

# The Soil Behaviours of the GNSS Station

Ayca Cirmik<sup>1</sup>, Ozkan Cevdet Ozdag<sup>2</sup>, Fikret Dogru<sup>1</sup>, Eren Pamuk<sup>1</sup>, Tolga Gonenc<sup>1</sup>,  
Oya Pamukcu<sup>1,\*</sup>, Mustafa Akgun<sup>1</sup>, Ahmet Turan Arslan<sup>1</sup>

<sup>1</sup>Dokuz Eylul University Engineering Faculty Department of Geophysical Engineering Buca, Izmir, Turkey

<sup>2</sup>Dokuz Eylul University Rectorate Cumhuriyet Blv. Alsancak, Izmir, Turkey

## Email address:

oya.pamukcu@deu.edu.tr (O. Pamukcu)

\*Corresponding author

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**Abstract:** The quality of GNSS data is very significant for determining the locations and kinematic structures of the station points. Therefore, the quality of the measurements needs to be high as well as the geological stratigraphy and the continuity of tectonic mechanism in subsurface of the point where the GNSS station is built should be investigated in detail. For this purpose in this study, the geophysical studies realized in the GNSS station are presented for interpreting the kinematic origin of the results of GNSS measurements which were obtained in Izmir (Turkey). In this scope, the GNSS data processing results and gravity changes were evaluated of the GNSS station wherein obtained GNSS and microgravity data for 3 years. In the results of 3 years measurements, it was pointed out that this GNSS station presented different movements relative to other GNSS stations. Therefore, it is requested to investigate whether the tectonic mechanism or the soil causes these differences. In this way, the soil dynamic analysis was realized by using the S velocity and density values obtained from the multichannel analysis of surface waves (MASW) method and gravity measurements realized in the GNSS station and its surrounding. Consequently, it is pointed out that the soil of GNSS station wherein seismically active region is also affected by the active environment. Therefore, all physical conditions needs to be taken account while interpreting the tectonic features of the findings obtained from this type of GNSS station.

**Keywords:** Soil, GNSS, Gravity, MASW

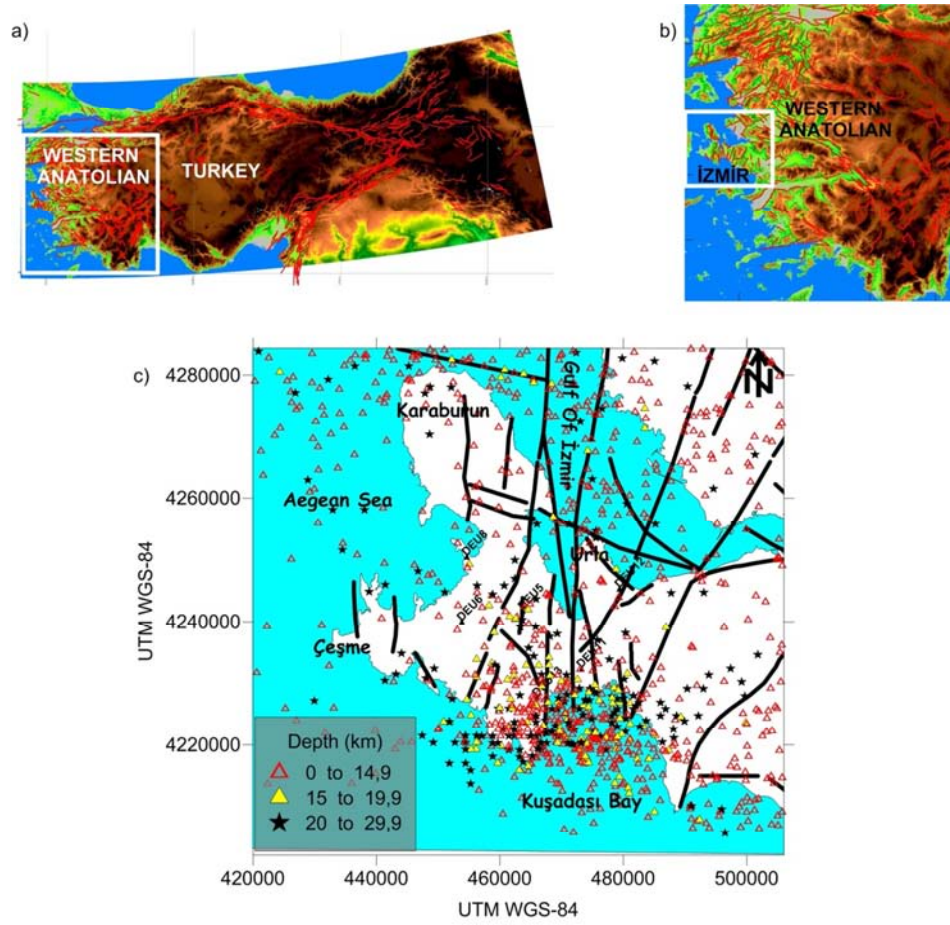
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## 1. Introduction

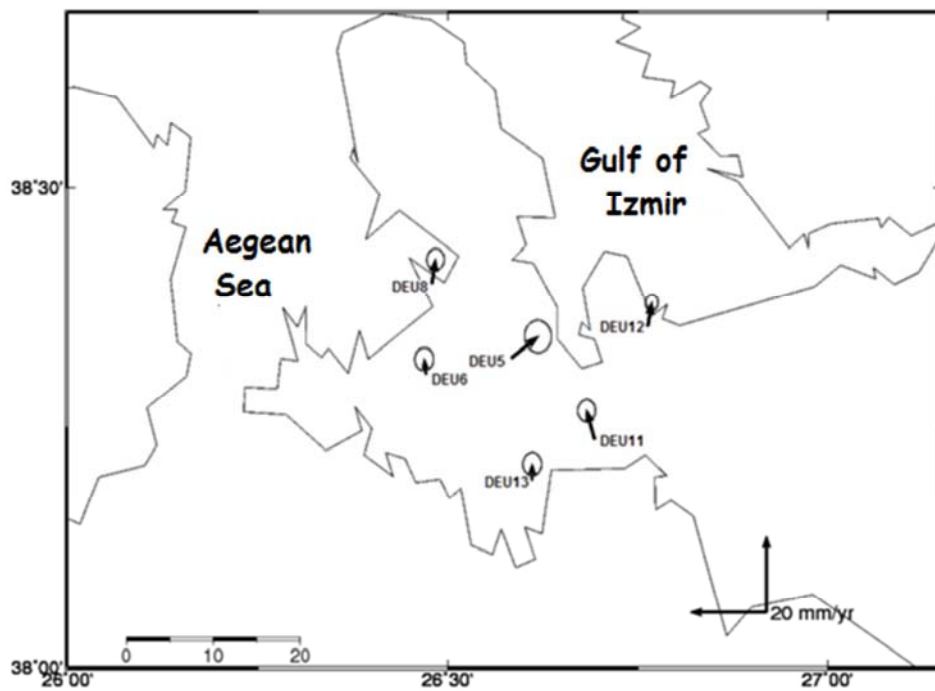
The campaign GNSS measurements were realized in The Scientific and Technological Research Council of Turkey (TUBITAK) Project (No:108Y285) for monitoring the stress increases, velocity changes and horizontal motions in the blocks which controlled the tectonism of Izmir and its surrounding (Figure 1). While the results of the project were investigated, it was noticed that one of the GNSS stations; DEU5 (Figure 2) represented dissimilarities on displacement relative to other stations. DEU5 locates on andesitic lava-breccias of early Miocene Kocadağ volcanites [1] (Figure 3) and is affected by three distinct local fault blocks (Figure 1). In the detailed field observation, it was found that there was a basin which holds water in the western side as well as there were geothermal natural hot water outlets in the southern fault block of this station point. Additionally, DEU5 locates

in the western boundary of a great fault zone system which exists between Izmir and Balıkesir (Figure 1). Therefore, in this study, the detailed geophysical studies were realized for investigating the kinematic mechanism of the dissimilarities of DEU5 and clarifying its soil behaviour.

