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# Determining bedrock of the northern part of İzmir Bay, western Anatolia, using a combination of microtremor, ESPAC, VES, and microgravity methods

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**ABSTRACT** To decrease the damage in case of earthquake, the creation of soil-engineering bedrock models for new constructions planned on weak soil, which are located in seismically active zone, is very important. In some cases, preparing soil-engineering bedrock model can be economically difficult where engineering bedrock depth is deeper. In this study, in order to indicate the important results of low-cost geophysical studies, the Menemen Plain and Gediz Delta area, located in the north of the inner İzmir Bay, were selected as new growing industrial zones. In this context, microgravity, microtremor, for obtaining predominant vibration period, and ESPAC methods, for defining $V_S$ profile along the soil and engineering bedrock, were conducted all over a study area. After that, all results of these methods were compared and, then, combined with VES results. Finally, soil-engineering bedrock models were prepared for obtaining a 2.5D model and it was observed that the Bornova Flysch reaches up to the surface on an SW-NE line extending to the east of the area. This confirms that the applied geophysical studies resulted very successful and appropriate methods providing a correct interpretation for low-cost bedrock modelling.

**Key words:** soil dynamic analysis, earthquake-resistant building design, microgravity, modified spatial auto-correlation method, observed soil transfer function, İzmir.

## 1. Introduction

In this study, the importance of forming bedrock soil models at low cost in the context of earthquake-resistant building design researches depending on different geophysical methods and the reliability of the approaches, based on the results of mechanical drilling in large areas, were investigated.

In order to minimise the economic losses, an earthquake may cause, initially, the physical parameters that define the soil properties must be determined. The design of the building based on these physical parameters will minimise the socio-economic damage in the habitat affected by the earthquake.

The most important parameter in earthquake-resistant structure design is the prediction of lateral earthquake forces. As a result of the effect of lateral earthquake forces, the joint behaviour of the soil and the structure causes tension and deformation changes in the soil (Kramer, 1996). These stress/deformation changes should be examined through the investigation of the stress/deformation changes in the structural static load, building height, and soil-engineering bedrock model ($V_S$ > 760 m/s) (NEHRP, 2004) under the influence of different earthquake forces.

Recently, depending on the equipment development and computer facilities in geophysical methods, the soil-engineering bedrock models can be prepared in 1, 2, and 3-dimensions (Pamuk *et al*., 2017a, 2017b, 2018). In order to fully establish the relationship between soil and engineering bedrock and soil amplification, it is necessary both to investigate S-wave value > 760 m/s condition and to determine the thickness and density of the soil layers together with S-wave values (Field and Petersen, 2000). In this way, the soil transfer function used in earthquake-resistant structure design will be defined by on-site measurements (Nath, 2007). Especially the $V_S$ > 760 m/s condition, which is necessary for defining the bedrock, can be controlled extending down to kilometres deep (Komazawa *et al*., 2002; Okada, 2003; Özalaybey *et al*., 2011).

During the preparation process of a 1D soil-engineering bedrock model, it is assumed that the soil layers are horizontal, semi-infinite, homogeneous, and isotropic. However, this situation is very unlikely to be valid in real nature conditions. For this reason, it is much more important to define 2D soil-engineering bedrock models. In this way, the horizontal and vertical properties of the soil layers are defined as detailed as possible.

In the case that the engineering bedrock is too deep, the high cost of soil drilling and the difficulties in supplying the necessary specimens for laboratory analysis increase the cost of the projects. Furthermore, the use of S wave, as equivalent seismic velocity data up to 30 m in the plains and valleys with thick sedimentary layers, is not sufficient to calculate the actual motion of the soil during the earthquake (Ansal *et al*., 2010).

Application of geophysical in-situ measurement methods in identifying the depth of the bedrock both reduces the cost and provides successful results in obtaining the soil parameters required for on-site design (Kuruoğlu and Eskişar, 2012, 2015; Akgün *et al*., 2013a, 2013b, 2013c; Eskişar *et al*., 2013; Gönenç, 2014). Preliminary work in the areas planned for construction should be carried out primarily based on the definition of the engineering bedrock and the thickness of the soil.

The determination of the thickness of the soil and the related base geometry directly depends on the site-wide settlement and age of the bedrock ingrained all across the area. The presence of low-velocity zones can cause misleading findings, especially in the definition of the bedrock in areas with high sediment deposition. Good analysis of these misleading findings is an important point. For this reason, it is always misleading to perform soil analysis with only a small number of mechanical drilling findings in areas with high earthquake risk. From this point of view, a pilot region was selected within the Gediz Delta, a sedimentary accumulation zone in the northern part of İzmir Bay.

Single station microtremor method for site effect determination is frequently used to have information about sediment bedrock structure (Nakamura, 1989; Yamanaka *et al*.,1994; Ibs-Von Seht and Wohlenberg, 1999; Delgado *et al*., 2000; Parolai *et al*., 2002; Köhler *et al.,* 2004, 2007; Dolenc and Dreger, 2005). In this study, single station microtremor measurements (HVSR) were performed in order to determine the period of predominant vibration of the soil at 55 points throughout the area.

The interpretations of the obtained predominant soil vibration period values and the depth of the bedrock (around 30 m) were based on the approach of Teves-Costa *et al.* (1996). According to this approach, it may be asserted that the depth of the bedrock is more than 30 m in areas where the predominant soil vibration period is observed to be greater than 1 s.

For environments with acoustic impedance differences, it is important to sample density and shear wave parameters with a good distribution. In this way, it is possible to present a 2.5D basement model that well reflects the region characteristics. For this reason, in addition to the microtremor method, microgravity measurements were carried out at 242 points in the study area. After the drift, latitude, elevation, and terrain corrections were made on the generated gravity data set, the Bouguer anomaly map was obtained. The density values, derived from ESPAC shear wave velocity using empirical relations, were used and the topography of the bedrock was determined by performing Talwani *et al.* (1959) modelling on 4 profiles. The bedrock topographies resulted at this stage were combined to obtain the 2.5D bedrock model. The calculated model was combined with the data obtained from the vertical electric sounding (VES) studies performed by the General Directorate of Mineral Research and Exploration (MTA) and were compared with the 2.5D bedrock model.

