

DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

**INVESTIGATION OF SOIL DYNAMIC
CHARACTERISTICS AND MODELING SOIL-
BEDROCK INTERFACES OF BORNOVA PLAIN
AND ITS SURROUNDINGS (EASTERN İZMİR
BAY/WESTERN TURKEY)**

by
Eren PAMUK

May, 2018
İZMİR

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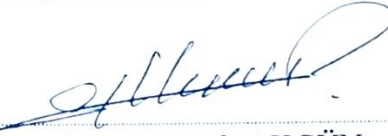
**A Thesis Submitted to the
Graduate School of Natural and Applied Sciences of Dokuz Eylül University
In Partial Fulfillment of the Requirements for the Degree of Doctor of
Philosophy in Geophysical Engineering**

**by
Eren PAMUK**

**May, 2018
İZMİR**

Ph.D. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled “INVESTIGATION OF SOIL DYNAMIC CHARACTERISTICS AND MODELING SOIL-BEDROCK INTERFACES OF BORNOVA PLAIN AND ITS SURROUNDINGS (EASTERN İZMİR BAY/WESTERN TURKEY)” completed by **EREN PAMUK** under supervision of **PROF. DR. MUSTAFA AKGÜN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Doctor of Philosophy.



Prof. Dr. Mustafa AKGÜN

Supervisor



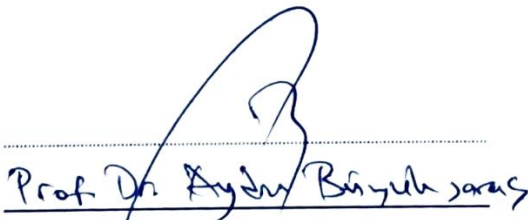
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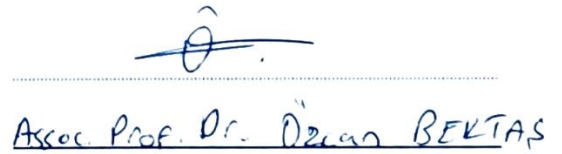


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Eren PAMUK

INVESTIGATION OF SOIL DYNAMIC CHARACTERISTICS AND MODELING SOIL-BEDROCK INTERFACES OF BORNOVA PLAIN AND ITS SURROUNDINGS (EASTERN İZMİR BAY/WESTERN TURKEY)

ABSTRACT

In order to control the possible damages that may occur during the earthquake, soil dynamic behaviour under the unique dynamic earthquake load to the study area should be defined accurately and reliably. For this purpose, studies of earthquake hazard analysis studies, determination of soil dynamic characteristics, soil-bedrock models used for soil deformation analysis and ground response analyzes are required for the study area. Within the scope of this thesis, earthquake hazard analysis was firstly carried out for İzmir and its surroundings. In the next stage, the soil dynamic characteristics of the Bornova Plain and its surroundings were investigated by using surface wave methods and previously geotechnical studies in the study area. In addition, NEHRP soil classification and soil-structure resonance maps were created. According to these studies, risk maps were prepared for the study area. At the final stage of the thesis, surface wave and microgravity methods were used together to model 2D and 3D soil-bedrock interfaces. As a result of seismic hazard analysis studies, it was determined that the b value changes from 0.6 to 1.05. The return period varies from 20 to 140 years for $M= 6.0$. The predominant period values are between 0.4-1.6 sec and V_{s30} values were obtained between 100 m/sec and 1500 m/sec. There is resonance risk that the buildings which have periods varying from 1 to 1.6 sec within Bornova Plain. G_{max} calculated up to 50 m depth and G_{max} values range between 280 kg/cm²-100000 kg/cm². According to the NEHRP, B-C and F soil classes have been spotted in the whole study area. According to soil-bedrock models, the soil thickness is in the range of 300-400 m in Bornova Plain. Focusing problems can be seen in Bornova Plain during an earthquake. The interfaces of soil-bedrock don't have the feature of horizontal and semi-infinite.

Keywords: Seismic hazard analysis, shear wave velocity (V_s), predominant period, resonance, soil-bedrock model

BORNOVA OVASI VE ÇEVRESİNİN (İZMİR KÖRFEZİ DOĞUSU/BATI TÜRKİYE) ZEMİN DİNAMİK ÖZELLİKLERİNİN ARAŞTIRILMASI VE ZEMİN-ANAKAYA ARAYÜZEYLERİNİN MODELLENMESİ

ÖZ

Deprem sırasında oluşabilecek olası zararları kontrol altına alabilmek için zeminlerin çalışma alanına özgün dinamik deprem yükü altında yapacağı davranışların doğru ve güvenilir bir şekilde tanımlanması gerekir. Bu amaçla çalışma alanı için deprem tehlike analizi çalışmaları, zemin dinamik özelliklerinin belirlenmesi ve yer tepki analizleri, zemin deformasyon analizleri için kullanılan zemin-anakaya modellerinin oluşturulması gerekmektedir. Bu tez kapsamında, öncelikle İzmir ve çevresi için deprem tehlike analizi çalışması gerçekleştirilmiştir. Sonraki aşamada ise yüzey dalgası yöntemleri ve çalışma alanında daha önceden gerçekleştirilen geoteknik çalışmalar birlikte kullanılarak Bornova Ovası ve çevresinin zemin dinamik özellikleri irdelenmiştir. Ayrıca NEHRP zemin sınıflaması ve zemin-yapı rezonans haritası oluşturulmuştur. Bu çalışmalar ışığında çalışma alanı için risk haritaları hazırlanmıştır. Tezin son aşamasında ise yüzey dalgası ve mikrogravite yöntemleri birlikte kullanılarak 2B ve 3B'lu zemin-anakaya ara yüzeyleri modellenmiştir. Sismik tehlike analizi çalışmaları sonucunda b değerinin 0.6 ile 1.05 arasında değiştiği saptanmıştır. Geri dönüş periyodu $M=6.0$ için 20 ile 140 yıl arasında değişmektedir. Zemin baskın periyot değerleri 0.4-1.6 s arasındayken V_{s30} değerleri de 100 m/s ile 1500 m/s arasında değişmektedir. Bornova Ovası'nda periyotları 1- 1.6 s arasında değişen yapılar rezonans riski taşımaktadır. G_{max} , 50 m derinliğe kadar hesaplanmıştır ve bu değerler 280 kg/cm² ile 100000 kg/cm² arasında değişmektedir. NEHRP zemin sınıflamasına göre çalışma alanı genelinde B-C ve F zemin sınıfları saptanmıştır. Zemin kalınlığı Bornova Ovası'nda 300 ile 400 m arasında değişmektedir. Deprem sırasında Bornova Ovası'nda odaklanma problemleri görülebilir. Zemin-anakaya arayüzeyleri yatay ve yarı sonsuz özelliğe sahip değildir.

Anahtar Kelimeler: Sismik tehlike analizi, kayma dalgası hızı (V_s), baskın periyot, rezonans, zemin-anakaya modeli

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CHAPTER ONE

INTRODUCTION

In chapter two, It was given information about geology, tectonic and seismicity of the study area.

In chapter three (article one: Seismic Hazard Analysis In İzmir And Its Surroundings (Western Turkey)), it was investigated the b-values using the Gutenberg–Richter frequency–magnitude relationship in İzmir City and its surroundings in western Turkey where accommodated the 12 June 2017 Mw 6.2 Midilli earthquake and 21 May 2017 Mw 4.9; 27 May 2017 Mw 5.2 Manisa earthquakes. For this purpose, it was calculated and mapped the b values as 2D and 3D using maximum likelihood method (ML). In addition, It was determined the recurrence time distribution map for the region. It was obtained the lowest b value in northwest and southeast parts of the study area. Minimum the recurrence time period of $M_s=6.0$ from is 20 years where b values change from 0.6 to 0.76.

In chapter four (article two: Soil Characterization of Bornova Plain (Izmir/Turkey) and Its surroundings using Combined Survey of MASW and ReMi Methods and Nakamura (HVSr) Technique), structural damage which occurs during earthquakes is related to both the soil dynamic behavior attributes and soil response spectrums. Therefore, soil and bedrock descriptions should be done according to S-wave velocity (V_s) values. Being an important input parameter of ground and soil type definition in geotechnical earthquake analysis and having a significant role in determining the soil behavior during an earthquake, V_s values were obtained, from an area located east of İzmir Bay, in this study using multi-channel analysis of surface waves (MASW) and refraction microtremor (ReMi) methods. Maximum shear modulus (G_{max}) has been estimated from shear wave velocity. The level maps were created up to 50 m using V_s and G_{max} values at different depths as 2D and 3D. By obtaining H/V spectral ratio spectrums from Nakamura Technique, predominant period values, which can be used to define soils, were also obtained from this study. Groundwater Level (GL), SPT- N_{30} , Poisson Ratio which is other dynamic parameter of the soil were evaluated using

previously geotechnics studies in the study area. In addition, It was calculated building periods using the empirical relationship between height (or a number of floors) of buildings and predominant period of the buildings to examine soil-structure resonance. According to NEHRP (National Earthquake Hazard Reduction Program) (1997) soil classification, study site consists of B, C and F-type soils. Risk maps were created using dynamic properties of the soil.

In chapter five (article three: 2D Soil And Engineering-Seismic Bedrock Modeling of Eastern Part of İzmir Inner Bay/Turkey), Soil-bedrock models are used as a base when the earthquake-soil common behaviour is defined. Moreover, the medium which is defined as bedrock is classified as engineering and seismic bedrock in itself. In these descriptions, S-wave velocity is (V_s) used as a base. The mediums are called soil where the V_s is 760 m/sec, the bigger ones are called bedrock as well. Additionally, the parts are called engineering bedrock where the V_s is between 3000 m/sec and 760 m/sec, the parts where are bigger than 3000 m/sec called seismic bedrock. The interfacial's horizontal topography where is between engineering and seismic bedrock is effective on earthquake's effect changing on the soil surface. That's why, 2D soil-bedrock models must be used to estimate the earthquake effect that could occur on the soil surface. In this research, surface wave methods and microgravity method were used for occurring the 2D soil-bedrock models in the east of İzmir bay. In the first stage, velocity values were obtained by the studies using surface wave methods. Then, density values were calculated from these velocity values by the help of the empiric relations. 2D soil-bedrock models were occurred based upon both V_s and changing of density by using these density values in microgravity model. When evaluating the models, it was determined that the soil is 300–400 m thickness and composed of more than one layers in parts where are especially closer to the bay. Moreover, it was observed that the soil thickness changes in the direction of N-S. In the study area, geologically, it should be thought the engineering bedrock is composed of Bornova melange and seismic bedrock unit is composed of Menderes massif. Also, according to the geophysical results, Neogene limestone and andesite units at between 200 and 400 m depth show that engineering bedrock characteristic.

In chapter six (article four: 3D Bedrock Structure of Bornova Plain and its surroundings (İzmir/Western Turkey)), There is needed an earthquake record on engineering bedrock to perform soil deformation analysis. This record could be obtained in different ways (seismographs on engineering bedrock; with the help of the soil transfer function; scenario earthquakes). S-wave velocity profile must be known at least till engineering bedrock for calculating soil transfer functions true and complete. In addition, 2D or 3D soil, engineering-seismic bedrock models are needed for soil response analyses to be carried out. These models are used to determine changes in the amplitude and frequency content of earthquake waves depending on the seismic impedance from seismic bedrock to the ground surface and the basin effects. In this context, it is important to use multiple in-situ geophysical techniques to create the soil-bedrock models. In this study, 2D and 3D soil bedrock models of Bornova Plain and its surroundings (Western Turkey), which are very risky in terms of seismicity, were obtained by using combined survey of surface wave and microgravity methods. The result of 3D bedrock structure shows stratigraphy cross sections that consist of many layers, where the engineering bedrock depths in the middle part of Bornova Plain range from 200-400 m and in the southern and northern parts which are covered limestone and andesite show the engineering bedrock ($V_s > 760$ m/sec) feature. In addition, seismic bedrock ($V_s < 3000$ m/sec) depth changes from 550 to 1350 m. The predominant period values obtained from single station microtremor method change from 0.45 sec to 1.6 sec while they are higher than 1 sec in middle part of Bornova Plain where the basin is deeper.

CHAPTER TWO

GEOLOGY, TECTONIC AND SEISMICITY OF THE STUDY AREA

2.1 Study Area

Izmir a city in western Turkey is a third most populous city in Turkey. The 2016 census put İzmir's population at approximately 4 200 000. Many active faults resulting from the tectonic structure of the Aegean region causes high seismicity and has resulted in numerous destructive earthquakes. The Bornova Plain, which is the one of largest plain in İzmir and surroundings, borders the Karsiyaka Fault Zone in the north and the İzmir Fault Zone in the south and new building sites of new high-rise building have been planned in this region (Figure 2.1).

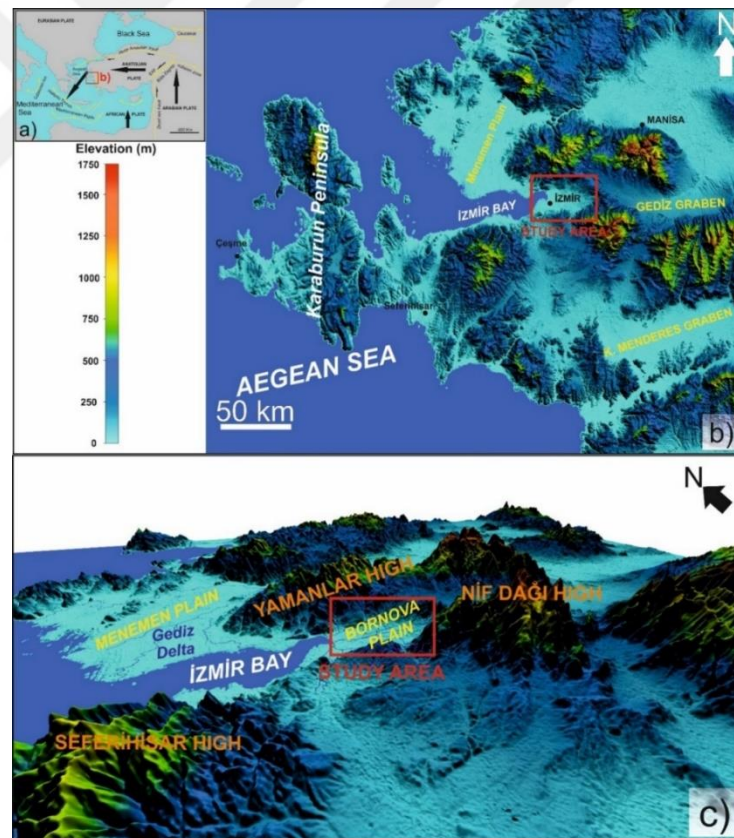


Figure 2.1 Site location map of study area together with a) Tectonic setting of the Anatolian plate, b) General morphology and c) Focused view of Bornova Plain with the main streams as blue lines and uplift systems (Yamanlar High, Nif Dağı High and Seferihisar High)

2.2 Geology and Geomorphology of the Study Area

There are three tectonic belts around İzmir in western Anatolia. These belts are from east to west; Menderes Massif, İzmir-Ankara Zone and Karaburun (Zone) Belt (Bozkurt & Oberhänsli, 2001; Gessner et al., 2013) (Figure 2.2b). Menderes massif is composed of metamorphic rocks which's top level reaches to early Eocene. İzmir-Ankara Zone where mounts on Menderes massif is represented with a matrix that is composed of basalt and precipitated sedimentary rocks in facies flysch that Campanian – Danian aged in a large region from Manisa to Seferihisar and unit composed of limestone blocks more than 20 km heights in this matrix. While the precipitation of matrix of the Bornova melange unit, the limestone block and mega blocks are transferred to sedimentation environment and by the result of this complex contact structures that observed soft sediment deformations were developed around the blocks. This limestone mega block's generalized stratigraphy which is obtained as associated the measured sections is similar to carbonate sequence outcrops on Karaburun Peninsula (Erdoğan, 1990). Upper Cretaceous Bornovamelange constitutes the base in İzmir and territory. Limestone mega olistoliths are in Bornova melange matrix randomly which are older than a matrix of melange. These limestones are known as Işıklar limestone in the territory of Altındağ (Özer & İrtəm, 1982). Bornova melange is composed of pebble stone lens/channel fillings and diabase blocks-platform typed limestone in a matrix which is composed of sandstone/shale-calcareous shale alternating (Erdoğan, 1990). Neogene aged lacustrine sediments come on the Bornova melange as an angular unconformity. Yamanlar volcanites cover the available units as unconformity aswell. Quaternary soil covers all available units as unconformity either (Figure 2.2d). Typical Bornova melange unit is differentiated with limestone olistoliths which are in this matrix and precipitates through flysch facies in the age range of upper cretaceous-paleocene, matrix's composed of sandstone-shale alternating and pebble lens and older than this matrix also (different age and sizes). Bornova melange is in the oldest unit position in the area of investigation. Neogene aged sedimentary rocks come on to Bornova melange as unconformity. These sedimentary rocks are; pebbles, argillaceous limestones and silicified limestones. Yamanlar volcanites are represented with andesitic-dacitic massif lava, tuff, andesite and agglomerates in the study area. Volcanites cover the Neogene sedimentary rocks

as unconformity in the region. There are determined NE-SW and E-W-trending two fault sets in the İzmir territory.

It is seen that the E-W-trending normal fault cut the oblique-slip fault. That's why Bornova graben get a sliced structure (Kıncal, 2004). Bornova melange is in the oldest unit position in the study area. Neogene aged sedimentary rocks come on to Bornova melange as an unconformity. These sedimentary rocks are; pebbles, argillaceous limestones and silicified limestones. Volcanites cover the Neogene sedimentary rocks as unconformity (Kıncal, 2004). Basically, the current alluvial plains around İzmir bay developed on the same continental fill as well as differ by in terms of geomorphological formations. Inner bay coasts, Balçova and Alsancak in the south, Karşıyaka deltas in the north are basic developed delta plains. On the other hand, Gediz Delta is a big and complex formation that is shaped with alluvions of Gediz River where collects the big part of Western Anatolian's water. Bornova Plain in the east is not a typical plain notwithstanding that starts from the coast. The reason of this is, there is not a big river reaches to sea from Bornova. Indeed, the mountain streams water part where falls to Bornova is too close to plain (Kayan, 2000). The geology of study area is shown in Figure 2.2d.

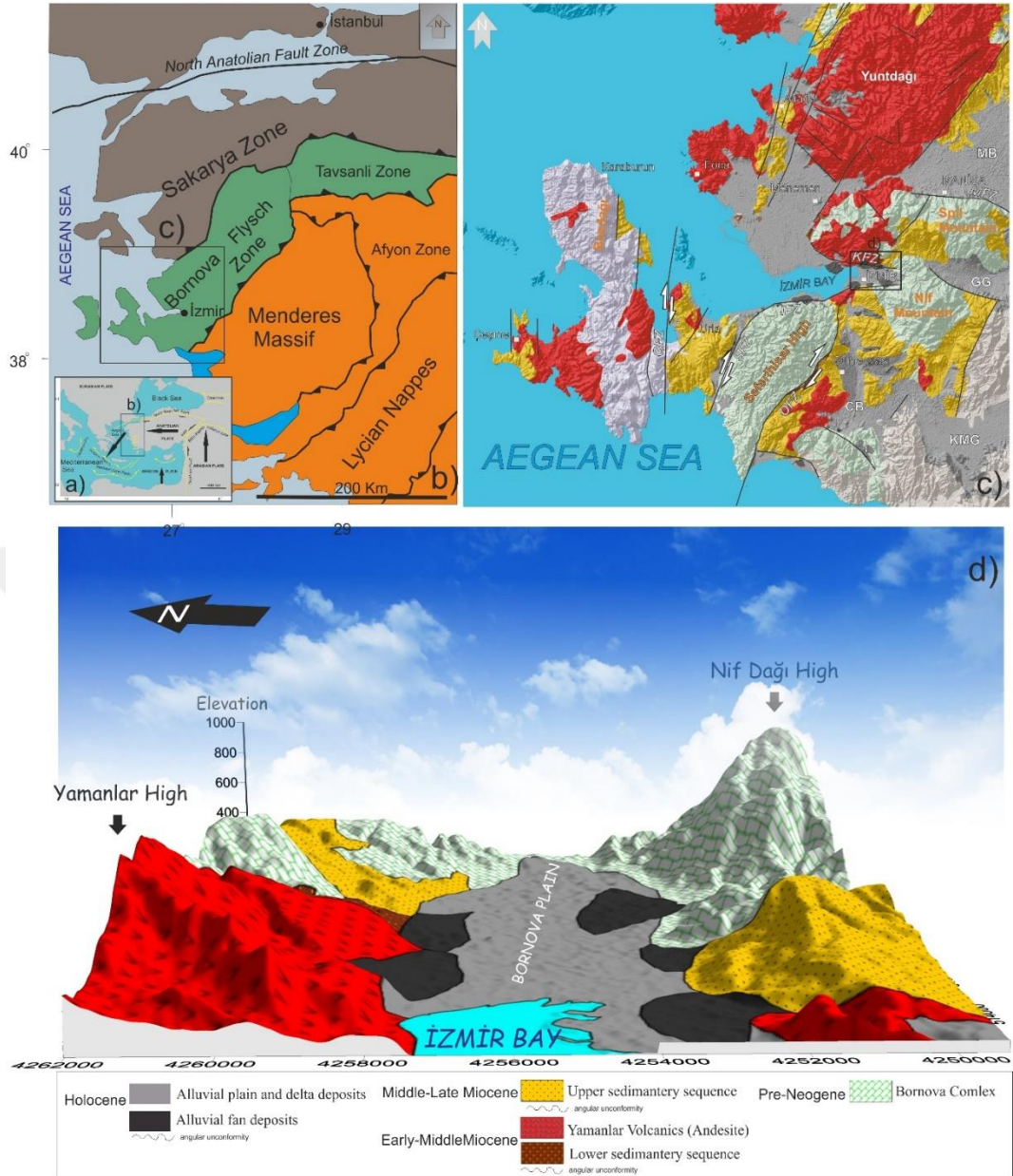


Figure 2.2 Representation of a) General tectonic of the Turkey b) Tectonic belts around İzmir in Western Anatolia (modified from Bozkurt & Oberhänsli, 2001; Gessner et al., 2013) c) Simplified geological map of Western Anatolia with main tectonic lines (modified from Uzel et al. 2012) OFZ– Orhanlı fault zone SFZ– Seferihisar fault zone GFZ– Gülbahçe fault zone İFZ– İzmir fault zone KFZ– Karşıyaka fault zone MFZ– Manisa fault zone KMG– Küçük Menderes graben CB– Cumaovası basin GG– Gediz Graben MB– Manisa Basin d) The geological map of the study area together with geomorphology (modified from Kıncal, 2004; Uzel et al., 2012)

2.3 Tectonics and Seismicity of the Study Area

Izmir and its surroundings are an important settlement area in the Western Anatolia, which is tectonically active. The Middle East Aegean Collapse is a product of vertical displacements, which was inherited from the Pre-Neogene and advanced basically along with the NE and N-inclined structural surfaces. The collapse is surrounded by the structural elevations of Karaburun- Midilli from the west and Menderes from the east; and divided into Foça collapse consisting of structural- stratigraphic steps from west to east, Yamanlar high and Akhisar collapse. Collapse fill consists of multi-layered, repeated accumulations of sedimentary and volcanic products. Rock units are mostly separated by erosion surfaces and transgressive overthrust on neighboring elevations. The great lower part of the sedimentary and volcanic community forming the Neogene stowage developed in the Foça collapse and the uppermost part developed in the Foça and Akhisar collapses (Kıncal, 2004).

There are many active faults that can produce an earthquake in a radius of about 50-60 km in Izmir and its surrounding. The Manisa Fault, Izmir Fault, Tuzla Fault and Gülbahçe-Karaburun Faults are those faults that have such an important potential of an earthquake (Emre et al., 2005). The Manisa Fault is a normal fault located at the northwest side of Gediz graben. The Manisa fault, which is about 40 km long between Turgutlu and Muradiye at the west of Manisa, is about 50 km away from Izmir. The Izmir fault located at the east of the Izmir Gulf has the feature of a normal fault and is about 35 km long and E-W trending. The Tuzla Fault, consisting of three parts with NE-SW direction, is located between Izmir and Doganbey Tongue. The part of this fault between the Aegean Sea and the Cumalı thermal springs is 15-16 km long and an active fault with a right-oriented direction pulse. The Gülbahçe-Karaburun Fault located at the southwest of the Izmir Gulf is a fault with an N-S direction and about 15 km long on land. In addition, one of the most important features of this fault is that it is an important structural line separating the Karaburun peninsula and the Izmir Gulf. Although it is supposed that the fault continues even in the sea at the north and south, its distance to the study area is about 55 km (Emre et al. 2005). The Orhanlı-Tuzla Fault Zone (OFZ), which is ~50-60 km long trending NE-SW starting from the Doğanbey Tongue (DT) at the SW of Izmir; the Seferihisar Fault Zone (SFZ), which

is ~30 km long trending NE-SW starting from the Sığacık Gulf (SG); the Zeytindağ-Bergama Fault Zone (ZBFZ) continuing from the Çandarlı Gulf (ÇG) to the North; the Menemen Fault Zone (MFZ), which is ~15 km long trending NW-SE at the west of the Yamanlar Mountain (YM); the Karşıyaka Fault Zone (KFZ), which is ~40 km long; the Uzunada Fault Zone (UFZ) trending NW-SE at the east of Uzunada (UA); the Gediz Graben (GB), which is described as a low-angled elusion fault; and the Büyük Menderes Graben (BMG) can be given (Emre et al.,2005;2013;Özer and Polat 2017a;2017b). Furthermore, the Küçük Menderes Graben (KMG) plays an important role in explaining the Western Anatolian tectonics (Seyitoğlu & Işık, 2015, Özer & Polat, 2017a) (Figure 2.3).

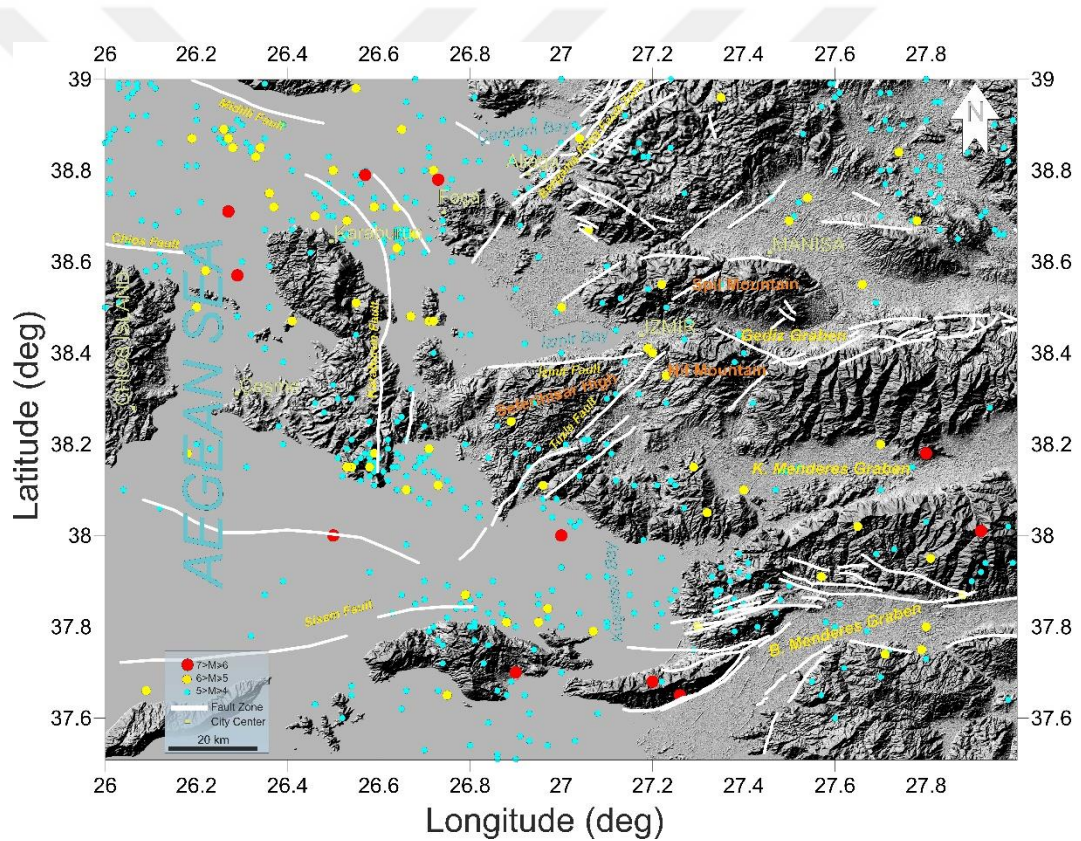


Figure 2.3 Main tectonic elements and seismicity of the İzmir and surroundings (Earthquake data (M>4) between 1900 and 2017)

When looked at the earthquake history of İzmir and its surroundings based on the records of seismology, it is seen that the earliest earthquake occurred in 26 BC. When these records are considered from 1900 to June 12th, 2017, it is understood that 687 earthquakes at least with 4.0 magnitude occurred in the region. The distribution of

these earthquakes in Izmir and its surroundings is seen in Figure 2.3. It is understood from this distribution that Izmir and its surroundings have an active earthquake regime. When looked at the instrumental period, the seismotectonic region had a dynamic earthquake regime between 1900 and 2017. The historical earthquakes giving damage in Izmir and its surroundings are given in Table 2.1 and the instrumental earthquakes are given in Table 2.2 (Figure 2.4).