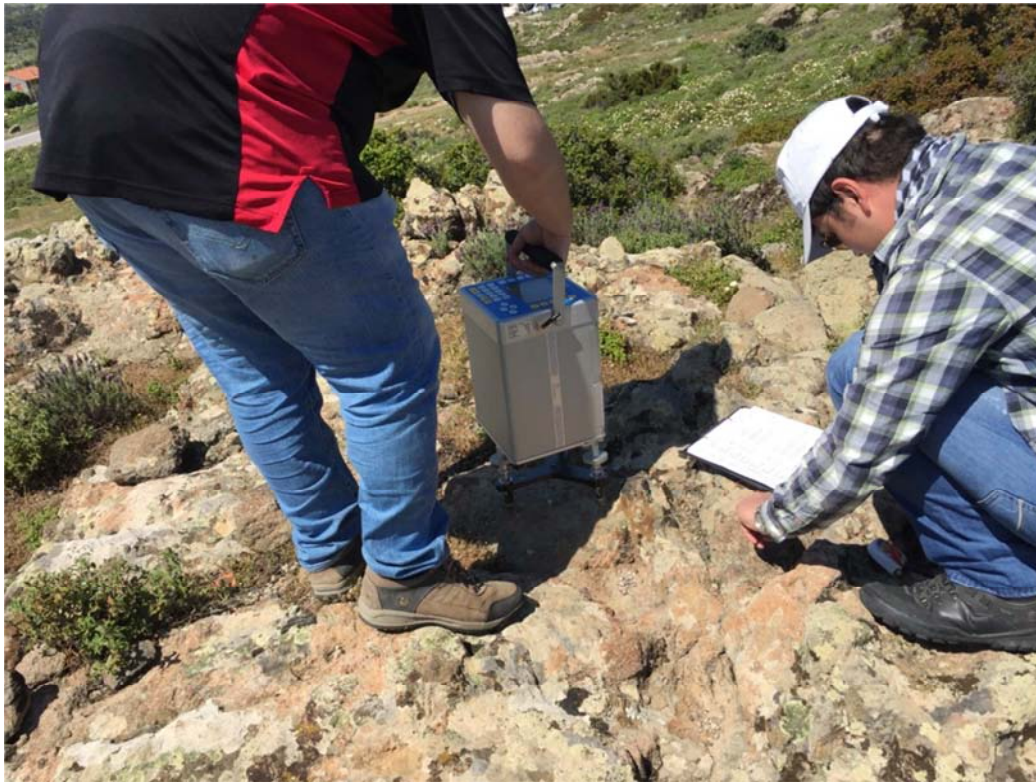
In this scope, MASW and gravity measurements were obtained in DEU5 and its surrounding. Therefore, it was observed that the S velocities ( $V_s$ ) of surface waves varied between 200-850 m/sec, but 850 m/sec value was not seen as very dominant. According to the anomaly changes obtained from gravity profile measurements, both high and low density structures were monitored in the region. In the other step, the physical behaviours (elastic, plastic) of the soil was calculated with non-linear soil dynamic analysis by using the findings of seismic and gravity measurements. Consequently, the geological structure features of DEU5 were investigated in detail.



**Figure 1.** a) The location of the study area. b) The main tectonic elements of the study area. Red lines represent the faults. c) The focal depths distributions of earthquakes occurred between the years 1973-2012. Black lines represent the faults.



**Figure 2.** Aegean block-fixed frame solutions of the study area and its surroundings [2].



**Figure 3.** The view of DEU5 GNSS station.

## 2. Applications

For investigating the horizontal and vertical displacements of a point with the effect of dynamic forces; 1) the earthquake force as the dynamic force, 2) the horizontal and vertical displacements of a surface point under the effect of dynamic load, 3) The features of these changes on elastic or elasto-plastic and plastic limits, 4) the features of elasto-plastic and plastic deformations if the point locates on the soil, 5) the elastic deformation limits if the point locates engineering bedrock, 6) the model of the soil engineering bedrock under the station for determining the features of the point, need to be defined. According to these, for the soil definition the detailed studies should be realized.  $V_s$  is related to the some parameters as elasticity modulus, natural vibration frequency, Poisson's ratio, seismic amplification coefficient, shearing strength etc. For this reason, varying of  $V_s$  values are depth dependent [3].  $V_s$  should be lower than 760 m/sec for defining the soil [4]. The deformation (horizontal and vertical displacements) on soil surface should be determined and the type of the displacements (elastic, plastic or elasto-plastic) occurred depending on the magnitudes of earthquake forces should be investigated. If the domain presents plastic behaviours, the point may show permanent horizontal and vertical displacement. For defining these changes, the soil dynamic analysis should be realized by using soil engineering bedrock models. Therefore, as the result of the soil dynamic analysis, it is pointed out that which magnitude of earthquakes causes the permanent deformation (displacement) on the domain [5], [6], [7].

In the soil definition, defining the engineering bedrock is the significant point. It is defined as the rock which has  $V_s$  values higher (rigid) than 760 m/sec. [4]. The deformation on the engineering bedrock is assumed as elastic regardless the magnitudes of earthquakes and geometrically, it needs to represent thick and wide distributions. The rock is not accepted as the engineering bedrock if the velocity continuity on z direction is not existed, even if,  $V_s$  is higher than 760 m/sec [8], [9].