The aim of this study is to determine the importance and cost advantages of the bedrock soil models performed in earthquake-resistant structure design studies in the northern part of İzmir Bay by using the presented geophysical methods.

## 2. Geological setting

İzmir is located in western Turkey, Anatolia region, characterised by an extensional tectonics: it is a coastal city where several rivers meet the sea wide areas of high sedimentation, especially along the coastline. The study area is surrounded by the İzmir Bay to the south and west and by the Yamanlar Mountain to the east and it is today a possible sediment agglomeration area bounded by faults to the east (Fig. 1).

The main soil characteristics of the northern part of the İzmir Bay were formed by the influence of the Gediz River. In this context, the study area was influenced both by the old beds of the Gediz River and, from time to time, by the sea. The underground morphology of the Gediz Delta is similar to the deltas seen in the eastern Mediterranean in terms of the style of sediment and deposition patterns (Aksu *et al.*, 1990). The Gediz River (Hermos), which plays a very active role in the morphology of the area, is approximately 400 km long and its flow rate is 40-70 $m^3/s$ (Aksu *et al.*, 1990; Kiymaz *et al.*, 2007). The Gediz River is fed by numerous tributaries along the basin. Until the 19th century, this river was pouring into the sea from the İzmir Camalti salt pan (Figs. 1 and 2). In 1886, the bed of Gediz River was changed to prevent the İzmir Bay from floodings. The river forms a delta of 40,000 hectares within the borders of İzmir Province and has flown into the Gulf of İzmir (Aegean Sea) from the northern boundary of the mid bay between Foça and İzmir Bird Paradise from 1886 to the present day (Kiymaz *et al.*, 2007). The bed of Gediz River, which had flowed through Papas Village (present-day Deniz Bostanlisi region) into the Gulf of İzmir until 1886, was changed and the portion included in our study area was dried in 1888.

Within the fluvial geomorphology mechanism, the formation of alluvial fans and deltas

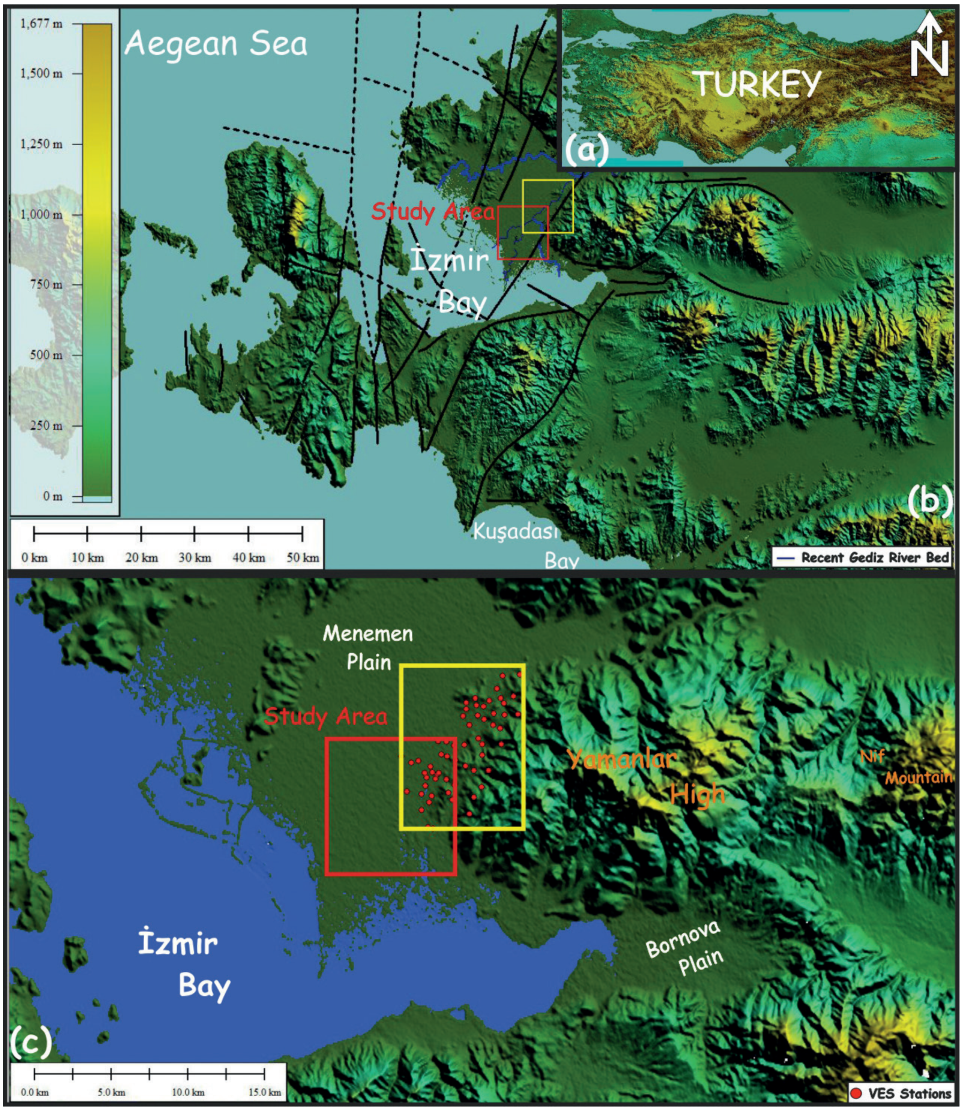

Fig. 1 - Study area (microgravity = red, VES = yellow) and VES measurement stations.

during processes such as seasonal cycles, global changes at sea level (Aksu *et al*., 1987, 1990; Shackleton, 1987; Fairbanks, 1989; Bard *et al*., 1990; Perissoratis and Conispoliatis, 2003), floods, and aggradation, degradation, propagation processes produced very small areas which show extremely variable soil properties, at square metre basis, in the study area. As a result, the soil characteristics of the study area depend on the accumulation areas of the Gediz River, the tidal effects of the sea and the tectonically collapsed area geometry.

Melange (complex) is composed of limestone and diabase blocks of platform type floating in a matrix comprising sandstone/shale-calcareous shale intercalation and conglomerate lens/channel fillings (Erdoğan, 1990).

