The Investigation of Halabjah / Iraq Earthquakes Effects from Turkish National Permanent GNSS Network Data

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Key words: Halabjah Earthquakes, GNSS, AUSPOS, TNPGN

SUMMARY

It is an important issue to determine the magnitudes and effects of earthquakes in order to engineering projects to continue their quality, service sustainable and safe. Therefore, studies on determination of crust and structural deformations have been increasing day by day. Especially, before the major engineering projects accomplish, the feasibility studies have great importance. Among the geodetic methods, GNSS technique, which is widely used, with high sensitivity positioning facilitates the monitoring of fault lines by applying deformation analysis. Thanks to the availability of highly accurate location data from the Continuous Observing Reference Stations (CORS), these data have been made available for pre and post processing analysis of the earthquake.

Anatolia is prone to earthquakes. The much destructions have been occasion of the various earthquakes, which have plagued Turkey. The East Anatolian Fault System (EAFS) is the secondary important fault system in Turkey, afterwards the North Anatolian Fault System (NAFS). The EAFS has the potential to produce large earthquakes. Near the EAFS, Halabjah earthquake occurred on 12 November 2017 (M=7.3), 19.0 km depth. The Halabjah is near the Iran-Iraq border in 220 km northeast of Baghdad, Iraq. The earthquake was a result of the collision of the Arabian and Eurasian plates. The positional displacements results from this earthquake were estimated by using data from the Turkish National Permanent GNSS Network (TNPGN)

The purpose of this study is to determine the magnitude and direction of earthquake-induced displacements with the help of Global Navigational Satellite Systems (GNSS) at certain periods. Rinex data obtained from TNPGN stations were evaluated and the results are presented. The data of the TNPGN stations, in particular southeast of Turkey, near the Halabjah/ Iraq were analyzed 5 days before and after the earthquake to determine co-seismic deformations.

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1. INTRODUCTION

The major earthquakes have created dangerous effects such as shaking and ground rupture. These effects have resulted vigorous damage to nature, buildings and the other human made structures. It is an important issue to determine the magnitudes and effects of earthquakes in order to engineering projects to continue their quality, service sustainable and safe. So, many techniques such as Global Navigational Satellite Systems (GNSS), Interferometric Synthetic Aperture Radar (InSAR), Satellite Laser Ranging (SLR) have been used to monitoring earthquakes and for geomatics investigations of the displacements of the earthquakes results.

The studies on determination of crust and structural deformations have been increasing day by day. Especially, before the major engineering projects accomplish, the feasibility studies have great importance. Among the geodetic methods, GNSS technique, which is widely used, with high sensitivity positioning facilitates the monitoring of fault lines by applying deformation analysis (Tiryakioğlu et al. 2018, Aktuğ et al. 2013, Özener et al. 2010,) Thanks to the availability of highly accurate location data from the Continuous Observing Reference Stations (CORS), these data have been made available for pre and post processing analysis of the earthquake (Yıldırım et al. 2014). Nowadays the scientists have increasingly used online processing with precise point positioning (PPP) method in the earthquake monitoring and other deformation studies. (Srivarom et al. 2017, Pikridas et al. 2016, Yiğit et al. 2016). The scientist, who used this GNSS online web service, does not feel the need using commercial or academically processing softwares.

Anatolia is prone to earthquakes. The much destruction has been occasion of the various earthquakes, which have plagued Turkey. The East Anatolian Fault System (EAFS) is the secondary important fault system in Turkey, afterwards the North Anatolian Fault System (NAFS). The EAFS has the potential to produce large earthquakes (Aktuğ et al. 2016). Near the EAFS, Halabjah earthquake occurred on 12 November 2017 (M=7.3), 19.0 km depth. The Halabjah is near the Iran-Iraq border in 220 km northeast of Baghdad, Iraq. The earthquake was a result of the collision of the Arabian and Eurasian plates (USGS, 2017). The some of Turkish National Permanent GNSS Network (TNPGN) stations are thought to be affected by the Halabjah / Iraq earthquake. So in this study the positional displacements results from Halabjah earthquake were estimated by using data from the TNPGN

The purpose of this study is to determine the magnitude and direction of earthquake-induced displacements with the help of GNSS at certain periods. Rinex data received from TNPGN stations were processed and the results are presented. The data of the TNPGN stations, in particular southeast of Turkey, near the Halabjah/ Iraq were analyzed on 5 days before and after the earthquake to determine tectonic deformations.

2. SEISMIC STRUCTURE OF THE HALEBJAH EARTHQUAKE REGION

According to United States Geology Survey, the earthquake was occured the border area at 18:18:17 UTC, 29 km southwest of Halabjah and nearby the border between Iran and Iraq at latitude 34.911^0 N, longitude 45.959^0 E, depth 19 km (USGS, 2017). The epicenter of the earthquake was pretty shallow at 11.7 kilometers below the Earth's surface. The Halebjah earthquake magnitude was calculated as 7.3 M by USGS (*Figure 1*)

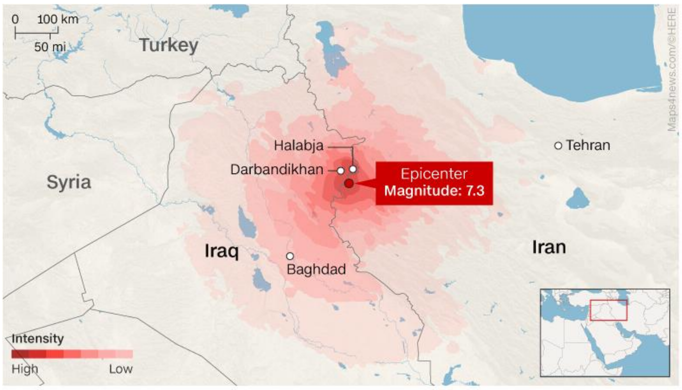

Figure 1. Demonstration of the effects of the Halabjah Earthquake on thematic map (Bozorgmehr and Masters 2017)

