Importance of Bedrock Depth Knowledge in Basins: Çanakkale (Dardanalles) Case History

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Abstract. It is not correct to produce the necessary information for structuring, especially in environments such as Çanakkale, which exhibit a basin structure, without determining the bedrock or the strict ground conditions in bedrock. This approach is the basis of earthquake resistant building design. In this study, which was carried out to determine the bedrock/seismic foundation depth for the central settlement of Çanakkale and to define the basin structure to a certain extent, microgravity measurements were taken on a large scale, and the study area was modelled in three dimensions based on the obtained gravity data. By taking long-term microtremor measurements, one-dimensional depth-shear wave (Vs) velocity models were obtained using the Rayleigh ellipticity method. A depth map of the engineering bedrock was created, in which the velocity Vs reached to 2500 m/s.

Keywords: Soil · Bedrock · Microgravity · Rayleigh ellipticity · Vs velocity · Seismic foundation

1 Introduction

Accurate definition of soil-structure interaction has become very important for in terms of both earthquake damages and environmental safety. How seismic waves propagate, change and transfer to structures in the rock and soil environment remains an important research topic [1, 2]. Earthquake codes, on the other hand, are updated periodically by evaluating the new information and findings obtained through this research and the lessons of damage caused by earthquakes [3]. In the Building Earthquake Code [4–7] published in Turkey, the acceleration spectra required for the earthquake design of the structures, the desired earthquake level (ground motion) and the average shear wave velocity at the top 30 m, (Vs)30, SPT impact number, it defines it with six local soil classes ranging from (N60)30 or undrained shear strength (cu)30 to ZA-ZF [6, 7]. Accordingly, in the presence of certain thicknesses of fill, loess, peat, high plasticity clay units, very thick, soft/medium solid clay deposits or liquefiable soils in the environment, site-specific research should be carried out by defining the local soil class as ZF, soil

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behavior (response) analysis of the site-specific acceleration spectrum and requires the use of a design supervisor in this process. Since TBEC-2018 came into force on January 1, 2019, many soils behavior analyses have been carried out in many regions, especially in Çanakkale, where thick alluvial and liquefiable ZF soils are found. Shallow soil investigation is made in the investigations. The location of the engineering bedrock, the size and shape of the basin are not known. Therefore, the basin and basin-corner effect are not defined, the absence of microzonation studies, the Vs profile of the units up to the bedrock cannot be fully defined, and the lack of experiments revealing the nonlinear dynamic behavior of rocks emerged as important shortcomings.

As it can be understood from here, the necessary information cannot be reached in the soil behaviors analyses with the soil survey studies carried out on the parcel basis. Moreover, it is not possible to determine the topography and characteristics of the sedimentary basin, if any, while it is not attempted to find the bedrock depth with site-specific surveys. However, on the parcel basis, the depth information called $Z_{2.5}$ along with Vs30 and at which Vs = 2.5 km/s is reached should be measured [8, 9]. The deepness of the bedrock and the presence of soft-medium solid clay deposits or liquefiable soils with low shear wave velocity on them and the inclusion of basin effects increase the PGV values and extend the period of the acceleration spectra. In this case, ductile structures such as high-period structures, multi-story buildings and bridges may be adversely affected. The location and topography of the bedrock in Çanakkale, which is in a basin with very high earthquake hazard, thick alluvium, and liquefiable soils, was obtained using geophysical methods.

2 Seismicity of the Region

The main seismotectonic structures of this region are the North Anatolian Fault Zone (NAFZ) in the north, the Yenice-Gönen Fault Zone (YGFZ) in the east, and the Ganos Fault (GF), which is the continuation of the NAFZ in the northwest. In fact, the Biga Peninsula forms the southwest of the NAFZ. The most important active fault that may affect the study area is the Ganos Fault along the Gaziköy-Gölcük-Kavakköy line and the SW-NE trending Yenice-Gönen faults, one of the most active fault systems in Southern Marmara. The distance of these faults to the study area is approximately 50 km (Fig. 1) [10]. On the other hand, Çanakkale is affected by all earthquakes in the Aegean Sea. When the distribution of earthquakes affecting Çanakkale is examined, four sub-seismic zones can be mentioned. The outer focus distribution of the earthquake with a magnitude of $M \geq 3$ that occurred between 1900 and 2021 is given in Fig. 2 [11]. As can be seen from this map, Çanakkale is in the affected zone of faults that produce intense and destructive earthquakes. For this reason, information such as soil thickness and soil behaviors are much more important. Acceleration distribution is also given on the map, and Çanakkale central settlement is seen as the region where 0.3–0.4 g maximum acceleration can occur.