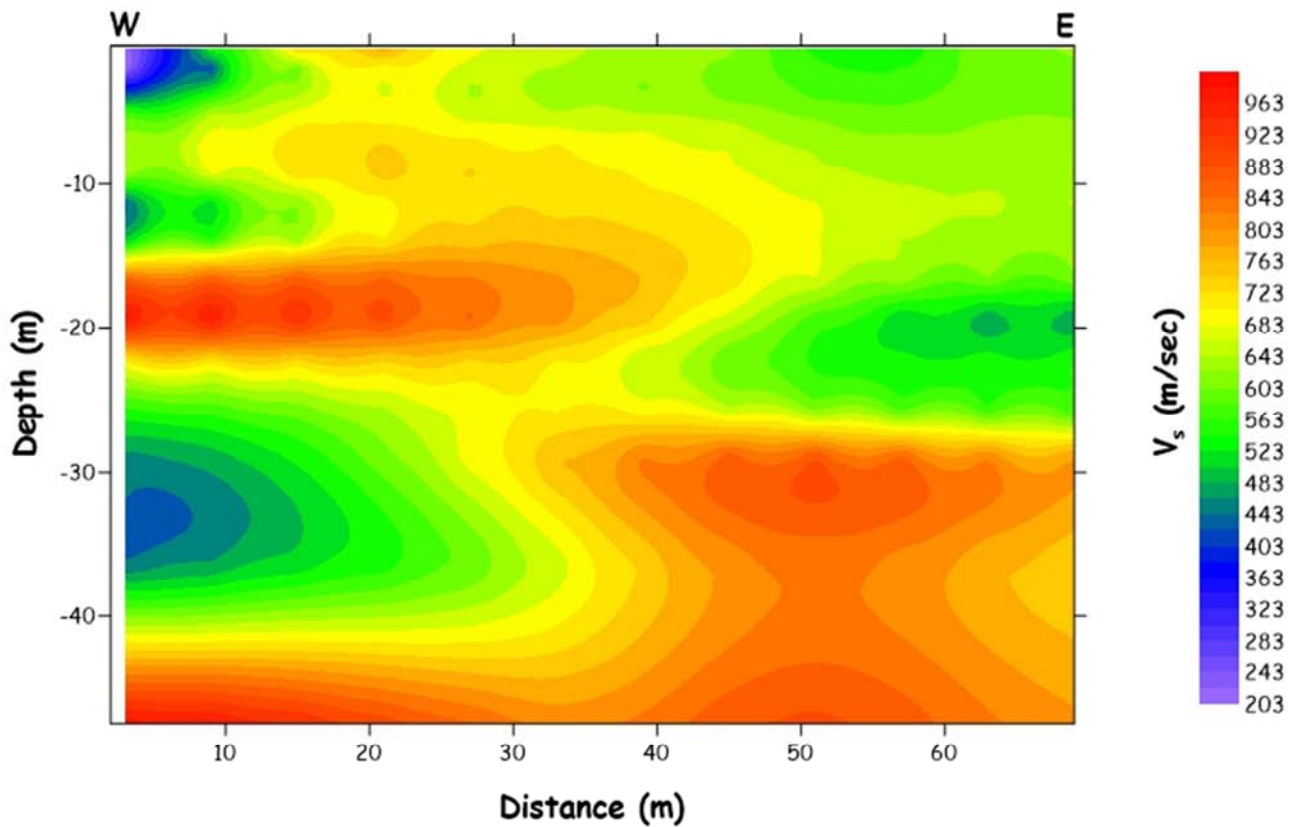
As the first application, the soil definition studies were realized for the GNSS station, DEU5 (Figure 2). For this purpose, MASW measurements were conducted through three different directional profiles (Figure 4) in DEU5 and its surrounding and were processed (Figure 5, Figure 6 and Figure 7). In the second step, the microgravity measurements and topography were obtained with 5 meters sampling distance in the same area by using Scintrex CG-5 gravity meter. Then, the Bouguer gravity anomalies (Figure 8) were obtained by applying terrain corrections and removing the 2<sup>nd</sup> trend.

The graphical changes over the years in the gravity measurements, which are obtained in a GNSS point, provide importance [10]. Due to the years if the gravity changes represent amplitude changes as decreasing, increasing and then decreasing (-+-) or increasing, decreasing and then increasing (-+-), it can be said that this point needs to include the physical parameters which support the elastic behaviour. But, the gravity changes of DEU5 obtained from the microgravity studies realized between 2009-2010-2011 represented increasing character [10].





**Figure 4.** The location of MASW measurements realized in GNSS station; DEU5 and its surrounding. (Red arrows represent the MASW profiles and their directions.)



**Figure 5.**  $V_s$  values obtained from Profile 1 shown in Figure 4.

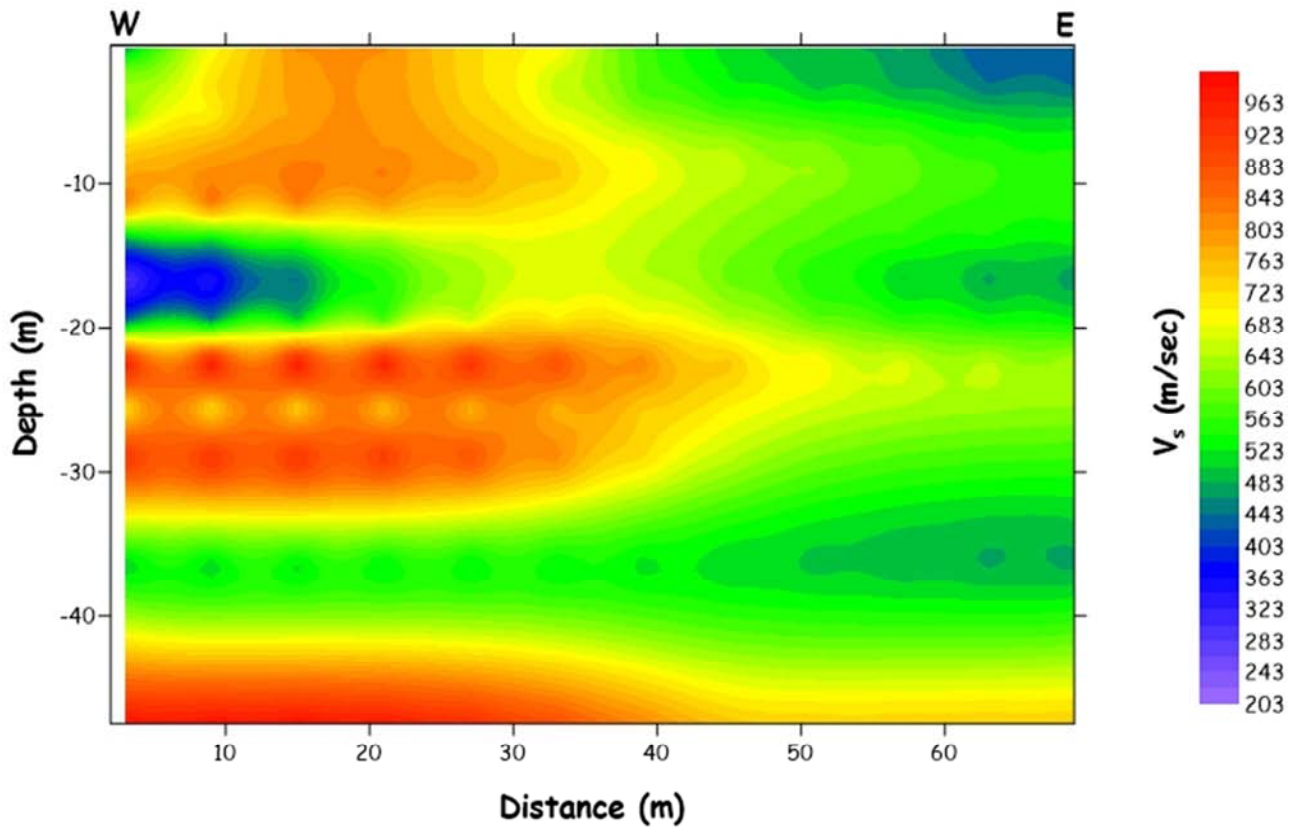


Figure 6.  $V_s$  values obtained from Profile 2 shown in Figure 4.

