surface wave methods, to obtain the shear wave velocity profile of the subsurface. When compared with the conventional non-invasive and invasive seismic methods (for example, S-wave refraction, reflection), the surface wave method has several advantages: Field data acquisition is very simple and tolerant because surface waves always take the strongest energy [4]. In the unconsolidated soil, the characterization of the dipping layers or a higher velocity layer on the top of a lower velocity layer is performed by using surface wave techniques. This is not possible by using non-destructive conventional seismic methods because of refractions [5]. The data processing procedure is relatively simple. In non-destructive conventional seismic methods (i.e., the S-wave refraction method), SH seismic motion must be used. However, P-waves and Love waves sometimes interfere with the seismic motion and they complicate first arrival picking [6]. A large area can be covered within a relatively short time period in active surface wave measurements (e.g., MASW).

Usually when such proposed studies are performed in a project area, they require a pattern of measurements which should be dense enough to determine a given geological setting in terms of shear wave velocity classification and to develop a representative map reflecting site conditions.

The selected soil profile acquired from Quaternary sediment at 112 by the combined surface wave method is given in Fig. 2. As can be seen in Fig. 2, an example of the shear wave velocity results of the layers are relatively changes with depth and velocity cross-section.

The surface wave methods are based on the dispersive nature of Rayleigh waves in a layered media to derive subsurface shear wave velocity profiles. One of surface wave types, the Rayleigh wave travels along a free surface such as earth-air or the earth-water interface. A relatively low velocity, low frequency and high amplitude are the characteristic properties of the Rayleigh wave. These waves are the result of interfering P and SV waves which are the vertical and radial components of the surface waves, respectively. Particle motion of the Rayleigh waves in a homogeneous medium moving from left to right is elliptical in a counterclockwise (retrograde) direction along the free surface. The amplitude of this wave motion decreases exponentially with depth. Surface waves become planar towards sufficient depth.

The motion is constrained to a vertical plane consistent with the direction of wave propagation [5]. Also, the depth is the function of wavelength [2]. 195 surface wave measurements from different locations were taken to study the seismic response of different lithologies around Denizli city. To characterize the geological sites according to their age and depositional settings, these measurements were carried out at Quaternary sediments. The field measurements were conducted by adopting a grid system where the seismic measurement points were attempted to be spaced at about 300 m.

IV. Surface Wave Survey Results

The vertical and lateral variation of the shear wave velocity over the study area was generated for characterizing the sedimentary units and to discriminate the sediment type. The countuor maps can be seen in Fig. 3. In creating 3D Vp and Vs models in Fig. 3, a digital elevation map of the study area was produced from the location values from Google Earth. Upper surface limit of the models was adjusted with respect to the topography. The lower surface of the models was truncated based on the Vp and Vs surfaces. All of the surfers' anomalies were obtained by MASW measurements. These velocity anomalies also gave information about the depositional systems dominating the Quaternary period.

V. Seismic Zonation

The seismic velocity maps and the other geologic with interpolation maps of the study area used to develop for showing the elastic distributions of the Denizli city. In the generation of the acceleration, underground water, soil amplification and predominant soil period interpolation maps, ordinary kriging method was performed to quantify the spatial structure of the data (Fig. 3).

VI. Evaluation of Liquefaction Potential

It is known that earthquakes are among the most severe natural disasters causing significant damages such as failure of earth structure, settlement or tipping of buildings, lateral spreading of sloping ground and densification causing vertical settlements. The reasons for these failures can be attributed either due to the compaction of loose deposits of soils or by a phenomenon called liquefaction. Liquefaction has been most abundant in areas where ground water lies within 10 m of the ground surface; few instances of liquefaction have occurred in areas with ground water deeper than 20 m. Dense soils, including well-compacted fills, have low susceptibility to liquefaction. Liquefaction potential is evaluated by using the shear wave velocity, density of soils and water table depth [7].