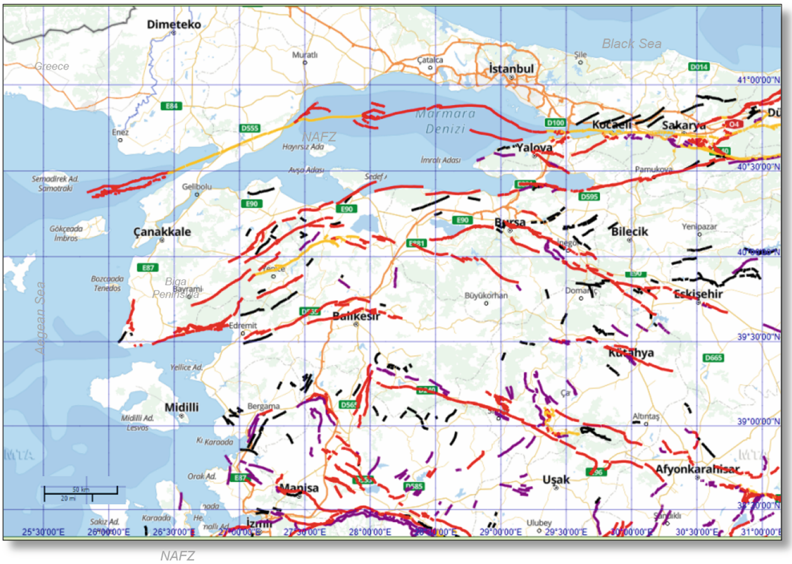

Fig. 1. Active Fault map of the study area and its surroundings [10] Here, the red lines are the Holocene Faults; black lines, Possible Quaternary Fault or lineaments; purple lines, Quaternary Fault; yellow lines indicate Surface Fracture.

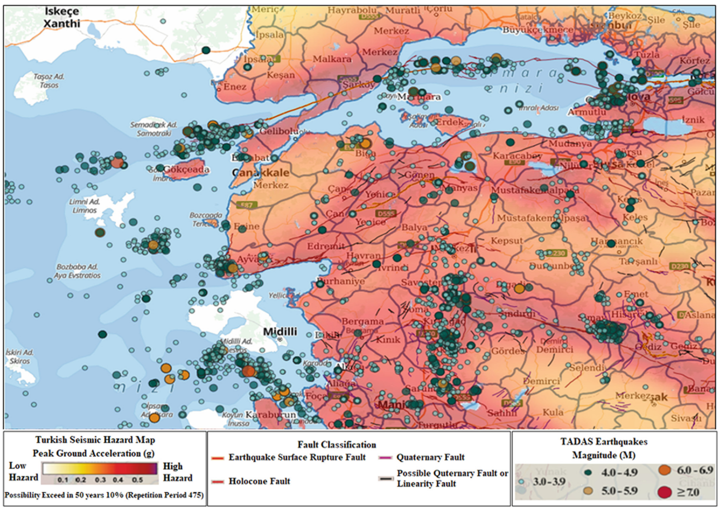

Fig. 2. Active faults, epicentres (M $\geq$ 3.0) and acceleration distribution of Biga Peninsula and its surroundings [11]

3 Soil Conditions of the Region

When the soil structure of Çanakkale is examined, it is widely exposed on both sides of the Dardanelles Strait and consists of four litho-stratigraphic units. The lowest levels of the Çanakkale soils are composed of the Gazhanedere formation, which was deposited in a terrestrial environment and represented by conglomerate, sandstone and mudstone. On top of this unit, the Kirazlı formation consists of fine-coarse grained sandstone and lesser amounts of fine conglomerate, siltstone and mudstone. At the upper level of the Kirazlı Formation, there is the Çamrakdere formation consisting of mudstone-claystone units. The Alçıtepe Formation, which starts with the clastics of the Çamrakdere Formation, transitionally, with moderately bedded, pebbly and sandy carbonates, generally consists of mudstone, marl, siltstone, sandstone, calcarenite and occasionally fine conglomerate and is located on top of the Çamrakdere Formation. At the top are alluviums, which are very commonly unconsolidated sediments. These sediments were defined as three separate units according to their formation types and the locations of the lithology types that compose them (Fig. 3). These; a) Sand, clayey sand, partly gravel channeled sand unit; b) Sand, silty sand (with occasional clay lenses) unit; c) Block, gravel and sand (current stream bed and floodplain sediments) unit.