Bornova Melange is not observed in İzmir Bird Paradise. Neogene sedimentary rocks, that contain limestone, claystone, clayey limestone, alternately overlay the Bornova Melange

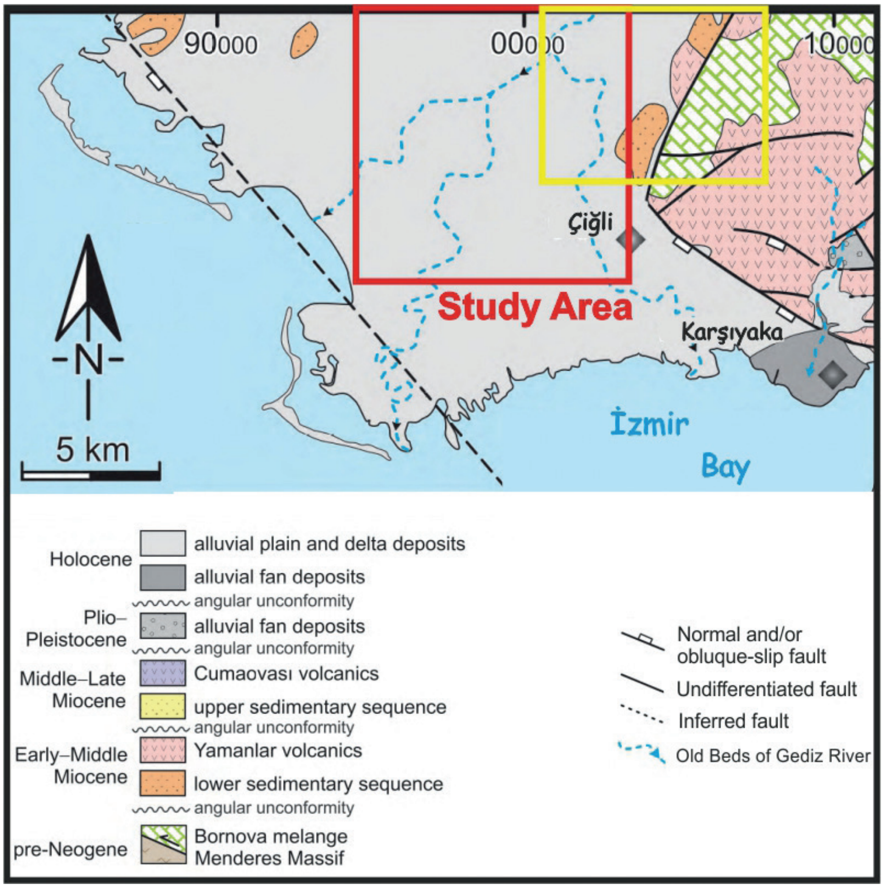

Fig. 2 - Geological map of the study area (Uzel *et al*., 2012).

cacophonously in discordance. Miocene volcanic rocks, which are composed of tuff, agglomerates, and andesites, overlay the Neogene sedimentary rocks. The Quaternary alluvium that consists of clayey, silty, sandy, and gravely levels overlays all of these rocks (Somay and Filiz, 2003; Akgün *et al*., 2014). Holocene aged alluvial formation, Yamanlar volcanics, and Bornova Complex (Bornova Melange or Bornova Flysch Zone) units are geologically observed from shallow to deep layers in the investigated area and immediate vicinity (Uzel *et al*., 2012) (Fig. 2).

## 3. Methodology

### *3.1. Vertical electrical sounding (VES) method*

The vertical electrical sounding method is widely used for geothermal investigations (Meidav, 1970), groundwater determination (Hamzah *et al*., 2007) and environmental or engineering applications (Dahlin, 1996). Loke (1999) and Reynolds (2011) describe the general definitions related to VES studies in detail. In this study, the VES data set, which was collected in 1999 as project code of 99-13D12 for geothermal exploration purposes by using a 38 Schlumberger electrode array, was provided by MTA.

The resistivity fundemental models obtained from the VES data were transformed into 2.5D engineering bedrock models, which were compared to engineering bedrock models obtained from microgravity measurements.

### *3.2. Microgravity method*

The microgravity method is based on the principle of measuring the vertical component of the gravitational acceleration resulting from the density difference of underground structures. Recently, the microgravity method is used for investigating subterranean resources, identifying crustal structures (Dogru *et al.*, 2018), calculating relative plate motion in GPS studies (Pamukçu *et al.,* 2015a, 2015b), solving engineering problems (Akgün *et al.*, 2013a, 2013b, 2013c), and obtaining underground models (Gönenç, 2014). Also, it is an effective method especially in the identification of karstic cavities (Benavente *et al.*, 2017) and yields efficient results in subterranean areas where high contrast is expected in density values.

In this study, the used microgravity data set was collected by using Scintrex CG-5 auto gravity meter at 242 stations. The main base station which has absolute gravity value in Dokuz Eylül University Tinaztepe Campus within measurement planning was used. All measurements were brought to term as connecting this station. The duration of the measurements was at least 60 s. In addition, we repeated the reading 5-15 times to get low standard deviation values and acceptable tilt angle values.

In the data process, a digital elevation model was compiled by combining a 1:25,000 scale local map and global digital elevation data for calculating the free air, Bouguer slap correction and terrain correction at each station. After that, latitude correction ($gL$), free air correction, Bouguer correction and terrain correction ($gT$) were applied to the station readings (gobs) for obtaining the Bouguer gravity anomaly values ($gB$) as given in Eq. 1 (Panisova *et al.*, 2012; Pamukcu *et al.*, 2014). Terrain correction accounts for variations in the observed gravitational acceleration caused by variations in topography near each observation point. Because of the assumptions made during the Bouguer slap correction, the terrain correction is positive regardless of whether the local topography consists of a mountain or a valley. A rectangular grid (Kane, 1962; Nagy, 1966) and Hammer segments (Hammer, 1939) are the methods applied for calculating the terrain correction. In this study, we used rectangular method. $\Delta h$ is the height difference between the observation point and the base level, $\rho$ the average density of the subterranean structure:

$$gB = gobs \pm dgL + 0.3086\ \Delta h - (0.04191\rho)\ \Delta h + dgT \qquad (1)$$

2D modelling was performed by using the Bouguer gravity anomaly map observed, and, then, all these 2D models were combined and a 2.5D bedrock model was created.

