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MONITORING POSTSISMIC SHELL DEFORMATION USING GPS / GNSS SURVEYING BY 06 FEBRUARY 2017 AYVACIK-ÇANAKKALE EARTHQUAKE

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ABSTRACT

GPS/GNSS has been established for military purposes over the world is a satellite-based positioning system. A multi-disciplinary study has been executed just right after the 6 Feb 2017, Mw 5.5 and earthquake swarm that happened in the vicinity of Ayvacik south-western end of the Biga Peninsula The experts researchers from the Canakkale Onsekiz Mart University, collaborated to investigate the conditions leading to intense Ayvacık earthquake activity in and around Çanakkale and to reduce seismic hazard and damage. Along with being geological and geophysical studies on active faults in the region were rarely performed in geodetic terms.

Geodetic optimization techniques were used to reflect the characteristics of the Tuzla Fault and micro-geodetic GPS / GNSS deformation monitoring network campaign type measurements were followed. The data were evaluated in scientific software in order to be able to detect the high degree of accuracy of the postsynthesis deformations. After the Ayvacık / Çanakkale earthquakes, the coordinates found in the campaign type measurements were differentiated during the project period and the post-seismic location changes were detected. Based on GPS / GNSS measurements in the tectonically active Ayvacik region, contribution to better understanding of earthquakes and future earthquake prediction has been contributed.

Keywords: Earthquake, postseismic deformation, GPS / GNSS, velocity vector, Ayvacık.

1. INTRODUCTION

In the Marmara Region, which is the most active part of our country in terms of seismicity, more than 500 earthquakes have occurred in the last 100 years, over 4 in size. In particular, the North Anatolian Fault (NAF), the most active fault in the region, has had 15 major earthquakes in the same period. Due to the effect of the earthquakes, approximately 1000 km of rupture occurred on the shell surface (Özalp et al., 2013; Duman et al., 2016). Some of them are formed in the fault segments extending in the Marmara Region.

The use of GPS as a tool to determine shell movements is now widespread in the world (Chan, 2002, Hutton, 2000, Mao, 1998, Zhang, 1996). In practice, with the help of nets of GPS points that can represent all of the plates, local movements are going to be determined. For this, first of all the observations which are scattered on the surface of the earth and whose coordinates are very long are utilized from known points with high accuracy.

In the region, geodetic studies are small scales, with geological and geophysical studies being generally carried out on active faults. This project, which is carried out in the vicinity of Tuzla Fault, comes to the forefront with the capability of realizing the work in large scale. In this study, all the developments from the beginning of the project to the present are explained. Information about GPS stations, images, measurements and results will be provided in this report.

2. AYVACIK EARTHQUAKE, NW TURKEY (FEB 6th 2017, Mw 5.5)

The largest earthquake in the study area is the Yenice-Gönen earthquake of 18 March 1953, which is the closest point to Tuzla and its immediate surroundings. When the other major earthquakes in the region are examined, it is clear that the Marmara Region is mostly formed by a deformation effect related to strike-slip faulting. In addition, there are normal faults along the northern margin of the NAF and south of the Marmara Region and counter-component earthquakes on the southern limb.

On the southwestern tip of the Biga Peninsula, Ayvacık and its immediate surroundings continued to be intensive with the Mw = 5.5, (Mw = 5.5, KRDAE), Mw = 5.3, AFAD, Mw = 5.4, COMU), which started at Mw = 4.6 on January 14, studies are being carried out to observe earthquake activity. The region contains an active earthquake and contains some of the important tectonic elements of the Northwest Aegean region (Figure 1).

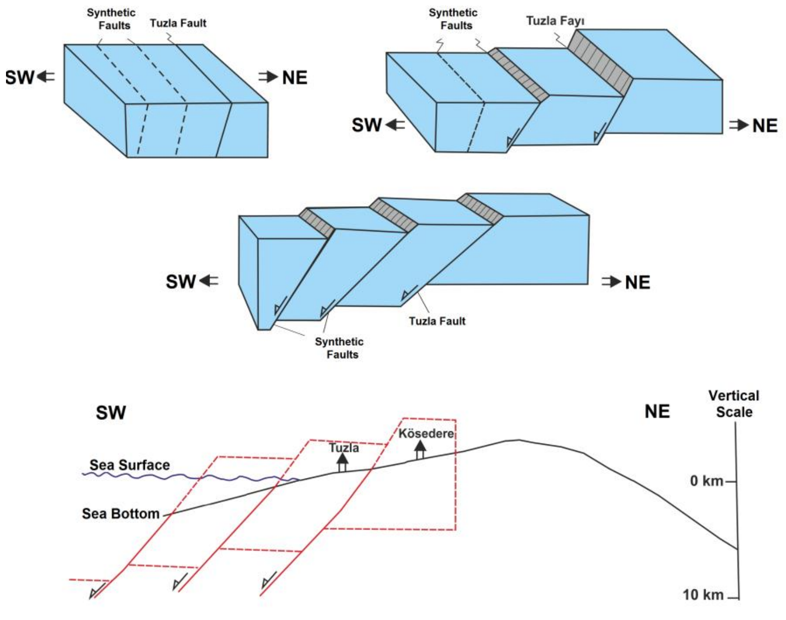


Figure 1. Tuzla Fault and view of synthetic faults (Özden, 2017)..