Tablo 2.1 Destructive earthquakes in the study area during the historical period (Emre et al., 2005)

Date	Latitude (Deg)	Longitude (Deg)	M
17	38.40	27.50	7.0
105	38.90	27.00	6.4
176 and 177	38.60	26.65	5.8
178	38.30	27.10	6.5
688	38.41	27.20	6.5
1039	38.40	27.30	6.8
20 March 1389	38.40	26.30	6.7
20 May 1654	38.50	27.10	6.4
02 June 1664	38.41	27.20	5.8
14 Feb 1680	38.41	27.20	6.2
10 July 1688	38.40	26.90	6.8
13 Jan 1690	38.60	27.40	6.4
1723	38.40	27.00	6.4
04 April 1739	38.50	26.90	6.8
24 Nov 1772	38.80	26.70	6.4
03-05 July 1778	38.40	26.80	6.4
03 Nov 1862	38.50	27.90	6.9
29 July 1880	38.60	27.10	6.7
15 Oct 1883	38.30	26.20	6.8

Tablo 2.2 Destructive earthquakes in the study area during the instrumental period (modified from Emre et al., 2005)

Date and Location	Latitude (Deg)	Longitude (Deg)	M
19 Jan 1909 Foça	38.66	26.94	6.0
31 March 1928 Torbalı	38.18	27.80	6.5
22 Sep 1939 Dikili	39.07	26.94	6.6
23 July 1949 Karaburun	38.57	26.29	6.6
2 May 1953 Karaburun	38.48	26.57	5.0
16 July 1955 Söke-Balat	37.65	27.26	6.8
6 April 1969 Karaburun	38.47	26.41	5.9
1 Feb 1974 İzmir	38.41	27.19	5.5
14 Jun 1979 Karaburun	38.79	26.57	5.7
6 Nov 1992 Doğanbey	38.16	26.99	5.7
28 Jan 1994 Manisa	38.69	27.49	5.2
24 May 1994 Karaburun	38.66	26.54	5.0
10 April 2003 Urla	38.26	26.83	5.6
17 Oct 2005 Sığacık	38.19	26.71	5.4
17 Oct 2005 Sığacık	38.11	26.73	5.6
17 Oct 2005 Sığacık	38.15	26.53	5.8
20 Oct 2005 Sığacık	38.11	26.73	5.6
20 Oct 2005 Sığacık	38.18	26.59	5.9
26 March 2010 Çeşme	38.18	26.18	5.0
5 Dec 2011 İzmir	38.85	26.34	5.3
1 May 2012 İzmir	38.63	26.64	5.0
1 May 2012 İzmir	38.66	26.68	5.3
06 Dec 2014 İzmir	38.85	26.28	5.1
06 Dec 2014 İzmir	38.87	26.27	5.4
06 Dec 2014 İzmir	38.89	26.26	5.3
06 Dec 2014 İzmir	38.89	26.26	5.5
06 Dec 2015 Aegean Sea	38.87	26.19	5.0
21 April 2017 Manisa	38.63	27.58	4.9
27 May 2017 Manisa	38.73	27.81	5.1
12 June 2017 Midilli	38.85	26.25	6.2

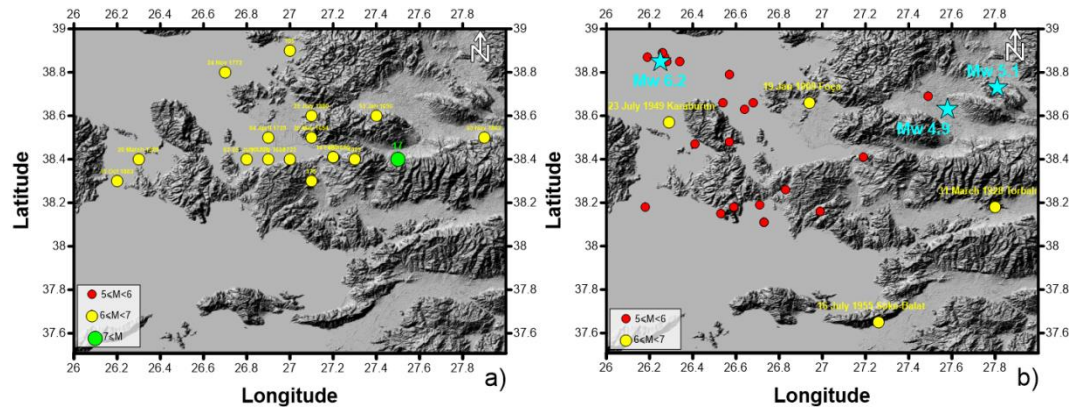


Figure 2.4 Destructive earthquakes in the study area during a) The historical period b) The instrumental period ($M > 5.0$)

CHAPTER THREE

SEISMIC HAZARD ANALYSIS IN İZMİR AND ITS SURROUNDINGS (WESTERN TURKEY)

Probabilistic earthquakes studies provide the important information of future seismicity for any period and magnitude change in any area. In the first stage of probabilistic seismic hazard is the evaluation of earthquake hazard parameters (b value, recurrence time etc.) Many researchers used different techniques for calculating the b-value and its uncertainty; the most common is the least-squares regression and the maximum-likelihood methods (e.g. Aki, 1965; Utsu, 1965; Hamilton, 1967; Wiemer & Wyss, 1997).

Polat et al. (2008) analyzed to reveal seismic hazard by using fractal behaviour, seismic quiescence z- and Gutenberg-Richter b-parameters in West Turkey. Ghosh et al. (2008) examined seismicity patterns across Nicoya, Costa Rica for determining the overall and spatial variability in the earthquake frequency-magnitude distribution along the interface. Bayrak et al. (2009) determined seismicity and earthquake hazard parameters for Turkey and the adjacent areas using the maximum likelihood method. Yadav et al. (2012) applied the maximum likelihood method for earthquake hazard parameters and seismicity in some source zones of NW Himalaya and the adjoining regions. Görgün (2013) investigated the b-values from the Gutenberg–Richter frequency–magnitude relation in the Lake Van region in eastern Turkey. Özmen et al. (2014) investigated the seismicity of Central Anatolia, by determining the “a” and “b” parameters in a Gutenberg–Richter magnitude–frequency relationship using data from earthquakes of moment magnitude ($M_w \geq 4.0$) that occurred between 1900 and 2010. Bayrak et al. (2015) investigated the earthquake hazard of the East Anatolian Fault Zone by determining the a and b parameters in a Gutenberg–Richter magnitude–frequency relationship.

The study area is bordered between 26–28°E and 37.5–39°N, in İzmir and surroundings (Western Anatolia of Turkey) (Figure 2.3). İzmir a city in western Turkey is a third most populous city in Turkey. The 2016 census put İzmir's population at approximately 4 200 000. Many active faults resulting from the tectonic structure of

the Aegean region causes high seismicity and has resulted in numerous destructive earthquakes. It was used the accuracy of the seismic catalog in the study until 2011 (Kalafat et al.,2011), and earthquake catalogue between 2010 and added previously catalogue by the homogenizing process. It was focused on the analysis of the b-values before and after the Midilli and Manisa earthquakes, return period of İzmir and its surroundings of Western Turkey. The standard deviations of the b values were also estimated. The b-value is approximately 0.81 ± 0.03 after the Midilli and Manisa earthquakes. The b-value is lower in southeast and northwest part of the study area and higher in other parts of the study area after the Midilli and Manisa earthquakes.

Midilli Earthquake (12 June 2017 Mw 6.2); An earthquake, centered in the Aegean Sea at about 23 km north of Karaburun district of İzmir (at the south of Midilli) on June 12th, 2017 at 15:28 TSI, occurred. It was felt in İzmir, Denizli, Uşak, Aydın, Balıkesir, Eskişehir, İstanbul and the surrounding provinces. More than 200 aftershocks occurred in the same region according to the KANDILLI and AFAD records (the largest with Mw 4.9) after the main shock, which occurred on the Midilli Fault having the feature of a normal fault. Small scaled damages occurred especially in some buildings located on alluvion unit in İzmir province. The maximum earthquake intensity was given as VII (Sözbilir et al. 2017). The presence of a deformation zone, which is southward inclined, with a stepped geometry, containing a small amount of lateral component and characterized by a normal faulting with an inclination pulse, emerges at the south of Midilli. This deformation zone, defined as Midilli Fault Zone, is about 10 km wide and 60 km long (Sözbilir et al., 2017).

Manisa Earthquakes (21 April 2017 Mw 4.9 and 27 May 2017 Mw 5.1); An earthquake, centered in Manisa-Şehzadeler on April 21st, 2017 at 17:12 am with the TSI, occurred. The magnitude of the earthquake was determined as Mw=4.9 and its depth as ~13 km. Tension cracks and damages occurred in the buildings of the surrounding villages during the earthquake (Dokuz Eylül University, Department of Geophysical Engineering [DGE], 2017). 71 aftershocks occurred in the first 20 hours after the main shock. The epicenter zone witnessed an intense earthquake activity in the last month before the main shock (from March 28th to April 21st, 2017). The number of earthquakes even in the last 3 weeks before the main shock was ~ 150

(DGE, 2017). Although the seismogenic zone generally shows a circular foreshock and aftershock distribution, it is observed that the dominant seismic activity is the N-S or NW-SE trending. The sum of all the aftershocks within three days after the earthquake exceeded 150 (DGE, 2017).

The earthquake with a magnitude of M_w 5.1, whose epicenter was Manisa (Saruhanlı) on 27.05.2017 at 18.53, was severely felt in Manisa and Izmir. 214 aftershocks, ranging from 1.2 to 4.8 in magnitude, occurred just after the earthquake (as of 28.05.2017 at 13:00) (Afet ve Acil Durum Yönetimi Başkanlığı [AFAD], 2017). According to the ground motion recorded at the earthquake accelerometer station located in Manisa Gölarmara, the active duration of the earthquake is 6.12 seconds (AFAD, 2017).

3.1 Data Analysis

It was used a revised and extended earthquake catalogue from the Kandilli Observatory and Earthquake Research Institute (KOERI)- İstanbul (Kalafat et al., 2011), and used the data from 1900 to 2010 $M \geq 4$ for the Western part of Aegean Region covering an area between $26-28^\circ$ E longitudes and $37.5-39^\circ$ N latitudes. Also, earthquake catalog between 2010 and 2017 added previously cataloged by the homogenizing process. The earthquake catalog includes M_b , M_d , M_L , M_s and M_w scales. Therefore, it was derived M_s values from M_b , M_d , M_L and M_w empiric relations ($M_d=1.0377+0.7863*M_s$; $M_w=0.3247+0.9870*M_b$; $M_L=1.0553+0.7782*M_s$; $M_b=1.4429+0.7123*M_s$) developed by Kalafat et al. (2011). It was examined earthquake catalog includes 647 events ($M \geq 4$).

Depth, magnitude, time and hour histograms for the study area are shown in figure 3.1(a-d). In recent years, much more earthquake records with an increase in the seismic network. When examining the distribution of earthquake focus, it was noticed that hypocentres are below 40 km mostly (figure 3.3a). Magnitude histograms show that magnitude of earthquakes changes from 4.0 to 4.5 predominately (figure 3.1c) in the used catalog. It is noteworthy that peaks in the number of earthquakes in 1976,

1996, 2006, 2014 (Figure 3.1c). It was performed an analysis of the daily events. It is seen that earthquakes occur almost every hour (Figure 3.1d).

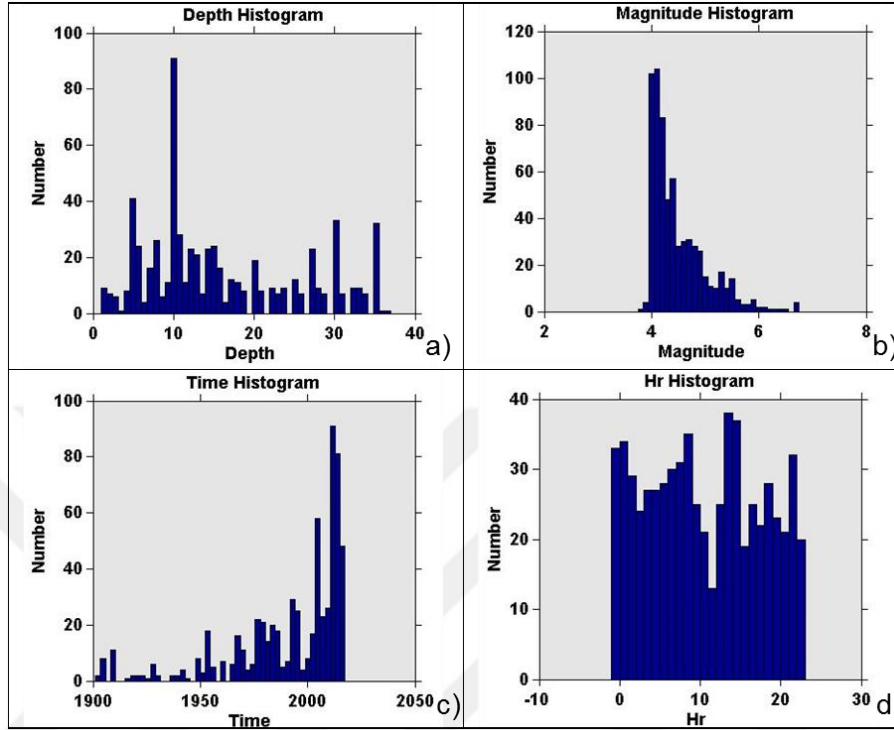


Figure 3.1 Various histograms from a number of recorded events versus a) Depth histogram b) Magnitude histogram c) Time histogram and d) Hour of the day histogram in İzmir and its surroundings (1900–2017, $M \geq 4.0$)

3.2 The b-value Analysis

The famous relationship of Gutenberg and Richter (1944) has been widely used in the field of earthquake seismology and seismic hazard studies. This seismic hazard, magnitude–frequency relationship defines the frequency of earthquake occurrence and magnitude in an area. The mathematical form of this relationship is given by

$$\text{Log } N = a - bM \quad (3.1)$$

where N is the cumulative number of earthquakes and a and b are the constants. In this study, it was used maximum likelihood method (Aki 1965; Wiemer & Wyss 2002) for the estimation of b-values. When The b value which is an important parameter for

earthquake source characteristics is higher, this value reflects the slightly larger proportion of small events (Wiemer & Wyss 1997; Schorlemmer et al. 2005; Singh et al., 2015). The b-value approximately is 1.0 in a seismically active zone. Higher b-value (more than 1.0) shows heterogeneity of a medium in a seismically active region (Mogi 1962; Wyss 1973; Kayal et al. 2012; Singh et al. 2012; Singh et al. 2015). In addition, lower b-value indicates the possible increase in effective stress (Scholz 1968; Urbancic et al. 1992; Singh et al. 2012; Singh et al., 2015). The estimated threshold magnitude M_c is 4.1 in the study area. (Figure 3.2). It was determined M_c and b-value as 2D and 3D using ZMAP, an open source program developed and written in MATLAB by Wiemer (2001).

It was calculated b-value using the maximum likelihood method based on Aki (1965; Utsu 1965); the equation is given as follows:

$$b = \frac{\log_{10} e}{M_{mean} - M_c} \quad (3.2)$$

where, M_c is the minimum (cut-off) magnitude, and M_{mean} is the mean magnitude, and e is the Napier base equal to 2.71 approximately. The mapping of b is utilized in a $0.01^\circ \times 0.01^\circ$ grid, selecting the nearest 100 events in each node and 20 events of the minimum number. The minimum magnitudes of completeness (M_c) at each node are very important in computing spatial variations of b value. It was calculated the magnitude of completeness and eliminated all the events having magnitudes less than M_c (figure 3.2). The calculated M_c was found as 4.1. The 2D b-value map was shown in Figure 3.3. It was detected that b-values ranges between 0.6 and 1.05 with standard deviations (δb) in the range of 0.05 to 0.15 (Figure 3.3a and b). When the standard deviation is very low, determined b-values are statistically significant. (Bayrak et al., 2013).

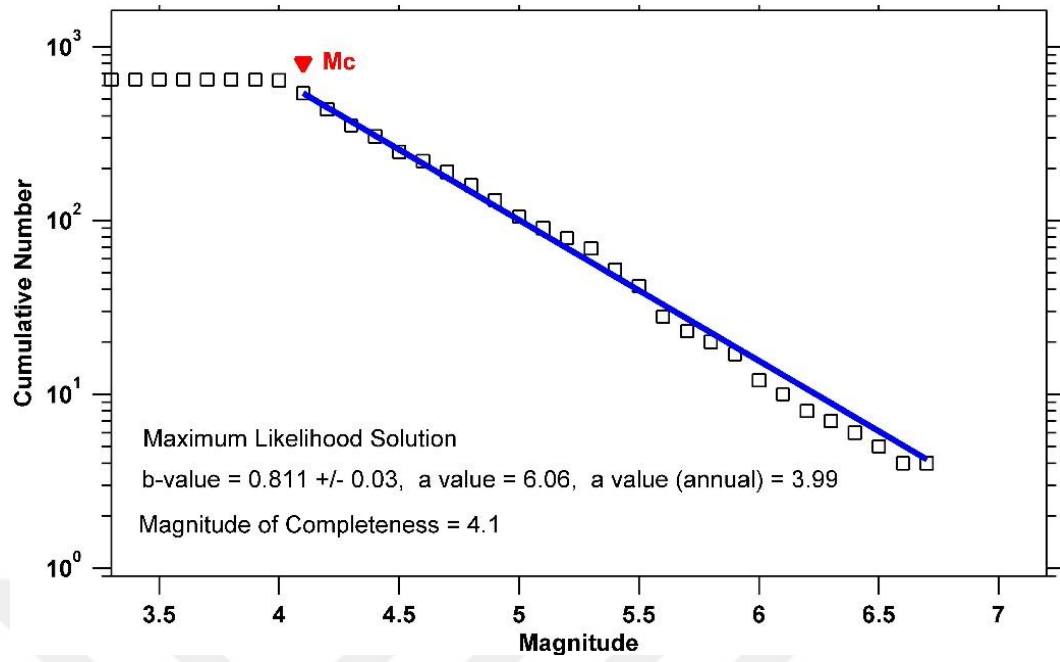


Figure 3.2 Completeness magnitude (M_c) as a function of time (plotted is both the cumulative (squares)) after the Midilli and Manisa earthquakes

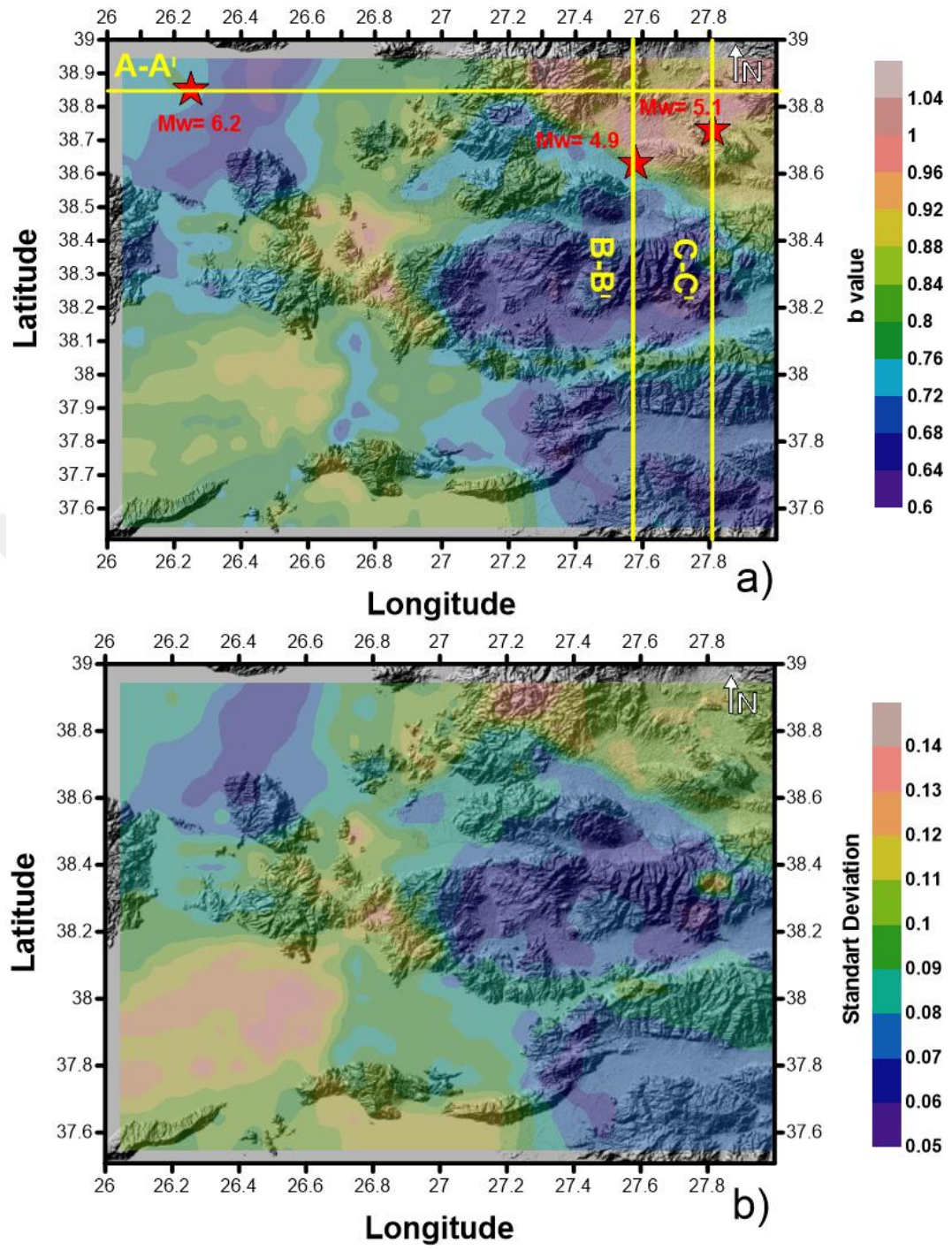


Figure 3.3 a) The b-value distribution, b) Standard deviation of b-value for the study area

3.3 Depth Distribution of b-value

Depth variation of b-value in the study area has been mapped along three cross sections (A-A', B-B' and C-C') using the maximum-likelihood method (Fig 3.3a). The b-value mapping for all cross-sections is performed in $0.01^\circ \times 0.01^\circ \times 2$ km grid intervals, selecting the nearest 100 events in each node with 20 events of a minimum number. The b-value in A-A' sections varies between 0.7 and 1.05 while the b-value changes from 0.6 to 0.9 in B-B' and C-C' sections (Figure 3.4).

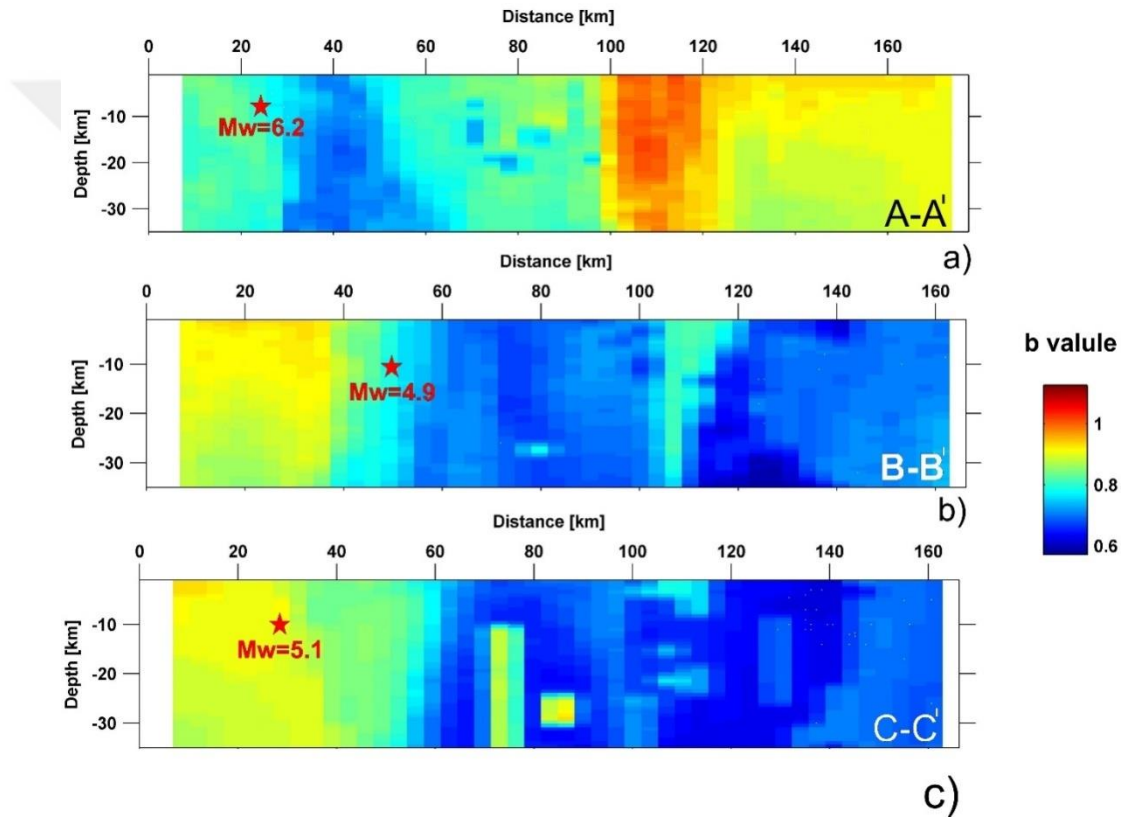


Figure 3.4 Distribution of b-value along A-A', B-B' and C-C' cross sections after Manisa and Midilli earthquakes. The mapping is performed in $0.01^\circ \times 0.01^\circ \times 2$ km grid intervals, selecting the nearest 100 events in each node and selecting 20 events of the minimum number in each node

3.4 3D b-value Mapping

Estimation of 3D b-value mapping in this study area is performed using $0.01^\circ \times 0.01^\circ \times 2$ km grid interval, selecting the nearest 100 events with 20 numbers in a minimum at each node using ZMAP software. The 3D b-value map, shown in Figure

3.5, is computed using the ML method. Also, the b-value vertical cross sections for the study area are showed in Figure 3.4. Three vertical slices are created at different locations. In 3D b-value mapping, it is observed that b-values in the study area change from 0.5 to 1.0 towards to horizontal and vertical direction. The middle parts of the region (up to 35 km depth) exhibit a low b-value whereas the south parts have a high b-values which change from 0.7 to 1.0. In the north part of the study area, b value changes from 0.5 to 0.7. In the northern part of the study area, lower b-value (0.6–1.0) at the depth 0–35 km and higher b-values (above 1.0) at depth 0–35 km is observed in the southwest of the study area (Figure 3.5).