### *3.3. Single station microtremor method*

Microtremor measurements are used for describing the soil types, number of layers, fundamental period, and empirical transfer function (Nakamura, 1989, 2000; Lermo and Chavez-Garcia, 1994; Ansal *et al.*, 1997; Paudyal *et al.*, 2012, 2013; Akgün *et al.*, 2013a, 2013b) The microtremor analysis-based method for the site effects study was first introduced by Kanai (1957). Later, Nakamura (1989) improved this method, and now it has become widespread as a low-cost and effective tool to estimate the fundamental resonant frequency of sediments by

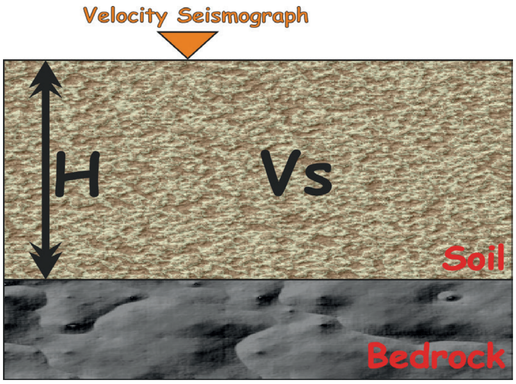

Fig. 3 - Single station microtremor method.

measuring the microtremors at a single station (Fig. 3). The Horizontal-to-Vertical (H/V) spectral ratio method has been widely applied in the last two decades for the study of site effects in different geographical and geological regions of the world. The detailed discussion, applications, validations, and limitations about the H/V method have been presented by many researchers, such as Field and Jacob (1993), Lachet *et al*. (1996), Huang and Teng (1999), Delgado *et al*. (2000), Bonnefoy-Claudet *et al*. (2006a, 2006b), Gosar (2007), Langston *et al*. (2009), and Hardesty *et al*. (2010). These studies show that the microtremor H/V spectral ratios provide a reliable estimate of the resonance frequencies of soft soil deposits. Furthermore, other studies (Ibs-von Seht and Wohlenberg, 1999; Delgado *et al*., 2000; Parolai *et al*., 2002; D'Amico *et al*., 2004; Dinesh *et al*., 2010; Gosar and Lenart, 2010; Özalaybey *et al*., 2011; Sukumaran *et al*., 2011) have shown that there is a strong correlation between shear wave velocity, resonance frequency, and thickness of the sediments. In this study, the correlation between $T_0$ values and sediment thickness was examined with VES (Figs. 4 and 9) and microgravity (Figs. 8 and 9) models.

### *3.4. ESPAC method (extended spatial autocorrelation method)*

The spatial autocorrelation method (SPAC) was first proposed by Aki (1957) and Okada (2003) for horizontally propagating waves to determine deeper *Vs* profiles and was widely applied (Apostolidis *et al*., 2004; Chavez-Garcia *et al*., 2005, 2006; Wathelet *et al*., 2005; Asten, 2006; Köhler *et al*., 2007; Pamuk *et al*., 2017a, 2017b). SPAC measurements were conducted at each site using circular array CMG-6TD three-component seismometers, which consist of three recording stations on the ring and another in the centre. The radius of the circular arrays was individually adjusted for each site and the radius changes from 45 to 400 m. The recording duration changed from 30 to 60 minutes in each array. In this part of the study, accordance between SPAC coefficients obtained from observational values was searched and theoretical Bessel function values and dispersion curves were obtained by using values of fitting frequency range. After obtaining the dispersion curves, the 1D S-wave velocities were obtained by applying the damped least squares method (Levenberg, 1944; Marquardt, 1963) (Figs. 5a, 5b, and 6).

## 4. Data acquisition and data analysis

In the study area, microgravity studies at 242 points in 9×9 km$^2$ area, microtremor studies at 55 points, and Extended Spatial Autocorrelation (ESPAC) study at 1 point (Figs. 5a and 5b) were performed. As a result of these studies, 1) a 2.5D soil-engineering bedrock model was created, 2) observational soil transfer functions at 55 stations were obtained, 3) S-wave velocity-depth changes up to the limit of engineering bedrock were obtained at 1 location. Finally, all data sets were interpreted together.

In microtremor measurements, data were collected with Guralp Systems CMG-6TD 30 s seismometers for at least 45 minutes of measurement during the period 2009-2010. The open-source Geopsy V 2.5.0 software written under the project Securing the European Electricity Supply Against Malicious and Accidental Threats (SESAME) was used during the microtremor data evaluation phases. When evaluating the microtremor data, the Fast Fourier Transform (FFT) principles of this software were taken into consideration, and the window size was determined to be 81.92 s and the frequency domain sampling number was 8192. The period values obtained from the microtremor measurements of the study area range from 0.2 to 5 s.

According to findings, high amplitude period values have a N-S trend along the study area (Fig. 7). The alternation of high and low amplitude values from west to east displays the period-based anomaly characteristic of the study area (Fig. 7). This alternation is an expected situation for the area where the Gediz basin, which has been fed by deposited material for many years, merges with the sea. In addition, $T_0$ values being greater than 1 s indicates that the bedrock depth is more than 30 m (Teves-Costa *et al*., 1996).