In addition to the intensity and continuity of the micro-earthquake activity in the region, the geothermal fields of the region are covered, and the seismotectonic character of the region is examined and detailed study is required. The density of the station, along with the stationary stations belonging to the national institutions in the study area, will be insufficient to reveal these details. For this reason, it will contribute to the understanding of the tectonic character of the national seismic network or of the data station belonging to the temporary stations. The preliminary results show that transient stations established at close distances according to the main shock and epicentral distributions provide significant improvements in the detection and location of micro earthquakes, especially when compared to stationary networks. On the other hand, in the mid-scale earthquake data, the dominant failure is mainly observed in NW-SE directional normal inclination. According to the records of the Bogazici University Kandilli Observatory and Earthquake Research Institute, the earthquake near Çanakkale-Ayvacık earthquake occurred in the area of Tuzla Village in January / February 2017 and its size is 5.3 and smaller. A significant part of the earthquakes occurred along the deformation zone of the Tuzla Fault. The size of a part of the earthquakes is 4 or more (Table 1).

Table 1. Earthquakes that occurred between 06-07 February 2017 in Çanakkale Ayvacık (M≥4) (Kandilli Observatory and Earthquake Research Institute / KRDAE, 2017).

#	Date	Time (UTC)	Latitude	Longitude	Magnitude (Mw)	Depth (km)	Focus Mechanism Solution
1	06.02.2017	03:51:40.2	26.11 E	39.54 N	5.3	6	Tilt-slip earthquake
2	06.02.2017	04:17:29.3	26.14 E	39.54 N	4.2	2	Tilt-slip earthquake
3	06.02.2017	10:58:01.3	26.09 E	39.52 N	5.0	8	Tilt-slip earthquake
4	06.02.2017	11:45:01.2	26.08 E	39.53 N	4.2	10	Tilt-slip earthquake
5	06.02.2017	20:22:04.9	26.09 E	39.54 N	4.0	6	Tilt-slip earthquake
6	07.02.2017	02:24:03.4	26.12 E	39.53 N	5.3	8	Tilt-slip earthquake
7	07.02.2017	05:15:51.0	26.12 E	39.51 N	4.3	10	Tilt-slip earthquake
8	07.02.2017	05:17:09.0	26.19 E	39.53 N	4.4	4	Tilt-slip earthquake
9	07.02.2017	21:00:54.4	26.16 E	39.52 N	4.1	6	Tilt-slip earthquake
10	07.02.2017	21:35:00.2	26.18 E	39.52 N	4.0	4	Right-hand direction-strike earthquake
11	07.02.2017	22:53:29.5	26.05 E	39.52 N	4.1	10	Tilt-slip earthquake

2. MICRO DEFORMATION MONITORING NETWORK

In deformation determination processes, local networks are generally preferred, and the region or object undergoing deformation is surrounded by a certain number of geodetic points. The number of geodesic points depends directly on the amount of deformation and the amount of deformation. The determination of shell deformation is carried out by the contribution of several disciplines such as geodesy, geophysics and geology. Figure 4 shows an image of the field observations in the field section of the Tuzla Fault. The area selected as the study area covers 26 ° 04 '- 26 ° 20' east longitude and 39 ° 28 '- 39 ° 38' north latitudes. Observations were made with the geodetic measurement method based on the GPS method in order to determine the ground movements in the region in the geodetic network established in the study area.

Figure 2. A view from the field observations at Tuzla Fault.

Geodetic deformation analysis; healthy, continuous, and periodically performed measurements. In addition, supportive methods such as surface leveling are also used depending on the desired preparation. When the deformation of the shells is observed, the roads which are perpendicular to the fault line are used. In order to determine the deformation of Tuzla Fault and its surroundings, the data obtained from the support from the Special Provincial Administration, Çanakkale Municipality, Cadastre Directorate, Provincial Bank and some map offices as well as the findings obtained from the studies carried out in different disciplines in the region were evaluated and the web design was carried out. Parameters evaluated as input in network design; data obtained from local sources, topographic and economic conditions, hardware and fault geometry. The outputs of the design are shaped as the positions of the points forming the geodetic network, the number of the geodetic points, and measurement and evaluation methods.