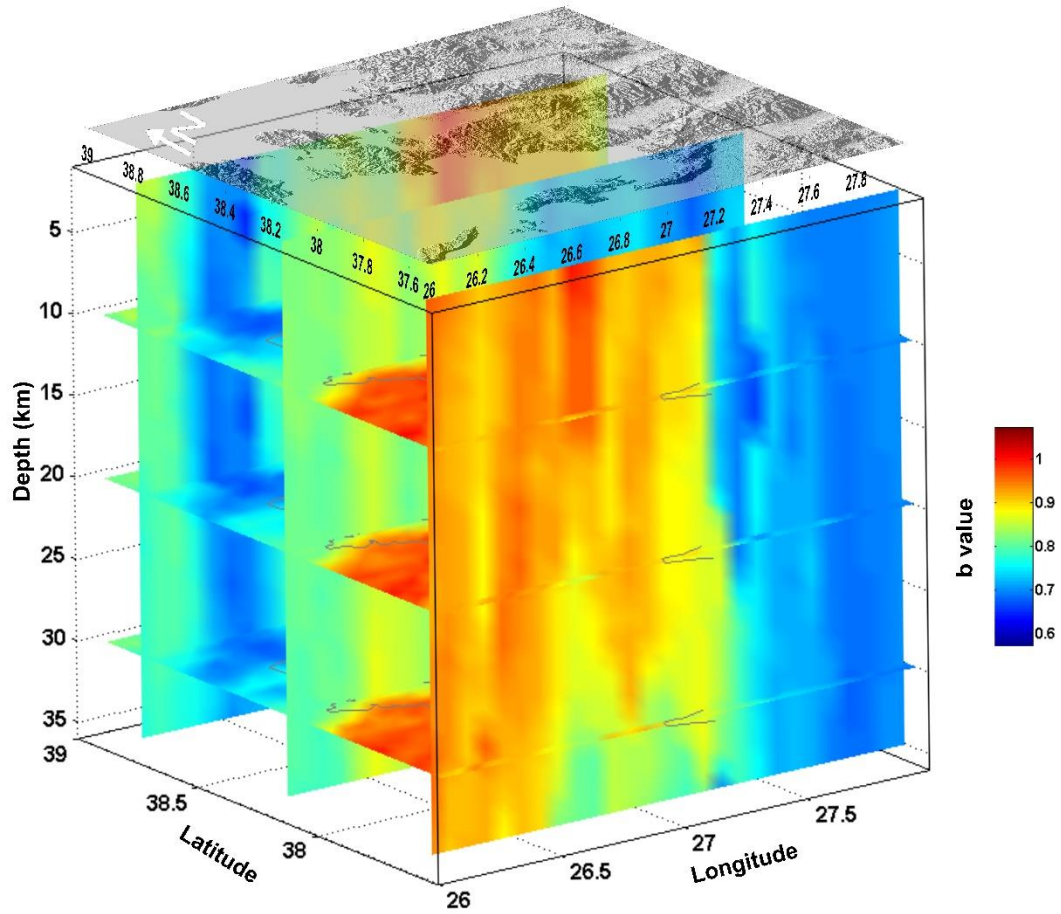


Figure 3.5 The map depicts a 3D view of b-value distribution. Mapping is performed in $0.01^\circ \times 0.01^\circ$ grid intervals, selecting the nearest 100 events in 20 each

Figure 3.6a and 3.6b show that recurrence time distribution (Tr) with magnitude $M_s=6.0$ and $M_s: 5.0$, respectively. Tr change from 20 to 140 years in the study area

for $M_s=6.0$. Return periods are between 20 and 40 years in northwest and southeast of the study area for $M_s=6.0$. In eastern of the Çandarlı gulf, T_r reaches up to 140 years for $M_s=6.0$. Further to the east from Karaburun, T_r increased up to 100 years for $M_s=6.0$. T_r changes from 4 to 20 years in the study area for $M_s=5.0$. Return periods are between 8 and 20 years in northeast and southwest of the study area for $M_s=5.0$. In eastern of the Çandarlı Gulf and Southwest of Karaburun Peninsula, T_r reaches up to 20 years for $M_s=5.0$.

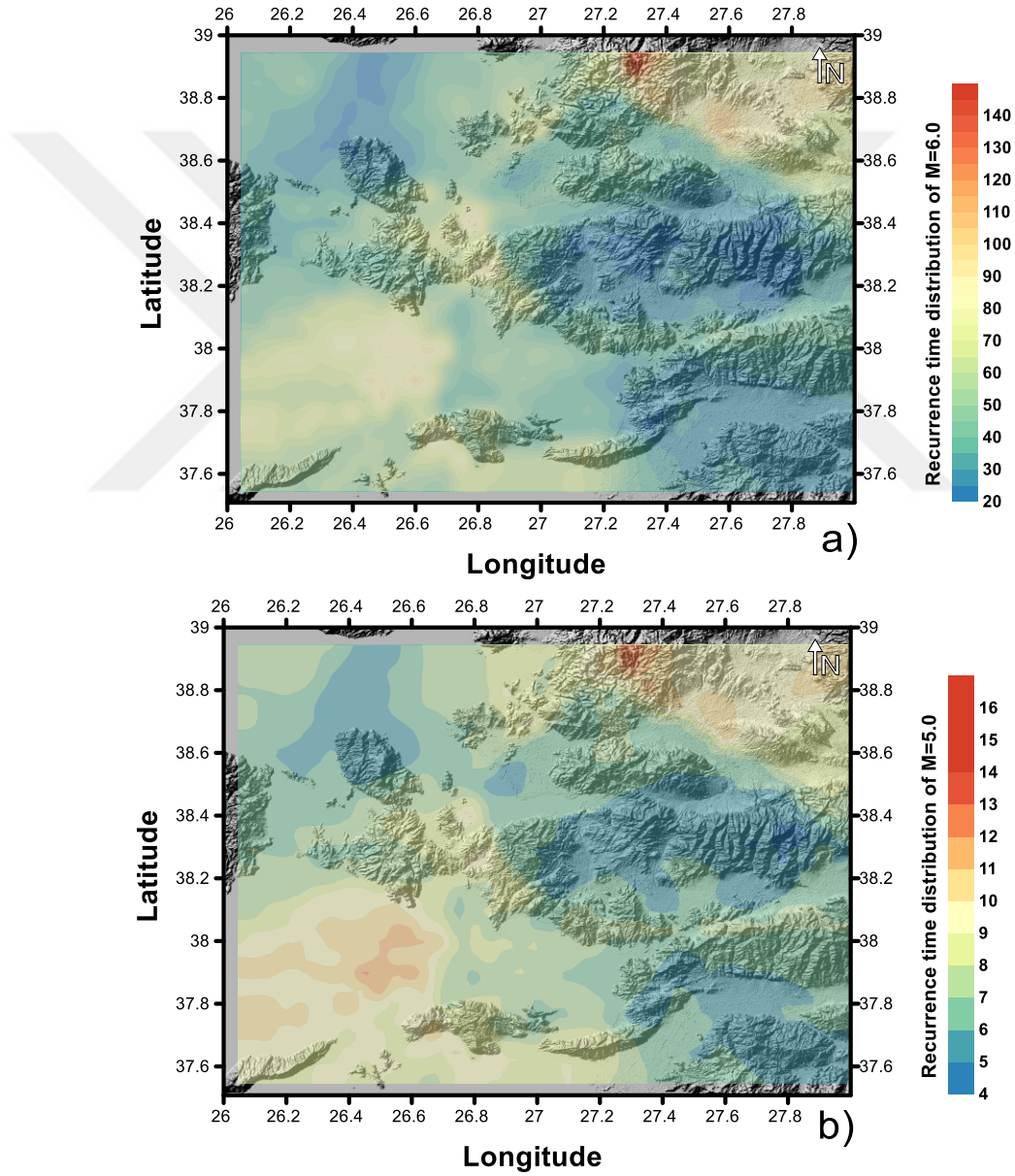


Figure 3.6 Recurrence time distribution a) $M_s=6.0$, and b) $M_s=5.0$ by using maximum likelihood algorithm

3.5 Conclusions

The b value of magnitude–frequency relationship was calculated by the Maximum Likelihood Method and was mapped as 2D and 3D for the İzmir and its surroundings in Western Turkey. In addition, the recurrence periods which is other seismic hazard parameters were determined.

The magnitude-frequency relationship is shown in Figure 3. The b-value is approximately 0.81 ± 0.03 after the Midilli and Manisa earthquakes with $M_c=4.1$ (cut of magnitudes) for the study area. When the 2D b values map is examined, b-values change from 0.6 and 1.05 after the Midilli and Manisa earthquakes in the study area. Some regions in the study area have low b-values, relatively. For example; These are i) eastern part of İzmir Bay ii) Northwest and western of Karaburun Peninsula, iii) Küçük Menderes Graben; iv) Büyük Menderes Graben. These areas should be described as a higher stress condition. Also, in the study area, b-value errors change from 0.06 to 0.15. The results show that area where b values are lower can produce large earthquakes. As the b-value suddenly changes in horizontal and vertical directions, it can be said that tectonics of the study area is complex. The higher b-value can be explained by more heterogeneities while high stress and lesser heterogeneity in the crust cause lower b-value.

It was calculated the mean return period for $M=6.0$ and $M=5.0$, and the minimum values of these parameters are respectively 20 years and 4 years in eastern and western parts of the study area. This study is compared with previous studies in the same region as follows;

Tablo 3.1 Comparison of this study with previous studies

Studies	Lat-Long	Mc	Earthquake Time	Data type	Number of Data	b value	Change of b value	Recurrence Period
Polat et al. (2008)	36.5 39.5 N 26–29° E	3.0	1976 to 2002	Instrumental	13527	0.9±0.01	0.7-1.2	Minimum 50 years (M>6.5)
This study	37.5–39 N 26–28° E	4.1	1900 to 2017	Instrumental	687	0.81±0.03	0.6 -1.05	Minimum 20 years (M=6.0)

In addition, Bayrak and Bayrak (2012) obtained b value between 0.9 and 1.0 using the historical and instrumental earthquake data in part of their studies.

CHAPTER FOUR

SOIL CHARACTERIZATION OF BORNOVA PLAIN (İZMİR/TURKEY) AND ITS SURROUNDINGS USING COMBINED SURVEY OF MASW AND REMI METHODS AND NAKAMURA (HVSr) TECHNIQUE

As it is known, when an area located above a seismic belt is being structured, behaviors of earthquake-soil-structure needs to be examined as a whole. Within this scope, three main factors which cause structural damage during an earthquake are defined based on the attributes of earthquake-soil-structure common behavior. These factors are; earthquake source parameters, local soil conditions and structure features. Studies conducted on structure damage caused by former earthquakes showed that in the areas where the earthquake source features and the structure quality are similar, changes in the local soil attributes play an impactful role in the distribution of the structural damage (Yalçinkaya, 2010). Therefore, local soil conditions which would have an impact on soil behavior under dynamic effects needs to be thoroughly examined and identified before an earthquake happens (Kramer, 1996). According to this definition, the soil is used when the V_s values are under 760 m/sec and bedrock is used when it is above 760 m/sec (Akgün et al., 2013a; Pamuk et al., 2017). Depending also on the structure's height, V_{s30} values are mostly considered the basis for soil identification. However, in order these identifications to be done with minimal error, V_{s30} values need to be calculated by using in-situ methods. V_{s30} is widely used in most building codes, including the NEHRP. The V_s of the upper 30 m (V_{s30}) should be calculated by the following formula in accordance with the following expression: $V_{s30} = 30 / \sum_i^N (h_i / V_i)$ where h_i and V_i denote the thickness (in meters) and shear-wave velocity of the i th formation or layer, in a total of N , existing in the top 30 m (Kanlı et al., 2006).

There are many studies in the literature about dynamic properties of soils and soil characterization. Donohue et al. (2004) calculated G_{max} values using MultichannelAnalysis of Surface Waves (MASW) method for two soft clay sites in Ireland. Pamuk et al. (2017) determined the shear wave velocity structure and predominant period features of Tinaztepe in İzmir using active-passive surface wave methods and single-station microtremor measurements. Carvalho et al. (2009)

estimated V_p/V_s ratios and the Poisson's and a subsoil classification based on geophysical and geotechnical parameters. Essien et al. (2014) determined Poisson's ratio using P- and S-wave measurements. Akin and Sayil (2016) utilized active-source (MASW) and passive-source (single-station microtremor) surface wave methods for the soil dynamic characteristics in Trabzon (Turkey).

The aim of this study is to determine soil dynamic properties of Bornova Plain and its surroundings using geophysical and geotechnical data (Figure 4.1a). At first, Surface wave data were collected using MASW, ReMi and single station microtremor methods. Afterly, the V_{s30} values were calculated by inverting dispersion curves obtained from a combined survey of MASW and ReMi. V_{s30} values change from 180 to 1400 m/sec calculated used to prepare soil classification map of the Bornova Plain according to NEHRP (Table 4.1). It was also created level maps of V_s values at 5, 10, 20, 30, 40 and 50 m depths. G_{max} values were calculated using V_s values at different depths as 2D and 3D up to 50 m depth. In the next stage, single-station microtremor data were evaluated according to the Nakamura method and predominant period of soil was determined. The predominant period in the range of 0.45–1.6 sec, which indicates that the area exhibits lower predominant periods and less sediment thickness. In the next step, previously geotechnical studies (SPT-N, Poisson Ratio, Groundwater Level) carried out by Kincal (2004) have been examined. Afterly, risk maps were created using geotechnical and geophysical data for the study area. In the last stage, the predominant periods of the high-rise buildings in the study area and hospitals and educational institutions in the risky areas were calculated with the help of empirical relations between height (or a number of floors) of buildings and predominant period of the buildings and thus the resonance condition was investigated.

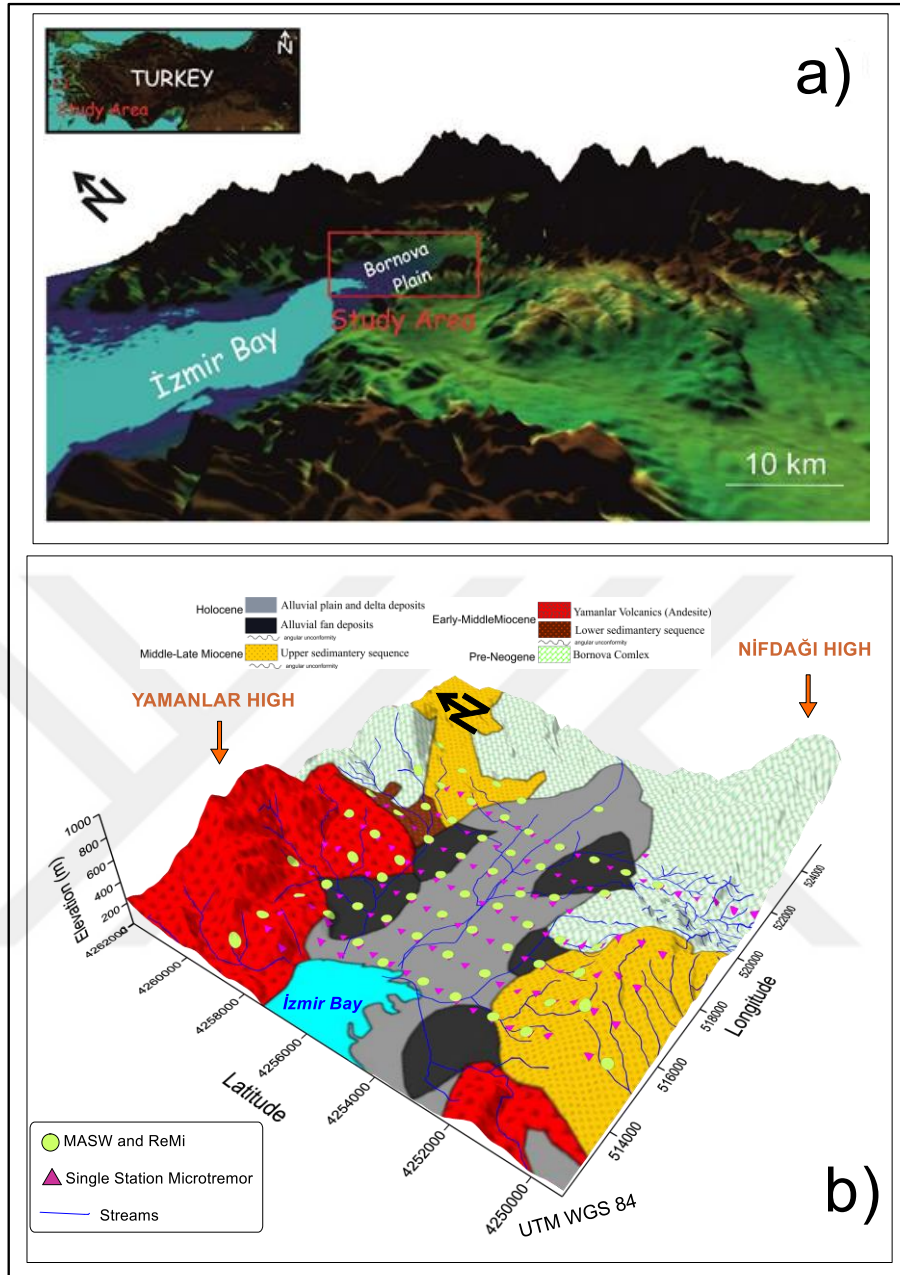


Figure 4.1 a) Representation of a) Site location map of study area b) The geological map of study area together with geomorphology (modified from Kınal, 2004; Uzel et. al., 2012)

4.1 Geophysical Survey

The geophysical site characterization has been utilized in the Bornova Plain. MASW and ReMi (64 sites), ReMi, single-station microtremor (137 sites) measurements were carried out in the study area (Figure 4.1b).

4.1.1 MASW Method

MASW is a method of estimating the shear-wave velocity profile from surface waves. It uses the dispersive properties of Rayleigh waves for imaging the subsurface layers. In MASW method, surface waves can be easily generated by an impact source (sledgehammer etc.) (Park et al., 1999).

MASW measurements were conducted at 64 sites. The MASW system consisting of a 24-channel Geode seismograph with 24 geophones of 4.5 Hz were used. The seismic waves are generated by the impulsive source of a hydraulic sledgehammer (100 lb) with three shots. The data processing contains three step. The first is the preparation of a multichannel record, the second is dispersion-curve analysis and the third is inversion (using a least-squares approach etc.).

4.1.2 ReMi Method

ReMi process, developed by Louie (2001) has widely been used to determine shear wave velocity profiles using ambient noise recordings. This array analysis technique finds average surface-wave velocity over the length of a refraction array. Also, 64 ReMi measurements were carried out at the same locations as the MASW measurements. For the ReMi measurements, 8 records were recorded at each site. The array lengths were 60 m and 120 m. In the ReMi interpretation and analysis, firstly, p - f transformation, which is the basis of velocity spectral analysis, takes a recorded section of multiple seismograms, with seismogram amplitudes relative to distance and time (x - t), and converts it to amplitudes relative to ray parameter, p (the inverse of apparent velocity). Secondly, the Rayleigh phase-velocity dispersion is selected. This analysis only adds a spectral power-ratio calculation for the spectral normalization of

noise records. The final step is shear-wave velocity modeling. The modeling iterates on phase velocity at each frequency.

Dispersion curves obtained by active (MASW) and passive (ReMi) surface wave methods were combined to enlarge the analyzable frequency range of dispersion and improve the modal identity of the dispersion trends. High-resolution Vs profiles were obtained by inverting the dispersion curve, and S-wave velocities by were obtained from the combined dispersion curves using the damped least-squares method (Levenberg, 1944; Marquardt, 1963) (Figure 4.2).

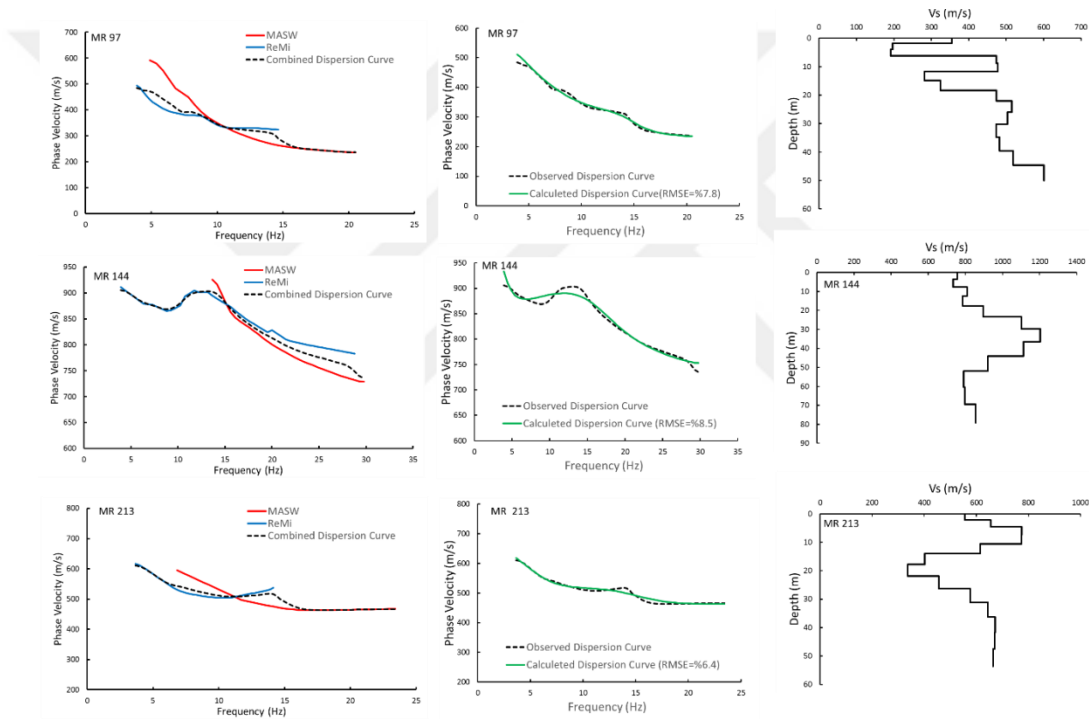


Figure 4.2 Examples of Vs-depth cross sections were obtained by inverting the combined dispersion curve

Combined dispersion curves were used in the study in order to increase the depth of the research and to identify the velocity differences that occur within the soil in detail. According to Vs-depth sections obtained from each measurement site, sudden velocity differences are observed in a lateral and vertical direction within the soil. These changes need to be considered for soil dynamic analysis studies. Based on the

V_{s30} distribution map which is made for soil type identification, it has been observed that V_{s30} values vary between 180 and 1400 m/sec (Figure 4.3).

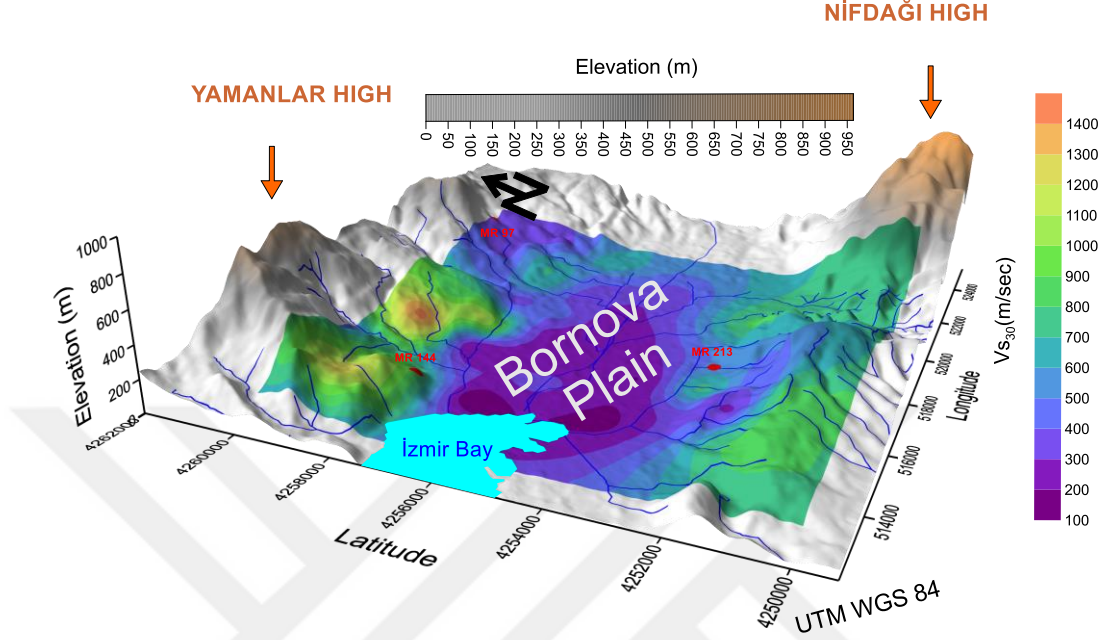


Figure 4.3 V_{s30} distribution values overlaid on the 3D topographic map of Bornova Plain and its surroundings

When these velocity changes and the geological structure of the area are considered together, andesites and Miocene pyroclastics north of the area of study and Miocene aged limestone in the south of area of the study are observed to have higher V_s values compared to the rest of the area of study and the threshold value of bedrock's V_{s30} values are also observed to be higher than 760 m/sec. In spite of this, V_{s30} values, especially in the areas nearby the sea, are confirmed to change between 100 and 300 m/sec and V_{s30} values along the Bornova Plain are confirmed to be lower than 500 m/sec (Figure 4.3). According to NEHRP regulations work site consists of B, C and F types of soil (Figure 4.4).