The ESPAC measurement was performed with Guralp Systems CMG-6TD 30 s velocity seismometers in January 2019. The measurement time per circle is at least 75 min. The measurements were made on concentric circles (Fig. 3) with 3 different radii (60 m = orange, 160 m = blue, and 420 m = red). The data were evaluated with the Geopsy V 2.5.0 software developed within the scope of the SESAME project. From the dispersion curves obtained, S-wave

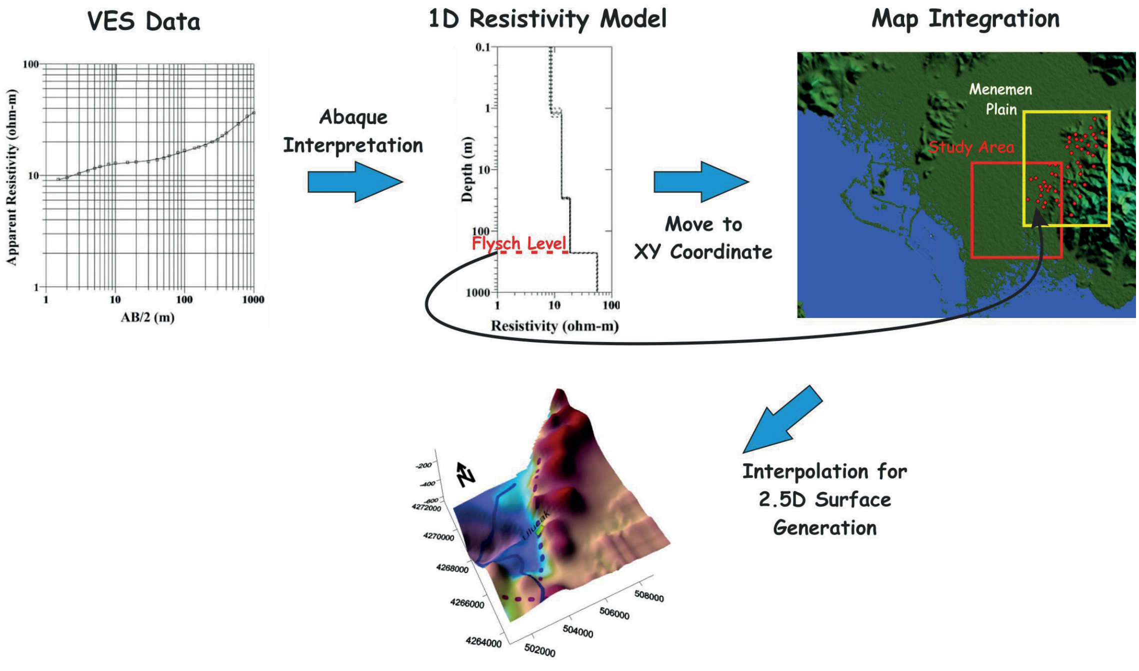

Fig. 4 - Schematic explanation for 2.5D bedrock modelling process by using flysch level from Table 1 via VES.

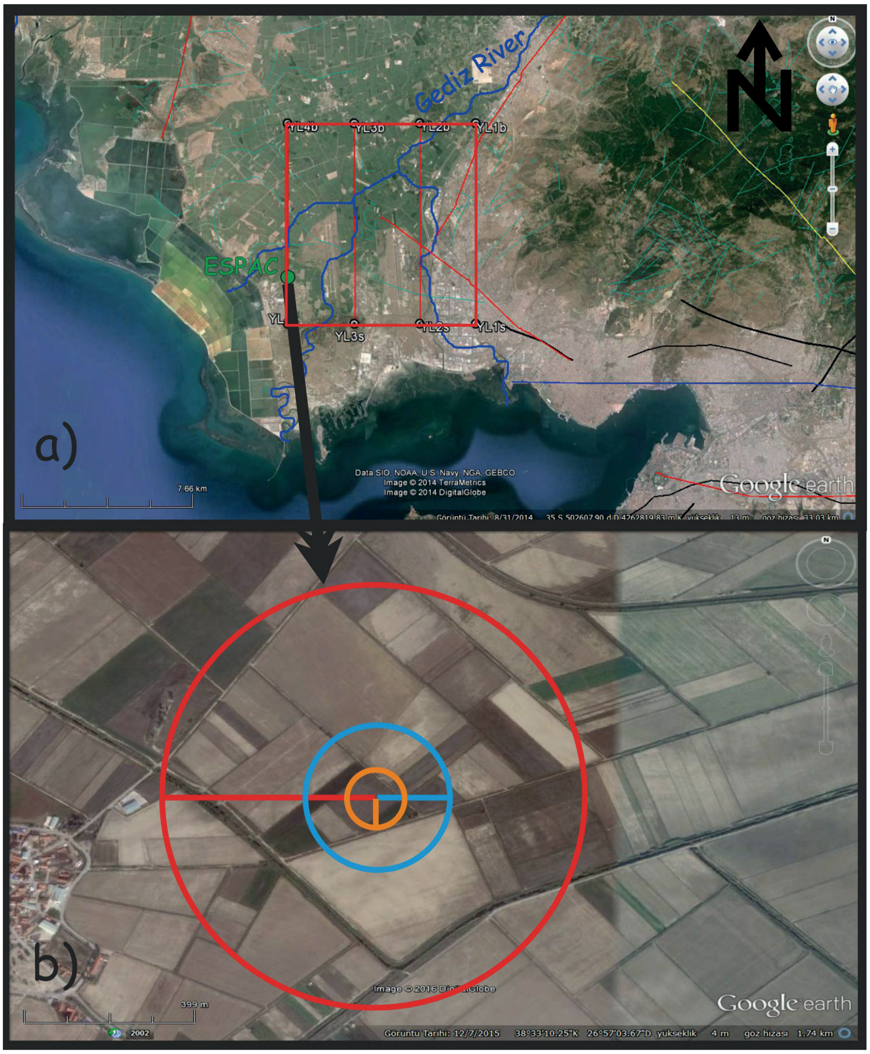

Fig. 5 - a) Study area of microgravity measurements, b) ESPAC measurement station (Google Earth).

velocity/depth changes were calculated by employing inverse solution methods (Fig. 6). According to the S-wave velocity, the results show the variation of high amplitude S-wave velocity in the segment of approximately 280 m depth: this may indicate the existence of a medium, which can be defined as engineering bedrock. The findings obtained were used as a basis for the calculation of density and depth information to be used in microgravity soil model studies (Figs. 8 and 9).

The general purpose in VES method is to examine the change of underground formations along the Z plane (depth) in the Cartesian coordinate system, and VES measurements are taken by using Schlumberger electrode array. VES data were evaluated with the help of Pascal (1970) conversion tables. In the study area, three different units were defined as alluvium, andesite, and resistive foundation (Bornova Flysch). On each outcropping geological unit in the area, formation measurements were carried out; the mean resistivity values of these units were determined and given in Table 1. According to these results, the Bornova Flysch segment was defined as engineering bedrock level for our purpose. All VES results of the 38 stations were studied to pick the Bornova Flysch Zone. After that, all these Bornova Flysch levels were interpolated to get individual engineering bedrock models. 2.5D bedrock modelling was performed by using these Bornova Flysch values (Fig. 9b). 2.5D bedrock modelling flow via VES was schematically given in Fig. 4.