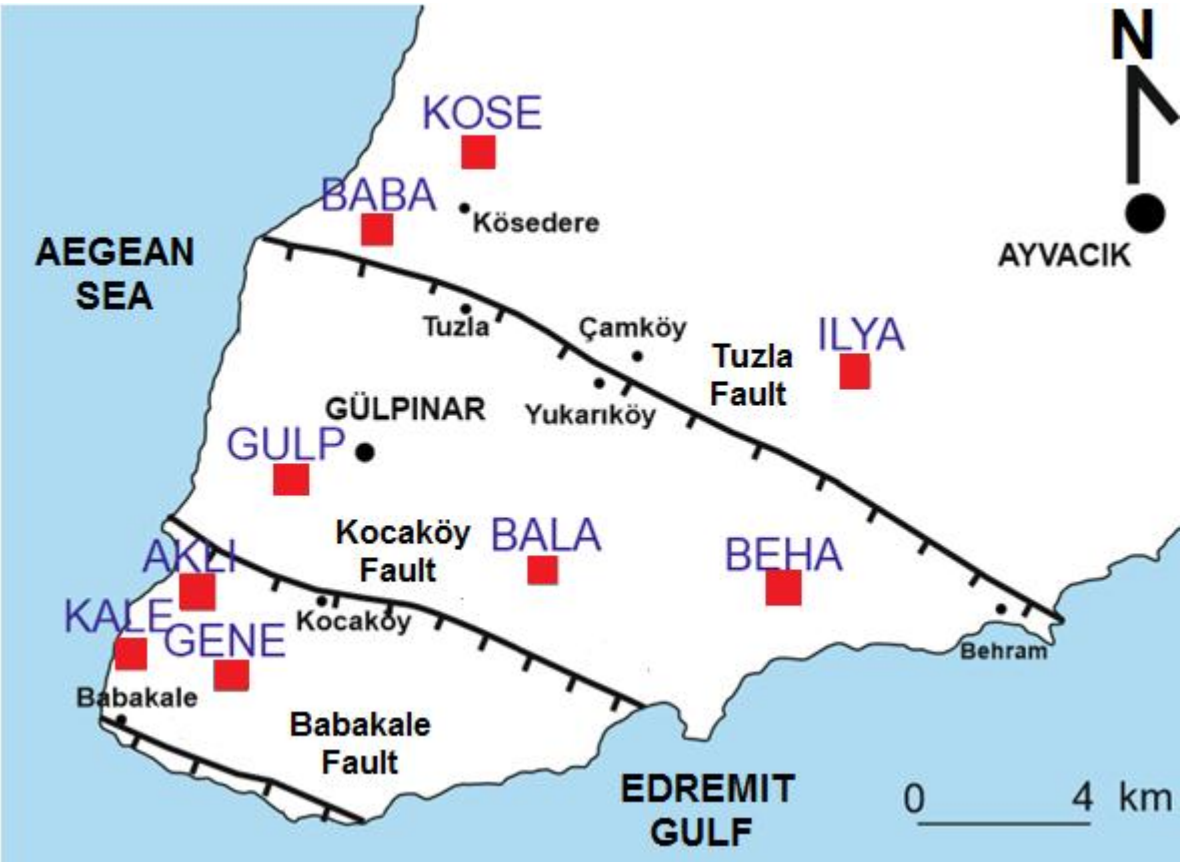


Figure 3. Faults that divide the locations and working regions of Google Earth satellite views into blocks in the micro-geodetic network.

- In order to ensure the proper installation of GPS points for the purpose of the project, aerial photographs of the project area have been examined and attempts have been made to identify faults that may be alive. These identified faults are transferred to digital medium.

- Aerial photographs were used to determine the best locations for the GPS points that were set up to measure the relative motion of the blocks identified by the observed faults (Figure 3). The following approach was used during this study:
• The regions where TUTGA GPS points are determined from the obtained explanatory protocols were examined from the aerial photographs. None of the existing points were found to be inappropriate.
• Within the scope of the project, the number of GPS points planned to be measured has been tried to be optimum.
• It has been noted that the fault zones of the identified GPS points are outside the elastic and plastic deformation areas. This work was done using aerial photographs.

• It has been tried to be in places that are not affected by the superficial mass movements of the specified GPS points. This work was carried out with aerial photographs.
• The GPS has been tried to be selected in the places that are reachable as hard as possible. This work has been completed using 1 / 100.000 scale maps and aerial photographs.

The study area is 672 km^2, 32 km in the east-west direction and 21 km in the north-south direction. Prior to the measurements, an exploratory study was conducted in the area and planning was made taking into consideration the existing personnel, land and equipment. As a result of the planning work outlined in the main principles above, 9 geodetic points have been set up to measure within the scope of the project. The locations of these points are briefly given below:
KÖSEDERE (KOSE): It is located on the Andesite rock with porphyritic texture on the right at 650 m on the Kösedere - Gülpınar road.

BABAKALE (BABA): When Babakale leaves the fields, the Alüvyal area is on the rock.

GULPINAR (GULP): It is located on the rock on the left side of the road after 50 meters past the entrance sign of Gülpınar Village. The point way is about 10 m away. The environmental geological units are aka breccia and iglimbirit.

AKLIMAN (AKLI): Gülpınar - Akpınar road on the right side of the settlement on the rock is not on the settlement area. Environmental geological units are in iglimbirit structure.

BABAKALE (KALE): It is located on the rock at the front of the company sign on the Akpınar - Babakale road. Environmental geological units are beige colored tuff.

BADEMLİ (GENE): Babakale - Bademli road is located near "Babakale" sign. Environmental geological units are in iglimbirit structure.

BALABANLI (BALA): The only ball on the right side natural park on the way to Balabanlı - Beştaş is located in the volcanic surface rocks near the tree. Environmental geological units are volcanic and iglimbite.

BERHAM (BEHA): It is located on the andesite rock on the right side of the football field on the road of Beştaş - Berham Village. Environmental geological units are andesite.

İLYASFAKI (ILYA): On the way to Paşaköy and Ilyasfakı Village, before reaching Paşaköy, on the right is the rock on the second sign. Environmental geological units are in iglimbirit structure.

The sites given as location instructions are newly constructed points within this project. The excavation work was carried out by a team of project managers and project researchers. The following criteria were used in the finalization of the locations of the points:
- The distant faults that we have identified using the data we have obtained from the examination of aerial photographs and in addition to those we already had have been determined to be near (about 1 km), midway (about 2 km) and distant (about 6 km) are provided.
- Points have been taken care not to be on the slopes, even if they have the chance to be on solid rock masses. For this reason, the dots are chosen either on broad plains or on the ridges.
- Points have been strived to be placed on solid rocks to make driving difficult.

GPS point facilities are specially manufactured from chrome-nickel 316-stainless steel. In the studies, the vehicle provided by the service procurement and obtained from the project budget was used. The names of the GPS points, the abbreviations and coordinates of the 4 characters are given in Table 2.

Table 2. The name / position, abbreviations and coordinates of the micro-geodetic network sites (Datum: WGS-84)

Site Name	Site ID	Latitude	Longitude
KÖSEDERE	KOSE	39°38'09.19" K	26°10'55.21" D
BABAKALE	BABA	39°35'45.42" K	26° 09'46.25" D
GÜLPINAR	GULP	39°32'40.43" K	26°07'24.64" D
AKLİMAN	AKLI	39°30'14.99" K	26°05'11.06" D
BABAKALE	KALE	39°29'12.06" K	26°04'00.97" D
BADEMLİ	GENE	39°28'47.79" K	26°06'12.64" D
BALABANLI	BALA	39°30'12.37" K	26°13'32.05" D
BERHAM	BEHA	39°29'48.61" K	26°18'39.24" D
İLYASFAKI	ILYA	39°32'58.62" K	26°20'29.66" D

Figure 4. Views from Kösedere, Babakale, Gülpınar and Akliman sites.