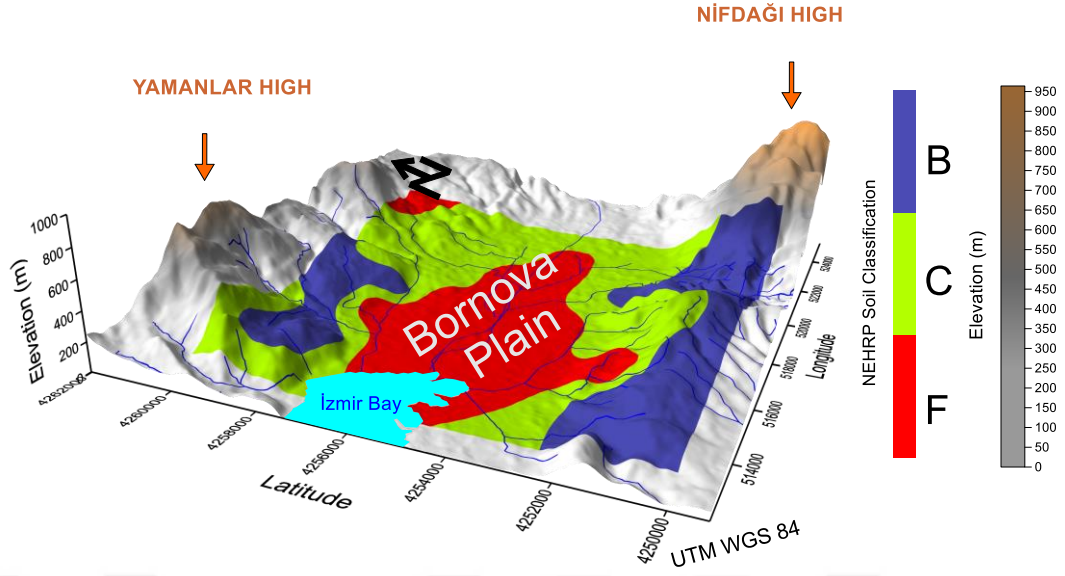


Figure 4.4 Soil classification map of study area according to NEHRP standards based on the average shear wave velocity distribution down to 30 m

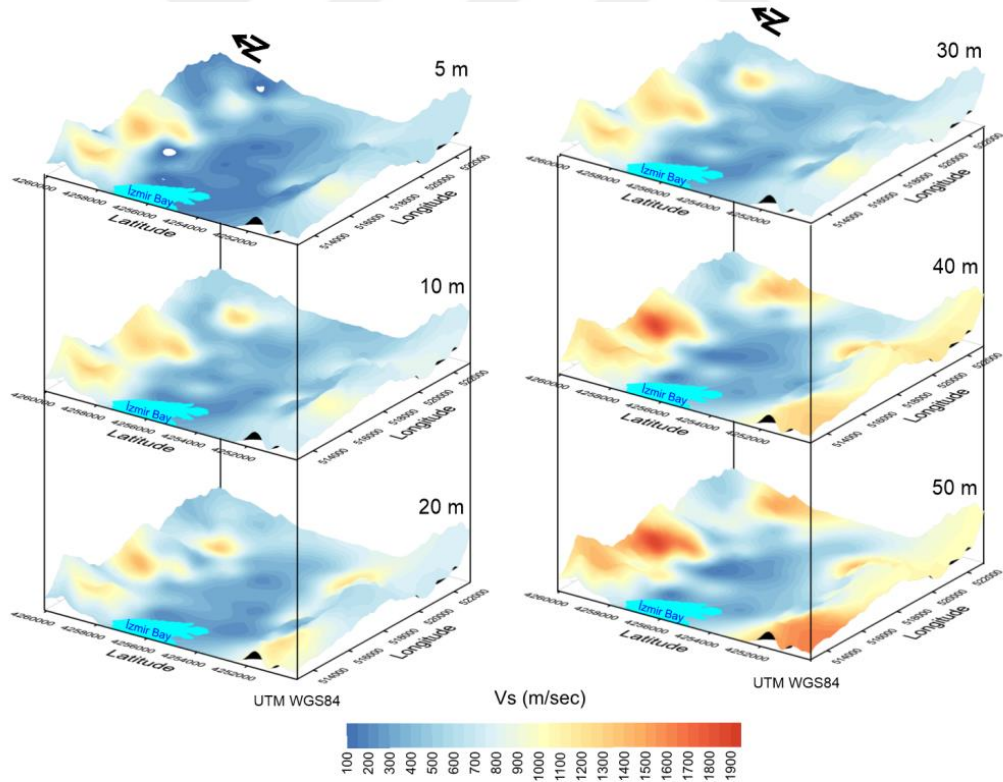


Figure 4.5 Average Vs distribution maps of Bornova Plain and its surroundings down to 5, 10, 20, 30, 40 and 50 meters depth, respectively

4.1.3 Single Station Microtremor (Nakamura Method (1989))

Microtremor method has widely used for assessing the effect of soil conditions on the earthquake shaking. The H/V spectral ratio was first introduced by Nogoshi and Igarashi (1970). The H/V method is convenient and inexpensive for soil investigations. It is based on a theory and hypothesis developed by Nakamura (1989), who demonstrated that the ratio between horizontal and vertical ambient noise records related to the fundamental frequency and amplification of the soil beneath the site. Microtremor observations were carried out at 137 sites in the study area. All microtremor measurements were taken with the Guralp Systems CMG-6TD seismometer with a sampling rate of 100 Hz in the study area. At each location, recording duration was approximately 30 minutes. To remove intensive artificial disturbance, all signals were band-pass filtered in a pass band-pass of 0.05-20 Hz. Then they were divided into 81.92 second long windows and tapered individually using Konno-Ohmachi smoothing. For each window, the amplitude spectra of the three components were computed using a Fast Fourier Transform (FFT) algorithm. As a result, the average spectral ratio of horizontal-to-vertical components was thus calculated (Figure 4.6). Predominant period values were determined using H/V spectral ratio and they are mapped (Figure 4.7). Microtremor measurements were processed and interpreted using GEOPSY software package (Geopsy, 2016).

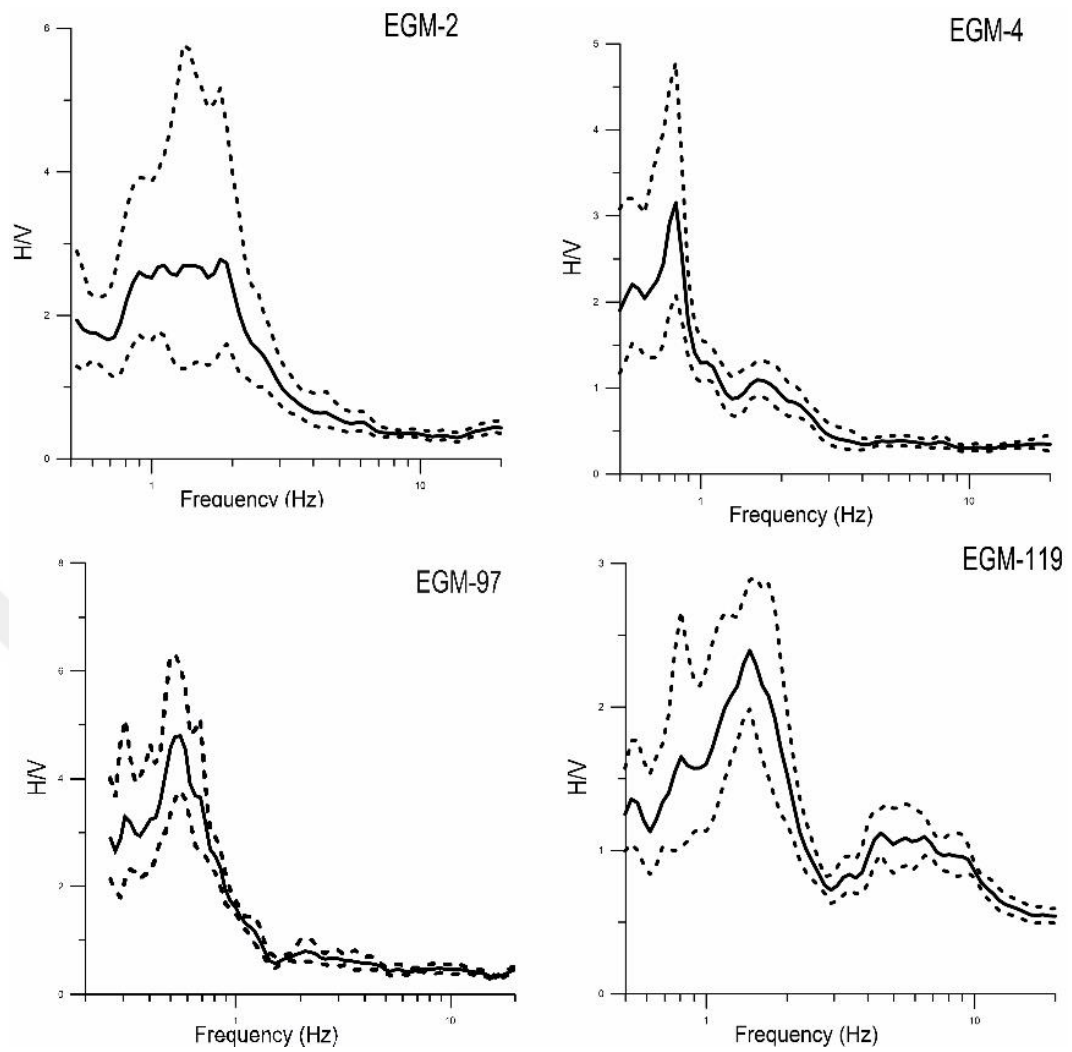


Figure 4.6 Examples of H/V spectral ratio for the study area (dashed lines demonstrates the standard deviation)

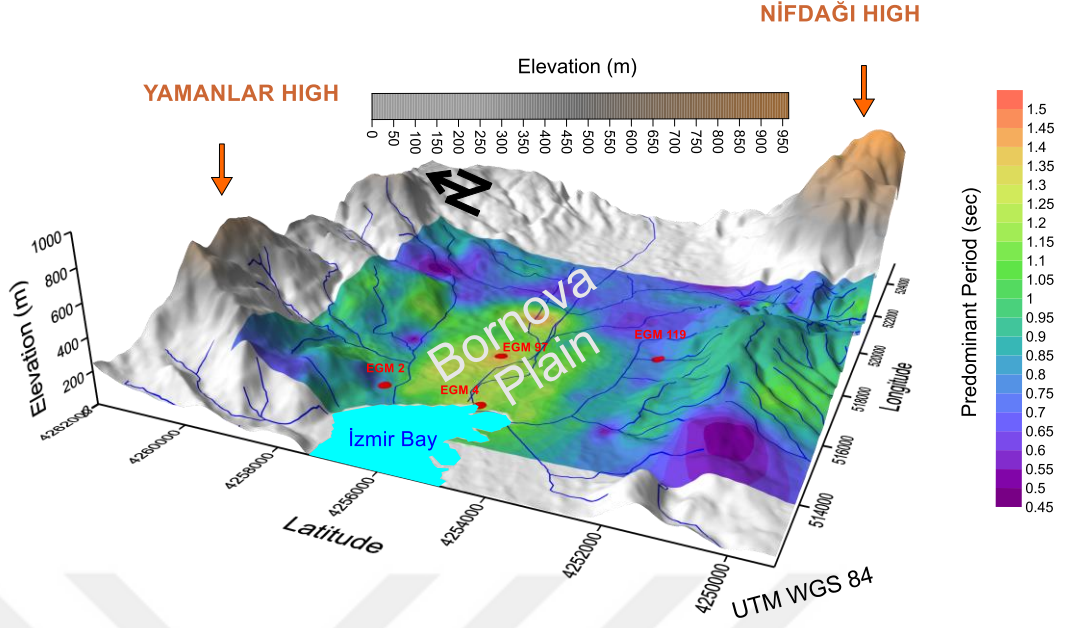


Figure 4.7 Predominant period distribution values overlaid on the 3D topographic map of Bornova Plain and its surroundings

There is seen during evaluating the predominant period map that the predominant period values change between 0.45 and 1.6 sec values are at a maximum value where the regions have thick soil layer that rivers collected which occur the Bornova Plain, but this values relatively reduced by farther from the bay. Decreasing in period values remarked by the reason of increasing topography in north and south part of the study area and finding a different geological unit (Figure 4.7). Towards the eastern part of the study area, the predominant period values shift towards the lower value. When maps of the predominant period and V_{s30} are compared; it matches up to higher V_s values where the period values are observed to be less than 1 sec. The period values are observed to be higher than 1 sec and V_{s30} velocity values are observed to be much lower than 500 m/sec, especially in the areas which are Quaternary aged and mostly consist of soil layers that are thicker than 30 m.

4.2 Dynamic Properties of The Study Area

G_{max} studies; For geotechnical investigations, the measurement of the small strain shear modulus, G_{max} of a soil is a very important parameter. G_{max} can be calculated from the shear wave velocity using the following equation:

$$G_{\max} = \rho \cdot V_s^2 * 100 \quad (4.1)$$

where $G_{\max}$ = shear modulus (kg/cm²), V_s = shear wave velocity (m/sec) and ρ = density (gr/cm³). The density values that will be used in modeling were calculated by the help of S- and P-velocity values and formulas on table 4.1.

Tablo 4.1 Relationship between Vs-Vp and density (P velocity values were calculated by using $V_p = V_s * 1.74$ equation)

References	Formula	Material type
Destici (2001)	$\rho = 0.6 * (V_s^{0.2})$	Soil-Bedrock
Keçeli (2009)	$\rho = 0.44 * (V_s^{0.25})$	Theoric
Komazawa et al. (2002)	$\rho = 0.7904 * (V_s^{0.138})$	?
Uyanık (2002)	$\rho = 0.4 * (V_p^{0.22})$	Soil-Bedrock
Uyanık and Çatlıoğlu (2015)	$\rho = 0.7 * ((V_s * V_p)^{0.08})$	Soil-Bedrock

The calculated $G_{\max}$ values were drawn as 3D until 50 meters of depth (Figure 4.11b). When the $G_{\max}$ distribution has been examined, it draws attention that the $G_{\max}$ values in the Bornova Plain are lower than 5000 kg/cm². As for the north and south parts of the working area, these values are greater than 10000 kg/cm².

SPT-N studies; the Standard Penetration Test (SPT-N) which is an in-situ, dynamic shear test has been conducted on the 422 bores in the work area (Kıncal, 2004). When the SPT-N₃₀ distribution map has been examined for 10 meters of depth, it has been observed that these values vary between 0 and 60. Especially on the waterfront, these values are lower than 20 and they increase towards the east (Figure 8b).

Poisson Ratio Studies; In the S- and P-seismic refraction studies of Kıncal (2004) carried out on the 29 sites of the Bornova Plain, the Poisson rate has been calculated for 10 meters of depth (Figure 8c). Poisson's ratio (ν) can be calculated using Equation 2;

$$\nu = \left(\frac{V_p^2 - 2V_s^2}{2(V_p^2 - V_s^2)} \right) \quad (4.2)$$

where V_p : P-wave velocity, V_s : S-wave velocity. When the distribution map of the Poisson ratio in the 10 meters of depth, it has been observed that the areas with the values between 0.3 and 0.5 have probably loose soil layer. The areas that are lower than 0.3 are the hard and firm soil.

Groundwater Level (GL) Studies; As a result of the measurements carried out in the 422 boreholes, the groundwater level map was prepared by Kincal (2004) (Figure 8d). When the GL distribution is examined the water level increases from west to east.

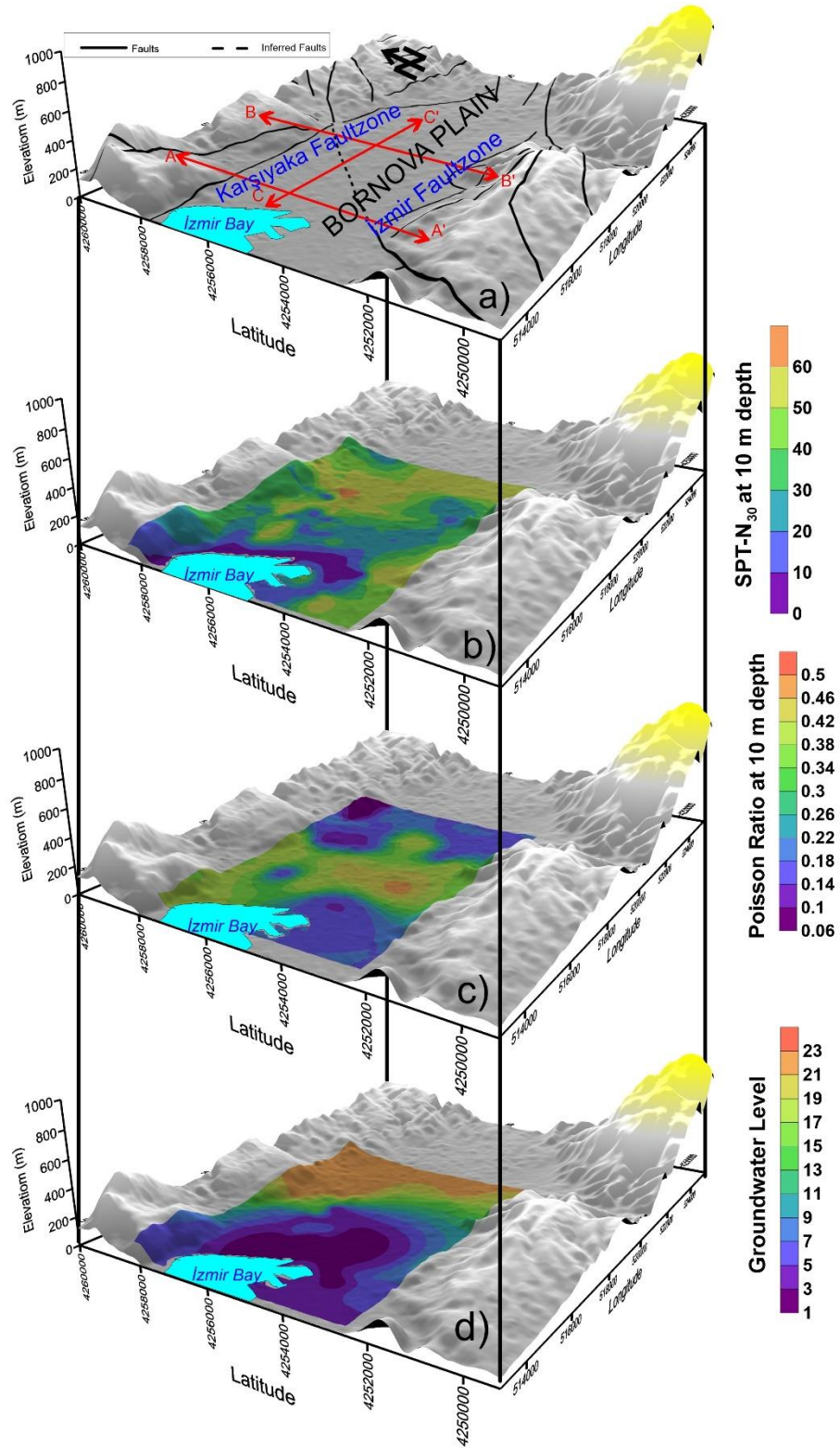


Figure 4.8 a) Fault zones in the study area with location of A-A', B-B' and C-C' cross section b) SPT-N₃₀ c) Poisson Ratio d) Groundwater Level distribution at 10 m depth distribution maps overlaid on the 3D topographic map of Bornova Plain and its surroundings

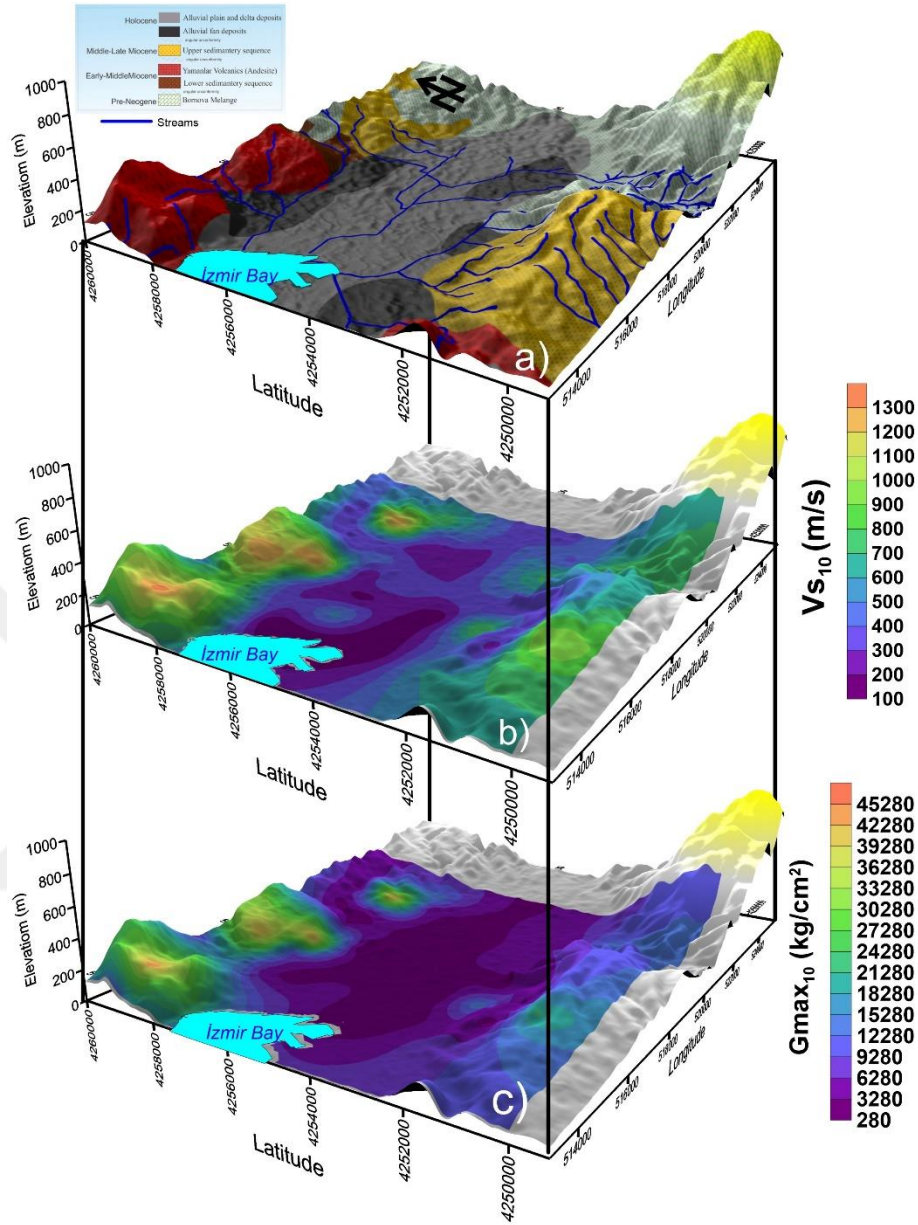


Figure 4.9 a) Geological map b) V_{s10} c) G_{max} at 10 m depth distribution maps overlaid on the 3D topographic map of Bornova Plain and its surroundings

The predominant period values, V_{s10} values, GL, Poisson Ratio and SPT- N_{30} were compared with each other at 10 m depth in A-A', B-B' and C-C' profiles (Figure 4.10). Predominant period values increase as expected on areas that equaled to bay coast and in middle parts of sections in A-A' and B-B' cross-sections. In C-C', predominant period values are higher than other sections. Lower V_{s10} (100-200 m/sec) and lower SPT- N_{30} (<30) values are obtained in middle parts of sections in A-A' section by the

reason of alluvial unit. In B-B' section, V_{s10} change from 250 m/sec to 1300 m/sec while SPT- N_{30} values are between 30 and 50 m. In C-C' section, V_{s10} change from 150 m/sec to 550 m/sec while SPT- N_{30} values are between 3 and 60 m. GL values change from 1 to 8 m in A-A' section while these values are between 1 and 20 m in B-B' and C-C' cross-sections. Poisson ratio values range from 0.15 to 0.42 in A-A' and C-C' section while these values are between 0.18 and 0.4 m in B-B' cross-section. Lower GL values are observed in middle parts of the section while lower Poisson ratio values are observed in southern part of A-A' section. Higher GL and lower Poisson ratio values are obtained in middle parts of B-B' section. Higher GL and lower Poisson ratio values are obtained in eastern of the C-C' section. Therefore, it is clearly seen that the values that are compared in each profile are generally compatible with each other (Figure 4.10).

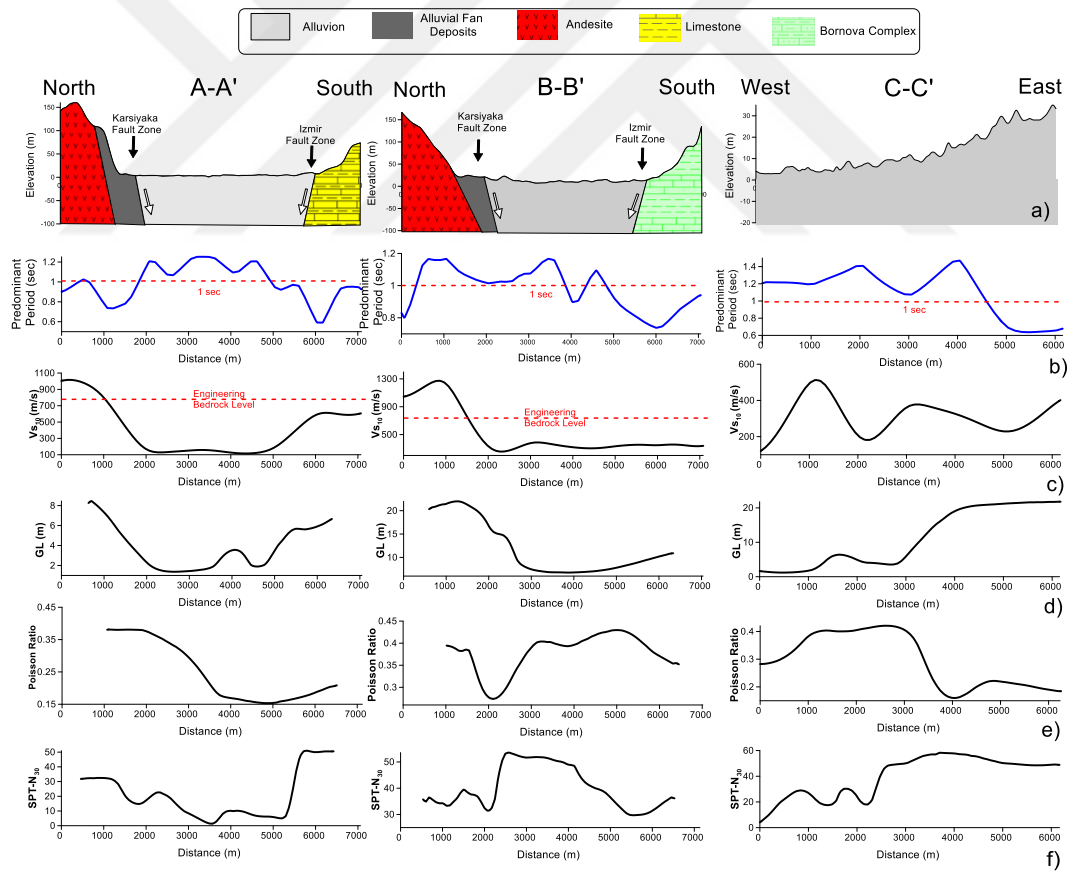


Figure 4.10 a) Geological cross-sections b) Predominant period c) V_{s10} d) Groundwater level e) Poisson Ratio f) SPT- N_{30} at 10 m depth on A-A', B-B' and C-C' cross sections

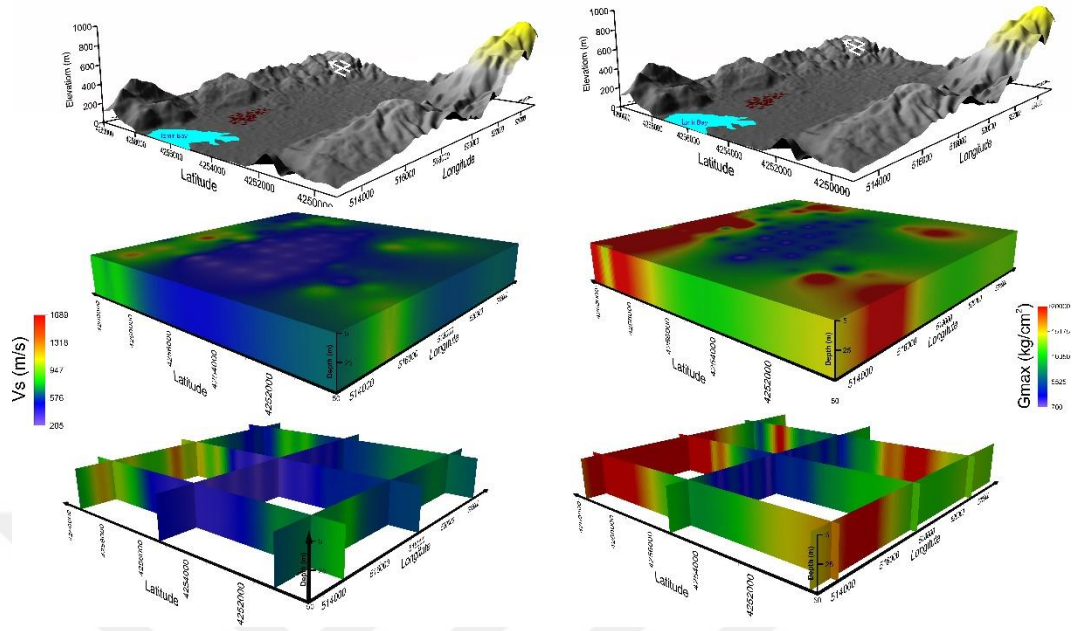


Figure 4.11 a) 3D V_s distribution map b) 3D G_{max} distribution of Bornova Plain and its surroundings up to 50 m depth

4.3 Soil-Structure Resonance Studies

The main goal of resonance study is to determine the expected resonance phenomena using the empirical relationship between the fundamental period of buildings and their height (or floor number) during future earthquakes. It has been calculated predominant periods of 9 high-rise buildings using empirical formulas in the study area. There are 9 buildings, whose heights range from 68 to 216 m (i.e. from 17 to 50 floors), listed in Table 2. The years of construction are from 2009 to 2017. The tallest building is the T8 and its height is 216 m while the shortest building is the T2 and its height is 68 m. Regions where high-rise buildings have lower V_s values. Moreover, the groundwater level in this region is quite shallow (Fig 8-9). If the dominant period of the building and the soil dominant period values are close to each other, soil-structure resonance may occur. The predominant periods calculated by the height-based area Gallipoli et al. (2010) approach ($T = 0.016H$; T - predominant period of building, H -height of building) varies between 1.1 and 3.5 sec while these values calculated by the floor-based area Navarro and Oliveira (2008) ($T = 0.049N$; T -predominant period of building, F -Number floor of building) change 0.8 to 2.5 sec. It

was calculated the average of the predominant periods of the high-rise buildings obtained from different formulas in this study (Table 4.2). In addition, period values obtained from microtremor measurements change from 1.00 to 1.6 sec in the high-rise building areas. Figure 13 shows the predominant period values of the buildings and the soil. It was determined 4 high-rise buildings which are T2, T5, T7 and T8 with potential soil structure resonance. Because periods of T4, T6 and T9 are higher than the periods, these buildings are not significantly affected by resonance.