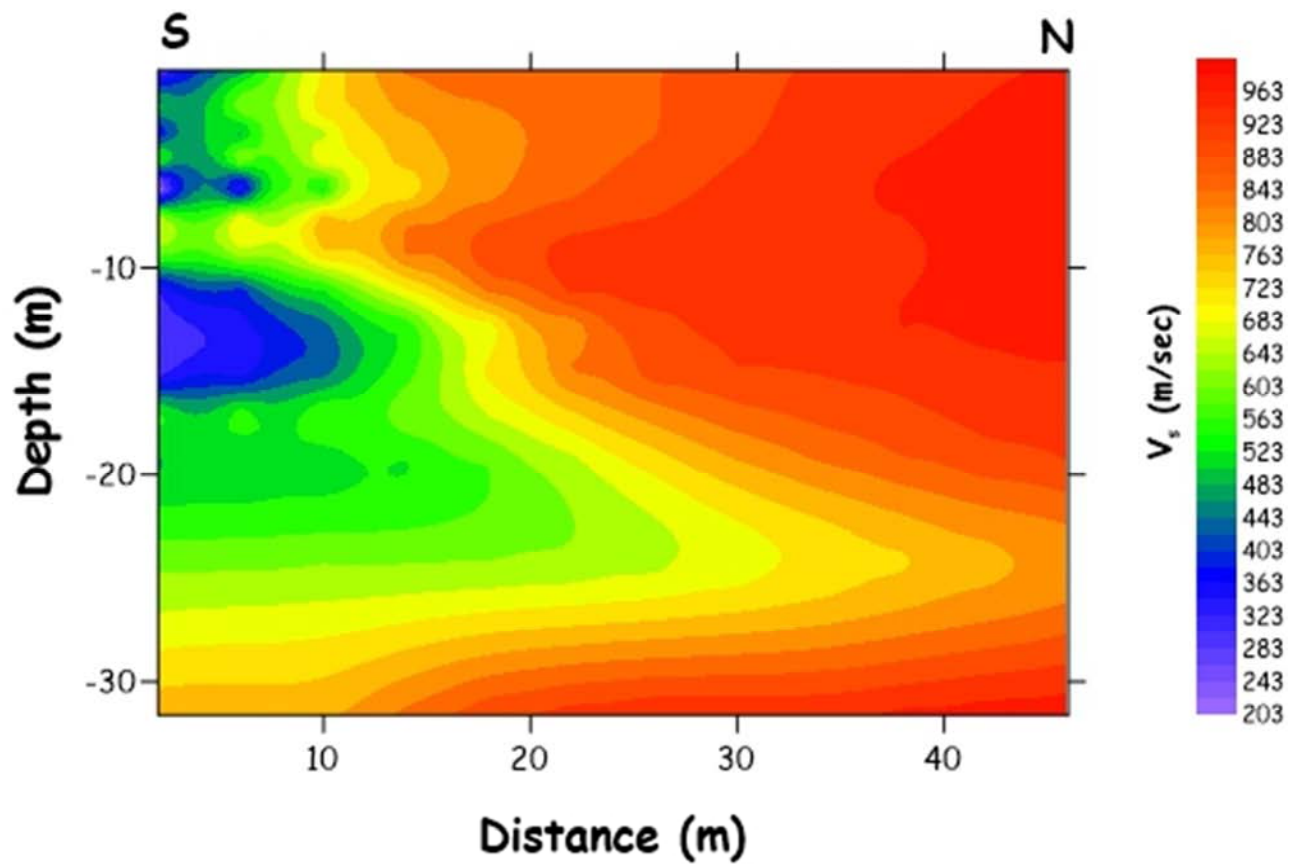
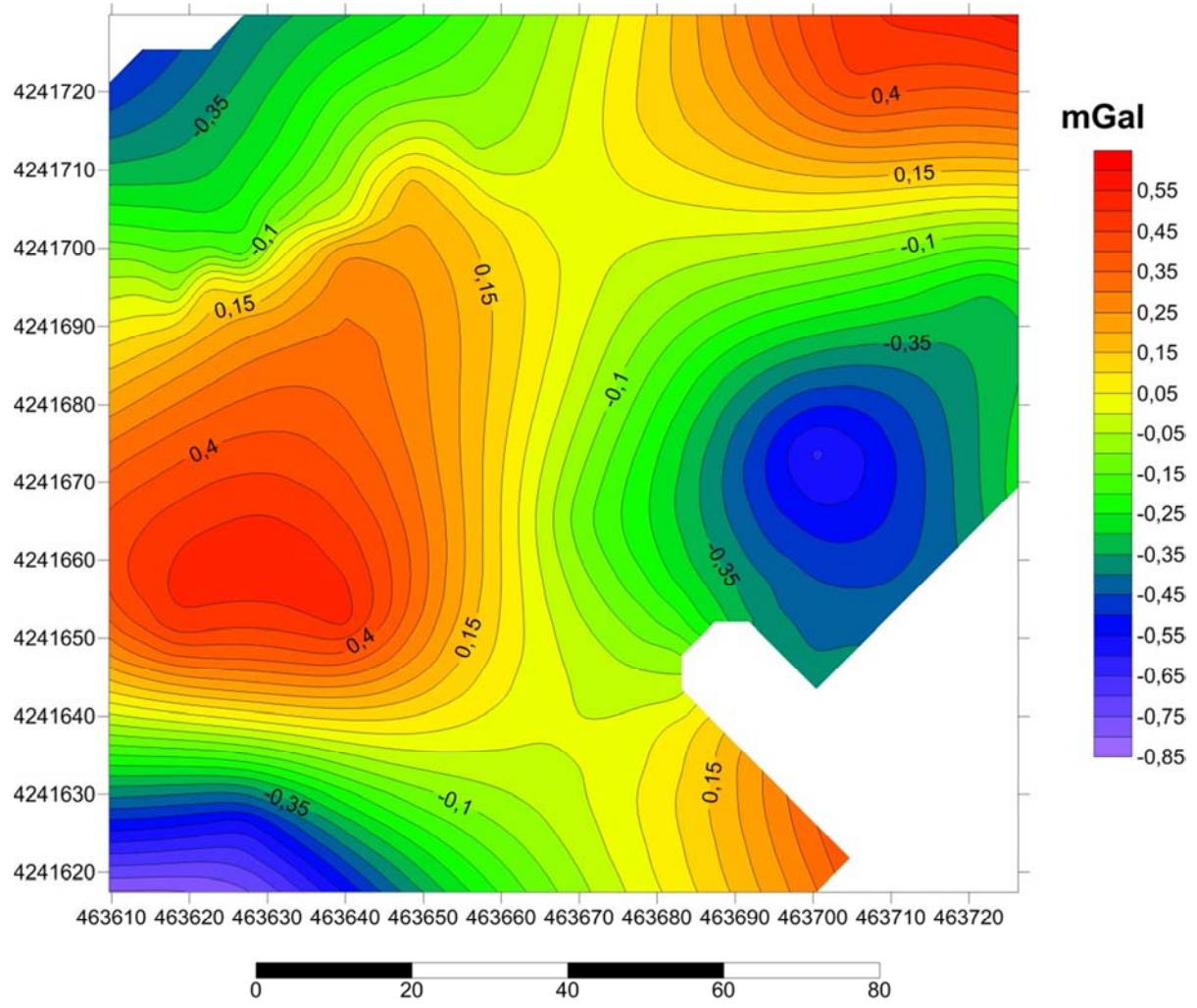


Figure 7.  $V_s$  values obtained from Profile 3 shown in Figure 4.





**Figure 8.** The Bouguer gravity anomalies obtained by applying terrain corrections and removing the 2<sup>nd</sup> trend for DEU5 and its surroundings.

As the third step, the non-linear soil dynamic analysis were done by using 2D finite element modelling (FEM) program, Phase2 software [11] with the help of the  $V_s$  values obtained from MASW measurements and calculated elasticity module (E), shear module (G), cohesion (C), angle of internal friction ( $\phi$ ), weight per unit volume ( $\gamma$ ) parameters (Table 1).

Therefore, the tension-shear deformation occurred during the earthquakes, the features of tension-deformation and horizontal-vertical displacements were calculated in static and dynamic conditions. Additionally, the maximum horizontal, vertical and total displacement analysis of a selected point in the region was realized.