The earthquake was a outcome of the collision of the Arabian plate and Eurasian plate (Reilinger et al. 2006). In the region where the earthquake occurred, the two crustal plates are slipping against one another. The Arabian plate is moving northwards with respect to Eurasia plate by 2-3 cm/year. The Plate is colliding into the Eurasian plate and driving uplift of the Zagros Mountains (*Figure 2*). This collision between two continental plates switches from a subduction to a strike-slip setting depending on particular positioning. The location of the earthquake and the shallow, northeast-dipping plane of the focal mechanism solution are consistent with rupture of a plate boundary related structure in this region (Stern and Johson 2010, USGS 2017, Reilinger et al 2006).

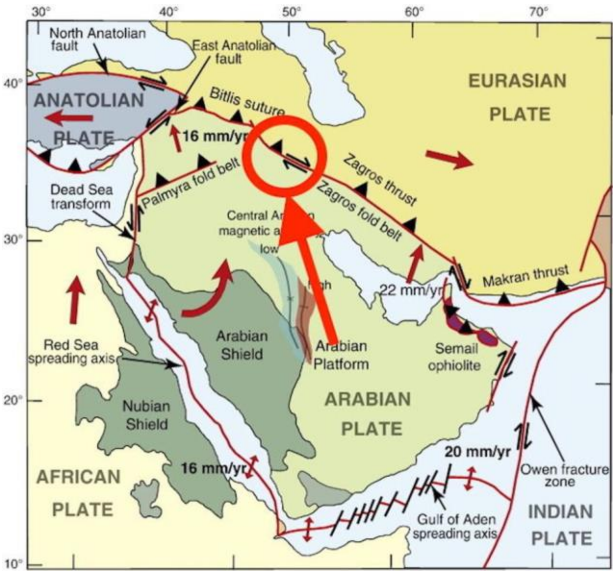

Figure 2. The crustal plate movements of the earthquake zone. (Stern and Johnson, 2010)

The shock of Halabjah/Iran-Iraq earthquake was felt far away in eastern Anatolia. This earthquake was a effect of a reverse fault. This fold and thrust belt which has constitute the Zagros Mountains. The compressing forces and friction of the two plates slipping against one another have caused a few major aftershock earthquakes (3<M<6). The cluster of M 6.0-6.7 earthquakes had been determined along the plate boundary about 200 km to the southeast of Halabjah in the past. For example the Tabas earthquake occurred (M 7.8) in 1978. The death toll was in the range of 15,000–25,000. The Manjil–Rudbar earthquake occurred on 21 June 1990. The loss of life is in the range of 35,000–50,000.

Turkey is one of the most tectonically active zones of the Middle East. Historical seismicity, according to earthquakes where occurred in the recent years, reveals the active tectonic features of this region. Van earthquakes may be an example recently. The Van earthquakes happened in eastern Turkey at the city of Van and the earthquake killed 604 citizen.

3. TURKISH NATIONAL PERMANENT GNSS SYSTEM

There are 146 constant stations on the Turkish National Permanent GNSS Network (TNPGN) in Turkey and Turkish Republic of Northern Cyprus. All of the permanent stations are called Continuously Operating Reference Stations (CORS –TR) in our country. The network has been controlled by the two control centers. The First Control Center has been worked as a master stations at the Photogrammetry and Geodesy Administration of the General Directorate of Land Registry and Cadastre (TKGM) and the second control center is worked as an auxiliary stations at the headquarters of the General Command of Mapping (HGK), both in Ankara, Turkey. All the CORS-TR reference stations are named in accordance with IGS regulations having only four characters. (For example Başkale – BASK). The TNPGN picks up data from all of the stations at one-second intervals for 24 hours. The system has been actively working since 2009 (Mekik et al 2011, Yıldırım et al. 2014). The distance of the TNPGN stations base is about 75-100 km.

The researchers may obtain high accuracy by using TNPGN data for measuring deformation and monitoring earthquakes (Eren at al. 2009). The scheme of the stations was established by using the stations providing best data to detect the tectonic crustal movements (Mekik et al. 2011). The determining the location and time of the earthquakes, establishing an early warning system has been a hard subject for the researchers. CORS - TR networks are one of the most important instruments in monitoring crustal movements for researchers (Uzel et al. 2013, Yıldırım et al. 2014). The distribution of the TNPGN stations is shown in Figure 3.

4. CALCULATIONS OF STATION DISPLACEMENTS

Ten number TNPGN stations were used in this study. These stations are BASK (Başkale, BTMN(Batman), CATK(Çatak), HAK1(Hakkari), MARD(Mardin), MUR1(Muradiye), OZAL(Özalp), SEMD(Şemdinli), SIR1(Şırnak), TVA2(Tatvan). These stations are thought to be affected by the Halebjah / Iraq earthquake (*Figure 3*)

The rinex data of ten stations which are established at Eastern Anatolia Region were processed with AUSPOS web based online GPS Processing (version: AUSPOS 2.3) and calculated the displacements of these stations.