After the excavation and construction work, the experts working on the project came together and started a planning work for the point to be observed. As a result of this planning, it was decided to create 3 land teams, each consisting of 2 people. Each team is considered to make observations at an average of 3 points. By means of rentals in the measurements, the transportation of the teams and the vehicles are provided. Field trials were carried out on 8-9 April 2017, 12-13 May 2017, 19-20 August 2017 and 5-8 October 2017 respectively (Table 3).

Figure 5. Views from Babakale, Bademli, Balabanlı, Berham ve İlyasfakı sites.

Table 3. Information about GPS measurement campaigns

Campain name	Period of observation	GPS receiver models	Number of observation sites	Data interval (sn)	Elevation mask (degree)	Average Observation Time (saat)
TuzlaGPS-1	April	SATLAB SL600	9	15	10	6
TuzlaGPS-2	May	SATLAB SL600	9	15	10	6
TuzlaGPS-3	August	SATLAB SL600	9	15	10	6
TuzlaGPS-4	October	SATLAB SL600	9	15	10	6

GPS measurements were carried out with SATLAB brand GPS receivers in the area of Komi Geotechnical Engineering Department, which is the institution where the project is run. An average of 6 hours of observations were made by taking a record every 15 seconds at each point. To ensure that these observations are as synchronous as possible, the start and end times are taken to be the same.

Initial evaluations of the data obtained from the GPS observations performed were made by Trimble Geomatics Office (TGO) software. Corrected coordinates and point error ellipses were calculated accordingly (Table 4).

3. EVALUATION OF GPS DATA

GPS data Bernese v. 5.0 (Dach et al., 2007). The steps of this evaluation are as follows:

• Sensitive orbital information is obtained from International GPS Service (IGS) in SP3 (Standard Product 3) format, SOPAC (Scripps Orbit and Permanent Array Center).

• Each campaign is evaluated according to ITRF_2008.

• Earth Rotation Parameters (ERP), USNO_bull_b (United States Naval Observatory_bulletin_b).

• 16 stations from the IGS global monitoring network were included in the evaluation. These stations are ANKR, ARTU, BOR1, BRUS, BUCU, GRAS, GRAZ, IRKT, ISTA, JOZE, KIT3, KOSG, MADR, MATE, METS, NICO, NSSP, NYAL, ONSA, ORID, SOFI, TRAB, TUBI, VILL, WTZR, ZECK, ZIMM.

• For the radiation-pressure effects, 9-parameter Berne model, which is also used as standard by SOPAC, is used.

• The Scherneck model was used for the ocean tide loading effect.

• Zenith latency unknowns were calculated at 2-hour intervals based on the Saastamonian premise standard troposphere model.

• An ionosphere independent LC (L3) linear combination of L1 and L2 carrier wave phases was used in the evaluation.

• The height-dependent model is preferred for antenna phase centers.

• The loose and coercive day-to-day solutions obtained after the above mentioned solutions are defined in the ITRF_2008 reference system with 7 parameters (3 translations, 3 turns and 1 scale) using 16 global IGS points.

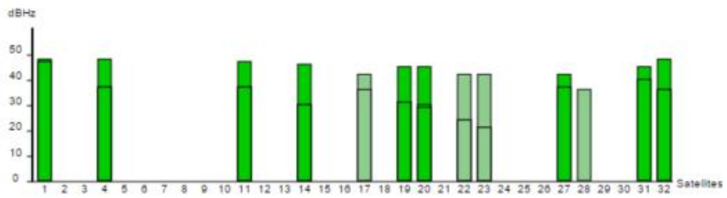
Table 4. The adjusted coordinates (Datum: WGS-84)

Site ID	Latitude	Longitude	Height (m)
KOSE	39°38'09.193" K	26°10'55.214" D	69.24
BABA	39°35'45.422" K	26°09'46.255" D	39.56
GULP	39°32'40.434" K	26°07'24.647" D	42.22
AKLI	39°30'14.990" K	26°05'11.066" D	78.06
KALE	39°29'12.061" K	26°04'00.971" D	64.35
GENE	39°28'47.795" K	26°06'12.644" D	350.85
BALA	39°30'12.373" K	26°13'32.057" D	292.74
BEHA	39°29'48.615" K	26°18'39.246" D	122.46
ILYA	39°32'58.629" K	26°20'29.663" D	425.19

After the data obtained from the observations were first tested with commercial software, then in the scientific academic research software from 4 measurement campaigns, Bernese v. 5.0. point positions of 9 stations are obtained by using scientific evaluation software. Then the velocity vectors will be estimated.

4. PARAMETERS COMPUTED FOR MICRO DEFORMATION NETWORK

With the processing of the data collected at the BALA GPS / GNSS station, which is the midpoint of the micro-deformation network formed within the scope of the project, many statistical information is obtained about the collected GNSS data. For example, according to the satellite distribution of GPS data collected in Figure 11, the BALA station point receives data from GPS satellites 1, 4, 11, 14, 17, 19, 20, 22, 23, 27, 28, 31 and 32, respectively. In addition, horizontal angles (azimuth angle) and elevation angles of satellites were obtained. These magnitudes carry important information about the quality of the signal from the satellite to the receiver. In addition, the signal to noise ratio (SNR) for each GPS signal was removed in Figure 6.