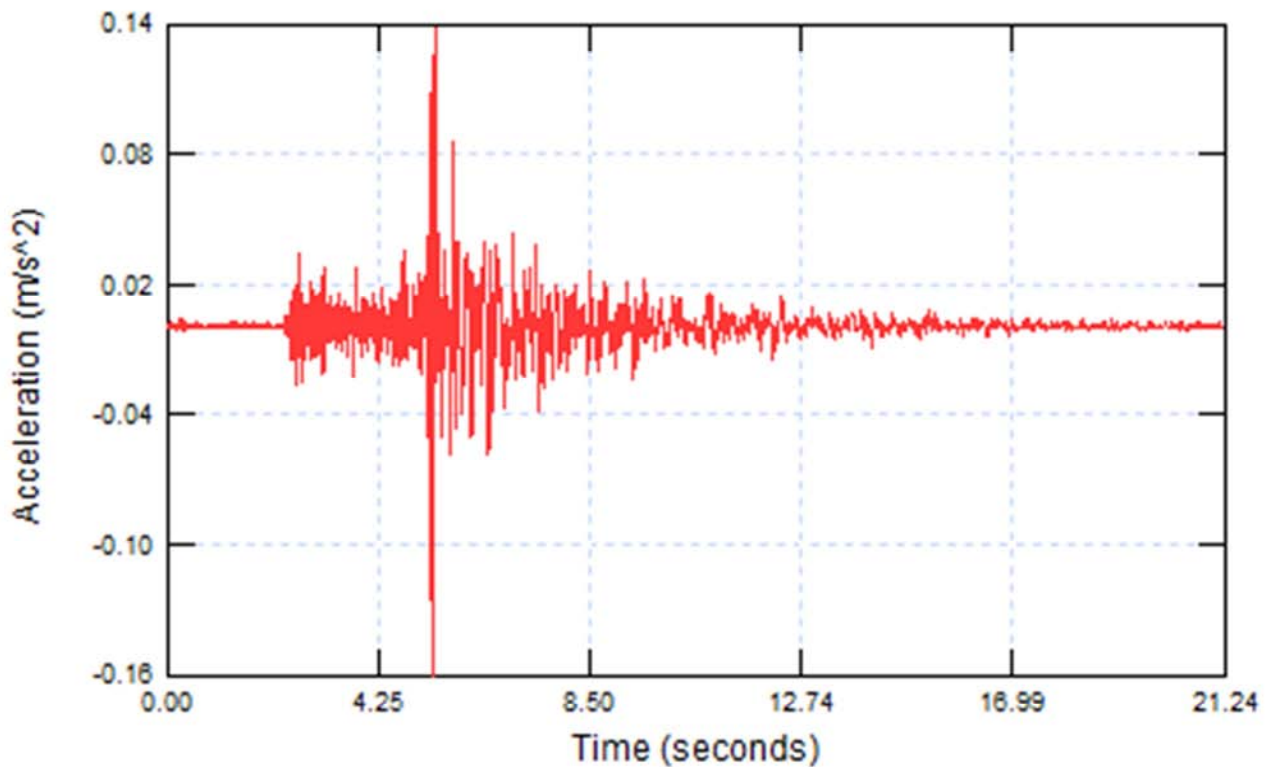
**Table 1.** The Parameters used in the Soil Dynamic analysis.

	$V_s$ (m/sec)			$V_p$ (m/sec)			E (MPa)			G (MPa)			v	C (MPa)	$\phi$ (°)	$\gamma$ (t/m <sup>3</sup> )	
	min	max	avg	min	max	avg	min	max	avg	min	max	avg				min	max
Soil-1	150	250	200	260	430	345	86	272	179	35	109	72		0.0025	30	1.54	1.74
Soil-2	400	500	450	690	865	778	782	1300	1041	315	520	418		0.15	35	1.97	2.08
Soil-3	250	300	275	430	520	475	270	412	341	109	165	137	0.2	0.10	35	1.74	1.83
Soil-4	500	600	550	865	1040	953	1290	1953	1622	520	782	651	5	0.17	35	2.08	2.17
EB*	1000	1150	1075	1732	1990	1861	6481	8664	7573	2614	3466	3040		9.00	38	2.46	2.55

EB\*: Engineering Bedrock

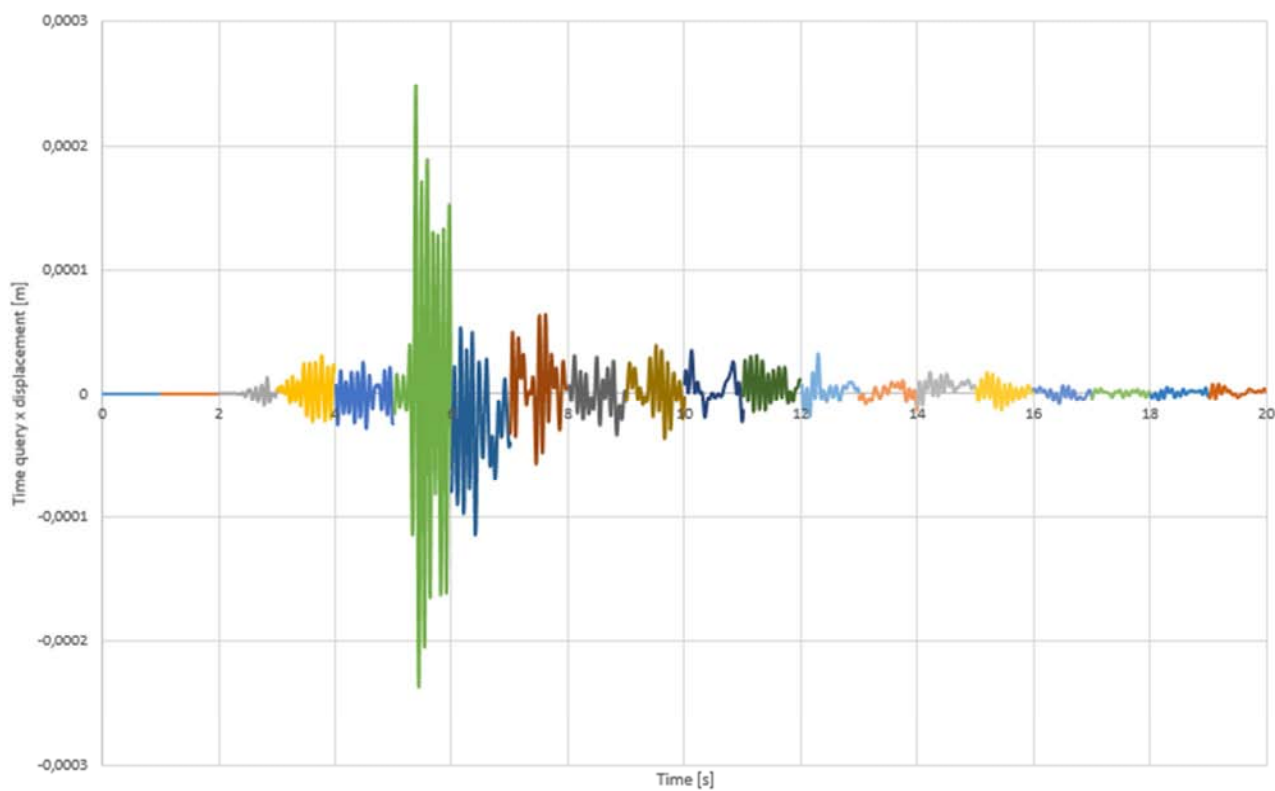
The profiles, which were used in the numerical modelling, were prepared with evaluating the results of the geophysical studies realized in the study area for revealing the dynamic features of the area. The modelling studies realized with Phase2 software is the probability assessment and provide the predictions. In the analysis realized in the dynamic conditions, it was intended to calculate the horizontal, vertical and total displacements of the selected point located around the DEU5. Therefore, the time history analysis was realized by using the acceleration time record of the earthquake occurred in Izmir as the input data (Figure 9,

Figure 10). While doing dynamic calculation, the viscose boundary conditions [12] were used instead of static dynamic conditions due to the effect of refraction of seismic waves in FEM. Since the rigidity parameters are different for each soil layer, the viscose boundary conditions were calculated for each of them (Figure 11, 12, 13). For analysing the effectiveness of the vibrational modes in dynamic analysis, the mode-mass distribution ratio was calculated. In the dynamic conditions analysis, the values of horizontal, vertical and total displacements for the selected point located around the DEU5 were predicted as between 0.24 – 0.42 mm.