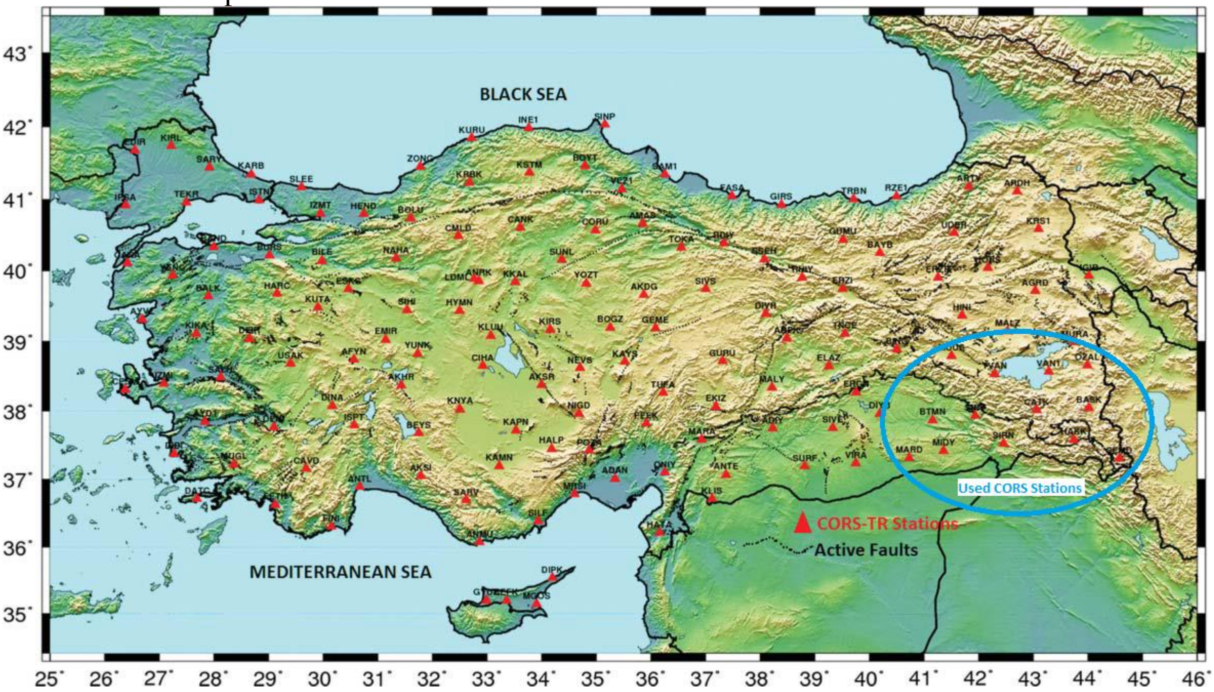

Figure 3. Distribution of the TNPGN and chosen stations (Yıldırım et al. 2014)

AUSPOS has used Bernese v5.2 GNSS software and it is used in point-position calculations. All over the world, according to International Terrestrial Reference Frame 2014 (ITRF14), The AUSPOS Service has used International GPS Service (IGS) products such as rinex files (observation and navigation) of global stations, GPS satellite ephemerides (sp3, ultra-rapid, rapid, final), earth rotation partameters (erp, final and rapid), coordinates and velocities of global stations, network meta data, IGS14 absolute antenna phase center variations to compute precise coordinates. The only dual frequency GPS phase data has been processed by AUSPOS, except Glonass data. All data have adjusted by weighted least-squares algorithm (Jia et al., 2014)

In AUSPOS Service, data processing has been executed by double differences and triple - differences with only L1/L2 and linear combinations of L1 and L2 such as L5/L3, quasi-ionosphere free according to baseline distance. At the processing elevation mask angle is 7^0, sampling rate of 30 seconds. Global Mapping Functions (GMF) has been used for tropospheric model. For eliminating of first-order ionospheric effect, L3 combination has been chosen also, second and third effect model has been applied. While atmospheric loading model has been considered, ocean tide loading has not been applied. Solid Earth tide displacements have been derived according to IERS conventions 2010. Web based online processing services have been widely used. The researchers and scientists has utilized from processing service for both deformation studies and comparing service capabilities (El-Mowafy, 2011, Ocalan et al., 2013, Yiğit et al., 2014, Şanlioglu et al., 2016)

To examine the movements in the TNPGN stations near the earthquake epicenter, we used data from 14 IGS stations around Turkey, where their coordinates were considered as fixed *(Figure 4)*. These reference stations are ANKR, ARTU, BHR3, BUCU, CRAO, GLSV, ISER, ISNA, JOZ2, MAT1, MDVJ, NOT1, POLV and SOFI on the Eurasian plate and and Arabian plate.

Figure 4. TNPGN Stations in the red circle and IGS Stations has been shown red triangles on the Earth

The rinex data of stations has been obtained from the TNPGN center on 5 days before and after the earthquake to determine tectonic deformations between 07 and 17 November 2017 and then this data has been forwarded to AUSPOS. The coordinates obtained from the AUSPOS Service on 07 November 2017 were considered fixed for the calculation of the displacements. The differences between the coordinates of the other days and coordinates of the day (07 Nov 11) were calculated for chart of the displacements. The Cartesian differences were transformed to topocentric coordinates north, east, up. The graph of displacements for each TNPGN stations were prepared and drawn in MS Office Excel and MATLAB software. The results are shown in *figure 4 (a) – 4 (j)*.The root mean square values had been estimated by equation 1 from displacements and are given table 1.

$$RMS = \pm\sqrt{\frac{[VV]}{n^2}} \tag{1}$$

Finally, the graph of displacements were drawn by using topocentric coordinates in figure 5. The station positions are in transversal mercator projection coordinate system, 3° of longitude in width at the 42^0 center meridian in figure 5.