				SNR (dBHz)					Smooth Count (s)				
ID	Status	Az.	El.	L1C	L1P(Y)	L2CS	L2P(Y)	L5	L1C	L1P(Y)	L2CS	L2P(Y)	L5
1	Used	316	60	48		47			>255		>255		
4	Used	348	85	48	37		37		>255	>255		>255	
11	Used	254	77	47	37		37		>255	>255		>255	
14	Used	48	34	46	30		30		>255	>255		>255	
17	Tracked	324	9	42		36			>255		>255		
19	Used	190	32	45	31		31		>255	>255		>255	
20	Used	274	31	45	30		29		>255	>255		>255	
22	Tracked	74	14	42	24		24		>255	>255		>255	
23	Tracked	212	11	42	21		21		>255	>255		>255	
27	Used	174	7	42		37			>255		>255		
28	Tracked	288	2	36									
31	Used	112	21	45		40			>255		>255		
32	Used	324	73	48	36		36		>255	>255		>255	

Figure 6. GPS satellite information calculated for BALA Station.

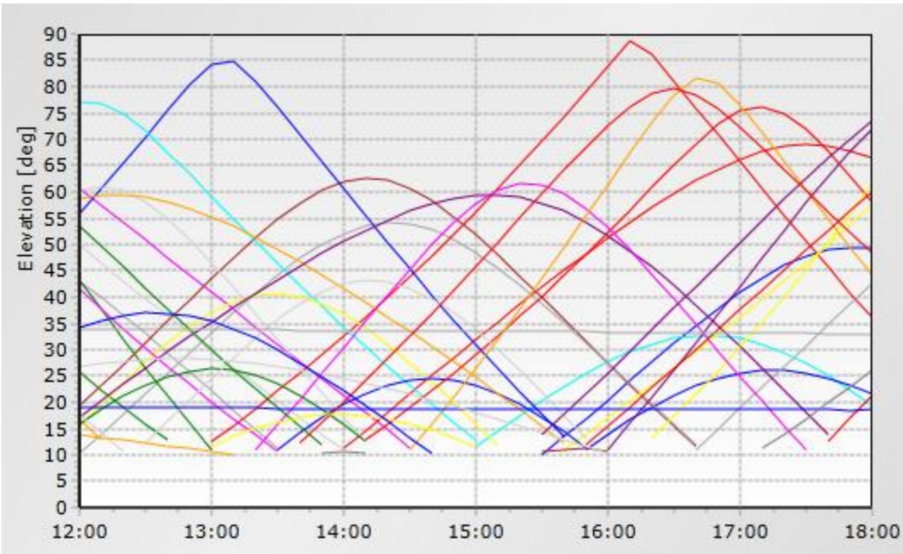


Figure 7. Satellite elevation angle distribution for BALA station.

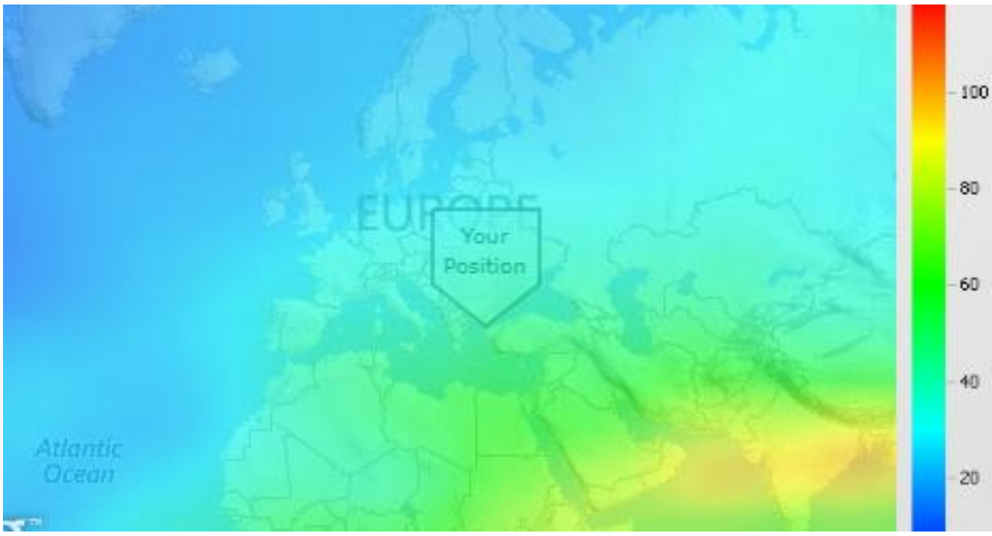


Figure 8. Ionosphere map calculated from satellite data.

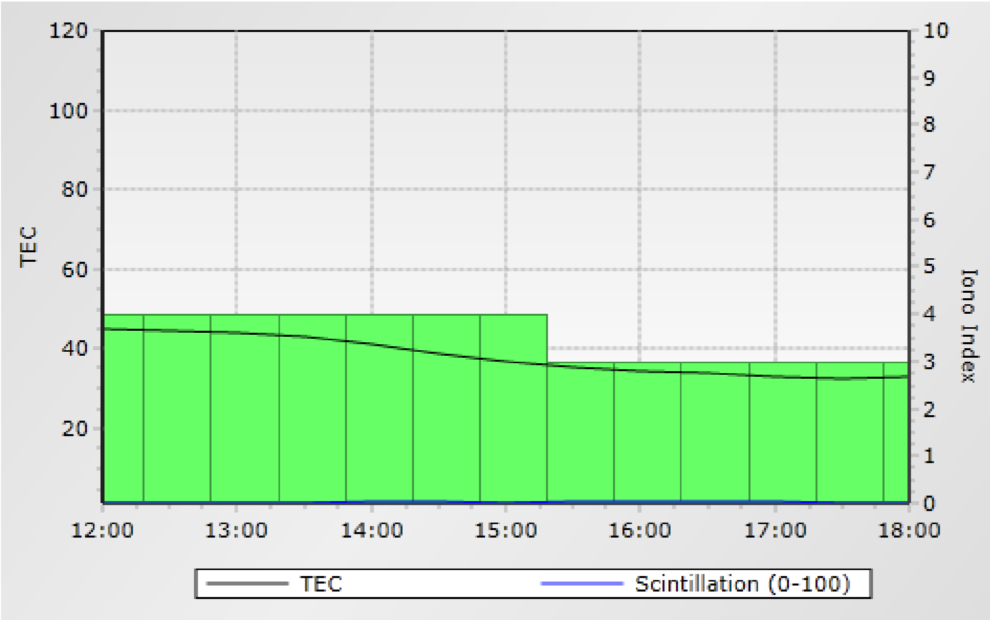


Figure 9. Ionosphere indices calculated from satellite data.