Table 1 - Resistivity values of geological formations in the study area.

| *Geological Unit* | *Resistivity (ohm×m)* |
|---|---|
| Alluvial Unit | 20 - 30 |
| Andesite | 30 - 40 |
| Bornova Flysch | 60 - 600 |

In the microgravity measurements conducted between 2009 and 2011, the data set was collected by using a Scintrex CG-5 Autograv gravimetry with 5-15 cycles and 60 s measurement time. The density parameter needed to reach the depth model from the Bouguer gravity anomaly values, obtained from the microgravity measurements carried out in the area, was calculated by using the S-wave velocity obtained from ESPAC studies (Keçeli, 2009):

$$\rho = 0,44.Vs^{(0,25)}. \qquad (2)$$

Microgravity depth modellings were performed on 4 profiles by using the Talwani *et al.* (1959) method with the density values obtained from 2 correlations, and 2.5D bedrock modelling was realised by combining them with the bedrock topography values which refer to the subterranean interface between soil and bedrock, obtained as a result of modellings.

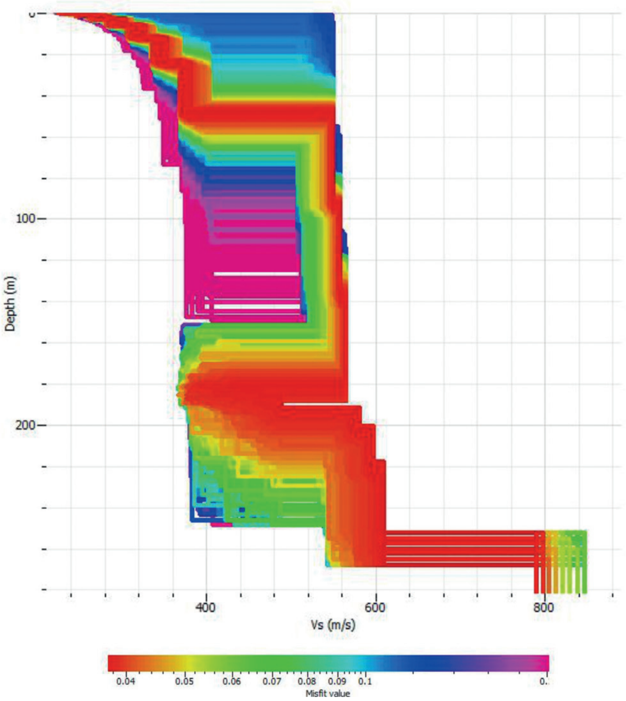

Fig. 6 - 1D S-wave velocity changes obtained from ESPAC measurements.

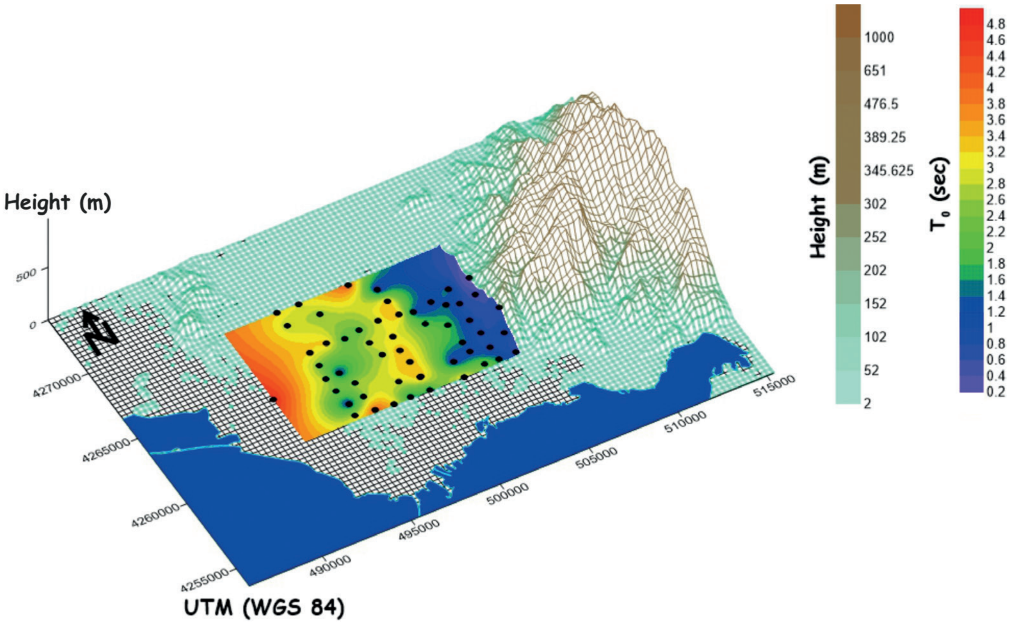

Fig. 7 - Map of the soil predominant period and measurement stations.

According to the Bouguer gravity anomaly map, the site is characterised approximately by a 32-mGal change interval (Fig. 8). A NW-SE alternation of high and low amplitude anomaly values was observed. While microgravity data provide information about the basin geometry, microtremor data indicate the presence of regions with different behaviour on this basic geometry.

