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Determination of Surface Deformations with Global Navigation Satellite System Time Series

I. Tiryakioglu, M. A. Ugur, C. Ozkaymak

***Abstract*—**The development of Global Navigation Satellite System (GNSS) technology has led to increasingly widely and successful applications of GNSS surveys for monitoring crustal movements. Instead of the multi-period GNSS solutions, this study utilizes GNSS time series that are required to more precisely determine the vertical deformations in the study area. In recent years, the surface deformations that are parallel and semi-parallel to Bolvadin fault have occurred in Western Anatolia. These surface deformations have continued to occur in Bolvadin settlement area that is located mostly on alluvium ground. Due to these surface deformations, a number of cracks in the buildings located in the residential areas and breaks in underground water and sewage systems have been observed. In order to determine the amount of vertical surface deformations, two continuous GNSS stations have been established in the region. The stations have been operating since 2015 and 2017, respectively. In this study, GNSS observations from the mentioned two GNSS stations were processed with GAMIT/GLOBK (GNSS Analysis Massachusetts Institute of Technology/GLOBal Kalman) program package to create coordinate time series. With the time series analyses, the GNSS stations' behaviour models (linear, periodical, etc.), the causes of these behaviours, and mathematical models were determined. The study results from the time series analysis of these two 2 GNSS stations show approximately 50-90 mm/yr vertical movement.

***Keywords*—**Bolvadin fault, GAMIT, GNSS time series, surface deformations.

I. INTRODUCTION

THE term of GNSS is generally used to describe a satellite constellation which provides geo-spatial position of any location in the world. In recent years, Continuously Operating Reference Station (CORS) networks that provide GNSS data to support the positioning applications have been widely used in many developed countries. A satellite navigation system is a system of satellites that enables small electronic receivers to determine their three dimensional positions within a few meters using the radio time signals from the satellites. The precisely determined position of the receivers can be used as a reference for civil, industrial, scientific, and military applications [1]. Nowadays, GNSS can be used as a positioning tool ranged from smart phones, airplanes to cars for the commercial areas and the determination and monitoring the crustal deformations along with various other applications for the scientific areas [1].

The development of GNSS measurement systems have been in advantage of not only the geodesy but also earth sciences. Starting from 1980's, GNSS has been rapidly favored of the conventional measurement techniques. Especially crustal deformation monitoring with GNSS study has been one of the most popular topics for the researchers in many areas of the earth sciences [2]-[6]. Earthquakes are one of the major natural events due to the crustal deformation. The studies on the prediction of the earthquakes have increased during the last century. It is possible to predict the possible location, not occurrence time, of the earthquake by computing the stress concentration on the seismic faults if where the observations are obtained through the deformation measurement instruments [4], [5], [7].

The GNSS measurements can determine three-dimensional crustal deformation, but the accuracy of vertical positioning is much lower than that of horizontal components, due to the effect of atmospheric refraction and uncertainties in the antenna phase center of GNSS satellites and receivers. However, vertical deformations can be determined by continuously GNSS survey solutions.

Study area is located in the Western Anatolia. Western Anatolia is one of the most important seismogenic zones in Turkey. The study area has a major tectonic structure that consists of Aksehir-Sultandagi Fault Zone (ASFZ), Fethiye-Burdur Fault Zone (FBFZ), and Isparta Angle (IA) [2]. ASFZ caused the formation of the grabens, from Southeast to Northwest, in Afyon-Aksehir [3]. The earthquake records from the historical and instrumental periods suggest the existence of a large number of earthquakes created the surface ruptures in this zone. On the date of 03.02.2002, this region has been shaken by the earthquakes with Mw 6.5 and Mw 6.2 in size. The epicentres were located Bolvadin and the southern Eber Lake (Fig. 1). The surface deformations have been observed for last five years even though there are not any destructive earthquakes observed in Bolvadin settlement. During the field studies in Bolvadin area, progressive surface deformations such as surface faults and earth fissures whose length varies between 300 meters and 2 kilometers and strike varies between N15°E and N70°E are mapped. The northernmost one of the surface deformations mapped in the settlement area of Bolvadin has the characteristics of the southwestern continuation of Bolvadin Fault [4].

İbrahim Tiryakioğlu is with the Department of Geomatics Engineering, Faculty of Engineering, Afyon Kocatepe University, Afyonkarahisar, Turkey (phone: +90 272 228 1423 (2349); e-mail: itiryakioglu@aku.edu.tr).