5. HALABJAH EARTHQUAKE FINDINGS

The coordinates of the external epicenter of the earthquake were latitude 34.911^0 N, longitude 45.959^0 E, depth 19 km in accordance with the records of the USGS 2017. The earthquake was felt in a wide area in East Anatolia including: Diyarbakır, Van, Hakkari, Batman, Adıyaman, Bitlis, Siirt, Şırnak and Kahramanmaraş. The closest TNPGN station is Şemdinli – SEMD about 293 km.

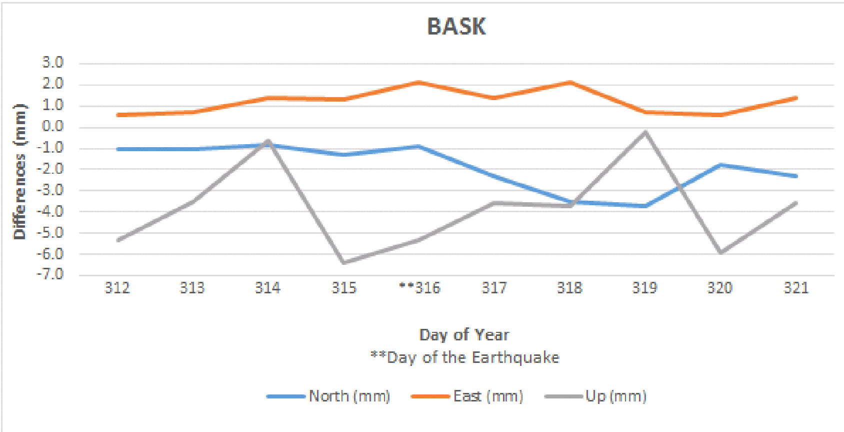

Figure 4(a). Başkale station displacements

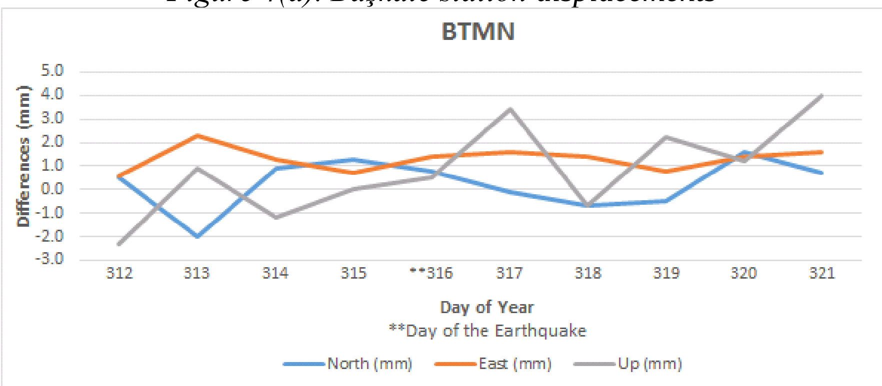

Figure 4(b). Batman station displacements.

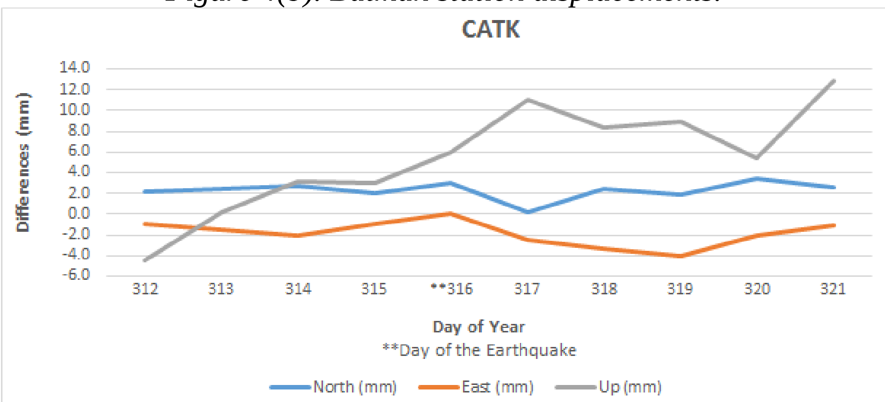

Figure 4(c). Çatak station displacements.

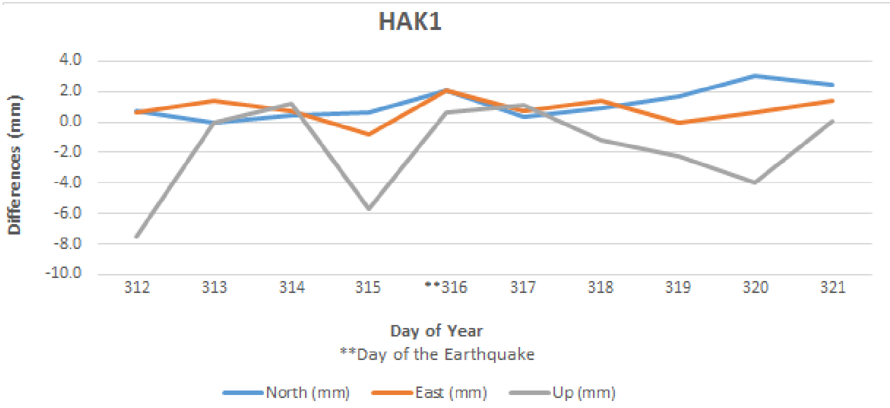

Figure 4(d). Hakkari station displacements.