Tablo 4.2 Comparison of the high-rise buildings' periods and soil predominant periods.

Building Name	Building height (m)	Number of Floors	Building Period (sec)			Soil Predominant Period (sec)	NEHRP soil type
			Gallipoli et al.(2010)	Navarro and Oliveira (2008)	Average Period (sec)		
T1	100	24	1.6	1.2	1.40	1.03	F
T2	68	17	1.1	0.8	0.95	1.13	F
T3	142	35	2.3	1.7	2.00	1.24	F
T4	200	45	3.2	2.2	2.70	1.20	F
T5	90	22	1.4	1.1	1.25	1.21	F
T6	216	48	3.5	2.4	2.95	1.22	F
T7	106	27	1.7	1.3	1.5	1.16	F
T8	100	27	1.6	1.3	1.45	1.28	F
T9	200	50	3.2	2.5	2.85	0.76	F

4.4 Risk Maps of the Study Area

4.4.1 Risk Map-I

This map has been formed by superposing the areas with the V_{s30} value lower than 760 m/sec and with soil predominant period value is greater than 1 sec (Figure 4.12). The Urla earthquake ($M_w=5.8$) that happened on 10 April 2003, partly damaged the building with 8-9 stories in the Bornova Plain (Kıncal, 2004) (Figure 4.12). The figure 4.12 also demonstrates the high-rise buildings (towers), the health and education institutions. The dominant periods of the education institutions, hospitals and towers were calculated with the help of empirical relations in the Risk Map-I. They were

compared with soil predominant period values in figure 4.13. The education institutions and the hospitals have generally less than 10 stories. Therefore, it was not predicted that most of these buildings would be affected by the resonance, in the area with the soil predominant period values greater than 1 sec. But this is not the same for towers. Because the average periods of these buildings that vary between 17 and 50 stories are between 0.95 and 2.95 seconds. The buildings that have the same or similar color with the soil predominant period have the resonance risk (Figure 4.13). The area including the buildings with 8 or 9 stories that were damaged in the Urla earthquake is completely in the Risk Map-I. In this area, the soil predominant period values vary between 0.8 and 1.4 seconds. The dominant period values of the buildings with 8-9 stories are between 0.4 and 0.5 seconds with the Navarro (2002) relationship. Then, it is possible to say that these buildings were not exposed to the resonance effect in the Urla earthquake.

4.4.2 Risk Map-II

Risk Map-II has been prepared by using the Groundwater Level (GL), G_{max} , Poisson ratio, SPT- N_{30} that were obtained for the 10 meters level from this study and the study of Kincal (2004). The considered values for each of the data layer in the Risk Map-II are presented below; the places where $SPT-N_{30} \leq 30$; $0.3 \leq \text{Poisson Ratio} \leq 0.5$; $G_{max} \leq 3000 \text{ kg/cm}^2$ and $GL \leq 10$ values superposed are determined as the risk areas. Risk Map –II is included in the Risk Map-I. Also, some of the buildings damaged during the Urla earthquake are included in Risk Map-II.

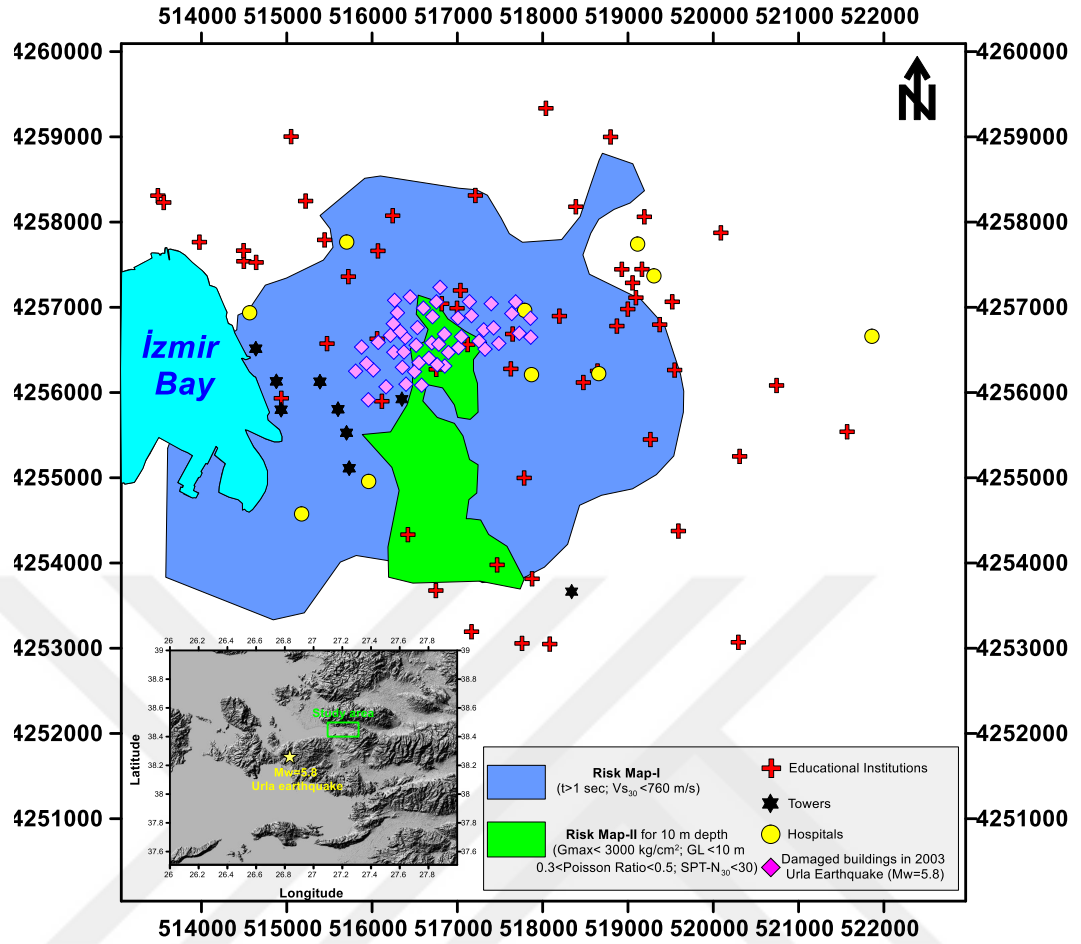


Figure 4.12 Risk maps of the study area

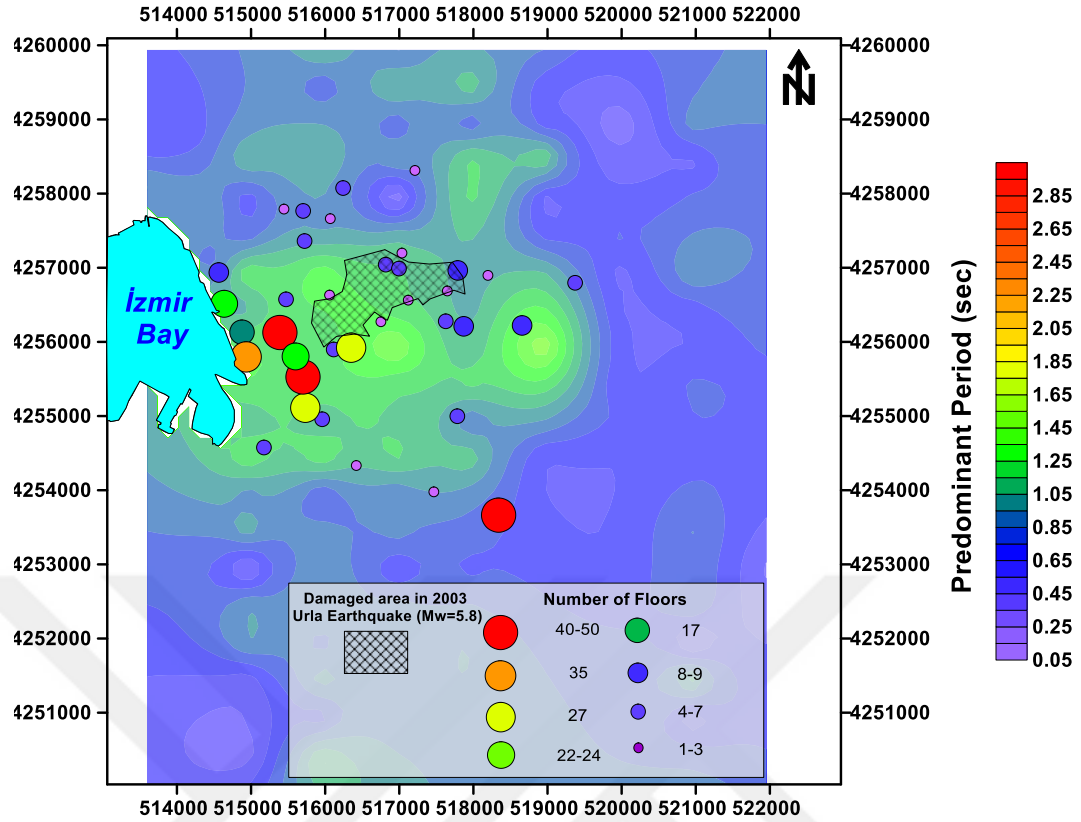


Figure 4.13 Distribution of expected resonance effect in the buildings in Risk-1 area on soil predominant period map. The circle shows building periods. Colour harmony means probable resonance phenomena

4.5 Conclusion

This study shows that V_s and predominant period characteristics of different soil units in Bornova Plain. The V_s profiles were determined by using MASW and ReMi combined survey at 64 sites. Also, predominant periods were determined by using Nakamura method at 137 sites. The predominant period in the range of 0.45–1.6 sec, which indicates that the area exhibits lower predominant periods and less sediment thickness (Figure 4.5, 4.7). The V_{s30} values which change from 180 to 1400 m/sec used to obtain soil classification map of the Bornova Plain according to NEHRP (Figure 4.3).

Soil classification results show that most parts of the region, located in the alluvial basin, have low shear wave velocity values. These values are within the range of 180–400 m/sec and thus classified the C and F categories according to NEHRP, generally.

Some parts located on the north and the south part of the study area have better soil conditions and have comparatively high shear wave velocities in the range of 500–1400 m/sec. V_{s30} and soil classification maps were compared with predominant distribution associated with the earthquake. According to results of comparing these parameters, in general, it is noticed that there is a correlation between the V_{s30} values and the predominant distribution of the region (Figure 4.3, 4.4).

According to V_{s30} values; bedrock is mostly dominant in the regions south of the bay and north of the bay due to V_{s30} values being higher than 760 m/sec. These regions are classified as B-type soil according to NEHRP regulations. Soil definition is used in other regions due to V_{s30} values being lower than 760 m/sec. C and F types of soil are dominant in these regions according to NEHRP regulations.

Prepared by the V_s level maps that are created by identifying up to 50 m, soil thickness in the regions where C and F types are dominant is more than 30 m (Figure 4.5). The predominant period values being higher than 1 sec in these regions supports the notion that claims the soil thickness of these regions is more than 30 m.

Soil deformation analysis of the regions where the soil thickness is higher than 30 m and there are sudden V_s differences in lateral and vertical directions within are suggested to be conducted by using distinctive soil bedrock models. Therefore, 2D or 3D soil-engineering bedrock models should be created for these regions.

The Risk Map- I almost cover Bornova Plain. It can be seen that there are many educational institutions and hospitals within risk-1 area. All of the buildings partially damaged in the earthquake is located in the risk map. The existing Turkish earthquake regulations (TDY (2007)) for buildings to be built in this area are insufficient. Therefore, detailed studies are required to calculate the in situ design spectrum. There is resonance risk that the buildings which have periods varying from 1 to 1.6 sec within this area. Seismic impedance must be determined from the seismic bedrock ($V_s > 3000$ m/sec) to the surface in order to calculate the earthquake effect on the surface within this area. The risk II map is within the risk-I map and some of the buildings damaged by the earthquake are located within this area.

When examining the predominant periods of the high-rise buildings in the study area and hospitals and educational institutions in the risky areas, especially the number of floors of educational institutions and hospitals is less than 10. Therefore, it can not be said that these structures in risky areas carry a resonance risk. However, some of the high-rise buildings carry a resonance risk (Figure 4.13). The resonance effect must be taken into account when designing the buildings to be built in this area. Therefore, it is proposed to use the predominant period map in the design of new buildings.

The GL in the study area is close to the surface. This level ranges from 1 to 24 m and the level is very low especially in the western part of the study area. Since these areas have the risk of liquefaction during an earthquake, these areas should be examined in detail. The Poisson ratio which allows us to have information about the water saturation level of the soil varies from 0.3 to 0.5, especially on soft soil. The Poisson's ratio varies from 0.3 to 0.5 where the GL is 10 m lower in the study area. The G_{max} values at 10 depth are less than 4000 kg/cm^2 in accordance with these values.

CHAPTER FIVE

2D SOIL AND ENGINEERING-SEISMIC BEDROCK MODELING OF EASTERN PART OF İZMİR INNER BAY/TURKEY

While defining the common behaviour of earthquake-soil, earthquake's effect behaviour in seismic bedrock is evaluated where comes from a source with the attenuation relationship of peak ground acceleration. Impedance changings and law of energy conservation reveals in as from the seismic-engineering bedrock interface. According to energy conservation, changing happen in earthquake motion's amplitude frequency spectrum till the interface of engineering bedrock-soil. There could occur both elastoplastic-plastic deformations and amplitude frequency changing in earthquake spectrum except for elastic behaviour in the soil. Furthermore, the changing could be happened as horizontal in interface topography between seismic bedrock engineering bedrock and soil is affected by changes in earthquake effect on the soil surface. To be able to examine all these issues in detail, study areas must be modeled based on V_s as 2D. If the literature is analyzed for the meaning of the soil, engineering bedrock, seismic bedrock by using V_s values, many researchers have an individual explanation was given; Ambraseys et al. (1996) have defined the soil where the V_s is <760 m/sec Nath (2007) has defined that the seismic bedrock corresponds to the V_s of 3000 m/sec and above, and engineering bedrock has the V_s of 400 m/sec to 700 m/sec for the purpose of seismic microzonation. Morikawa et al. (2008) have defined the seismic bedrock where the V_s is higher than 3000 m/sec. In a study of Anbazhagan and Sitharam (2009), V_s of 330 ± 30 m/sec is considered for the weathered rock and V_s of 760 ± 60 m/sec is considered for the engineering bedrock. Additionally, suggested soil-bedrock classification by Akgün et al. (2013a) which applied in this study is explained as follow; V_s changing, the medium where the $V_s < 760$ m/sec is defined as soil, the medium where the V_s is between 760 m/sec and 3000 m/sec is defined as engineering bedrock and the medium where are bigger than 3000 m/sec is defined as seismic bedrock as. Thus, the deformation changings in soil and on the surface and the earthquake forces can create these changing could be determined by using earthquake motion comes to soil surface from seismic bedrock. There must be defined the engineering bedrock, soil, soil transfer function, dynamic loads on soil and the relationships of stress-deformation that are possibly occurred

based on these loads for defining the soil behaviours occurred under dynamic loads. To realize this, soil-bedrock modeling belongs to study area is created by in-situ methods firstly. For determining Vs up to engineering and seismic bedrock, researchers should use geophysical methods. At present, improved analytical methods originating from surface waves are used extensively (Park et al., 1999; Liu et al., 2000; Louie, 2001; Okada, 2003; Pamuk et al., 2014, 2015, 2016). Analytical methods originating from surface waves can be classified into two groups—namely, active source (e.g., multichannel analysis of surface waves, MASW) and passive source (e.g., refraction microtremor, ReMi, and spatial autocorrelation, SPAC). Basic parameters for making earth model are Vs and density values. Various geophysical methods (MASW, ReMi, SPAC etc.) are used for obtaining these parameters. At the same time, other researchers have used Nakamura's method for soil characterization involving soil resonance frequency (Nakamura, 1989; Lermo & Chavez-Garcia, 1993, 1994; Lachet & Bard, 1994; Gitterman et al., 1996; Bard, 1998; Mucciarelli, 1998). Microgravity method is being especially used in last years for searching shallow structures where the settlements are more in number (Issawy et al., 2010; Gönenç, 2014). The gravity data obtained from this method are evaluated with the results of surface waves measurements. Real-like gravity modeling could be done through the density values that will be calculated based on Vs difference because of the model's density contrast base. That's why the microgravity method is used with surface wave studies which are defined based on Vs differences in soil studies for searching bedrock-soil interface topography and occur the soil modeling (Xu & Butt, 2006; Crice, 2005; Koichi et al., 2005; Akgun et al., 2011; Akgün et al., 2013a, 2013b, 2014; Tunçel et al., 2016). In this research, 2D soil-engineering and seismic bedrock modeling studies were conducted in the east of İzmir Bay (Figure 2.1). Firstly, single station microtremor and microgravity data were collected at 128 sites. Predominant period and residual Bouguer gravity maps were correlated with each other which are obtained by these methods. 2D soil-bedrock models were occurred by residual gravity values by the help of density values that were obtained from deep and shallow Vs sections in SPAC, MASW and ReMi studies. It is seen that the soil thickness is between 300 and 400 m especially close by the bay, and determined about this thickness decreased towards northern parts. Engineering bedrock unit was commented as Bornova melange and seismic bedrock unit was commented as Menderes massif as well. Additionally, the

Neogene andesites and limestones have the feature of engineering bedrock also in the north and south part of the study area.

5.1 Surface Waves Methods

Single station microtremor observations were carried out at 128 sites in the study area (Figure 5.1a). Array microtremor observations (SPAC) were carried out at 4 sites on profiles A-A' and B-B' (Figure 5.1b). MASW and ReMi combined survey was conducted at 13 sites (Figure 5.1b). Also, two drilling reports are given in Figure 5.2 were used to compare with Vs-depth cross-section (Figure 5.1b).

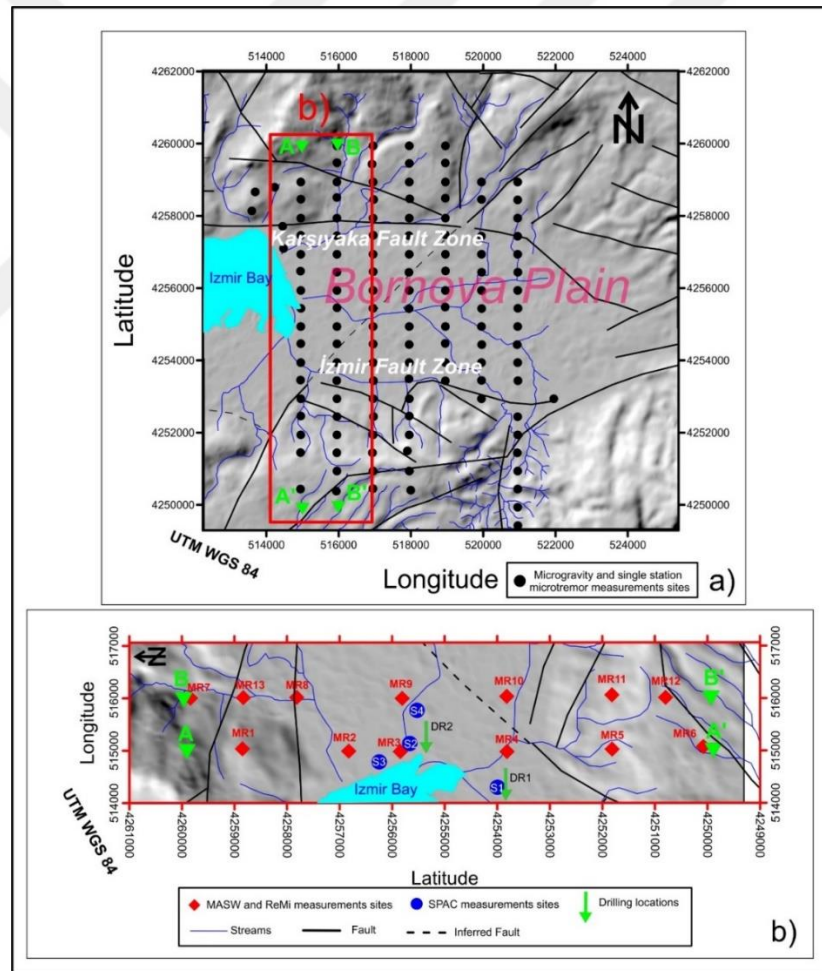


Figure 5.1 Representation of a) Microgravity and single station microtremor measurements sites b) MASW, ReMi, SPAC measurements sites and drilling locations in the study area (the fault zones were created from Uzel et al., 2012)

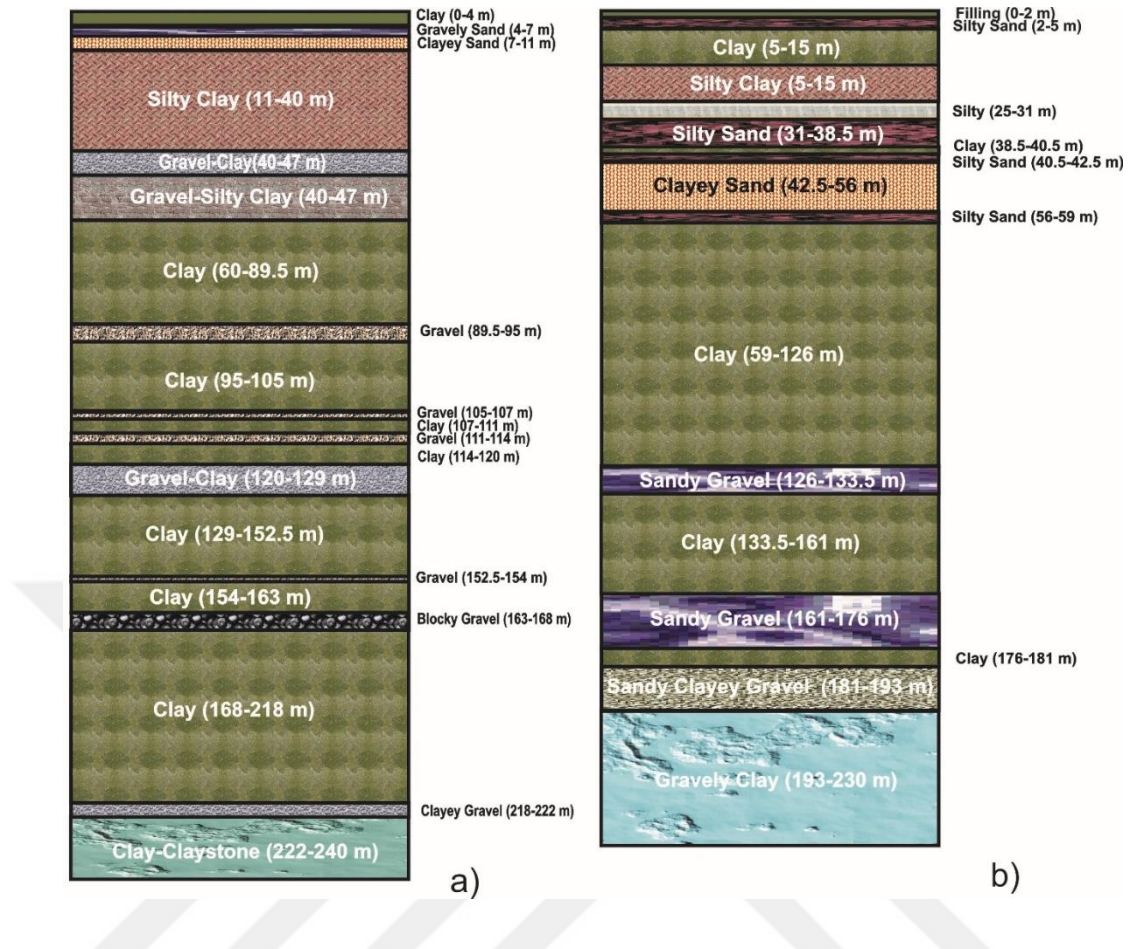


Figure 5.2 Drilling reports a) DR1 b) DR2

5.1.1 Single Station Microtremor (Nakamura method (1989))

Microtremor method has widely used for assessing the effect of soil conditions on the earthquake shaking. The H/V spectral ratio was first introduced by Nogoshi and Igarashi (1970). The H/V method is convenient and inexpensive for soil investigations. It is based on a theory and hypothesis developed by Nakamura (1989), who demonstrated that the ratio between horizontal and vertical ambient noise records related to the fundamental frequency and amplification of the soil beneath the site.

Microtremor observations were carried out more than at 128 sites (Figure 5.1a). All microtremor measurements were taken with the Guralp Systems CMG-6TD seismometer with a sampling rate of 100 Hz in the study area. At each location, recording duration was approximately 30 min. The records were processed using the Geopsy software (Geopsy, n.d). Geopsy was developed as integrated tools for

processing of ambient vibrations. To remove intensive artificial disturbance, all signals were band-pass filtered in a pass band-pass of 0.05–20 Hz. Then they were divided into 81.92 s (It means it was worked on $81.92 \times 100 = 8192$ data) long windows and tapered individually using Konno and Ohmachi (1998) smoothing. For each window, the amplitude spectra of the three components were computed using Fast Fourier Transform (FFT) algorithm. This is basic criteria using the FFT processing (2^n count data). However, based on the manual GEOPSY, window length can be specified with any value because, in the process, this software uses an algorithm developed by Frigo and Johnson (2005), known as FFTW (Fastest Fourier Transform in the West). SESAME European Research Project (2005) the length of the window has a minimum requirement $lw = 10/f_0$ which is lw is window length and f_0 is predominant frequency (Aswad et al., 2010).

According to previous studies which are performed single station microtremor on deeper alluvion unit (Komazawa et al., 2002; Akgün et al., 2013a, 2013b; Özdağ et al., 2015), the length of the time window is used as wide (for example 80 s). Because the length of the time window increases when spectrum width increase in the frequency medium. Therefore, in this study, it was used long window length with 81.92 s in data processing of microtremor. Also, there has not been a loss of data because of long window length with 81.92 s.

As a result, the average spectral ratio of horizontal-to-vertical components was thus calculated. Predominant period values were determined using H/V spectral ratio and they were mapped (Figure 4.5).