4 Rayleigh Ellipticity Curve Inversion

Many surface wave analysis studies have been carried out to obtain the structure of the earth from surface wave distribution analysis. The surface wave distribution varies along the propagation path depending on the nature of the place where these waves pass. Therefore, surface wave distribution analysis is a good tool to study the most important features of ground structure. For example, in the Iberian Peninsula, various slip rate models of the crust and upper mantle have been described by Corchete et al. (1993, 1995) from the analysis of the Rayleigh wave distribution [12, 13]. This analysis consists of filtering and inverting the Rayleigh wave distribution to obtain the variation in shear wave velocity versus depth. Sexton et al. (1977) showed that the Rayleigh wave ellipticity is mainly dependent on the local shell structure and does not exhibit azimuth dependence in the range of 10–50 s [14]. Therefore, for this period range, the observed ellipticity is primarily controlled by the local crustal geology below the seismic station and does not depend on the propagation path of Rayleigh waves. This essential feature of ellipticity means that ellipticity analysis is a very useful tool for obtaining local crustal models that can be used to determine site and/or local effects in seismic risk and/or seismic design studies [15, 16]. It is known that the observed ellipticity of a Rayleigh wave can be calculated using the formula (Eq. 1) [17, 18].

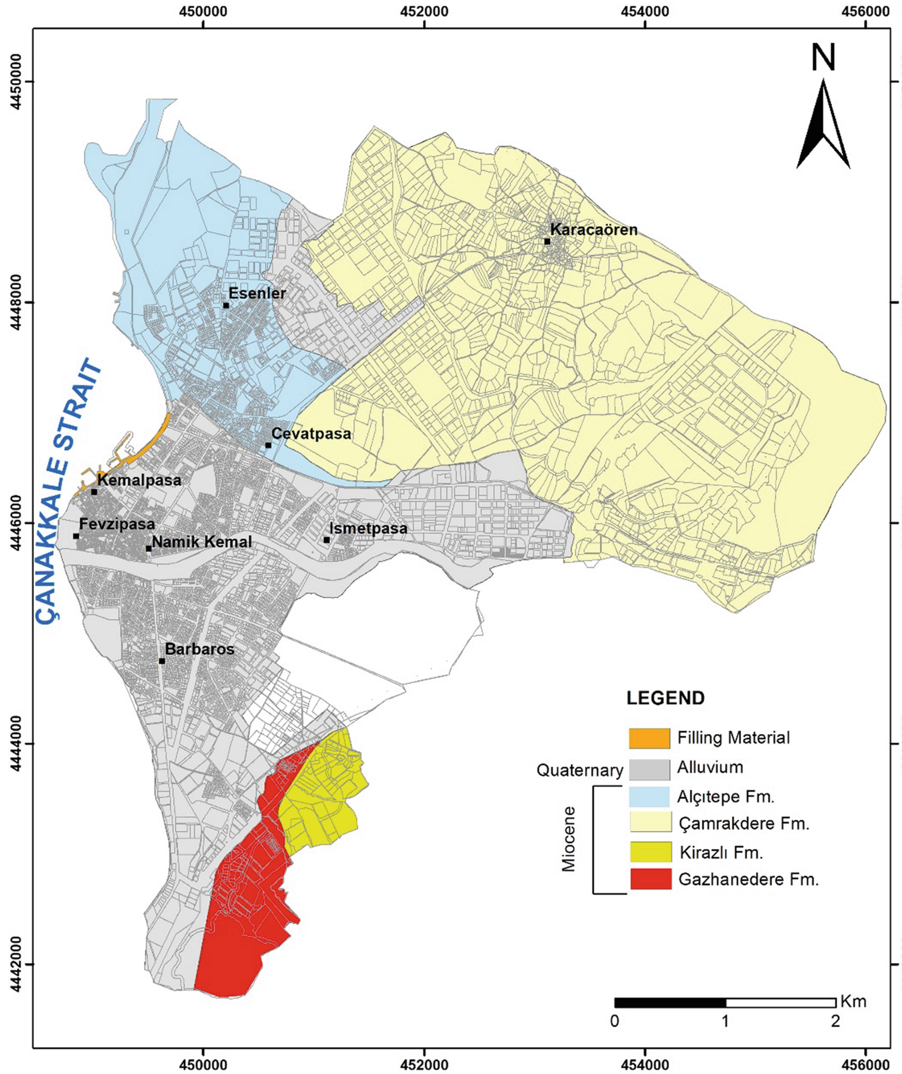

Fig. 3. Soil distribution map of the study area

$$\varepsilon(T) = A_L(T)/A_Z(T) \tag{1}$$

where $A_L(T)$ and $A_Z(T)$ are the instrument corrected spectral amplitudes of the longitudinal (also called radial) and vertical seismograms for the period T [14]. The inversion of the ellipticity curves of Rayleigh waves (Fig. 4) is done using Dinver software from the Geopsy package [19] based on the neighborhood algorithm (Fig. 5).

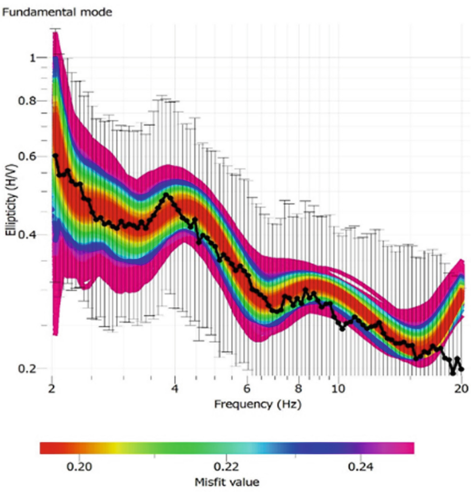

Fig. 4. Rayleigh ellipticity graph

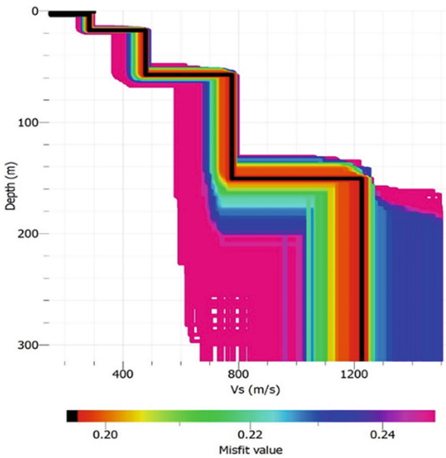

Fig. 5. Obtaining Vs velocity values

5 Microgravity

Microgravity data were collected with the grid network created in an area of approximately 10 × 10 km, which aims to reach the borders of the Çanakkale basin, which includes the study area and its surroundings. The distance between profiles and measurement points was equal and taken as 1 km. The 3D modeling application suggested by Cordell and Henderson (1968) [20] was applied to the Bouguer anomalies obtained from the microgravity measurements made in the study area.

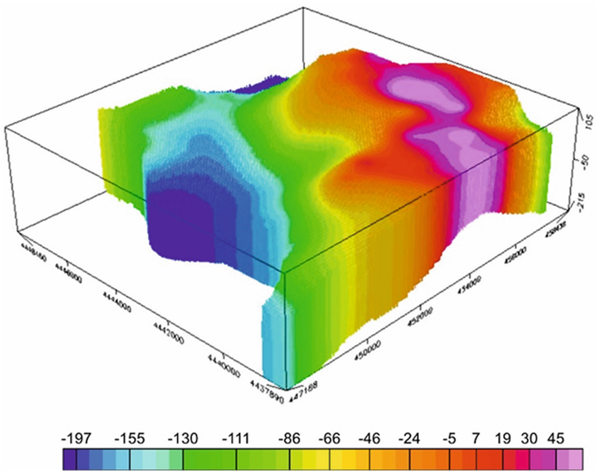

Fig. 6. 3D prismatic gravity depth map

As seen from the 3D depth model, the thickness of the young alluvial unit in the study area was determined to be approximately 300 m at most. The prismatic representation of the three-dimensional model is given in Fig. 6.