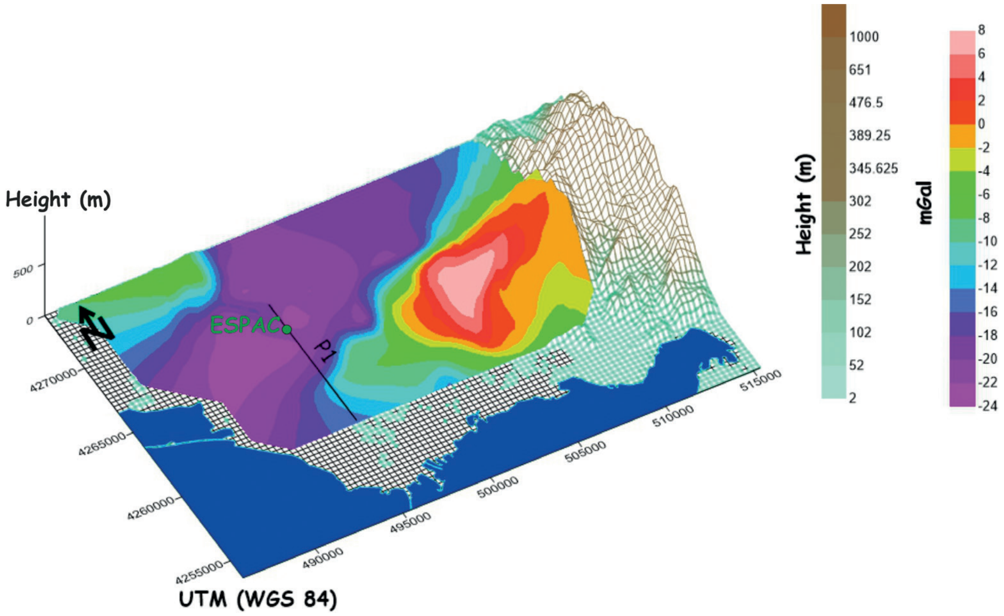

Fig. 8 - Bouguer gravity anomaly map of the study area.

In the Bouguer gravity anomaly map, values of the area decreasing to -24 mGal can be considered as a trace of the deep alluvial basin model of the Menemen Plain. The eastern part of this basin is morphologically bounded by the Yamanlar Mountain. The highest amplitude Bouguer gravity anomaly inclusion in the area, which is observed in the east of the basin (8 mGal), can be associated with the volcanic material content of the Yamanlar Mountain. The basin, which shows an anomaly of -24 mGal in the Bouguer gravity map, is characterised by a N-S bound (7 and 2 s period inclusions in the period map). This finding indicates that the soil behaviour of the study area, under the effect of an earthquake, can lead heterogeneity in results even in a very small area. Within the fluvial geomorphology mechanism, the formation of alluvial fans and deltas during processes such as seasonal cycles, global changes at sea level (Aksu *et al.*, 1987, 1990; Shackleton, 1987; Fairbanks, 1989; Bard *et al.*, 1990; Perissoratis and Conispoliatis 2003),

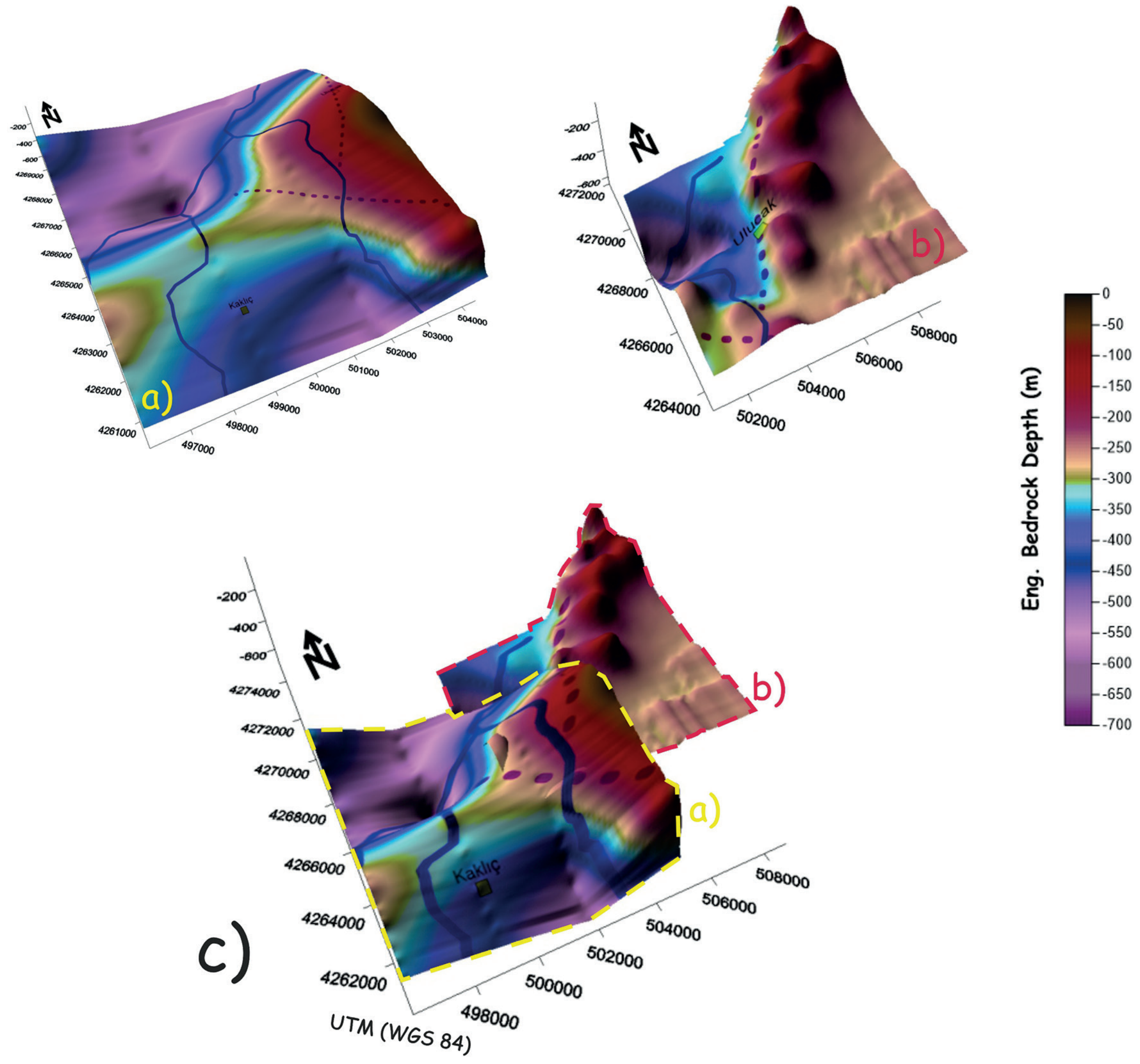

Fig. 9 - 2.5D engineering bedrock model of the study area: a) microgravity model, b) VES model, c) combined (microgravity and VES) engineering bedrock model.

floods, aggradations, degradations, and propagations in this formation process are effective in the dominant forming of the subterranean structure, which causes this soil behaviour model.