There is seen during evaluate the predominant period map that the predominant period values change between 0.45 and 1.6 s. Period values are at a maximum value where the regions have thick soil layer that rivers collected which occur in the Bornova Plain, but this values relatively reduced by further from the bay. Decreasing in period values remarked by the reason of increasing topography in north and south part of the study area and finding a different geological unit (Figure 5.3).

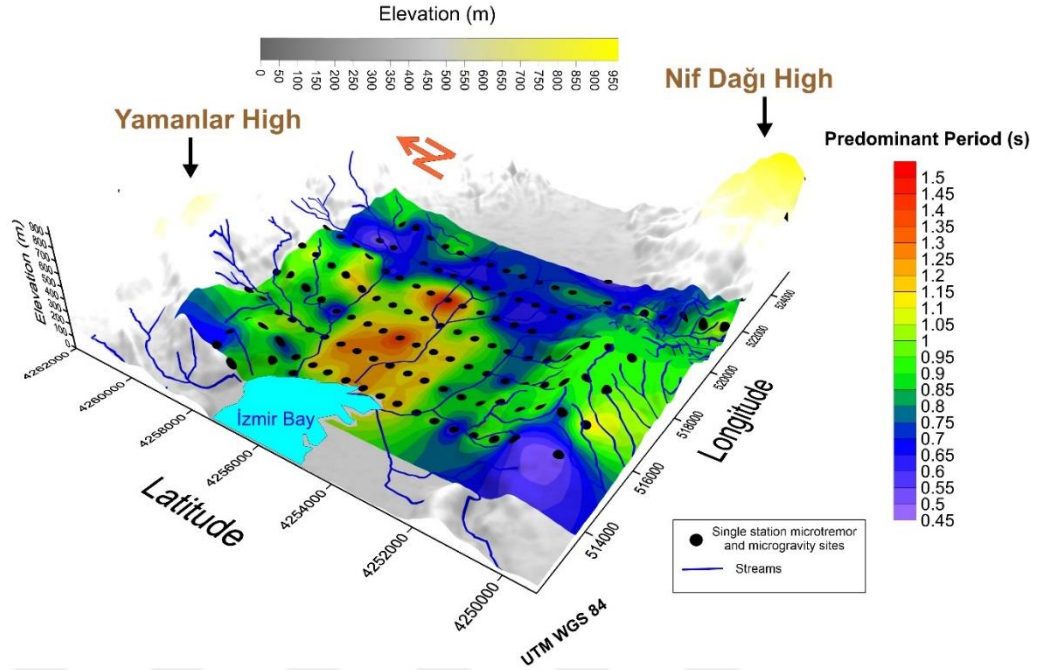


Figure 5.3 The predominant period map obtained from Nakamura method

5.1.2 Array Microtremor (Spatial Autocorrelation Method-SPAC)

It was also used the spatial autocorrelation method (SPAC) first proposed by Aki (1957) and Okada (2003) for horizontally propagating waves to determine deeper Vs profiles. 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 center (Figure 5.4a). Figure 5.4 shows that exemplary of data processing steps of the S1 site. The same data processing process was followed for the other three sites. The radius of the circular arrays was individually adjusted for each site. The recording duration changed from 30 to 60 min in at each array. The SPAC coefficients obtained from the observational values and the theoretical Bessel function values are an investigation by computed the dispersion curve values of the fitting frequency range. After obtaining the dispersion curves, the one-dimensional S-wave velocities were obtained by applying the least squares method (Levenberg, 1944; Marquardt, 1963) (Figure 5.5).

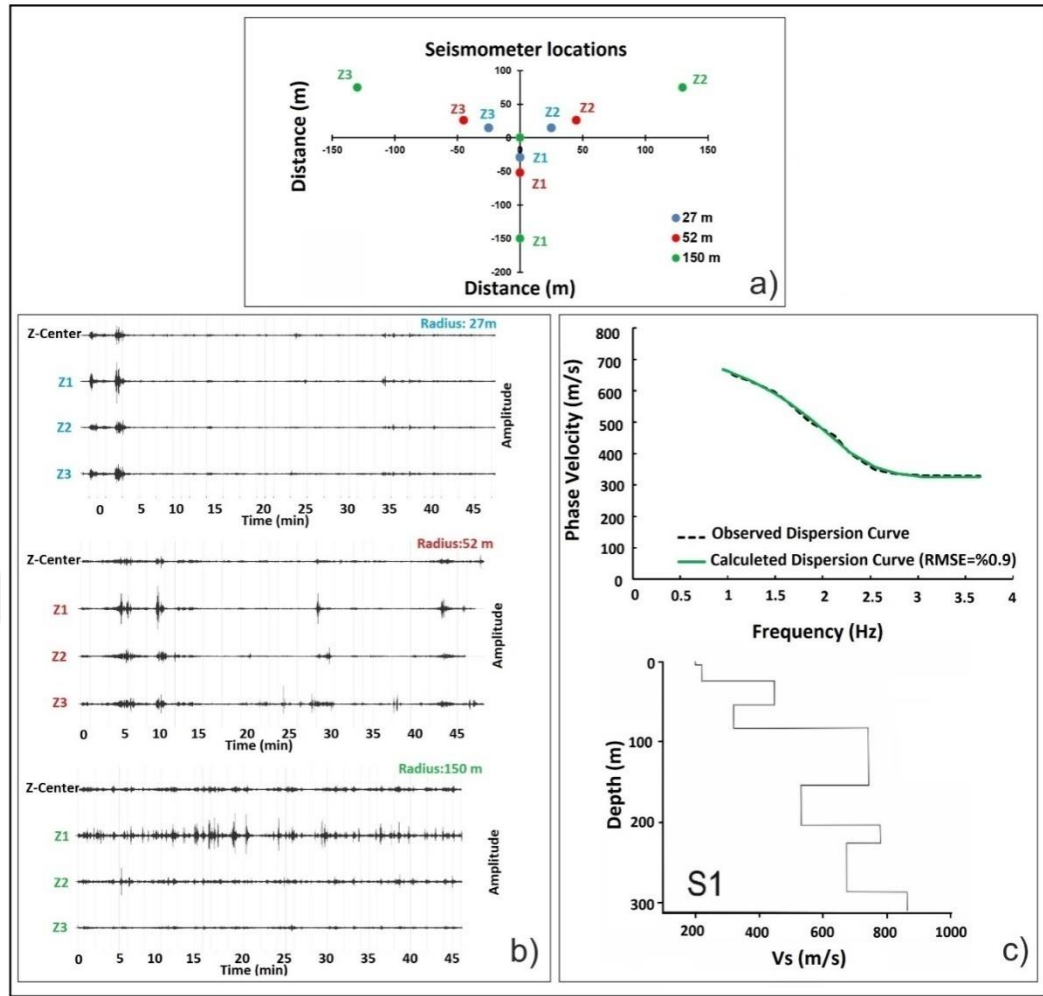


Figure 5.4 The process of obtaining Vs depth profile from SPAC at S1 site a) The array geometry of seismometer locations b) Microtremor data (Z-component) c) Dispersion curve and Vs profiles were obtained by inverting the dispersion curve

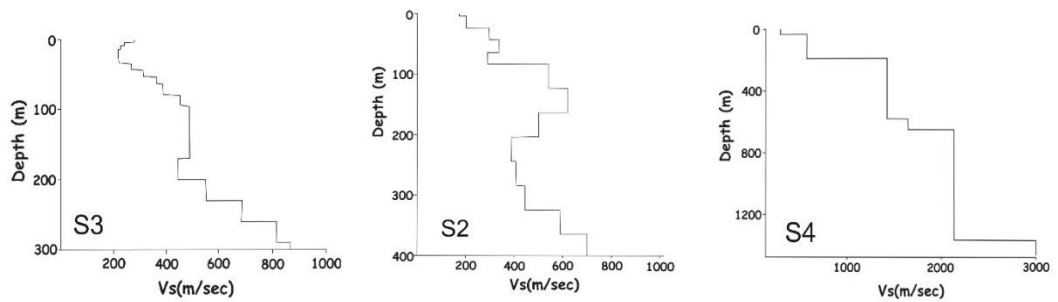


Figure 5.5 Vs depth cross sections obtained from SPAC.

5.1.3 MASW and ReMi Methods

Multi-Channel Analysis of Surface Waves (MASW) is a method of estimating the V_s - depth cross section from surface waves. It uses the dispersion properties of Rayleigh waves for imaging the subsurface layers. In MASW method, surface waves can be easily generated by an impact source (sledgehammer etc.) (Park et al., 1999). The refraction microtremor (ReMi) process, developed by Louie (2001) has widely been used to determine shear wave velocity profile using ambient noise recordings. This array analysis technique finds average surface-wave velocity over the length of a refraction array.

MASW (13 sites) and ReMi (13 sites) measurements were carried out in this study area (Figure 4.3b). MASW system consisting of 24 channels Geode seismograph with 24 geophones of 4.5 Hz were used. The seismic waves were generated by the impulsive source of a hydraulic sledgehammer (100 lb) or sledgehammer (18 lb) with three stacks. The progress of data process has three steps. The first step is the preparation of a multichannel record, the second step is dispersion curve analysis and the last step is inversion (using least-squares approach). The recorded seismic waves are further used to generate a dispersion curve, which displays a function of phase velocity against frequency. Also, ReMi measurements were carried out at the same locations where the MASW measurements conducted. The recording time was 30 s for one record. In the ReMi measurements, 8–10 records were recorded at each site. The array lengths change from 46 m and 115 m. The ReMi data processing consisted of three steps like MASW data analysis; 1) Velocity spectral (p-f) analysis. 2) Rayleigh phase-velocity dispersion picking, 3) Shear wave velocity modeling (Louie, 2001). In this study, V_s -depth cross section was obtained from combined dispersion of ReMi and MASW (Figs. 5.6–5.7).

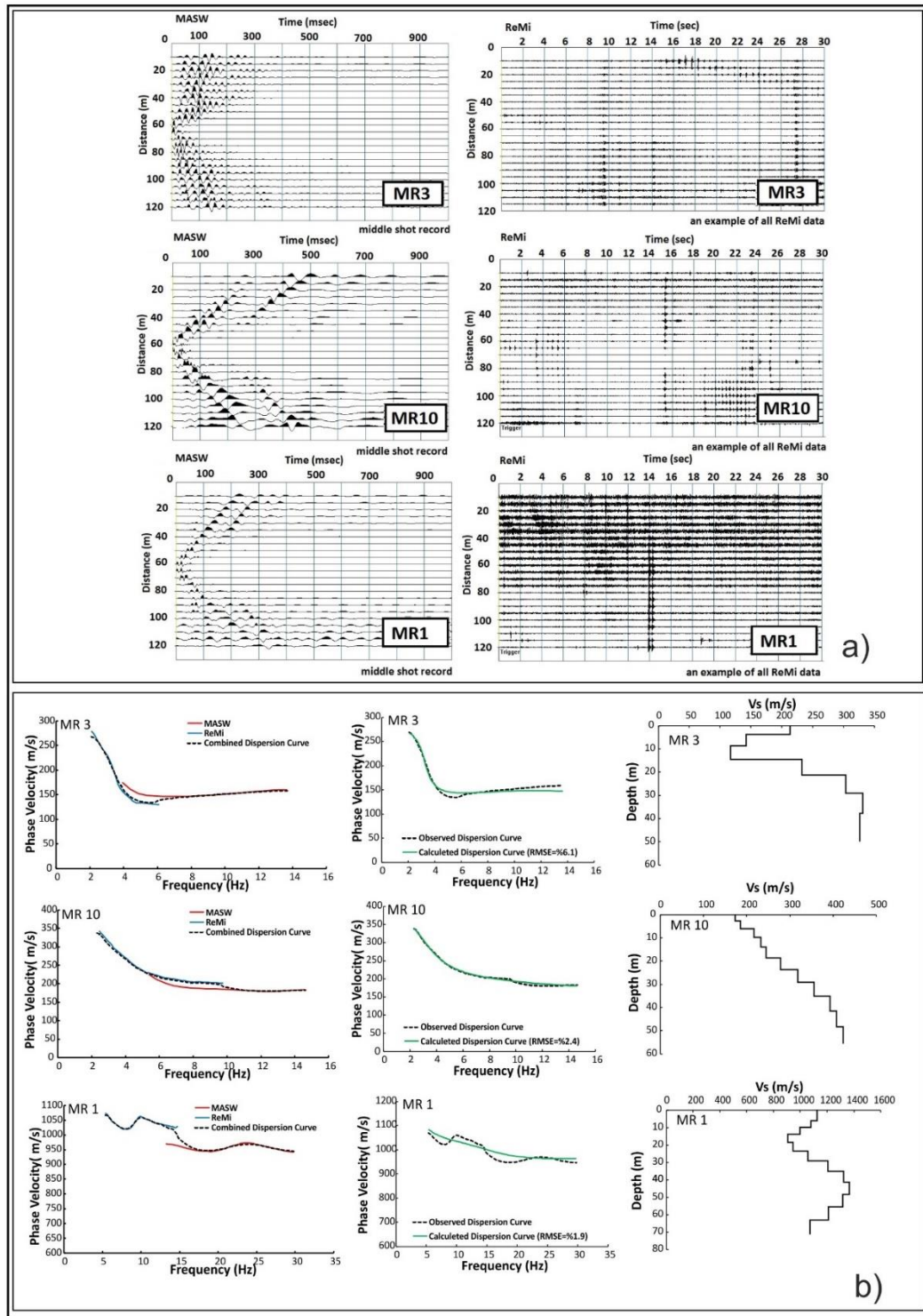


Figure 5.6 Representation of a) Surface wave data b) Vs profiles were obtained by inverting the combined dispersion curve

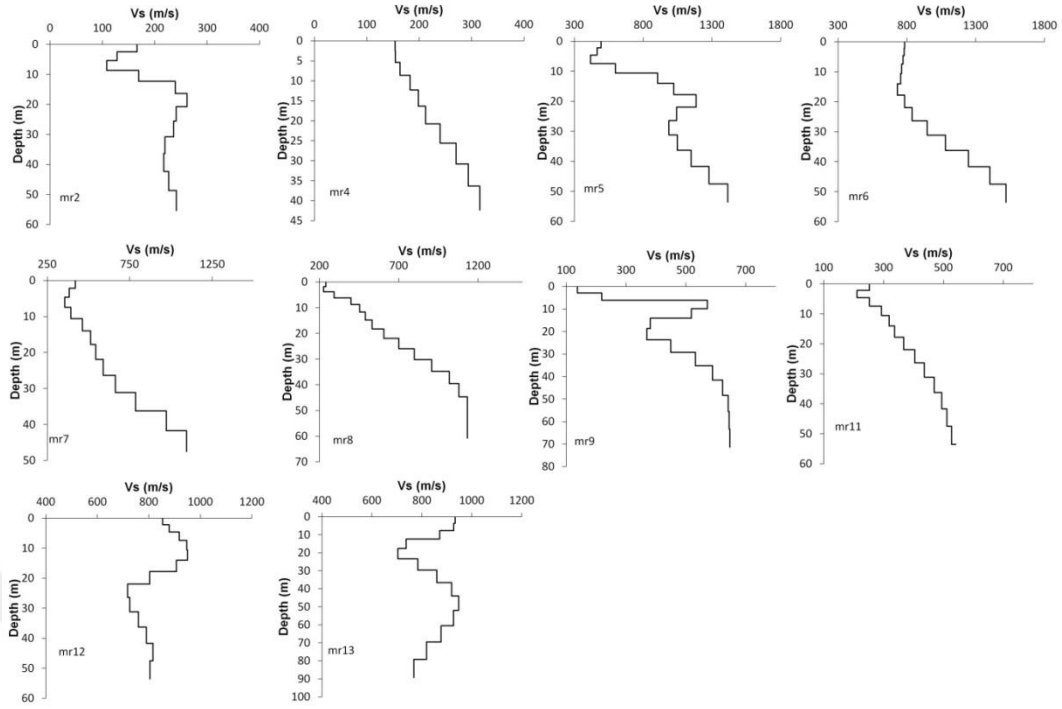


Figure 5.7 Vs depth cross sections obtained from MASW and ReMi combined survey

5.2 Microgravity Studies

Microgravity measurements were conducted by Scintrex CG-5 gravity-meter as approximately 500 m sampling interval based on land and urbanizing conditions along 10 km profiles north-south direction together with single station microtremor. The base station which's absolute gravity value is determined in Dokuz Eylül University Campus, was used as the main base station within measurement planning. All measurements were brought to term as connecting this station. Totally seven profiles were measured. Measurements were made as minimum 60 s, 5–15 repeated reading to provide to get well tilt angle and low standard deviation values and the error amount also.

At the first step of the data process, a digital elevation model was compiled by combining a 1/25000 scale local map and Aster global digital elevation map for calculating the free air, Bouguer slap correction and terrain correction at each station. After that, Latitude correction (g_L), free air correction (d_{gFA}), Bouguer correction (d_{gB}) and terrain correction (g_T) were applied to the station readings (g_{obs}) for obtaining the

Bouguer gravity anomaly values (g_B) as given below (Panisova et al., 2012; Pamukçu et al., 2014);

$$g_B = g_{obs} \mp dg_L + 0,3086\Delta h - (0,04191\rho)\Delta h + dg_T \quad (5.1)$$

$$g_B = g_{obs} \mp dg_L + dg_{FA} - dg_B + dg_T \quad (5.2)$$

Regarding corrections (height, Bouguer, terrain) were made and the Bouguer gravity map was obtained belongs to study area (Figure 5.8a). 6 and -11 mGal valued low anomaly inclusions on obtained Bouguer gravity map were defined appropriately to basin geometry of study area. 2nd-degree trend analysis was applied to evaluate better the bottom topography geometry of shallow plain in the region where Bornova Plain encounters with İzmir bay. The regional effect was resolved by the obtained values from Bouguer gravity values, then residual anomaly map was obtained (Figure 5.8b).

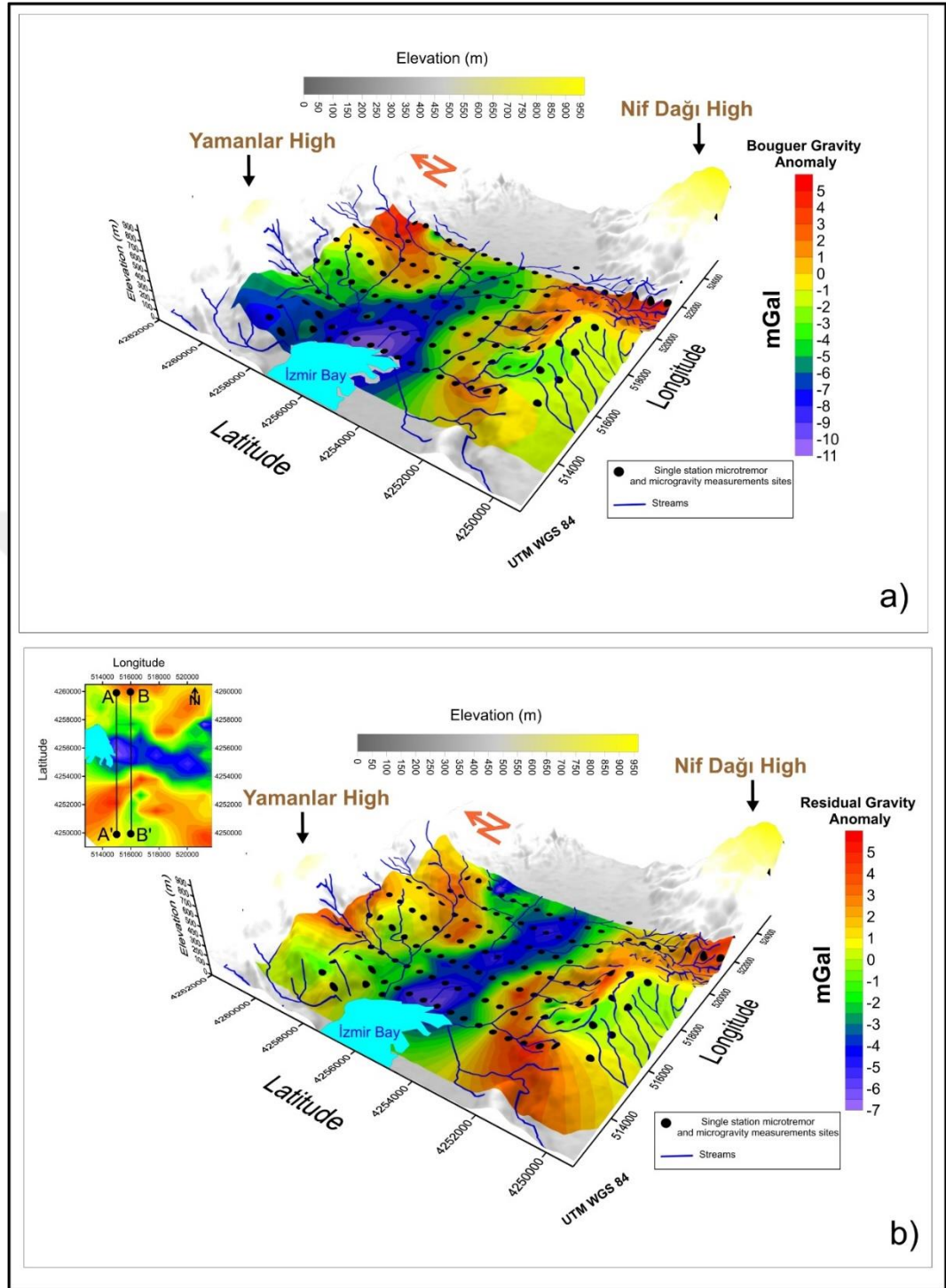


Figure 5. 8 a) Bouguer gravity anomaly map b) Residual gravity anomaly map obtained by using 2nd-degree trend analysis which subtracted from Bouguer gravity anomaly map of the study area

The gravity values change between -7 and 6 mGal on residual Bouguer gravity anomaly map. These values are between -7 and -3 mGal in middle parts of the study area where the soil thickness is thought deeper than around. There is observed partially

increasing by closing from the part near the sea. The gravity values are increased in north and south part of the study area where the topography is increased and soil thickness is decreased as expected. It is seen that generally compatible while comparing with predominant period values. The parts have higher period values become characterized by low gravity values than around.

The density values that will be used in modeling were calculated with the help of S- and P-velocity values and formulas on Table 1 on the purpose of occurring 2D soil-bedrock models for A-A' and B-B' profiles on residual gravity map. Soil models that composed of density values were determined consideringly general rock types and Vs, P-velocity (V_p) and density (ρ) relations on Table 4.1. There were defined nine layers based on density and Vs values for modeling of soil bedrock (Table 5.1).

Tablo 5.1 Used parameters for 2D soil-bedrock modeling

Models	Average Vs (m/sec)	Thickness (m) Variable	Average Density (gr/cm³)	Probable Geological Content
Soil-1	200	15-120	1.66	Clay, Silt Clay (commonly)
Soil-2	600	30-110	2.03	Clay, Sandy Gravel (commonly)
Soil-3	400	40-100	1.87	Clay, Gravel Clay (commonly)
Soil-4	650	60-150	2.06	Clayey Gravel, Clay-Claystone
Engineering Bedrock-1	1200	100-300	2.38	Bornova Melange ??
Engineering Bedrock-2	2000	600-850	2.56	Bornova Melange ??
Engineering bedrock-3	860		2.17	Neogene Andesite
Engineering bedrock-4	770	100-350	2.12	Neogene Limestone
Seismic Bedrock	>3000	-	2.78	Menderes Massif ??

The predominant period in A-A' and B-B' profiles was compared with Residual gravity anomaly values and elevation values. Predominant period values were increased as expected on areas that equaled to bay coast and in middle parts of sections. Low values in residual gravity values are remarked by the reason of increased soil thickness. Topography is instantly increased by away from the bay and the period values decreased in accordance with this, gravity values increased also. So, it is clearly seen that these parameters of two profiles that are compared extremity compatible with each other (Figure 5.9). Residual gravity values were modeled by the method of Talwani et al. (1959) and the soil-bedrock model was occurred (Figs. 5.10, 5.11).

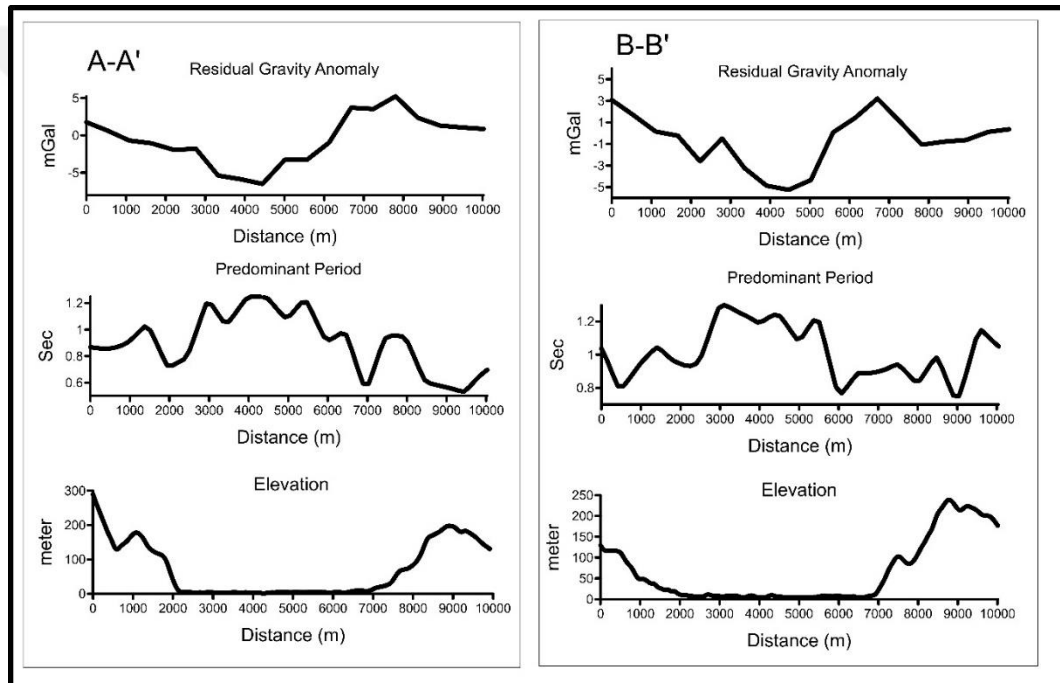


Figure 5.9 Presentations of comparing values which belong to Residual gravity anomaly, peak period and elevation along the A-A' and B-B' cross section

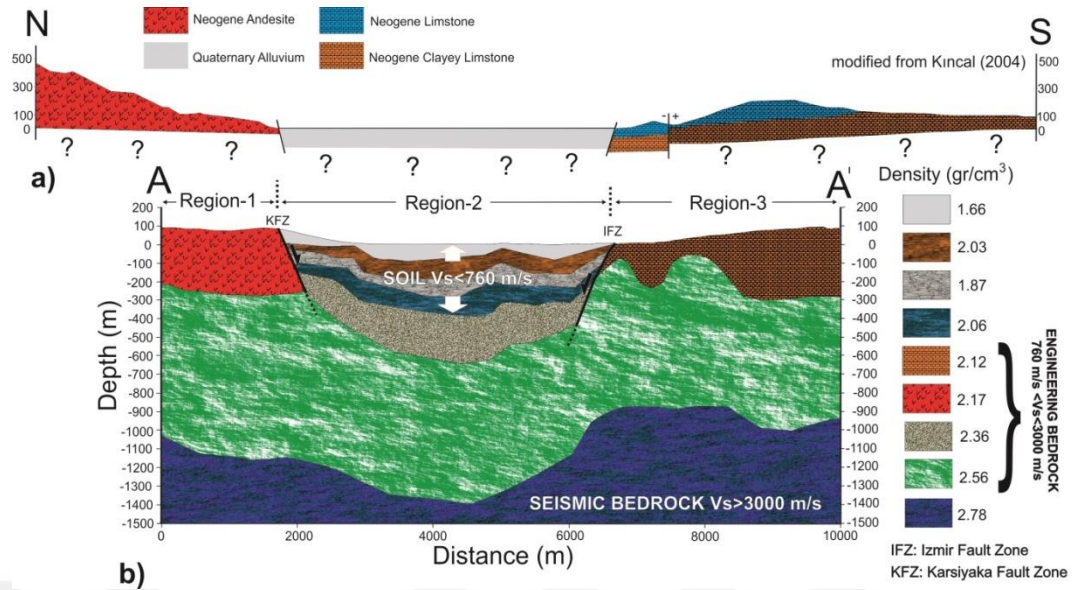


Figure 5.10 a) The geological cross section (modified from Kincal, 2004) b) The geophysical model along the A-A' cross section

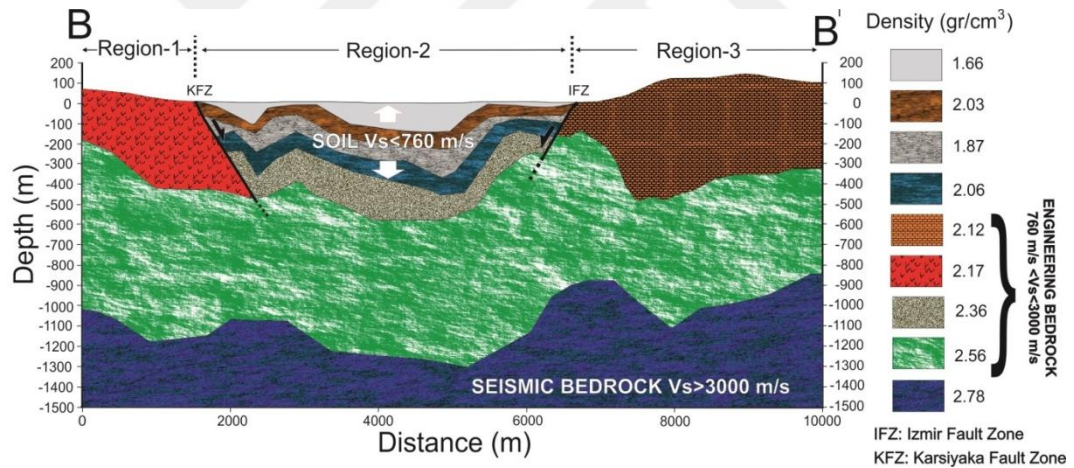


Figure 5.11 The geophysical model along the B-B' cross section

5.3 Results

A-A' and B-B' sections were obtained as 2D based on V_s and density values by using surface wave methods and microgravity methods. According to this process, soil thickness was determined as up to 400 m which caused by the effect of rivers and stream beds on the parts of close to the bay. Also, this situation is supported by data set belongs to average 230–240 m deep logs of borings. Finally, all results of

geophysical models (A-A'/B-B'), logs and geological structures were correlated together to interpret the final 2D soil-bedrock model. Three regions were defined based upon the changing in density and Vs values for A-A' and B-B' sections. A-A' and B-B' cross-sections, which were separated into three regions, was interpreted as given below;

A-A' section (Figure 5.10b) were correlated with the geological structure using geological map and borehole. These regions were entitled as a 1st region, 2nd region, and 3rd region.