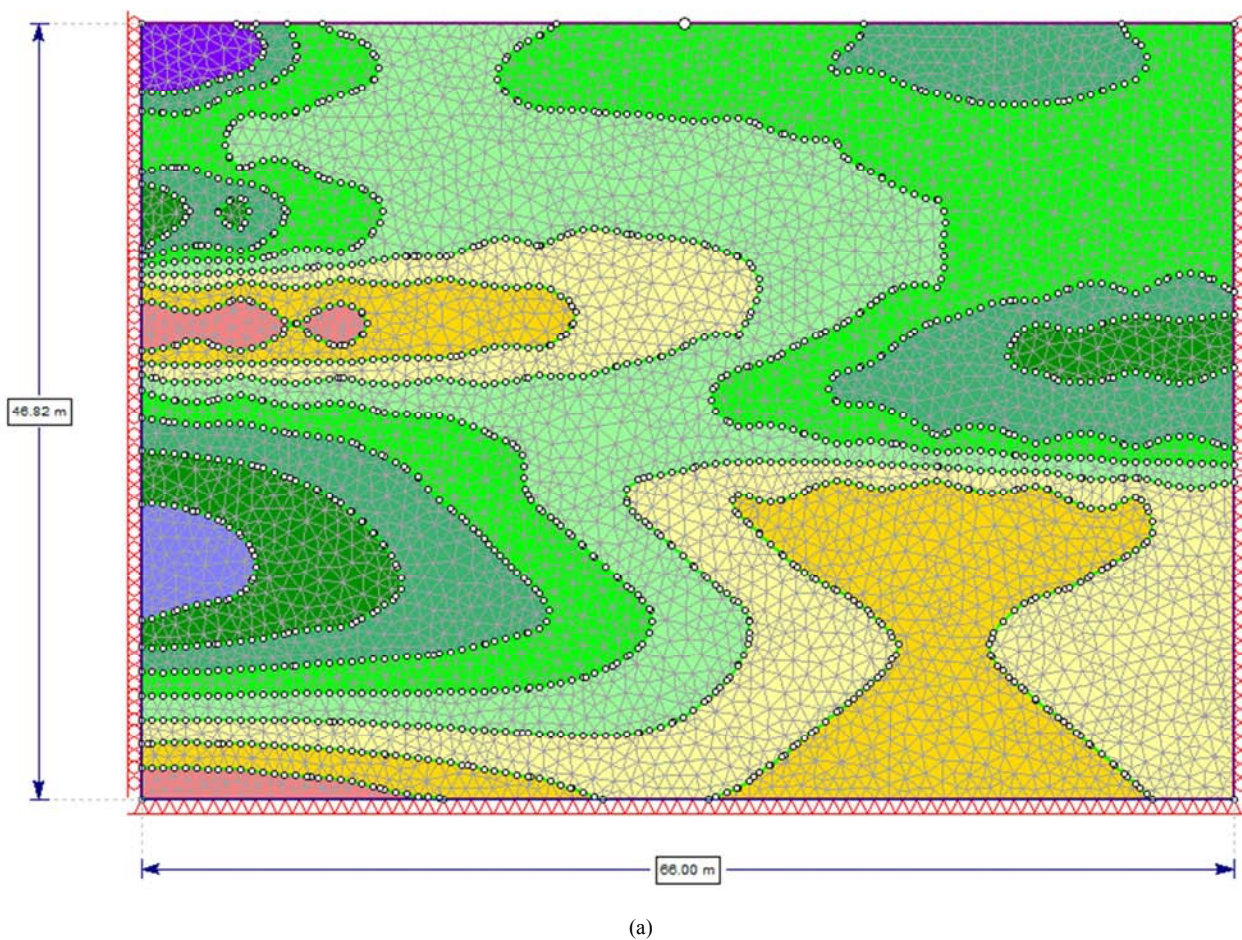


**Figure 9.** Acceleration - time graph of earthquake (Mw: 4.0) that occurred close around the study area used in the calculations.