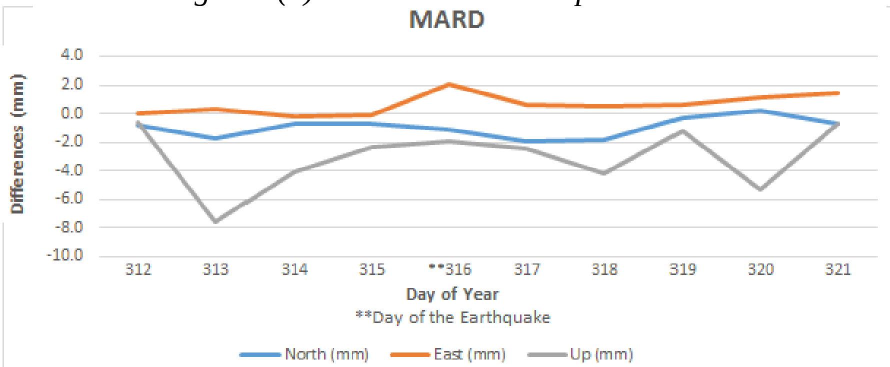

Figure 4(e). Mardin station displacements.

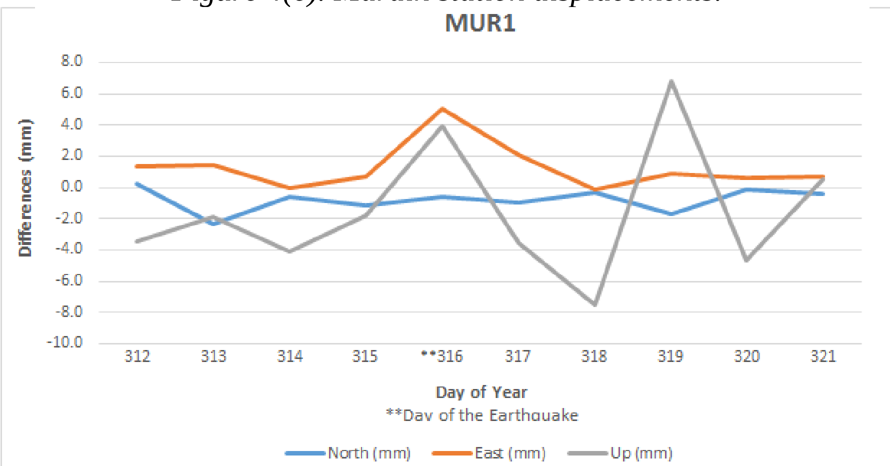

Figure 4(f). Muradiye station displacements.

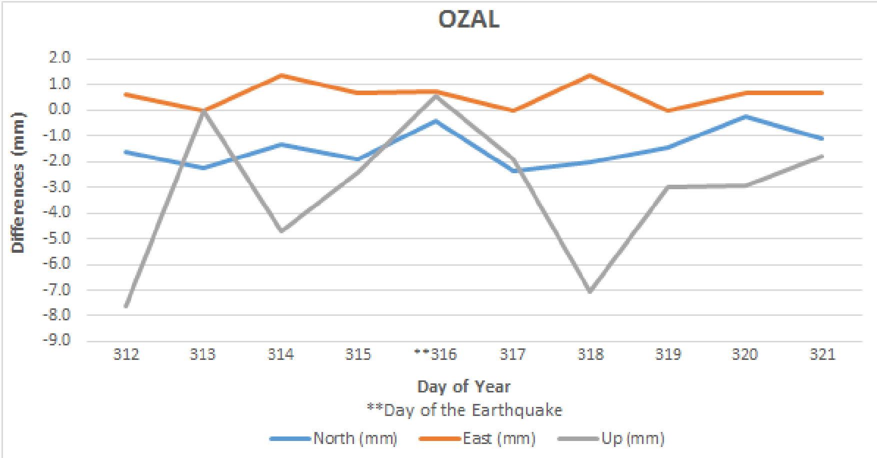

Figure 4(g). Özalp station displacements

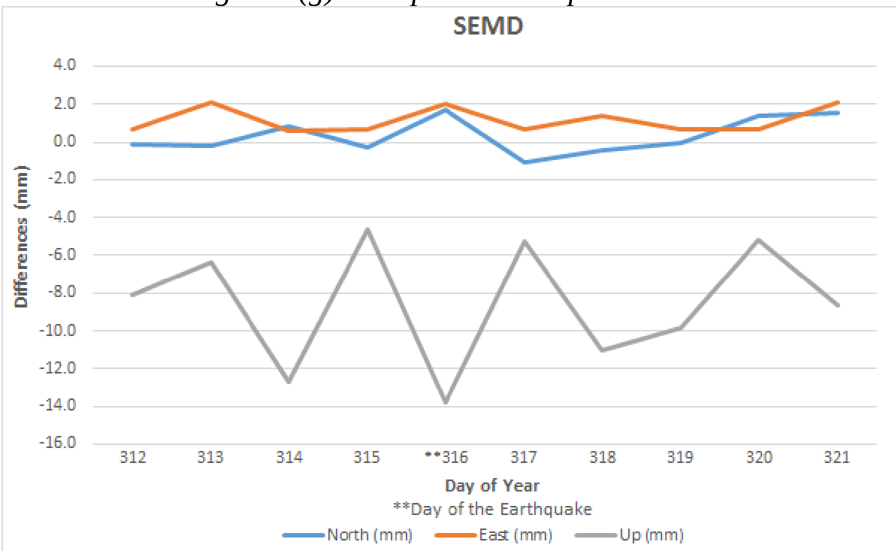

Figure 4(h). Şemdinli station displacements.