5. RESULTS AND DISCUSSION

As a result of this project, 9 geodetic points in the micro geodetic deformation monitoring network in the study area were utilized. GPS / GNSS observations are made at these points. A total of 6 campaign period static type measures were collected at these points. The reference coordinates of the GPS points were obtained as a result of the measurement campaigns. The point error ellipses calculated for the 1st measurement period of each GPS / GNSS point are given in Figure 10. Then, the coordinated point coordinates were obtained with a measurement period of 2 months each from the measurement campaigns (Table 5-10). Point error ellipses obtained from each measurement campaign were also calculated. Speed vectors were then found. The horizontal and vertical velocity areas of the project area were obtained from these velocity vectors (Figure 11). The Eurasian constant velocity values calculated between Tuzla GPS-1 and Tuzla GPS-6 GPS / GNSS campaigns are shown in Table 11.

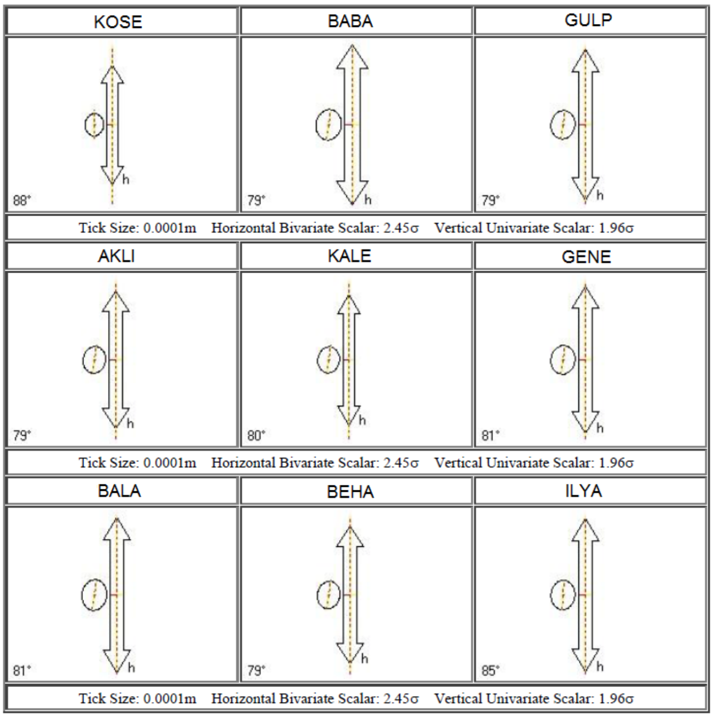


Figure 10. Point error ellipses.

Table 5. Adjusted coordinates / Tuzla GPS-1 Campaign (Datum: WGS-84).

Point ID	Latitude (deg)	Longitude(deg)	Height (m)
KOSE	39°38'09.193" N	26°10'55.214" E	69.2454
BABA	39°35'45.422" N	26°09'46.255" E	39.5665
GULP	39°32'40.434" N	26°07'24.647" E	42.2235
AKLI	39°30'14.990" N	26°05'11.066" E	78.0652
KALE	39°29'12.061" N	26°04'00.971" E	64.3575
GENE	39°28'47.795" N	26°06'12.644" E	350.8569
BALA	39°30'12.373" N	26°13'32.057" E	292.7495
BEHA	39°29'48.615" N	26°18'39.246" E	122.4625
ILYA	39°32'58.629" N	26°20'29.663" E	425.1954

Table 6. Adjusted coordinates / Tuzla GPS-2 Campaign (Datum: WGS-84).

Point ID	Latitude (deg)	Longitude(deg)	Height (m)
KOSE	39°38'09.145" N	26°10'55.204" E	69.2453
BABA	39°35'45.406" N	26°09'46.229" E	39.5622
GULP	39°32'40.475" N	26°07'24.625" E	42.2108
AKLI	39°30'14.914" N	26°05'11.045" E	78.0383
KALE	39°29'12.042" N	26°04'00.925" E	64.3494
GENE	39°28'47.775" N	26°06'12.679" E	350.8399
BALA	39°30'12.328" N	26°13'32.026" E	292.7461
BEHA	39°29'48.685" N	26°18'39.285" E	122.4651
ILYA	39°32'58.674" N	26°20'29.679" E	425.2069

Table 7. Adjusted coordinates / Tuzla GPS-3 Campaign (Datum: WGS-84).

Point ID	Latitude (deg)	Longitude(deg)	Height (m)
KOSE	39°38'09.175" N	26°10'55.241" E	69.2213
BABA	39°35'45.414" N	26°09'46.226" E	39.5643
GULP	39°32'40.496" N	26°07'24.682" E	42.2290
AKLI	39°30'14.925" N	26°05'11.037" E	78.0673
KALE	39°29'12.075" N	26°04'00.902" E	64.3558
GENE	39°28'47.735" N	26°06'12.645" E	350.8504
BALA	39°30'12.304" N	26°13'32.029" E	292.7468
BEHA	39°29'48.653" N	26°18'39.264" E	122.4657
ILYA	39°32'58.625" N	26°20'29.694" E	425.1874

Table 8. Adjusted coordinates / Tuzla GPS-4 Campaign (Datum: WGS-84).