As a result of 2D modeling performed depending on seismic velocities and densities, two different layers with Vs of >760 m/sec till seismic bedrock were identified as engineering bedrock in the 1st region. The seismic bedrock depth in this region is approximately 1000 m. A layer with average Vs of 860 m/sec and the average density of 2.17 g/cm³ are located at the top. A layer with average Vs of 2000 m/sec and the average density of 2.56 g/cm³ is located at below of it. A seismic bedrock's layer with Vs values >3000 m/sec and the average density of 2.78 g/cm³ is located at the bottom. When the region's geology and previous studies are considered, the top unit is Neogene andesite as being known as geological section (Figure 5.10a), the unit beneath it is likely Bornova melange and the unit at the bottom is likely Menderes massif.

Four different layers, of which Vs values are lower than 760 m/sec and total soil thickness are approximately 300 m, were observed in the 2nd region. The densities of these layers range from 1.66 to 2.06 g/cm³. Their average Vs values range between 200 and 650 m/sec. Two different layers, of which Vs values are >760 m/sec till seismic bedrock exists beneath these units. Seismic bedrock depth is approximately 1300 m. The geological contents of four surface layers, of which Vs <760m/sec, were widely observed as consisted of clay, silt-clay (commonly) clay, sandy gravel (commonly) clay, gravel-clay (commonly) clayey gravel, clay-claystone units by means of deep drillings. Regarding two layers known as engineering bedrock; it has been considered that the physical parameters (Vs, density) of Bornova melange unit

might have changed under different effects and Bornova melange unit was assumed to have two different velocities and densities in the 2nd region (Akgün et al., 2013a).

Likewise, 1st region, two different layers with Vs values of > 760 m/sec till seismic bedrock were identified as engineering bedrock in the 3rd region as well. Seismic bedrock depth in this region is approximately 1000 m. A layer with average Vs of 770 m/sec and the average density of 2.12 g/cm³ is located at the top. A layer with average Vs of 2000 m/sec and the average density of 2.56 g/cm³ is located at below of it. A seismic bedrock's layer with Vs values > 3000 m/sec and the average density of 2.78 g/cm³ is located at the bottom. When the region's geology and previous studies are considered, the top unit is Neogene limestones as being known as a geological section, the unit beneath it is likely Bornova melange and the unit at the bottom is likely Menderes massif.

When evaluating the B-B' section (Figure 5.11);

The 1st region is composed of 2 layers till seismic bedrock alike A-A' section in itself. The upper unit is Neogene aged andesite's which average thickness is ca. 300 m. The average depth of this layer with average Vs of 860 m/sec and the average density of 2.17 g/cm³. Layer, located beneath this layer and which geological unit is likely Bornova melange, likewise A-A section, continue till seismic bedrock, of which geological unit is Menderes massif. Seismic bedrock depth is approximately 1100 m.

When 2nd region examined, likewise A-A' section, it is seen that four different layers, of which Vs values are lower than 760 m/sec and total soil thickness are approximately 400 m have been in existence. Two different layers, of which Vs values are >760 m/sec till seismic bedrock, are located under these units. Seismic bedrock depth is approximately 1200 m.

Likewise, 1st region, two different layers with Vs values of >760 m/sec till seismic bedrock were identified as engineering bedrock in the 3rd region. A seismic bedrock's layer with Vs values are >3000 m/sec and the average density of 2.78 g/cm³ is located at the bottom. Seismic bedrock depth changes between 900 and 1200 m alike A-A'

section. It is seen in table 4.2 that layer thicknesses vary in the horizontal and vertical direction in B-B section located in eastern part of A-A' section modeled using density and velocity information. When obtained models were examined, it is seen that four layers exhibiting engineering bedrock attribute and four soil layers characteristics are in existence. There are two layers persisting in the horizontal direction. One of them is seismic bedrock, of which possible geological unit is Menderes massif, the other one is the unit, of which probable geological unit is Bornova melange and average V_s value is 2000 m/sec and average density is 2.56 g/cm³.

When resulting 2D models and predominant period map compared, it is seen that soil thickness reaches up to 300–400 m, the period values in the 2nd region are over 1 s. Moreover, when shallow and deep V_s -depth cross sections, predominant period values compared in these regions, it was seen that high values of the period ($t > 1$ s) were compatible with greater depth of the soil layers (approximately 300 m) and lower velocities ($V_s < 760$ m/sec). When the middle part of the geophysical model interpreted, V_s values of the region show that the tendency to increase from the center of the model to south and north directions. As the same situation is valid for from the west to east direction as increasing predominant period values. Accordingly, it can be concluded that soil thickness of study area decreases so long as getting away from the sea. According to the results of single station microtremor technique, performed on Neogene andesite (1st region) and limestone (2nd region); predominant period values are below 1 s.

According to these results, the interfaces of soil-engineering bedrock and seismic bedrock don't have the feature of horizontal and semi-infinite. Because it is observed sudden changes at the interfaces of the layer in horizontal and vertical directions.

5.4 Discussions & Suggestions

Approximately 400 m soil thickness in basin sides and average 1–1.6 s of predominant period values don't show consistency with soil classifications which are defined in Turkish earthquake regulations (Code, 2007) and the other classifications (NEHRP, Eurocode etc.) as well. V_{s30} description should not be used in areas where

have such an over soil thickness. According to the results, it is understood that the designing spectrums are used in Code (2007) fail to satisfy. It is offered to make special design spectrums for building area consideringly 2D soil-bedrock models which are obtained for study area where the high-rise buildings existed.

It is known that amplitude of movement and its duration may be increased in consequence of that body waves turns into surface waves and these waves are trapped in soil layers as result of discontinuities of basin margins. Moreover, seismic waves sometimes can be focused in small media on earth depending on the topography of bottom of basin and direction of the waves and they can lead to high losses at these parts (Liu & Heaton, 1984; Gao et al., 1996; Beliceli, 2006). When resulting 2D soil-bedrock models examined (Figs. 5.10a, 5.11), it is seen that particularly 2nd region focusing problems and effects of surface waves occurred at basin margins will likely be faced in case of an earthquake that will affect study area. Also, due to seismic impedances between engineering bedrock and soil in the 2nd region, resonance effect of earthquake waves can occur. This case is recommended to be taken into account at dynamic load calculations of engineering structures to be built on the 2nd region. As seen in this study, it is essential to consider engineering calculations to be performed in the regions where this kind of basin effect is observed, in two and three dimensional rather than one dimensional.

It is understood that the amplitude and frequency content of seismic waves will change in the limits of the layer down from 1000 to 1200 m, namely seismic bedrock. Its meaning is the seismic waves start to change the parameters down from this depth (amplitude and particle velocity values). It is not enough to only know the soil thickness for determining the earthquake effect on the surface. Furthermore, showing the seismic impedances are extremely important either.

To be able to make soil deformation analysis, there is needed an earthquake record obtained on engineering bedrock. This record could be obtained in three different ways, there are followed: seismographs on engineering bedrock; by the help of the soil transfer function which calculated the recorded earthquake via soil profile till engineering bedrock; and finally to get with scenario earthquakes. Vs-depth cross

sections must be known at least till engineering bedrock for calculating soil transfer functions true and complete. Usable models were produced to calculate the soil transfer functions along two profiles which were prepared for the study area.

Much as the unit called engineering bedrock-1 in A-A' and B-B' sections have high density and velocity value, there must be an extra object at issue about this unit which has different geological contents is Bornova melange or not. Because continuity of Bornova melange is shown based upon velocity and density values as a whole along profiles (approximately 10 km). But there is observed the models that engineering bedrock-1 is limited along basin and could be thought about there is a different layer occurs the base of soil layers composed of sediment structures. Especially deep borings in profiles in the 2nd region will be pretty important to enlighten the question marks.

CHAPTER SIX

3D BEDROCK STRUCTURE OF BORNOVA PLAIN AND ITS SURROUNDINGS (İZMİR/WESTERN TURKEY)

Two concepts are based on investigating the soil the effects of a dynamic earthquake load. One of these concepts is the identification of the earthquake-soil common behavior in the spectral medium. The other concept is to investigate the deformation changes in the soil due to this dynamic behavior. In order to investigate these two concepts, the earthquake motion must be defined for both the upper level of the seismic bedrock and the ground surface. In order to identify the earthquake-soil common behavior on the ground surface in the spectral medium, it is first necessary to calculate the soil response spectrum. The soil response spectrum is used to describe the effect of the section of the seismic bedrock and the ground surface on the earthquake motion in the spectral medium. When calculating the soil response spectrum, the thickness of the layers, damping factor, density and shear modulus are used from the top of the seismic bedrock to the ground surface in general. For this calculation, the 1D soil-bedrock model is mainly used with the assumption that these parameters change linearly (Kramer 1996). Many researchers defined the meaning of the soil, engineering bedrock, seismic bedrock by using V_s values. For example; Ambraseys et al. (1996) have defined the soil where the V_s is < 760 m/sec. Nath (2007) has described that the seismic bedrock corresponds to the V_s of 3000 m/sec and above, and engineering bedrock has the V_s of 400 m/sec to 700 m/sec for the purpose of seismic microzonation. Morikawa et al. (2008) have defined the seismic bedrock where the V_s is higher than 3000 m/sec. In a study of Anbazhagan and Sitharam (2009), V_s of 330 ± 30 m/sec is considered for the weathered rock and V_s of 760 ± 60 m/sec is considered for the engineering bedrock. In the studies of Akgün et al. (2013) and Pamuk et al. (2017), V_s changing, the medium where the V_s is < 760 m/sec is defined as soil, the medium where the V_s is between 760 m/sec and 3000 m/sec is defined as engineering bedrock and the medium where are bigger than 3000 m/sec is defined as seismic bedrock as. Calculation of the soil response spectrum using 1D soil-bedrock models does not fully reflect the earthquake soil common behavior on the ground surface. Because layers in the 1D models are assumed to be horizontal, semi-infinite, homogeneous and isotropic. On the other hand, it is known that the changes

in the thickness, damping factor, density and shear modulus in the horizontal and vertical directions are effective the earthquake force on the ground surface. For this reason, 2D or 3D soil-bedrock models are needed.

In addition, in the first stage of the earthquake-soil common behavior studies, the behavior of earthquake in the seismic bedrock of the epicenter originating from the main source is investigated by means of attenuation relationship. The seismic impedance observed from seismic bedrock to ground surface causes changes in the amplitude frequency spectrum of the earthquake waves relative to energy conservation. Besides, the horizontal changes in the topography of the layers between the soil and engineering-seismic bedrocks cause the change of the effect on the surface of the earthquake. It is known that the trapped surface waves in the soil layers may lead to an increased amplitude and duration of the motion on the surface. Therefore surface waves play an important role in damage during earthquakes in the sedimentary basins depending on the topography of the bottom of the basin and wave direction (Graves 1993; Narayan 2004; Choi et al. 2005). In addition, creating 3-D structure models are one of the most important requirements for strong motion prediction (Iwaki and Iwata 2011). In order for these studies to be carried out S-wave velocity (V_s) should be used as a base. The mediums are called soil where the $V_s < 760$ m/sec the bigger ones are called bedrock as well. Additionally, the parts are called engineering bedrock where the V_s is between 3000 m/sec and 760 m/sec the parts where are bigger than 3000 m/sec called seismic bedrock (Akgün et al. 2013; Pamuk et al. 2017a).

İzmir a city is a third most populous city in western Turkey. According to the 2016 census, İzmir's population are at approximately 4 200 000. Many active faults resulting from the tectonic structure of the Aegean region causes high seismicity and has resulted in numerous destructive earthquakes. The Bornova Plain which is the one of largest plain in İzmir and surroundings borders the Karsiyaka Fault Zone in the north and the İzmir Fault Zone in the south and new building sites of new high-rise building have been planned in this region. Some of the most disastrous earthquakes are in this study area and its surroundings in instrumental period: 16 July 1955 Söke-Balat earthquake ($M=6.8$); 23 July 1949 Karaburun ($M=6.6$); 20 Oct 2005 Sığacık ($M=5.9$); 10 April 2003 Urla ($M=5.6$); 06 Dec 2014 İzmir ($M=5.5$) (Emre et al. 2005).

In the previous studies; Scheck et al. (1998) derived a 3D model of the basin structure using gravity and borehole data. Abbott and Louie (2000) investigated seismic bedrock depth in the sedimentary basin in Reno and Carson City urban areas of western Nevada helping gravity studies. Komazawa et al. (2002) utilized gravity survey and microtremor measurements to reveal mainly the configuration of bedrock in the basin and created 3D bedrock model in their study area. Martelet et al. (2004) created the 3D geometry of a segment of the Hercynian suture zone of western Europe in the Champtoceaux area (Brittany France) using geological and geophysical data. Malehmir et al. (2008) constructed a 3D geologic model using 3D inverse and forward gravity modeling in the mining area. Recently Iwaki and Iwata (2011) presented a method to estimate the boundary shape (i.e. interface topography of sediment and seismic bedrock) of a three-dimensional (3D) basin velocity structure by waveform inversion using real seismic data observed in the Osaka sedimentary basin.

In this study, it is purposed to obtain interface among soil, engineering bedrock and seismic bedrock as a three-dimensional (3D) in the Bornova Plain which is located in the east of İzmir which has high seismic activity region in Western Turkey. For this purpose, it was utilized microgravity and surface waves methods in Bornova Plain and its surroundings. This study is basically composed of three phases; 1) seismic velocities are obtained surface wave methods. Active source (multichannel analysis of surface waves, MASW) method was used to obtain shallow S-wave velocity (V_s) while passive source (refraction microtremor, ReMi, and spatial autocorrelation, SPAC) was used to estimate deeper V_s profiles. 2) Density values were calculated using the seismic velocities by helping empirical relations 3) The soil bedrock models were created by using residual density variations which dataset was obtained from microgravity method along seven profiles. It was determined that the soil thickness is a change from 300 to 400 m and soil layers composed of more than one layer in especially closer to the bay. Moreover, it is observed that the soil thickness decreased in the direction of N-S and E-W.

6.1 Field Studies

MASW and ReMi were carried out at 64 sites in the study area (Fig 6.1). SPAC measurements were carried out at 6 sites. Also, three drilling reports are given in Figure 6.2.

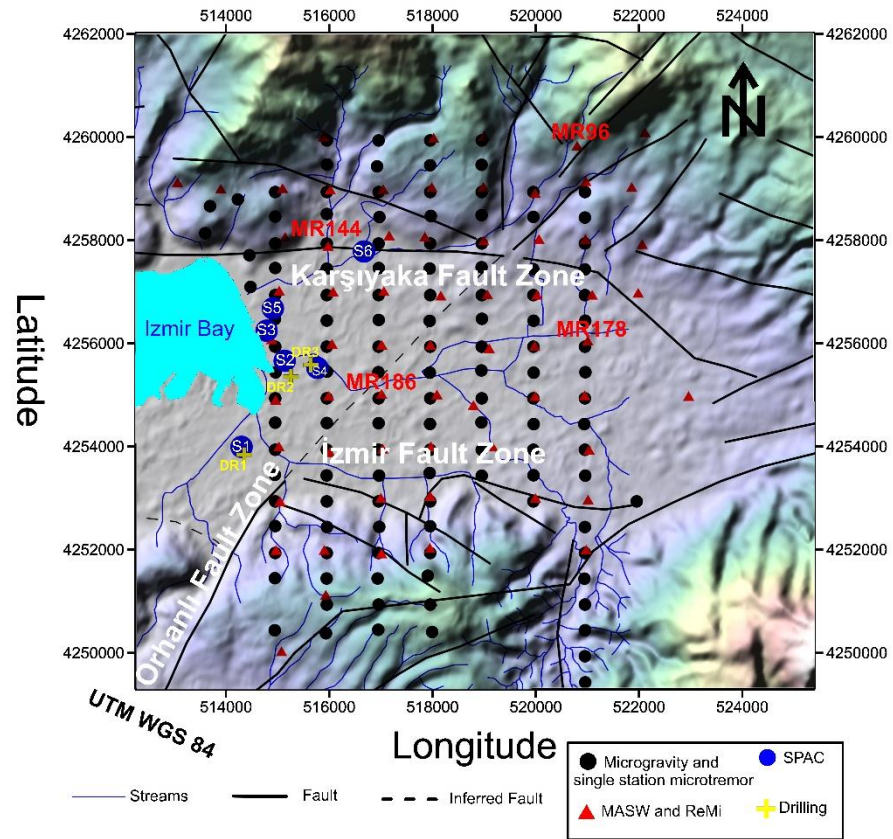


Figure 6.1 Microgravity, MASW, ReMi, SPAC measurements sites and drilling locations in the study area (the fault zones were created from Uzel et al. 2012)

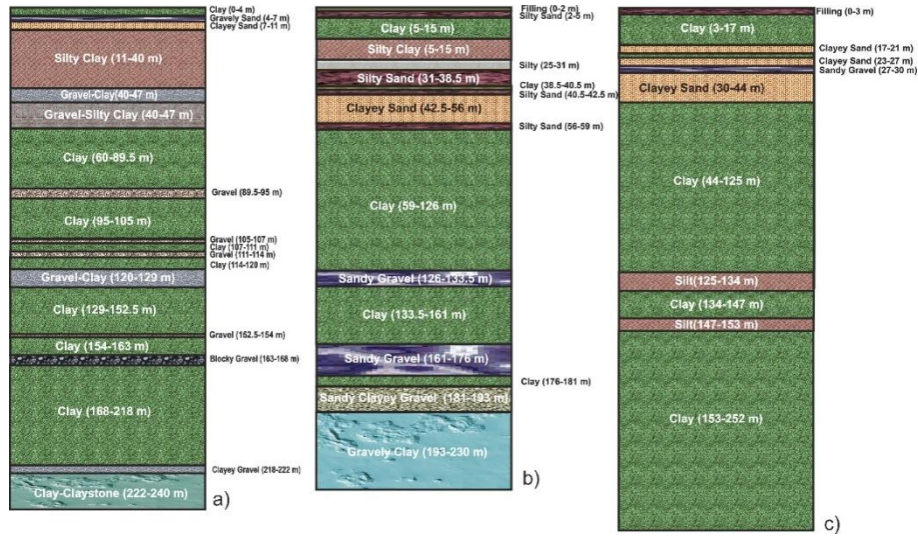


Figure 6.2 Drilling reports a) DR1 b) DR2 and c) DR3

6.1.1 Nakamura Method (HVSR)

Nakamura method (single station microtremor) has been defined by Nakamura (1989). This method which is a convenient and inexpensive for soil investigations has widely used for assessing the effect of soil conditions on the earthquake shaking. Nakamura (1989) demonstrated that the ratio between horizontal and vertical ambient noise records was related to the fundamental frequency and amplification of the soil beneath the site. Recently many researchers have used Nakamura's method for soil characterization (Lermo & Chávez-García 1993 1994; Lachet & Bard 1994; Konno & Ohmachi 1998; Dikmen & Mirzaoğlu 2005; Akin & Sayil 2016; Pamuk et al. 2017a; 2017b).

Single station microtremor measurements were utilized at more than 64 sites in the study area. It was used Guralp Systems CMG-6TD seismometer (velocimeter) at each site. The recording time was approximately 30 minutes with a sampling rate of 100 Hz. All data were filtered in a band-pass of 0.05-20 Hz for removing intensive artificial disturbance. Then data were divided into 81.92-sec windows and tapered individually using the Konno-Ohmachi smoothing method. For each window, the amplitude spectra of the three components were computed using a Fast Fourier Transform (FFT) algorithm. As a result, the average spectral ratio of horizontal-to-vertical noise

components was thus calculated. Microtremor measurements were processed using GEOPSY software package (Geopsy, n.d.).

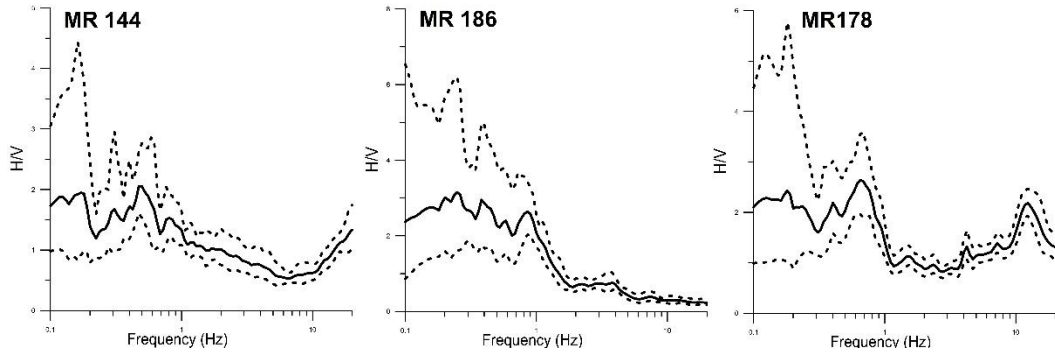


Figure 6.3 Examples of H/V spectral ratio for the study area (dashed lines demonstrates the standard deviation)

6.1.2 Array Microtremor (*Spatial Autocorrelation Method-SPAC*)

It was also used the spatial autocorrelation method (SPAC) first proposed by Aki (1957) and Okada (2003) for horizontally propagating waves to determine deeper Vs profiles. Numerous researchers have used the SPAC method (Wathelet et al. 2005; Chavez-Garcia et al. 2005, 2006; 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 center. The radius of the circular arrays was individually adjusted for each site and the radius change 45 m to 400 m. The recording duration changed from 30 to 60 minutes in at each array. The SPAC coefficients obtained from the observational values and the theoretical Bessel function values are an investigation by computed the dispersion curve values of the fitting frequency range. After obtaining the dispersion curves the one-dimensional S-wave velocities were obtained by applying the damped least squares method (Levenberg, 1944 and Marquardt, 1963) (Figure 5).

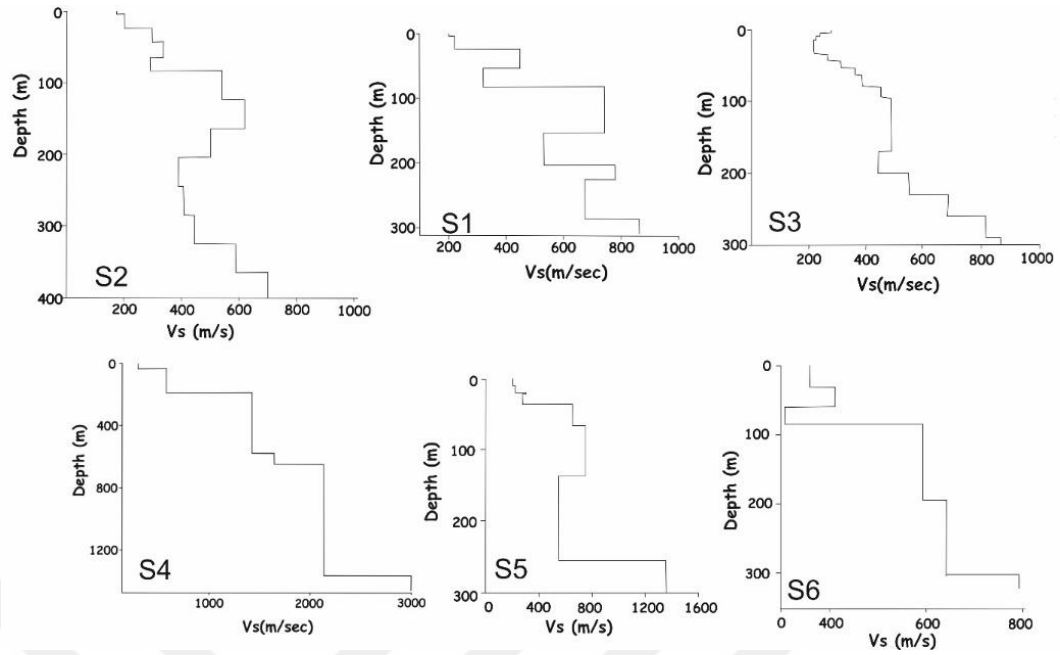


Figure 6.4 Vs depth cross sections obtained from SPAC

6.1.3 MASW and ReMi Methods

Multi-Channel Analysis of Surface Waves (MASW) is a method for estimating the Vs- depth cross section from surface waves. It uses the dispersion properties of Rayleigh waves for imaging the subsurface layers. In MASW method surface waves can be easily generated by an impact source (sledgehammer etc.) (Park et al. 1999). The refraction microtremor (ReMi) process developed by Louie (2001) has widely been used to determine S-wave velocity profiles using ambient noise recordings. This array analysis finds average surface-wave velocity over the length of a refraction array. These methods have been used by numerous researchers (Tokimatsu et al. 1992; Ohori et al. 2002; Morikawa et al. 2004; Park et al. 2005; Akin & Sayil 2016; Pamuk et al. 2015 2016 2017a 2017b).