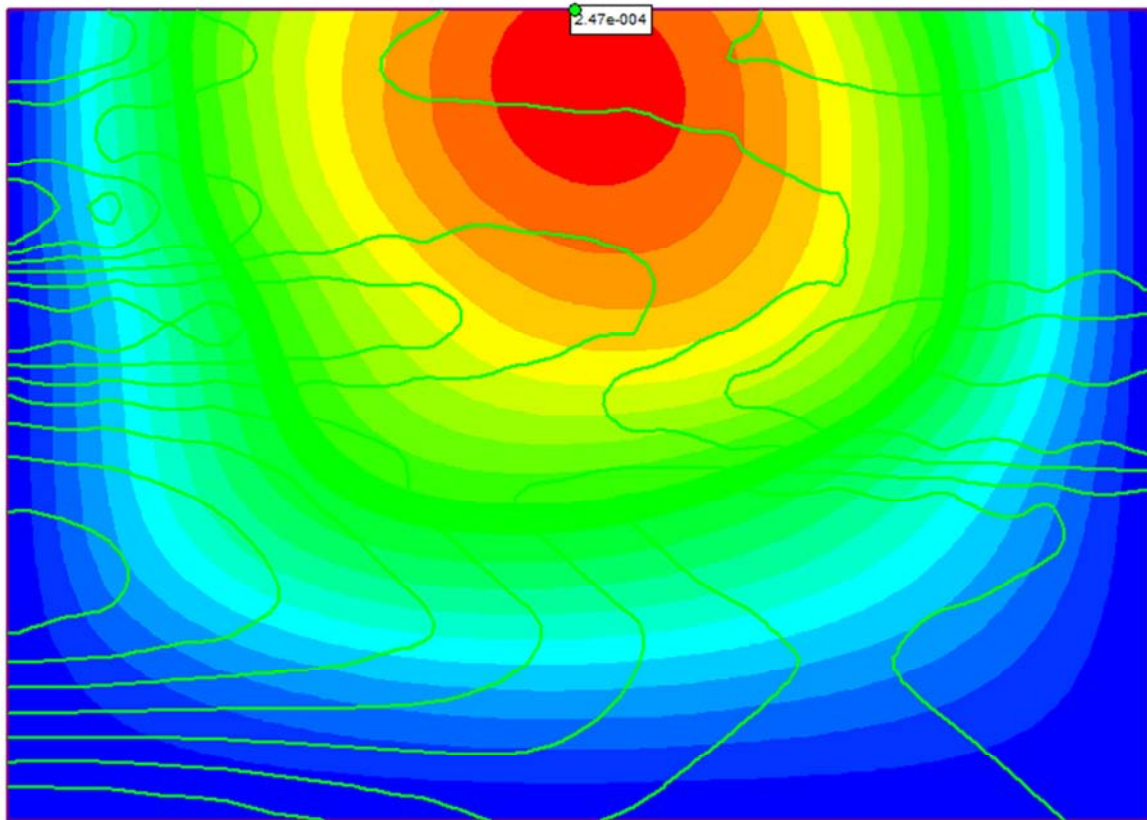




**Figure 10.** Horizontal deformation under seismic effect of a point which received on ground surface.

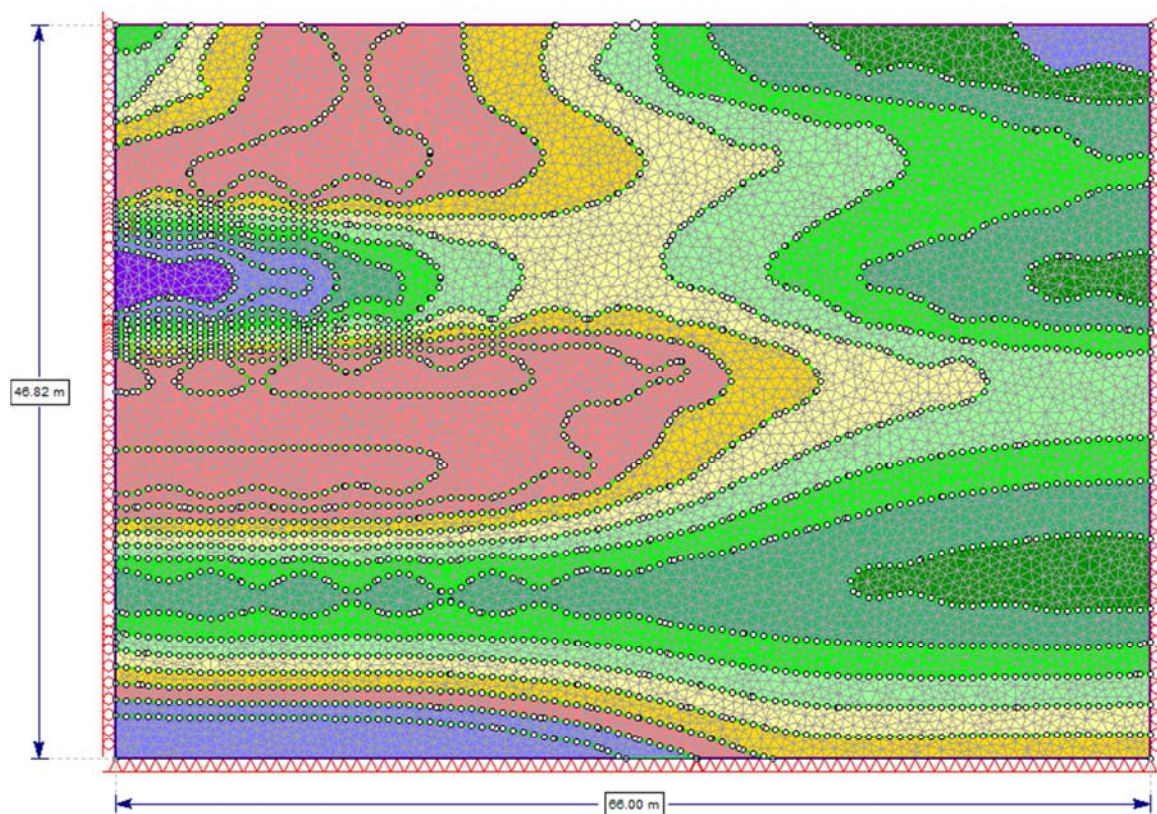






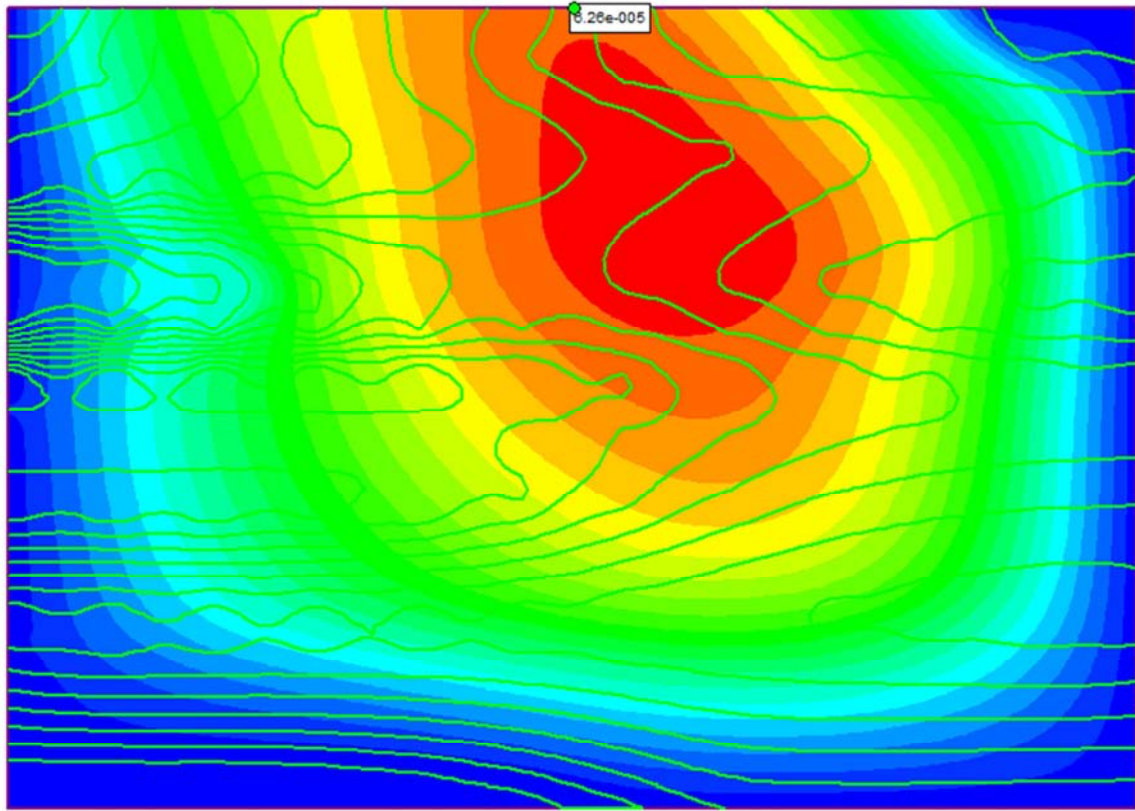
(b)

**Figure 11.** a. The Profile 1 (Figure 4) used in numerical modelling 11b. Maximum displacement ( $2.47 \times 10^{-4}$  m) of the selected point located around the DEU5 in the Profile 1 (Figure 4).