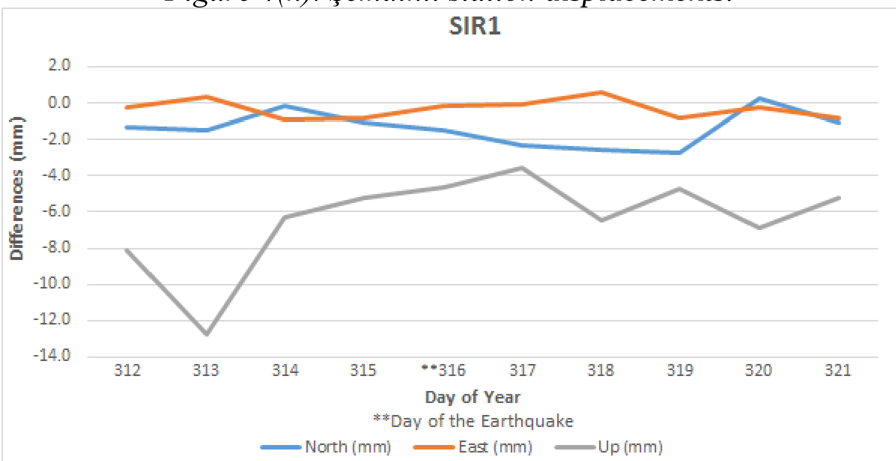

Figure 4(i). Şırnak station displacements.

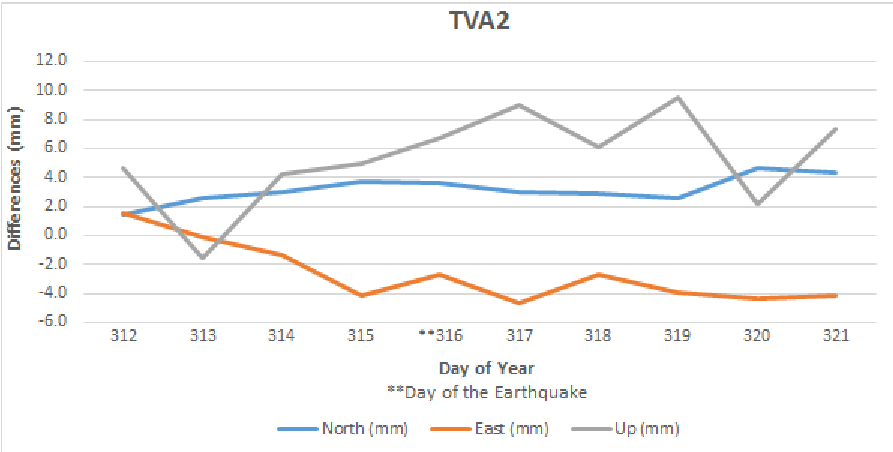

Figure 4(j). Tatvan station displacements.

Table 1. The RMS values of TNPGN stations displacements

Station ID	Root Mean Square			Distance From Earthquake Epicenter (km)
	East (mm)	**North (mm)**	**Up (mm)**	
BASK	2.1	1.3	4.3	389
BTMN	1.1	1.4	2.1	541
CATK	2.4	2.2	7.4	431
HAK1	1.6	1.1	3.4	357
MARD	1.2	0.9	3.7	541
MUR1	1.1	1.9	4.3	493
OZAL	1.6	0.8	4.0	451
SEMD	1.0	1.3	9.1	293
SIR1	1.7	0.6	6.9	428
TVA2	3.3	3.3	6.2	518

The graph of the all TNPGN stations shows that the variations before and after of the earthquake is appeared the same. So, there is no significant difference between the before fifth day and the after days. Because the displacement values are lower than three times values of rms.

When the above charts of horizontal and vertical displacements are examined, the positional displacements are not exceeded the standard deviations. They are seen in the evaluation of 5 days before and 5 days after data charts *(figure 4*. So it can be said that the Southeastern Anatolian region is not affected by the Halabjah earthquake and the aftershocks.

In addition to this study, the observations of these stations were divided into two before and after at 09:18:18 PM (November 12). For first interval, the time of observations is 21 hour 18 minute before earthquake and 2 hour 42 minute after earthquake. The second interval the time of observations is 21 hour 18 minute before earthquake and 26 hour 42 minute after earthquake. The all observations were processed by AUSPOS Service. The differences between coordinates of before the earthquake time and coordinates of after the earthquake time were calculated. The Cartesian coordinates differences obtained from the processing were converted to the topocentric coordinates. The results and displacements of first interval are drawn *figure 5(a) and 5(b).* The results and displacements of second interval are drawn *figure 6(a) and 6(b).*