6 Results

It is known that there is not enough information about the depth of the bedrock under the influence of shallow groundwater. For this purpose, it is aimed to obtain a bedrock depth map by creating three-dimensional modeling of the plain regime settlement area, in which the central settlement of Çanakkale is located. Thus, the effects of the results, which will be achieved in an area with a one-dimensional wave shallow surface depth (15–30 m) and bedrock depth, on the earthquake soil behavior will be observed. Since the shear wave velocity of the basement rock is almost constant, the possible earthquake damage, in other words the unit shear deformation that will occur, will be determined by the acceleration in the basement rock and the dominant frequency and amplification value of the ground above it [21, 22]. In the proposed project, it is aimed to obtain the detailed earthquake site behavior of the study area, to determine the bedrock depth of the Çanakkale city center settlement, which is not well defined and mostly uncertain, and to be a case study of the most appropriate method selection for future studies by using more than one method together. Considering the geological units defined in the deep soundings up to 240 m across Çanakkale, a clear unit that is the bedrock could not be reached. However, this statement does not coincide with compression, which may be a seismic basis. In other words, a clear distinction could not be made within the definition of loose and tight material of the basin. Equation 2 was developed by Campbell and Bozorgnia (2013) [23] to determine the level at which the generally accepted ground reaches the shear wave of 2500 m/s.

$$\ln Z2.5 = 6.510 - 1.181 \times \ln Vs30 \quad (2)$$

The Vs2.5 velocity distribution based on the Vs velocity values obtained by the Rayleigh Ellipticity method from microtremor measurements made in Çanakkale given in Fig. 6. Accordingly, the slowness limit of the earthquake waves that will affect the structures starts at 320 m in the Çanakkale Basin and shows significant amplification effects as it approaches the surface. A bedrock depth of up to 2 km is expected in the south of the area (Fig. 7).

The estimated $Z_{2.5}$ map in Fig. 7 can be used as very useful information in seismic hazard studies for further measurements. Further geophysical investigations are required to determine $Z_{1.0}$ and $Z_{2.5}$ to provide additional constraints and refine these models in the future. At Çanakkale, efforts are underway to measure $Z_{2.5}$ depths and integrate the geophysical view of the basin. The necessary working algorithm for these studies, which is expected to be an example for other basin-based practices throughout Çanakkale, will also be completed.

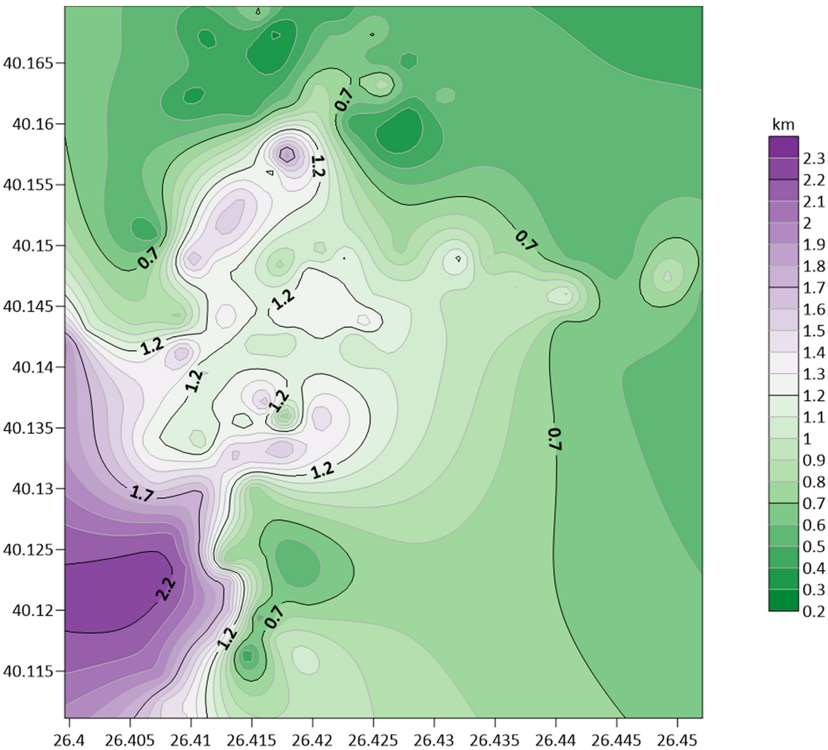

Fig. 7. Depth distribution up to 2.5 km/h (Z2.5)

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