Analysis of Strain Accumulation of the Faulting Zones by the Help of Continuous GPS Stations

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Key words: Strain measurements, GPS, Continuous GPS Network.

SUMMARY

The North Anatolian Fault Zone (NAFZ) belongs to one of the largest recent active fault systems around the Earth. During the last decades a westward expansion of large earthquakes along the North Anatolian Fault has shown an extension around Marmara Sea. The researchers give attention to the seismic gap in the Marmara Sea. It is expected that northern and middle strand of NAFZ have a strong risk for future actions. To be able to measure displacements and crustal deformations, a series of continuously operating GPS stations were installed around the Marmara Sea, Turkey, by TUBITAK. This network is named as Marmara Continuous GPS Network (MAGNET).

The purpose of this study is to estimate velocity field of the region, and to investigate changes of the strain accumulation in the region by using seven MAGNET stations around the Marmara Sea. Velocity field estimation is done by using GIPSY-OASIS Software and strain accumulation investigation is done by triangulation method and coordinate differences method. Since there are two main goals of this study, then there are two main results. From the seven MAGNET stations, with GIPSY-OASIS Software, the displacement of the stations between the years of 2002 and 2004 is found to be 24±1 mm/year. Also the strain accumulation of the sub-regions around the Marmara Sea is determined as either extension or compression.

OZET

Kuzey Anadolu Fay Kusagi Dunyanin en genis aktif fay sistemleri arasinda bulunmaktadir ve Anadolu Plakasinin en etkili kusagidir. Son yillarda Kuzey Anadolu Fay Kusagi boyunca bati yonundeki genislemeler Marmara Denizine kadar ulasmaktadir. Arastirmacilar Marmara Denizi icerisindeki sismik bosluga dikkat cekmektedirler. Cunku bu bosluk KAFZ'un kuzey ve orta bolgelerinde gelecek icin buyuk bir risk tasimaktadir.

Bu calismanin iki amaci vardir. Birincisi bolgedeki hiz alaninin belirlenmesi ve ikincisi ise yedi sabit GPS istasyonundan alinan verilerle gerinim analizinin hesaplanmasidir. Bu arastirma ucgenleme ve koordinat farklari alinarak yapilmistir. Gerinim parametreleri; maksimm.minimum asal gerilme, maksimum-minimum gerinim parametreli donuklugu, maksimum kayme gerinimi olarak tanimlanmistir.

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1. INTRODUCTION

Global Positioning System (GPS) has been a very useful tool for the last two decades in the area of geodynamics. Its high accuracy in determination of relative positioning availability together with its modest budget, increases the use of GPS all around the world.

GPS measurements are used to determine the strain accumulation along fault lines. Moreover, GPS measurements provide a significant tool for determining tectonic strain rates, which are assumed to be indicative of earthquake potential (Jackson, D.D et al., 1999). GPS measurements can be analyzed in two main methods as continuous and campaign measurements.

The Marmara Continuous GPS network (MAGNET) was established to measure the deformations associated with strain accumulation along the western NAF system. In this study, firstly the velocity vectors of seven MAGNET stations which are located in western Marmara were determined. After that, the strain accumulation around the fault zone at western Marmara was calculated.

2. MARMARA REGION

NAF is a relatively simple, narrow, right-lateral strike-slip fault zone. NAF splits into several fault strands in the vicinity of the Sea of Marmara so that the deformation (surface faulting of the NAF) becomes distributed over a 120 km broad zone. The region of the Marmara Sea is a transition zone between the strike slip regime of the NAF and the extension regime of the Aegean Sea.

The main branch of the dextral strike-slip North Anatolian fault enters to Marmara Sea through the Gulf of Izmit to the east and comes out through the Ganos fault, north of the Gallipoli peninsula, to the west (Fig.1).