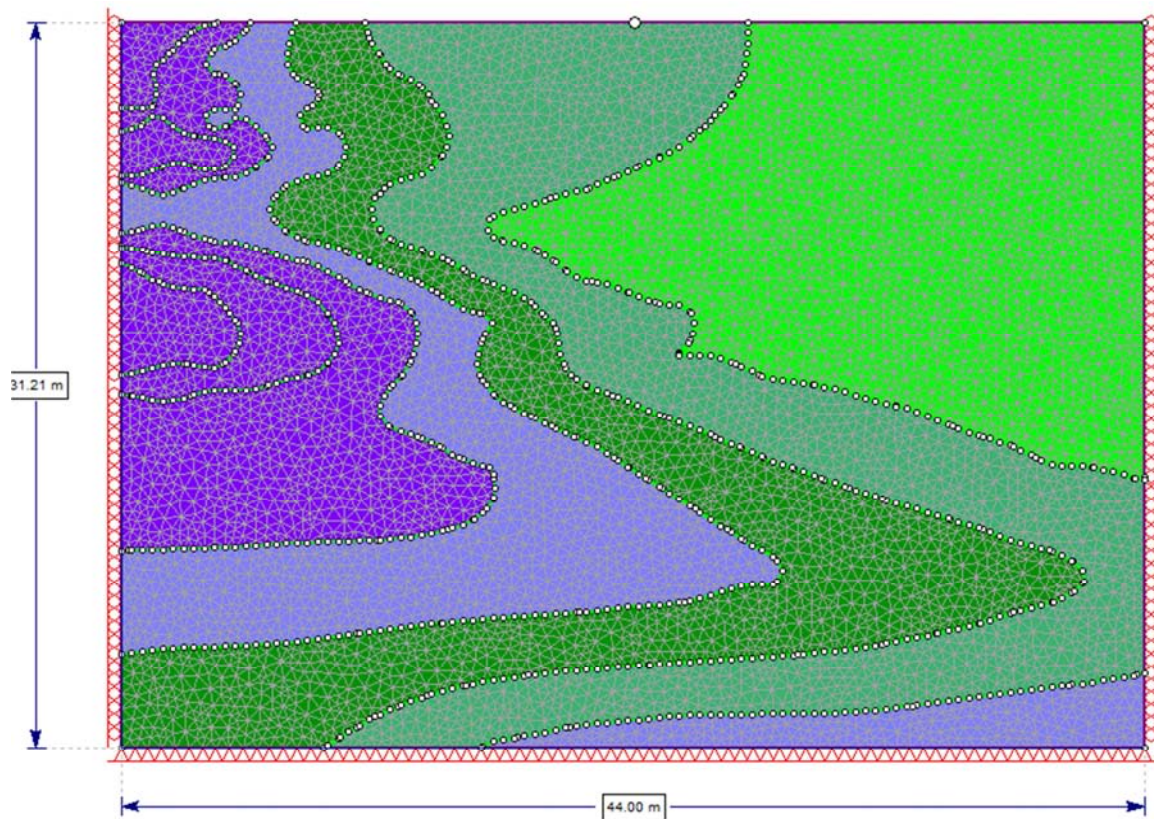
(a)





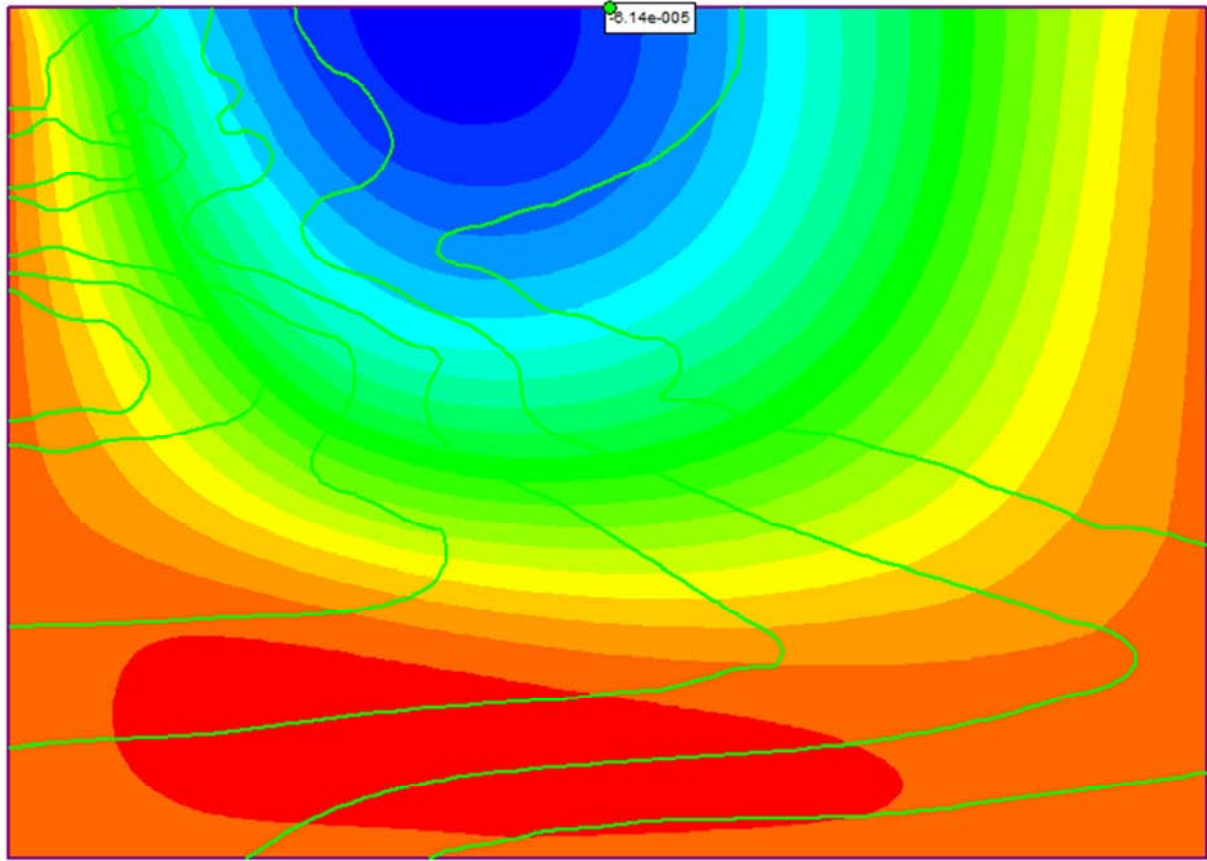
(b)

**Figure 12.** a. The Profile 2 (Figure 4) used in numerical modelling. b. Maximum displacement ( $6.26 \times 10^{-5}$  m) of the selected point located around the DEU5 in the Profile 2 (Figure 4).



(a)





(b)

**Figure 13.** a. The Profile 3 (Figure 4) used in numerical modelling. b. Maximum displacement ( $6.14 \times 10^{-5}$  m) of the selected point located around the DEU5 in the Profile 3 (Figure 4).

### 3. Results

The  $V_s$  values of obtained surface waves change between 200-850 m/sec as well as value 850m/sec  $V_s$  value is not dominant in the area generally. Therefore, it can be said that the soil features are not homogenous.

The amplitudes of Bouguer anomalies change between 0.4 mgal and -0.35 mgal. The similar changes are seen also at the seismic velocities. The graphic of the gravity changes due to the years represents decreasing character and not a symmetrical change (like as +,-,+).

In dynamic analysis, low displacement values were obtained. It can be said that the most important reasons of obtaining low values are using the earthquake magnitudes as  $M_w = 4.0$  and the small depth and width sized profiles. Additionally, it is needed to be analyzed the features such as the location, the degree of dissociation and discontinuities conditions of early Miocene Kocadağ volcanites which overlay the DEU5 GNSS station region and then, the interpretations should be done on the profiles by controlling the geological findings with geophysical data (MASW and gravity) and the profiles should be prepared in larger scales. For this purpose, 2D soil bedrock models should be used. Therefore, the MASW and gravity measurements area on

DEU5 and its surroundings is going to be enlarged in the next project.

### 4. Conclusion

DEU5 locates in a seismically active region and it is under the effect of seismogravitational forces. Therefore, the soil of GNSS station is affected by these effects due to the years. In this scope, it is planned to be increased the amount of the GNSS station and monitored by GNSS and microgravity networks in this region which have tectonically different features. It is important that the investigation of the soil behaviour during earthquake, hydrogeological process etc. to obtain the correct movement, vectors and velocity of GNSS station. Therefore before the settling of the GNSS station, soil type must be investigated by using geophysical methods to define the elastic, elasto- plastic limits of the probable GNSS location when under the effect of the natural hazards.

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