Mehmet Ali Uğur is with the Department of Geomatics Engineering, Faculty of Engineering, Afyon Kocatepe University, Afyonkarahisar, Turkey (phone: +90 272 228 1423 (2489); e-mail: maliugur@aku.edu.tr).

Çağlar Özkaymak is with the Department of Geology Engineering, Faculty of Engineering, Afyon Kocatepe University, Afyonkarahisar, Turkey (phone: +90 272 228 1423 (2367); e-mail: caglarozkaymak@aku.edu.tr).

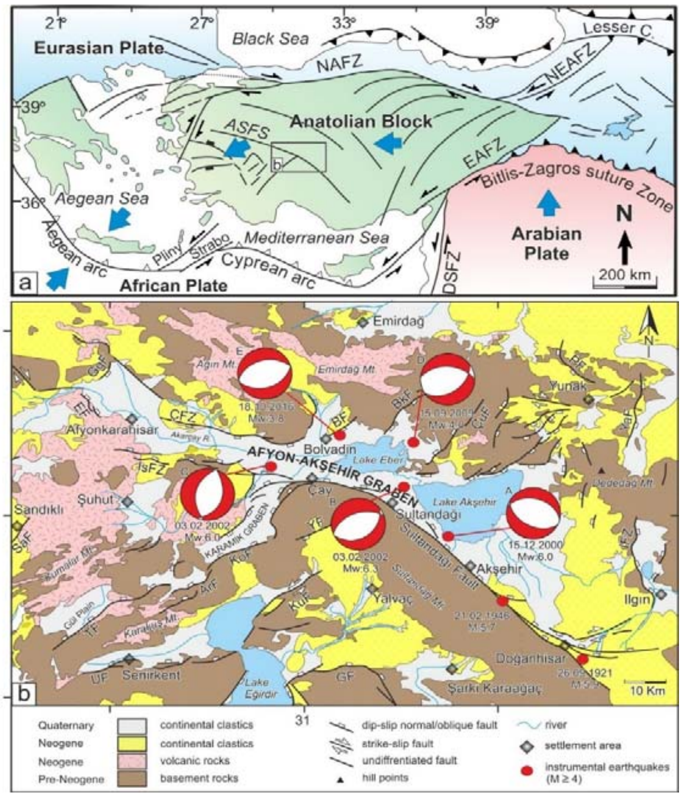

Fig. 1 (a) Tectonic outline of the eastern Mediterranean area (compiled from [5] and [6]). Abbreviations: ASFS, Akşehir-Simav Fault System; DSFZ, Dead Sea Fault Zone; EAFZ, East Anatolian Fault Zone; NAFZ, North Anatolian Fault Zone; NEAFZ, Northeast Anatolian Fault Zone. (b) The geology map of AAG and its immediate vicinity (compiled from [7]-[9]) Abbreviations: ÇFZ: Çobanlar Fault Zone; IsFZ: Işıklar Fault Zone; BF: Bolvadin Fault; BkF: Büyük Karabağ Fault; ÇuF; Çukurcak Fault; YF: Yarıkkaya Fault; KuF: Kumdanlı Fault; GF: Gelendost Fault; KoF: Kocbeyli Fault; ArF: Arızlı Fault; UF: Uluborlu Fault; TF: Tatarlı Fault.

Fig. 2 The surface deformations which are parallel and semi-parallel to Bolvadin fault

Some of the buildings in the linear deformation zone, such as houses, schools, and medical centres, have deformed critically, and most have been evacuated. In addition, these deformations have also damaged the underground water, gas or the sewage network in the urban areas of Bolvadin (Fig. 3).

Fig. 3 The Surface deformations observed within the Bolvadin settlement area: (a),(b) The divergence of garden walls of some buildings located on the surface fault near the Park Akcan, (c) Linear deformations on asphalt pavement of the school garden, (d) Extensional cracks in some buildings located on the surface fault (e), (f) Deformations on graves

In this study, the vertical deformation in Bolvadin settlement was determined based on continuous GNSS measurements from two continuously operating GNSS stations established in the region where the surface deformations are active (Bolvadin).