A quadrilateral area of 9 km with a width of about 8.6 km was defined to reveal the basement (flysch) geometry (Fig. 2). In order to form a 2.5D model from the Bouguer gravity anomaly values within the area, the depth-intensity values obtained from the ESPAC study, which refers to that flysch level, were used (Eq. 2, Figs. 6 and 9a). In the other phase of the study, the 2.5D engineering bedrock model was created based on the Bornova Flysch level map obtained as a result of VES (MTA, 1999) measurements (Figs. 4 and 9b). In the last step, the 2.5D engineering bedrock models which belong to flysch level (Figs. 9a and 9b) were combined at same intersected coordinates (Figs. 1 and 9c). As a result, it was determined that the two models complemented each other in terms of both geometry and depth information (Fig. 9c).

In addition, it was observed that the interfacial topography of the engineering bedrock along the P1 profile was consistent with the predominant soil vibration period and that this compliance was confirmed by the ESPAC measurement results (Fig. 10).

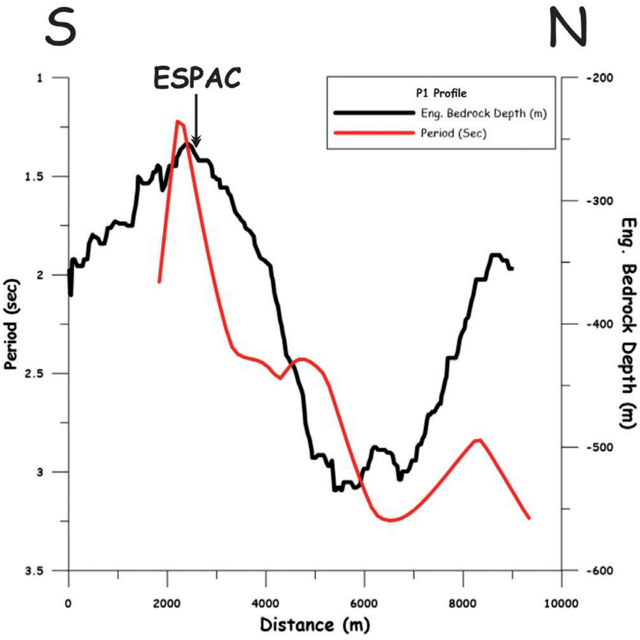

Fig. 10 - Engineering bedrock depth and predominant period comparison for the P1 profile.

## 5. Conclusions and discussion

In this study area, located in the north of İzmir Bay where in-situ geophysical methods were applied, the expected soil thickness, which was based on the previous studies performed by using P- and S-wave velocity and density parameters, was 300-350 m (Akgün *et al.*, 2013a, 2013b). The peak period values are $T_0 >> 1$ s on the soil. According to these results, it is necessary to take into account the amplitude changes in both soil thickness and low-frequency values, when preparing the soil engineering bedrock models for this area.

In the study of Eskişar *et al*. (2013), the northern part of İzmir Gulf has been investigated by using SPT-N values, to define NEHRP (2004) soil classifications, and also microtremor analysis, for obtaining the bedrock depth. This study indicated that the area contains C, D, and E type soils, $T_0$ values vary between 0.12 and 2.0 s and also the bedrock depth changes between 0 and 200 m. These results are coherent with our findings in the northern part of İzmir Gulf, which is located SE of our study area. Both study results are in good agreement for what concerns bedrock depth values and fundamental periods.

In the study of Eskişar *et al*. (2014) the maximum peak ground acceleration values (between 0.10 and 0.45 g) of soil surface for near and far sources have been calculated by using the data of Eskişar *et al*. (2013). These results show that calculating considerable changes in the small area reveals the importance of determining local soil conditions for the study area. Especially the delta zones are risky areas in terms of local soil condition behaviour under possible earthquake influence.

In an other step of the study, the ESPAC Method was applied to obtain S-wave velocities. The density values, calculated by using the obtained S-wave velocity and depth information, were included in the calculations for creating the depth model based on Bouguer gravity anomaly data. The obtained soil topography depth model was compared with the VES depth model, and it was concluded that the two models supported and complemented each other. In this context, it was observed that the base topography depths extended up to 600 m.

The study area was under the influence of the sedimentation by the Gediz River, whose bed changed in natural and artificial ways in time. In addition, as a result of the progression and withdrawal of the sea from the soil, the grain size structure in the soil has also changed. A gravel layer with depth and thickness variability is observed in most parts of the study area. However, the grain size decreases again under this layer. This situation lead to a decrease in the $Vs$ velocity values. So, it formed an inclusion which creates multiple reflections during an earthquake.

These changes affect $T_0$ peak amplitude values. In the study area, on the surface of the soil in the lateral direction, sudden $T_0$ changes greater than 1 s were detected. This finding indicates that the acoustic impedance changes ($Vs$ and intensity changes) that could occur between the layers in the soil will produce dangerous effects in the lateral and vertical directions.

When the joint 2.5D engineering bedrock model was examined, it was observed that the Bornova Flysch reaches up to the surface on a SW-NE line extending to the east of the area (Fig. 9). The same situation is clearly observed in the geology map given in Fig. 2. This congruence is an indicator that the presented geophysical studies are very successful and appropriate providing a correct interpretation.

The soil thickness presents many variable properties in lateral and vertical directions. For this reason, in areas to be granted for the construction permission, it is necessary to define the soil with special *in situ* geophysical methods, not according to the information obtained from 1-2 drilling points. In order to perform soil dynamic analyses, it is important to define the soil engineering bedrock models at small scales.

ESPAC, microgravity, and microtremor studies deploy the most effective and low-cost instruments for the identification of the soil, engineering bedrock, and seismic bedrock in the areas considered for industrial construction. With appropriate and correct works aimed at the purpose, protection from the regional effects of earthquakes and similar soil movements will be possible by defining the soil *in situ*.

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