Point ID	Latitude (deg)	Longitude(deg)	Height (m)
KOSE	39°38'09.206" N	26°10'55.241" E	69.2362
BABA	39°35'45.445" N	26°09'46.265" E	39.5570
GULP	39°32'40.454" N	26°07'24.675" E	42.2052
AKLI	39°30'14.998" N	26°05'11.082" E	78.0577
KALE	39°29'12.072" N	26°04'00.981" E	64.3512
GENE	39°28'47.815" N	26°06'12.664" E	350.8531
BALA	39°30'12.386" N	26°13'32.157" E	292.7544
BEHA	39°29'48.626" N	26°18'39.272" E	122.4565
ILYA	39°32'58.634" N	26°20'29.679" E	425.1962

Table 9. Adjusted coordinates / Tuzla GPS-5 Campaign (Datum: WGS-84)

Point ID	Latitude (deg)	Longitude(deg)	Height (m)
KOSE	39°38'09.199" N	26°10'55.224" E	69.2480
BABA	39°35'45.434" N	26°09'46.265" E	39.5694
GULP	39°32'40.439" N	26°07'24.657" E	42.2101
AKLI	39°30'14.998" N	26°05'11.087" E	78.0621
KALE	39°29'12.067" N	26°04'00.998" E	64.3524
GENE	39°28'47.799" N	26°06'12.674" E	350.8399
BALA	39°30'12.382" N	26°13'32.028" E	292.7326
BEHA	39°29'48.625" N	26°18'39.252" E	122.4708
ILYA	39°32'58.649" N	26°20'29.666" E	425.1887

Table 10. Adjusted coordinates / Tuzla GPS-6 Campaign (Datum: WGS-84)

Point ID	Latitude (deg)	Longitude(deg)	Height (m)
KOSE	39°38'09.201" N	26°10'55.228" E	69.2373
BABA	39°35'45.428" N	26°09'46.265" E	39.5481
GULP	39°32'40.442" N	26°07'24.651" E	42.1980
AKLI	39°30'14.999" N	26°05'11.067" E	78.0699
KALE	39°29'12.061" N	26°04'00.988" E	64.3448
GENE	39°28'47.802" N	26°06'12.654" E	350.8533
BALA	39°30'12.379" N	26°13'32.078" E	292.7423
BEHA	39°29'48.616" N	26°18'39.264" E	122.4602
ILYA	39°32'58.634" N	26°20'29.678" E	425.1800

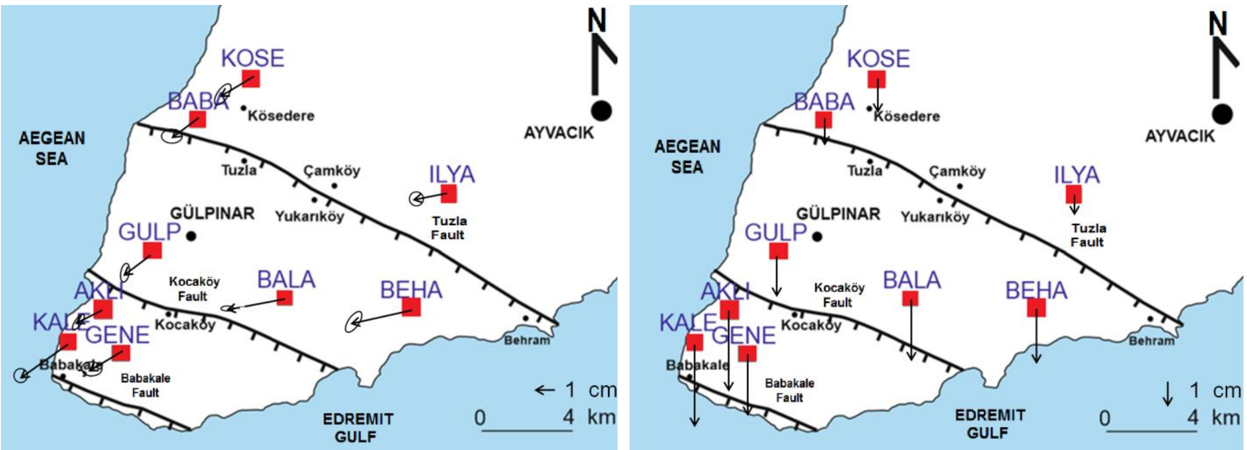


Figure 11. Eurasia fixed horizontal and vertical velocity area (from Tuzla GPS-1 and Tuzla GPS-6 GPS / GNSS campaigns data).

Deformation analysis studies conducted by geodetic methods are long term studies. According to similar studies carried out in different project areas in our country and abroad, the time required to achieve healthy results is at least 2.5-3 years. Similarly, geophysical studies using geodetic measurements to calculate surface deformations or strain accumulations require not only accurate estimation of relevant parameters but also accurate estimation of errors of these parameters. In this context, the geophysical results obtained by the Geophysics Department of our university in Çanakkale and its districts will be more useful for the evaluation of these project outputs.

Tablo 11. Eurasia-fixed velocity values calculated between Tuzla GPS-1 and Tuzla GPS-6 GPS / GNSS campaigns.