II. GNSS Observations and Time Series

Two continuously operating GNSS stations were established to determine the temporal behaviour of deformations occurring in the Bolvadin fault. The first GNSS station was established in January 2015 and was named AKTC. This station was located about 500 meters to the surface deformations. The second GNSS station that named BLV1 was established in June 2017 and located near the surface deformations. The energy needs of each of the 2 stations were supported by solar panels and they were able to make continuous measurements.

All GNSS data were processed using the GAMIT (GPS Analysis)/GLOBK (GLOBal Kalman) software developed by Massachusetts Institute of Technology. The GAMIT module can estimate 3D coordinates, satellite orbits, atmospheric zenith delays and earth rotation parameters using carrier phase measurements and pseudo-range observations. During the analysis, L3, the ionosphere-independent linear combination of the L1 and L2 carrier waves was used. The FES2004 OTL grid allowed interpolating the Ocean Tide Loading (OTL) components from a global grid [9]-[12]. The coordinates obtained by GAMIT software were used in the time series starting with the first measurement taken (2015.1). The linear (trend), periodic, and irregular (stochastic) movements of the reference stations can be determined by time series analysis. For the North, East, and Up coordinates of the reference stations, the times series of $\overline{x}(t_i)$ depending on the time of t_i $(i=1,2,3,...,N)$ can be expressed as [13], [14]:

$$\overline{x}(t_i) = \underbrace{\sum_{k=1}^{m} a_k t_i^{k-1}}_{\text{trend component}} + \underbrace{\sum_{s=1}^{r} \left[b_s \cos(2\pi f_s t_i) + c_s \sin(2\pi f_s t_i) \right]}_{\text{periodic component}} + \underbrace{\sum_{j=1}^{p} \alpha_j \overline{x}(t_{i\ j}) + \sum_{jj=1}^{q} \beta_{jj} v(t_{i\ jj})}_{\textit{Stochastic component}} + \underbrace{v(t_i)}_{\textit{resudial}} \quad (1)$$

where, a_k: Trend component parameters, b_s, c_s: Periodic component parameters, f_s: Frequency, α_j: Auto-regressive (AR (p)) model parameters, β_{jj}: Average Movement (MA (q)) model parameters, $v(t_i)$: Random errors with the Average zero and variance σ^2.

Other mathematical applications can be found in [1] and [14]. With the help of application written in the MATLAB environment, time series of height components of AKTC and BLV1 stations have been analysed and given in Fig. 5.

Fig. 4 The GNSS stations of AKTC (A) and BLV1 (B)

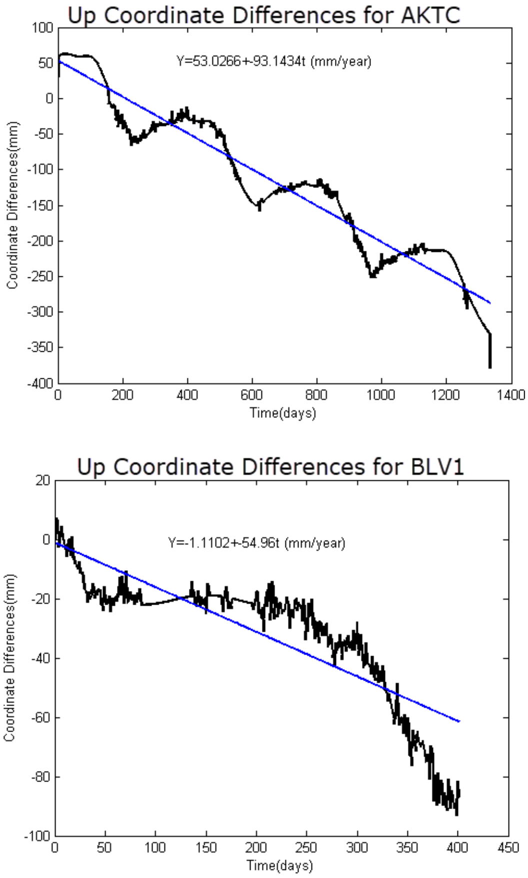

Fig. 5 The Time series of up coordinate differences of AKTC and BLV1 GNSS stations

III. Results and Conclusions

Two GNSS stations have been installed to monitor vertical deformations in the region. AKTC station collected approximately 1300 days and BLV1 collected 400 days of GNSS data. All GNSS data were processed using the GAMIT/GLOBK software to create the time series.