The water table depth, depth to bed rock details of the nearest bore well to the study locations along with computed Vs30 which is VS < 300 m/s corresponds to soft soil, VS 300–400 m/s corresponds to stiff soil, VS 400–500 m/s corresponds to very dense soils with soft rocks and VS > 600 m/s corresponds to very hard soil. Soil classification is carried out and it is observed that most of the sites consist of very dense soils and soft rocks with velocity of 500 m/s. Most of the sites do not show the VS > 600 m/s up to 30 m depth, which indicates deeper bed rock at the study locations.

VII. Conclusion

Seismic zonation studies in Quaternary alluvial deposits of the Denizli city were implemented by the non-invasive surface wave methods. By this study, sediment conditions were determined and the variations of the velocity throughout the soil profiles were characterized by the Multi-Spectral Analysis of Surface Wave Method at 195 locations.

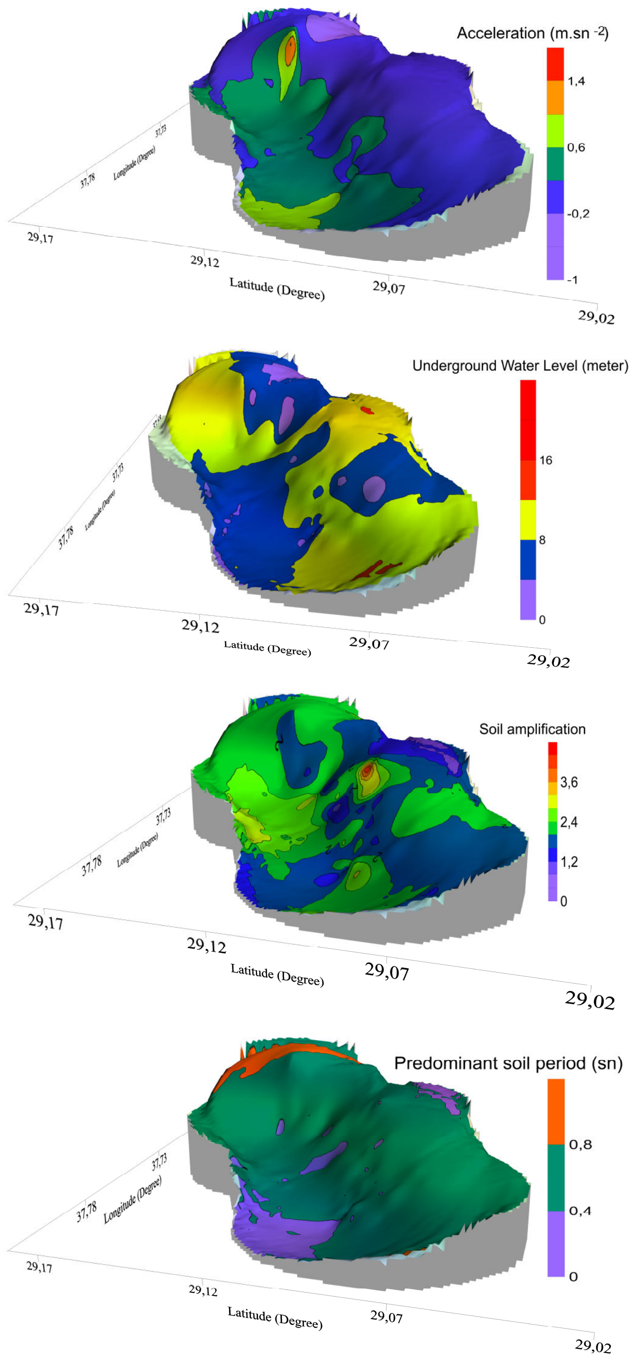

Fig. 3 Surface anomaly map of acceleration, underground water, soil amplification and predominant soil period

The active surface wave method gave compatible results with each other especially in terms of acceleration, underground water, soil amplification and predominant soil period values. This allowed checking of the reliability of the seismic survey results and enabled to assign shear wave velocity values to the corresponding layers. Therefore, the depositional environments and their products could be identified.

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