Point ID	Evel (mm/yr)	Nvel (mm/yr)	Esig (mm/yr)	Nsig (mm/yr)	RHO
KOSE	-21.27	-15.30	1.24	1.35	0.028
BABA	-18.58	-14.60	1.14	1.25	0.009
GULP	-20.45	-14.20	0.99	1.06	-0.014
AKLI	-21.77	-15.71	1.66	1.82	-0.036
KALE	-18.99	-17.36	1.23	1.34	-0.020
GENE	-21.68	-16.99	1.18	1.29	-0.002
BALA	-21.51	-15.04	1.08	1.20	0.021
BEHA	-20.09	-16.07	1.06	1.14	0.005
ILYA	-18.60	-16.63	1.30	1.42	0.012

6. CONCLUSION

As a result of the study, the following findings were obtained:

- According to the results of 6 campaign type measurement periods between Tuzla GPS-1 and Tuzla GPS-6, the horizontal velocities obtained vary between 22.8 ± 3 mm / year and 30.3 ± 3 mm / year.
- The vertical velocities obtained from the evaluation of GPS data range from 12.8 ± 2 mm / year to 22.3 ± 2 mm / year.
- The final velocities are consistent with the overall behavior of the region. The block between Kocaköy and Babakale Faults is more in the vertical direction than the other blocks during the study period.
- In the vertical direction at KALE point and at KALE and BEHA points, more point deformation occurred in horizontal direction than other points.
- In the part west of Tuzla Fault, deformation patterns related to compression are predominantly present. The findings were confirmed as the most active structure in the region, and the Tuzla Fault, which is the most active structure in the region, confirms that it is a geologically northwest oriented normal faulting.

REFERENCES

AFAD, 2017. 12.02.2017 Ayvacık-Çanakkale Earthquake Report (in Turkish).

Beavan, J. and H. Haines, 2001.Contemporary horizontal velocity and strain ratefields of the Pacific– Australian plate boundary zone through New Zealand, J. Geophys. Res., 106, 741– 770.

Brunner, F.K., Welsch, W.M., 1994. Effects of the Troposphere on GPS Measurements, GPS World, 4, 42-51.

Brunner, F.K., 1997. Continuous Monitoring of Deformation using The Global Positioning System, AvH Magazine, 69, 29-38.

Coe J.A., Ellis W.L., Godt J.W. , Savage W.Z., Savage J.E., Michael J.A.,Kibler J.D., Powers P.S., 2003. Lidke D.J., Debray S., Seasonal Movement of the Slumgullion Landslide Determined from

Global Positioning System Surveys and Field Instrumentation, July 1998–March 2002, Engineering Geology, 68, 67–101.
Dach et al., 2007 R. Dach, U. Hugentobler, P. Fridez, M. Meindl 2007. Bernese GPS Software Version 5.0 User manual Astronomical Institute, University of Bern.
Duman, T., Çan, T., Emre, Ö., Kadiroğlu, F.T., Baştürk., N.B., Kılıç, T., Arslan, S., Özlap, S., vd. (2016). Seismotectonic database of Turkey. Bull Earthquake Eng. 1-40, doi:10.1007/s10518-016-9965-9.
Featherstone, W.E., Dentith, M.C., Kirby, J.F., 1998. Strategies for the Accurate Determination of Orthometric Heights from GPS, Survey Review, 34, 267, 278-296.
Gerasimenko, M. D., Shestakov, N. V., and Kato, T. , 2000. On Optimal Geodetic Network Design for Fault-Mechanics Studies. Earth Planets Space, Vol. 52, pp. 985-987.
Gili, J. A., Corominas, J., Rius, J., 2000. Using Global Positioning System Techniques in Landslide Monitoring, Engineering Geology, 55, 167-192.
Haines, A.J. and Holt, W.E., 1993. A procedure to obtain the complete horizontal motions within zones of distributed deformation from the inversion of strain rate data. Journal of Geophysical Research 98, 12,057–12,082.
Haines, A.J., Jackson, J.A., Holt, W.E., Agnew, D.C., 1998. Representing distributed deformation by continuous velocity fields. Institute of Geological and Nuclear Sciences, Wellington, New Zealand, Science Report, 98/5.
Herring, T.A., King, R.W., McClusky, S.C., 2010. Introduction to GAMIT/GLOBK, Release 10.4, Massachusetts Institute of Technology, Cambridge. 66
Holt, W. E. ve Haines, A. J., 1995. The Kinematics of Northern South Island New Zealand Determined From Geologic Strain Rates, Journal of Geophysical Research, 100, 17991- 18010.
IGS: The International GNSS Service. http://igscb.jpl.nasa.gov/
KRDAE, 2017. Boğaziçi Üniversitesi Kandilli Rasathanesi ve Deprem Araştırma Enstitüsü, http://koeri.boun.edu.tr
Kreemer, C., Holt, W.E., Goes, S., Govers, R., 2000. Active deformation in eastern Indonesia and the Philippines from GPS and seismic data. J. Geophys. Res. (B1) 105, 663–680.
Mao, A., Harrison, C. G. A., and Dixon, T., 1999. Noise in GPS coordinate time series, Journal of Geophysical Research,104, 2797-2816.
Malet, J.P., Maquaire, O., Calais, E., 2002. The Use of Global Positioning System Techniques for The Continuous Monitoring of Landslides: Application to the Super-Sauze Earthflow (Alpes-de-Haute-Provence, France), Geomorphology, 43, 33-54.
Özalp, S., Emre, Ö., & Doğan, A. 2013. The segment structure of southern branch of the North Anatolian Fault and paleoseismological behaviour of the Gemlik Fault, NW Anatolia. General Directorate of Mineral Research and Exploration (MTA) Bulletin, 147, 1–17.
Özden, S., 2017, Ayvacık Depremleri Üzerine Değerlendirme Paneli, 9 Mart 2017, Çanakkale.
Sözbilir, H. vd., 2017, 14 Ocak - 28 Şubat 2017 Çanakkale - Ayvacık Depremleri ve Bölgenin Depremselliği, Dokuz Eylül Üniversitesi Deprem Araştırma ve Uygulama Merkezi Diri Fay Araştırma Grubu, 22 sayfa (in Turkish).
SOPAC, 2017. Scripps Orbit and Permanent Array Center. http://sopac.ucsd.edu/

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