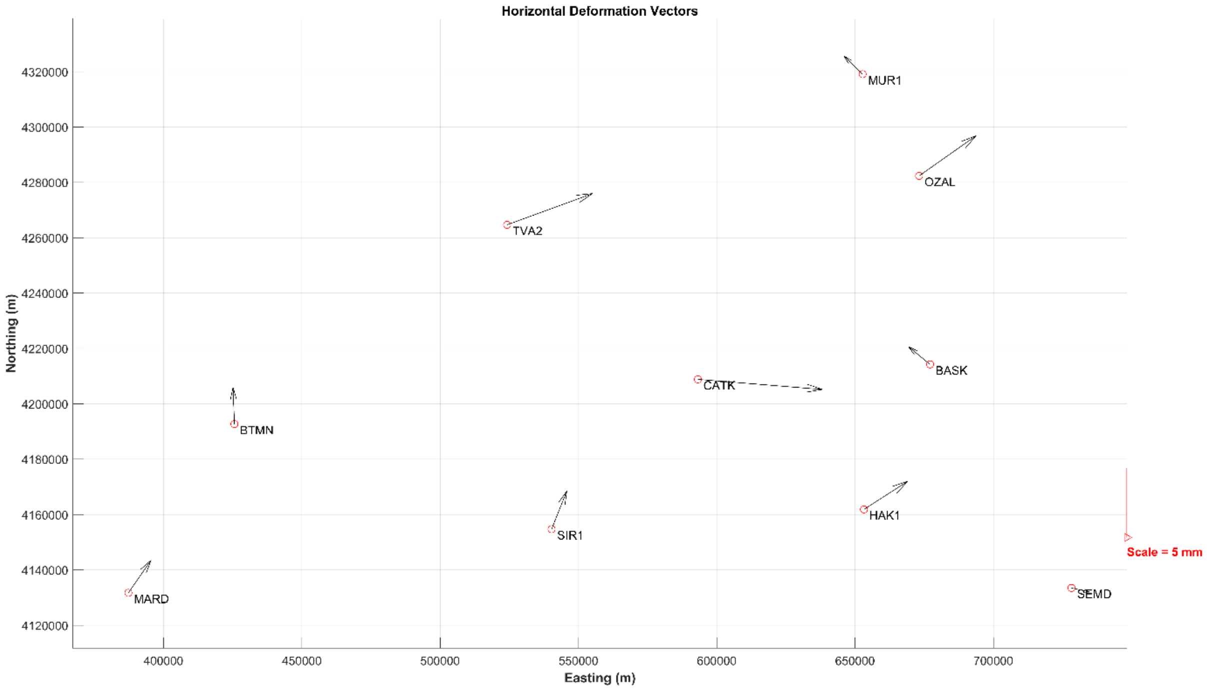

Figure 5 (a). Horizontal movements of first interval

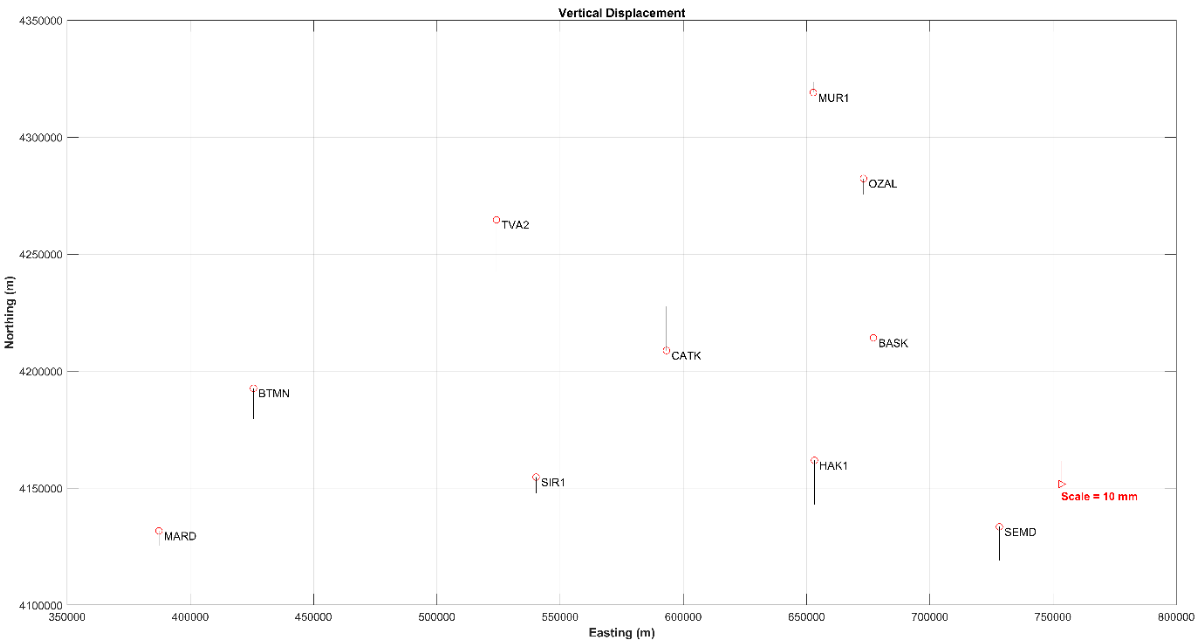

Figure 5 (b). Vertical movements of first interval

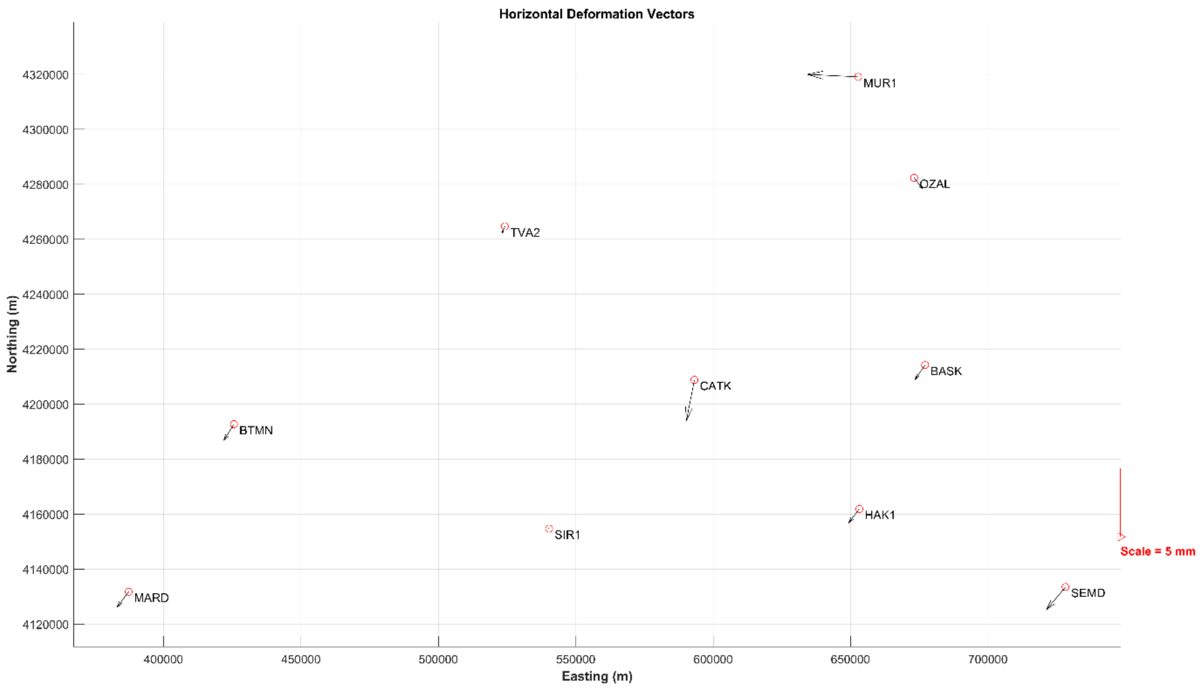

Figure 6 (a). The Horizontal movements of second interval

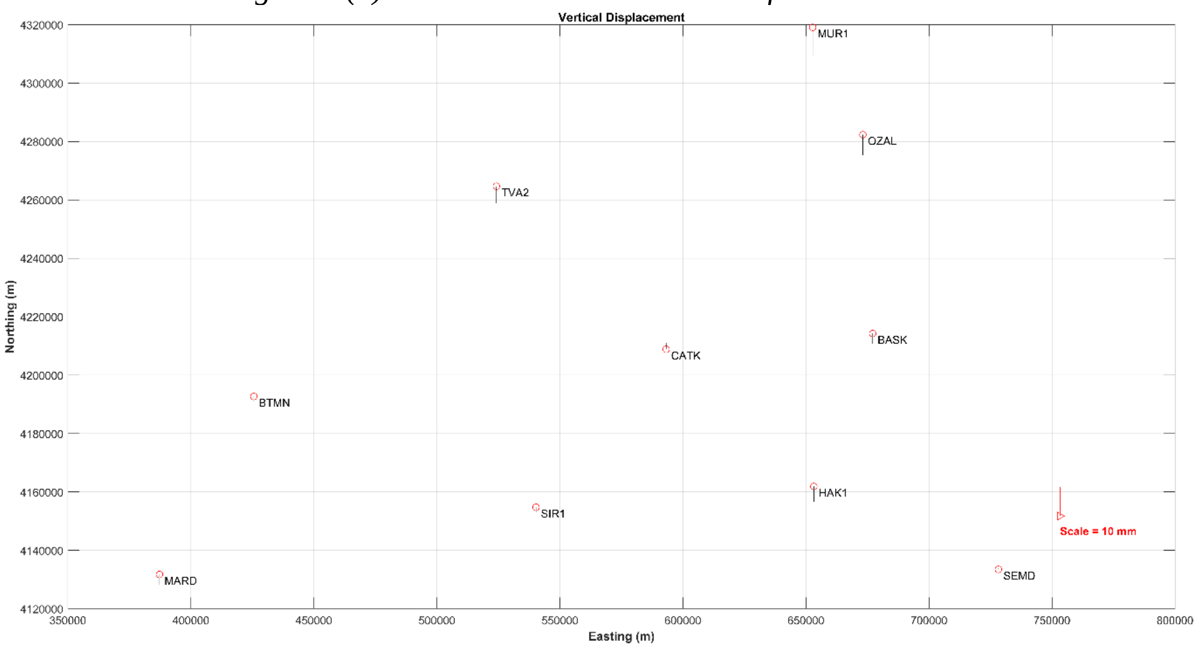

Figure 6 (b). The Vertical movements of second interval

6. CONCLUSION

According to processing results provided in this paper, Halabjah earthquake effects to the stations in the Turkey were insignificant. There are no changes in positions determined as a result of the earthquake. The intensity of effect is shown from the epicenter of earthquake to outward in Figure 1 thematic map with red color. As it can be seen, the red area of the earthquake effect is not included territory of Turkey.

Finally, in this study after examining the positional data measured before and after earthquake for first interval, it can be said that positional movements were detected in the TNPGN stations included in processing. It is estimated that these results may be short observation time. Because, the coordinates had been calculated by poor accuracy at the short observation time of stations. For second interval, it can be said that positional movements were not detected in the TNPGN stations.

The final coordinates obtained from AUSPOS have a precision of a few millimeters. So this web service can give very good results. For earthquake investigations and the other deformation studies, the processing of the permanent stations data is feasible by web-based processing services as AUSPOS.

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BIOGRAPHICAL NOTES

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