When Fig. 5 is examined, the vertical deformation is calculated at approximately 55 mm/year at BLV1 station and 93 mm/year at ACTC station. Based on the studies conducted in the region, it has been observed that in the last 20 years, as a result of intensive agricultural irrigation, the groundwater levels have decreased by 5-15 m.

The main reason for the deformations occurring in the region is thought to be decreases in ground water levels. However, the occurrence of deformations in the extension of a fault line indicates that this situation is originated from a tectonic formation. Therefore, extensive geodetic and geological studies were initiated in the region. In addition to the GNSS points, the leveling points were also established and observations were started.

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REFERENCES

[1] Gülal, E., Erdoğan, H., & Tiryakioğlu, İ. (2013). Research on the stability analysis of GNSS reference stations network by time series analysis.Elsevier, 13(8), 1945-1957.

[2] Blumenthal, M.M., 1963, Le système structural du Taurus sud Anatolies. Bull. Soc. Géol. Fr. In: Livre à Mémoire de Professor P. Fallot. Mém. Soc. Géol. Fr. 1, 2, 611–662.

[3] Koçyiğit, A., Bozkurt, E., Kaymakçı, N. ve Şaroğlu, F.,2002. 3 Şubat 2002 Çay (Afyon) Depreminin Kaynağı ve Ağır Hasarın Nedenleri: Akşehir Fay Zonu, ODTÜ Tektonik Araştırma Birimi Ön Raporu, 19 s.

[4] Özkaymak Ç., Sözbilir, H., Tiryakioğlu, İ. ve Baybura, T., 2017. Geologic, Geomorphologic and Geodetic Analysis of Surface Deformations Observed in Bolvadin (Afyon-Akşehir Graben, Afyon). Geological bulletin of Turkey, 60, 169-188

[5] Kaymakcı, N., 2006. Kinematic development and paleostress analysis of the Denizli Basin (Western Turkey): Implications of spatial variation of relative paleostress magnitudes and orientations. Journal of Asian Earth Sciences, 27, 207–222.

[6] Özkaymak, Ç., 2015. Tectonic analysis of the Honaz Fault (western Anatolia) using geomorphic indices and the regional implications. Geodinamica Acta, 27 (2-3), 110-129.

[7] Turan, N., 2002.Geological map of Turkey in 1:500.000 scale: Ankara sheet. Publication of Mineral Research and Explaniton Direction of Turkey (MTA), Ankara..

[8] Emre, Ö., Duman, T. Y., Özalp, S., Olgun, Ş. ve Elmacı, H., 2011. 1:250.000 scale active fault map series of Turkey, Afyon (NJ 36-5) Quadrangle. Serial number: 16, General Directorate of Mineral Research and Exploration, Ankara, Turkey.

[9] Tiryakioğlu, İ., Özkaymak, Ç., Baybura, T., Sözbilir, H., Uysal, M., (2018). Comparison of Palaeostress Analysis, Geodetic Strain Rates and Seismic Data in the Western Part of The Sultandağı Fault in Turkey. Annals of Geophysics, 61, 3, GD335. Doi: 10.4401/ag-7591.

[10] Lyard, F., Lefevre, F., Letellier, T. & Francis, O. (2006). Modelling the global ocean tides: Modern insights from FES2004. Ocean Dynamics, 56 (5-6), 394-415. doi:10.1007/s10236-006-0086-

[11] Herring, T.A., King, R.W. and Mcclusky, S.C., 2010, Introduction to GAMIT/GLOBK, Release 10.4, MIT, Cambridge, MA,.

[12] Tiryakioglu, I., 2015. Geodetic aspects of the 19 May 2011 Simav earthquake in Turkey. Geomatics. Nat. Hazards Risk 6 (1), 76e89..

[13] Gülal, E., Dindar, A.A., Akpınar, B., Tiryakioğlu, I., Aykut, N.O., Erdoğan, H., Analysis And Management Of Gnss Reference Station Data, Technical Gazette 22, 2(2015), 407-414

[14] Tiryakioğlu, I., Yavaşoğlu, H., Uğur, M.A., Özkaymak, Ç., Yılmaz, M., Kocaoğlu, H., Turgut, B. Analysis of October 23 (Mw 7.2) and November 9 (Mw 5.6), 2011 Van Earthquakes Using Long-Term GNSS Time Series, Earth Science Research Journal, 21, (3), 147-156, 2017.