MASW and ReMi measurements were utilized in this study area at 64 sites. The MASW which is the active source is used with 24 geophones of 4.5 Hz. Geophone intervals changed from 3 m to 5 m. The offset was selected as 15, 10 and 5 m in all the profiles respectively. The recording length was selected as 1 sec while and the sampling interval was selected as 1 msec. The seismic waves were generated by the

impulsive source of a hydraulic sledgehammer (45 kg) or sledgehammer (10 kg) with three stacks. After processing MASW measurements, it was obtained a function of phase velocity against frequency. Then the dispersion curves have been obtained by marking the highest amplitudes in phase velocity-frequency image. Lastly, it was used the damped least-squares technique for inversion process of the dispersion curve. Thus, 1D Vs-depth profile was obtained at each site. ReMi measurements were also used at the same locations where the MASW measurements conducted. The recording time was 30 sec for one record while 8-10 records were obtained at each site. Geophone intervals changed from 3 m to 5 m. The ReMi data processing consisted of three steps like MASW data analysis; Velocity spectral (p-f) analysis. Rayleigh phase-velocity dispersion picking. Shear wave velocity modeling (Louie 2001). In this study, Vs-depth Profile was obtained from combined dispersion of ReMi and MASW. Figure 6 shows Vs profiles obtained from MASW and ReMi at same sites.

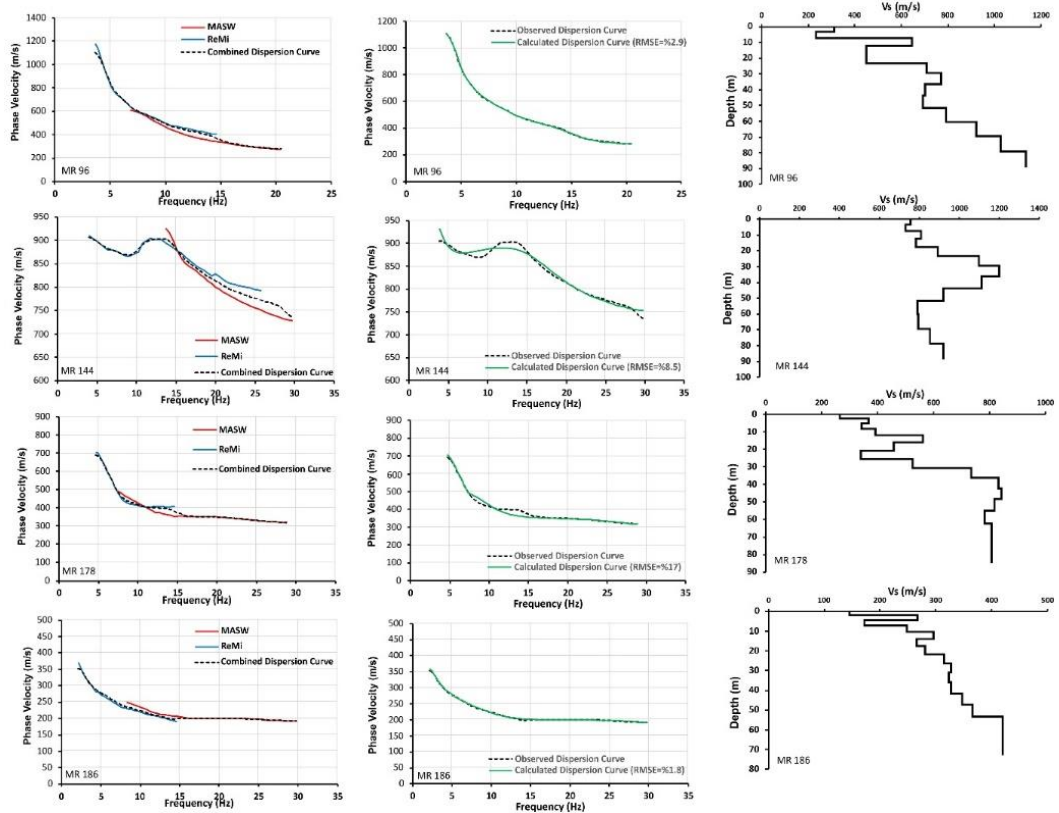


Figure 6.5 Vs profiles were obtained by inverting the combined dispersion curve

6.1.4 Microgravity Studies

It was utilized microgravity measurements by Scintrex CG-5 gravity-meter as approximately 500 m sampling interval based on land and urbanizing conditions along 10 km profiles north-south direction. It was used the main base station which is absolute gravity value in Dokuz Eylül University Tınaztepe Campus within measurement planning. All measurements were brought to term as connecting this station. It was measured microgravity data in seven profiles. Duration of the measurements was minimum 60 sec. In addition, it was repeated reading 5-15 times to provide to get low standard deviation values and well tilt angle. Bouguer gravity map was obtained after After that Latitude correction, free air correction, Bouguer correction and terrain correction. It was applied 2nd-degree trend analysis for evaluation better the bottom topography geometry of shallow plain in Bornova Plain and its surroundings. Lastly, residual anomaly map was obtained by removing of regional effect in Bouguer gravity values (Figure 6.6).

Seismic velocities (V_s and V_p) were used for calculating the density values that will be used in modeling using the empirical formulas on table 4.1 with general rock types. The density values used in the modeling were determined by taking the average of the densities obtained from the different formulas in table 4.1. It was used these density values for occurring 2D soil-bedrock models for all profiles on residual gravity map. For creating the soil-bedrock models from residual gravity map it was used the method of Talwani et al (1959). There were defined from seven to nine layers based on density and V_s values for modeling of soil-bedrock. All profiles were modeled up to 1500 m depth. Because there are more geophysical data and drilling report it was achieved modeling as multiple layers in the alluvium part of the study area for profile-1 and profile-2. For other profiles, alluvium part of the study area was modeled as one layer with 1.9 gr/cm^3 density value. Figure 6.7 shows that results of soil-bedrock modeling for profile-1 and profile-4. The gravity values in the P-1 profile range from -5 to +5 mGal while in the P-4 profile this value is between -6 and +4 mGal. When P-1 and P-4 profiles are examined it is observed that the thickness of the soil is approximately 300 m on two profiles. The RMS error between the observed gravity values and calculated gravity values is % 0.44 in the P-1 profile while this value is

approximately 0.19% for the P-4 profile. In the P-4 profile, the horizontal topography of the seismic bedrock is more variable than the P-1 profile. The depth of the seismic bedrock is between 900 and 1300 m in the P-1 profile while between 700 and 1100 m in the P-4 profile (Fig 6.7).

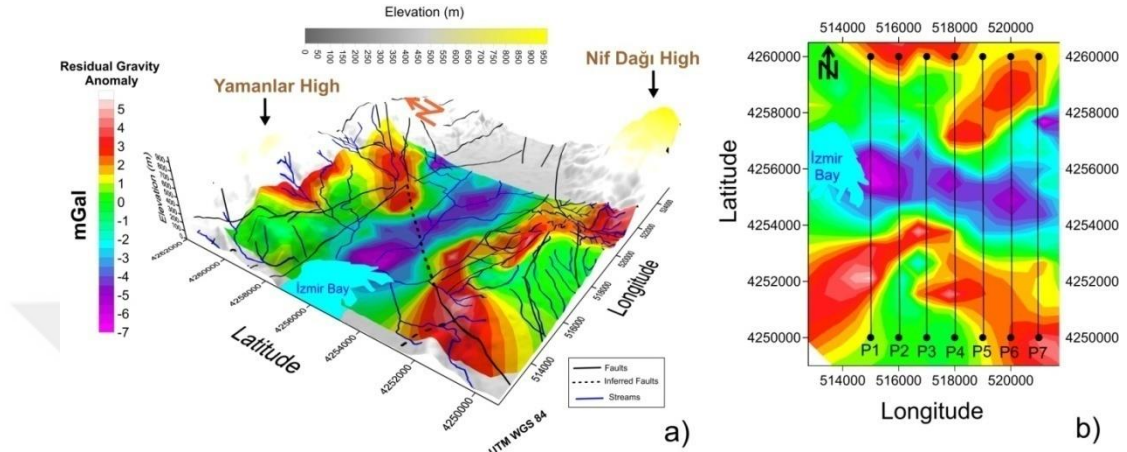


Figure 6.6 a) Residual gravity anomaly map obtained by using 2nd-degree trend analysis which subtracted from Bouguer gravity anomaly map of the study area. b) Modeled profiles on residual gravity anomaly map

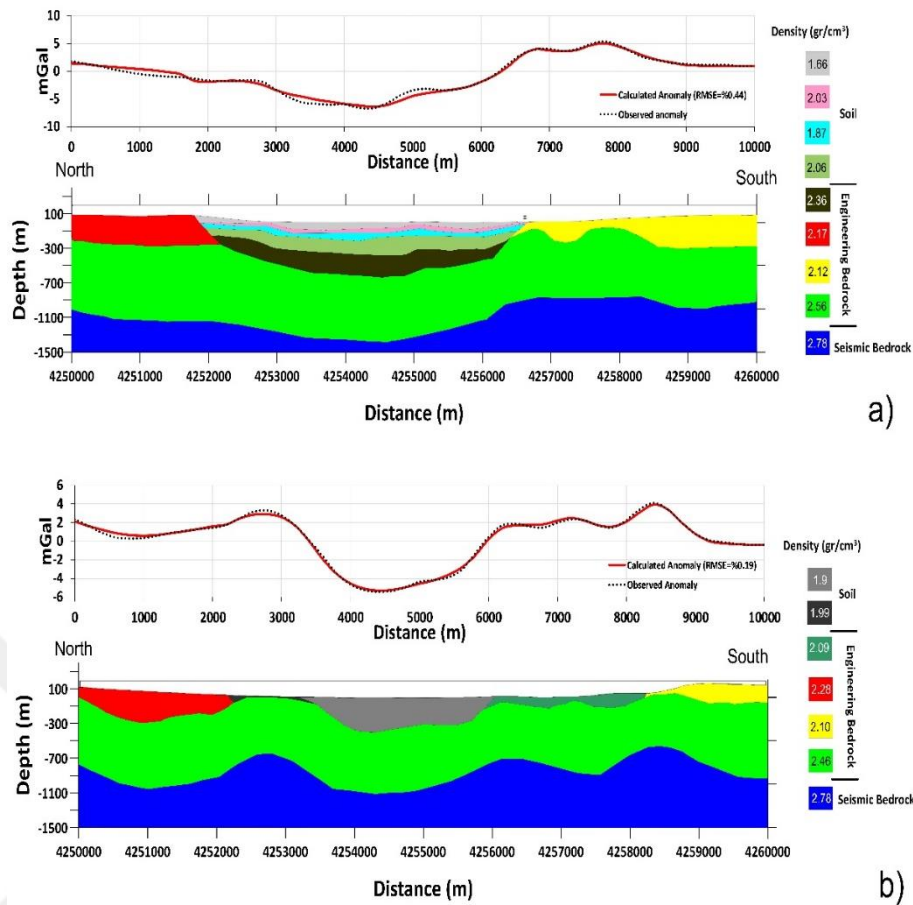


Figure 6.7 Geophysical models along a) The profile-1 b) The profile-4 with observed and calculated gravity values

3D soil-bedrock models are obtained from interpolation of 2D models (Fig 6.8). When the 3D geophysical model is examined it is seen that the thickness of the soil decreases toward the east of the plain. The depths of the engineering and seismic bedrocks are also higher where the soil thickness is greater. Parts of the study area where the soil thickness is higher are bordered by fault zones. For this reason, the topography of the layer interfaces in the N-S direction changes sharply. When the 3D model compared with the V_{s60} (V_s at 60 m depth) distribution map obtained from MASW and ReMi combined surveys and dominant period map the V_{s60} map is compatible with the 3D geophysical model obtained from the gravity modeling. The V_s values don't reach 760 m/sec at the depth of 60 m depth in the plain. As seen in the 3D model the soil thickness is much more than 60 m in these places. The predominant period values are above 1 sec in places where the soil thickness is approximately 300

m. As can be seen the 3D geophysical model V_{s60} and the predominant period distribution are suitable with each other (Fig 6.8).

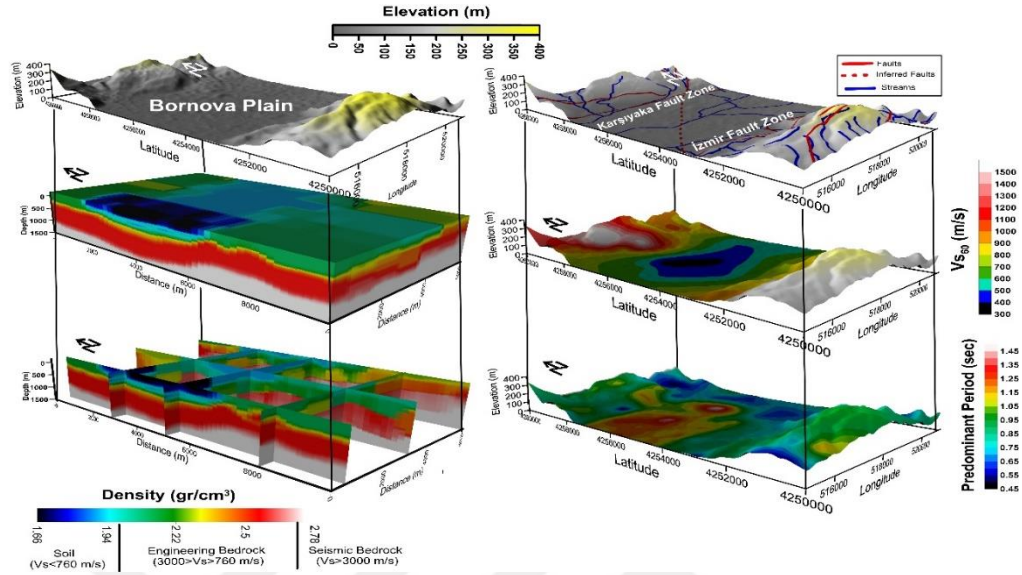


Figure 6.8 3D Geophysical models along Bornova Plain and its surroundings with predominant period and V_{s60} (m/sec) maps

Figure 6.9 shows that engineering and seismic bedrock depth as 3D. When the 3D distribution of the engineering bedrock is examined it is observed that the depth of the engineering bedrock is between 0 and 400 m. In the Bornova Plain covered alluvium unit borders the Karşıyaka fault zone in the north and the İzmir fault zone in the south soil thickness is much higher than in other regions and especially deep drilling up to approximately 250 m depth in alluvium unit supports this situation.

The topography of the engineering bedrock shows a sudden change especially in the direction of N-S. From the west to the east in the study area, it can be said that the thickness of the soil decreases relatively. When the seismic bedrock distribution is examined the seismic bedrock depth varies from 550 m to 1350 m. The depth of the seismic bedrock decreases from the west to the east of the study area. The seismic bedrock is deepest where alluvium units and parts of near the sea. The change of seismic bedrock topography is similar to that of the engineering bedrock.

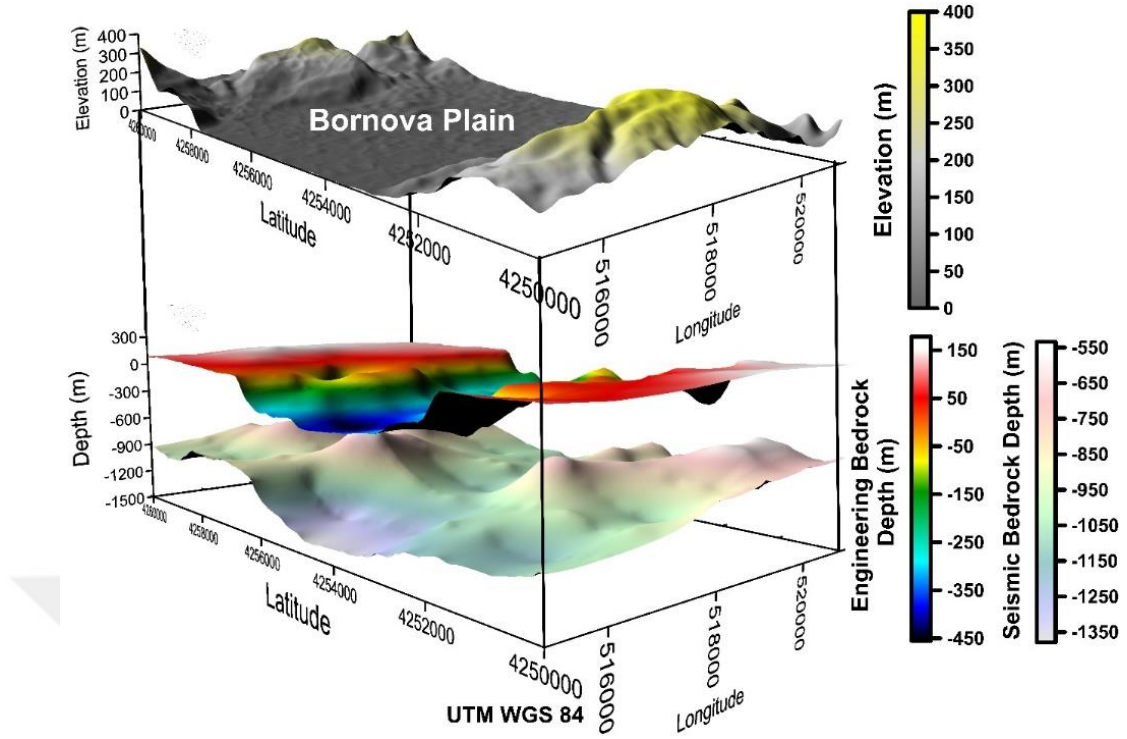


Figure 6.9 Engineering and seismic bedrock depth as 3D

6.2 Conclusion

The bedrock structure of Bornova Plain was studied based on Bouguer gravity anomaly and surface wave methods. Results of this study contribute important information in eastern İzmir bay which is poorly deeper studied zone. The accurate dynamic behavior of the Bornova Plain can be estimated during an earthquake using these results. The main results are as follows:

Residual gravity values in the northern parts of the P-1 profile range from +2 to -2 mGal. In this parts, there are two layers on the seismic bedrock and the depth of the seismic bedrock is approximately 1000 m. There is a Neogene andesite unit with an average V_s value of 860 m/sec and an average density of 2.17 g/cm^3 at the top. A layer with average V_s of 2000 m/sec and the average density of 2.56 g/cm^3 is located at below of it. its possible geological unit is Bornova Complex. At the bottom, there is a seismic bedrock layer with a V_s greater than 3000 m/sec and an average density of 2.78 g/cm^3 . The predominant period values are generally lower than 1 sec and the V_{s60} values are greater than 760 m/sec in this part. The central parts of the P1-section

covered by alluvium unit are bordered by İzmir Fay Zone in South and Karşıyaka Fault Zone in the north. In these parts, four layers were determined with a total soil thickness are approximately 300 m and Vs values are less than 760 m/sec. The densities of these layers range from 1.66 to 2.06 g/cm³. The average Vs values are between 200-650 m/sec. Below these layers there are two different layers which have Vs value greater than 760 m/sec. The residual gravity value of this parts varies between -1 and -5 mGal. Result of surface wave methods shows that most parts of alluvial basin region have low shear wave velocity values. The predominant period values in this region are generally above 1 sec, while the Vs₆₀ values are is lower than 760 m/sec. In the southern part of the P-1 section, there are two layers which have Vs values greater than 760 m/sec on the seismic bedrock. There is a Neogene limestone unit with an average Vs value of 770 m/sec and an average density of 2.12 g/cm³ at the top. A layer with average Vs of 2000 m/sec and the average density of 2.56 g/cm³ is located at below of it. At the bottom, there is a seismic bedrock layer with Vs values greater than 3000 m/sec and the average density of 2.78 gr/cm³. The values of the residual gravity range from 0 to +5 mGal in this parts.

The contours of engineering and seismic bedrocks with S-wave velocities of 760 m/sec and 3000 m/sec obtained from the results of microgravity and surface wave methods. The depth of the engineering bedrock changes from 150 to 450 m in the Bornova Plain and is approximately 450 m at the coastline. Engineering bedrock unit is covered by very thick alluvion units with very low shear velocities in the Bornova Plain. The depth of seismic bedrock depth increases from 1350 m in the Bornova Plain and it is approximately 550 m at the southeast of the plain. The shallow S-wave velocity structure shows that the Neogene andesites and limestones have the feature of engineering bedrock in the north and south part of the study area.

The predominant periods of the study area show a distribution in a wide range 0.45–1.6 sec. There is a good correlation between predominant periods and thickness of the Quaternary sediments in the plain. The low-predominant period range is characteristic of the southern and northern part of the study area, where Neogene limestones and andesites. The high amplitudes of the HVSr peaks indicate a great impedance contrast

between soil and bedrock. The middle part of the study area is characterized by very high sediment frequencies, indicating thick Quaternary sediments.

In this study, dispersion curves were combined from active (MASW) and passive (ReMi) surface waves the method. Combined dispersion curves were used in the study in order to increase the depth of the research and to identify the velocity differences that occur within the soil in detail. Investigation depth changes from 60 to 100 m for the combined survey. According to Vs-depth sections obtained from each measurement site, sudden velocity differences are observed in a lateral and vertical direction within the soil. it has been observed that V_{s60} values vary between 300 and 1600 m/sec. When these velocity changes and the geological structure of the area are considered together, andesites and Miocene pyroclastics north of the area of study and Miocene aged limestone in the south of area of the study are observed to have higher Vs values compared to the rest of the area of study and the threshold value of bedrock's V_{s60} values are also observed to be higher than 760 m/sec. In spite of this, V_{s60} values, especially in the areas nearby the sea, are below 500 m/sec. When maps of the predominant period and V_{s60} are compared; it matches up to higher Vs values where the period values are observed to be less than 1 sec. The predominant period values are observed to be higher than 1 sec and V_{s60} values are observed to be much lower than 500 m/sec, especially in the areas which are Quaternary aged and mostly consist of soil layers that are thicker than 30 m.

Soil-bedrock models were produced to calculate the soil transfer functions along two profiles which were prepared for the study area.

When resulting 3D soil-bedrock models examined it is seen that particularly Bornova Plain focusing (so-called basin-edge effect) problems and effects of surface waves occurred at basin margins will likely be faced in case of an earthquake that will affect study area.

It can be performed 3-D simulation of seismic wave propagation and long-period ground motion simulations using the 3D soil-bedrock model for the study area.

The bird view of the 3D engineering and seismic bedrock depth shows that the subsidence of Bornova Plain related to the Karşıyaka fault zone at north and İzmir fault zone at the south. The maximum depth of the seismic bedrock is 1.35 km in this study area. Holocene alluvium unit and older sediments fill this basin.



CHAPTER SEVEN

CONCLUSION

The b value of magnitude-frequency relationship was calculated by the Maximum Likelihood Method and was mapped as 2D and 3D for the İzmir and its surroundings in Western Turkey. The b-value is approximately 0.81 ± 0.03 after the Midilli and Manisa earthquakes with $M_c=4.1$ (cut of magnitudes) for the study area. When the 2D b values map is examined, b-values change from 0.6 and 1.05 after the Midilli and Manisa earthquakes in the study area. Some regions in the study area have low b-values, relatively. For example; These are i) eastern part of İzmir Bay ii) Northwest and western of Karaburun Peninsula, iii) Küçük Menderes Graben; iv) Büyük Menderes Graben. These areas should be described as a higher stress condition. The results show that area where b values are lower can produce large earthquakes. It was calculated the mean return period for $M=6.0$ and $M=5.0$, and the minimum values of these parameters are respectively 20 years and 4 years in eastern and western parts of the study area. As the b-value suddenly changes in horizontal and vertical directions, it can be said that tectonics of the study area is complex. The higher b-value can be explained by more heterogeneities while high stress and lesser heterogeneity in the crust cause lower b-value.

The predominant period in the range of 0.45–1.6 sec, which indicates that the area exhibits lower predominant periods and less sediment thickness. The V_{s30} values which change from 180 to 1400 m/sec. Soil classified as C and F type according to NEHRP, generally. Some parts located on the north and the south part of the study area have better soil conditions and have comparatively high shear wave velocities in the range of 500–1400 m/sec. In north and south part of the study area decreasing in predominant period values remarked by the reason of increasing topography and finding different geological units. The period values are observed to be higher than 1 sec and V_s values are observed to be much lower than 500 m/sec especially in Quaternary aged and mostly consist of soil layers that are thicker than 30 m.

According to V_{s30} values; bedrock is mostly dominant in the regions south of the bay and north of the bay due to V_{s30} values being higher than 760 m/sec. These regions

are classified as B-type soil according to NEHRP regulations. Soil definition is used in other regions due to V_{s30} values being lower than 760 m/sec. C and F types of soil are dominant in these regions according to NEHRP regulations. The Risk Map- I almost cover Bornova Plain. It can be seen that there are many educational institutions and hospitals within risk-1 area. All of the buildings partially damaged in the earthquake is located in the risk map. The existing Turkish earthquake regulations (Code (2007)) for buildings to be built in this area are insufficient. Therefore, detailed studies are required to calculate the in-situ design spectrum. There is resonance risk that the buildings which have periods varying from 1 to 1.6 sec within this area. Seismic impedance must be determined from the seismic bedrock ($V_s > 3000$ m/sec) to the surface in order to calculate the earthquake effect on the surface within this area. The risk-II map is within the risk-I map and some of the buildings damaged by the earthquake are located within this area.

When examining the predominant periods of the high-rise buildings in the study area and hospitals and educational institutions in the risky areas, especially the number of floors of educational institutions and hospitals is less than 10. Therefore, it can not be said that these structures in risky areas carry a resonance risk. However, some of the high-rise buildings carry a resonance risk. The resonance effect must be taken into account when designing the buildings to be built in this area. Therefore, it is proposed to use the predominant period map in the design of new buildings.

Soil, engineering, and seismic bedrock models were obtained as 2D and 3D based on V_s and density values by using surface wave methods and microgravity methods. According to this process, soil thickness was determined as up to 400 m which caused by the effect of rivers and stream beds on the parts of close to the bay. Also, this situation is supported by data set belongs to average 230–240 m deep logs of borings. According to these results, the interfaces of soil-engineering bedrock and seismic bedrock don't have the feature of horizontal and semi-infinite. Because it is observed sudden changes at the interfaces of the layer in horizontal and vertical directions.

Approximately 400 m soil thickness in basin sides and average 1–1.6 sec of predominant period values doesn't show consistency with soil classifications which

are defined in Turkish earthquake regulations (Code, 2007) and the other classifications (NEHRP, Eurocode etc.) as well. V_{s30} description should not be used in areas where have such an over soil thickness. According to the results, it is understood that the designing spectrums are used in Code (2007) fail to satisfy. It is offered to make special design spectrums for building area considering 2D soil-bedrock models which are obtained for study area where the high-rise buildings existed.

It can be performed 3-D simulation of seismic wave propagation and long-period ground motion simulations using the 3D soil-bedrock model for the study area. 3D soil-bedrock models are seen that the subsidence of Bornova Plain relating to the Karşıyaka fault zone at north and İzmir fault zone at south the maximum depth of the seismic bedrock is 1.35 km in this study area. Holocene alluvium unit and older sediments fill this basin.

It is seen that particularly Bornova Plain focusing problems and effects of surface waves occurred at basin margins will likely be faced in case of an earthquake that will affect study area. Also, due to seismic impedances between engineering bedrock and soil in this region, resonance effect of earthquake waves can occur. As seen in this study, it is essential to consider engineering calculations to be performed in the regions where this kind of basin effect is observed, in two and three dimensional rather than one dimensional.

It is understood that the amplitude and frequency content of seismic waves will change in the limits of the layer down from 1000 to 1350 m, namely seismic bedrock. Its meaning is the seismic waves start to change the parameters down from this depth (amplitude and particle velocity values). It is not enough to only know the soil thickness for determining the earthquake effect on the surface. Furthermore, showing the seismic impedances are extremely important either. V_s -depth cross sections must be known at least till engineering bedrock for calculating soil transfer functions true and complete. Usable models were produced to calculate the soil transfer functions along the profiles which were prepared for the study area.

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