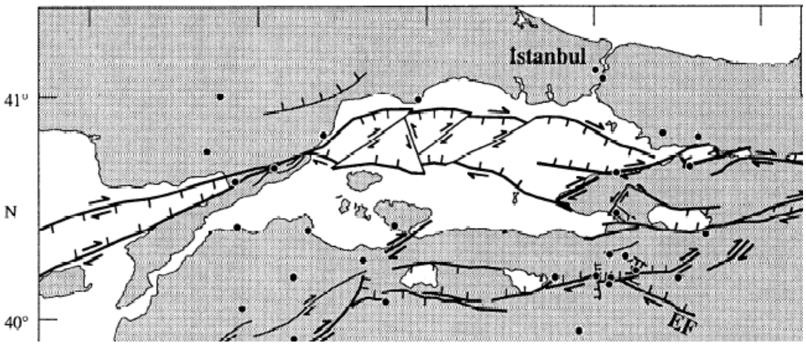

Figure 1: The Marmara region showing the mapped faults (Barka et al., 1988)

3. DATA ANALYSIS with GIPSY

The software used for the processing of the GPS data is GIPSY OASIS II (GPS Inferred Positioning SYstem Orbit Analysis and Simulation Software), (Gregorious, 1996) (Zumberge et al., 1997). It is capable of PPP processing of the GPS data as well as processing of SAR and DORIS data. In this study seven continuous GPS points of Marmara GPS Network (MAGNET) were used. These points are located at the Marmara region. Figure 2 shows the locations of the seven GPS points used in the processing. Data was collected over a period of three years, between 2002 and 2004.

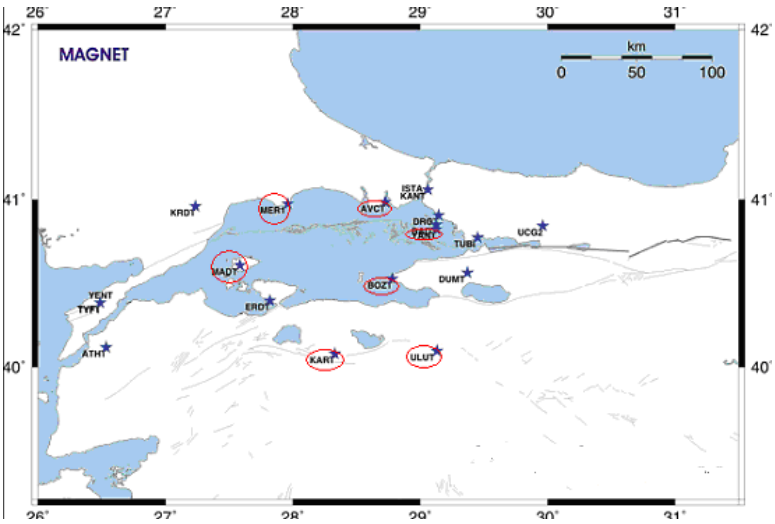

Figure 2: GPS Points used in this study. (Taken from TUBITAK MAM)

In general, data analysis can be performed in five steps (Sanli, 1999):

1. Preparing (i.e. cleaning and compressing the data for the solution)
2. Forming the design matrix,
3. Applying filtering and least square (LS) estimation,
4. Removing outliers and reprocessing.

3.1. Evaluation of Velocity Field

The temporary postseismic ground deformation observations after major earthquakes is an important tool to understand the mechanics of the earthquake process. Besides, it is also important to understand the mechanical behavior of the region surround the fault zone. Postseismic deformations can continue from immediately after the earthquake time to several tens of years as a function of time dependent stress relaxation (Ergintav et al., 2002).

In this study, the results of GIPSY Software show that at the year of 2002, the velocities of the stations close to the fault are two times as big as the ones which are far away from the fault. At the years 2003 and 2004, it is observed that these velocities are decreasing. Figure 3 shows the displacement vectors which are calculated according to the north (N), east (E), up (U) values by GIPSY. The rate of GPS velocities can be seen in Table1.

Figure 3: Displacements of stations between 2002 and 2004

Table 1. Horizontal GPS velocities of the Marmara Region at Eurasian fixed frame

Site	Longitude (θ)	Latitude (θ)	East & North rate (mm/year)		East & North (mm/year) ±	
ULUT	29,131	40,098	−23,02	−2,59	0,30	0,28
BAD1	29,118	40,852	0,29	1,20	0,31	0,29
BOZT	28,782	40,534	−15,84	−2,82	0,46	0,48
AVCT	28,724	40,989	−4,84	3,11	0,41	0,42
KART	28,333	40,265	−19,69	−2,11	0,28	0,26
MER1	27,962	40,967	1,10	1,87	0,29	0,26
MADT	27,587	40,611	−15,86	−3,30	0,37	0,38

4. STRAIN

As a result of tectonic plates movements, enormous forces are applied to the earth's crust. These forces change the plate configurations and make some variations in states of stress in the rocks. When stresses are applied to rocks, the rocks may change position and shape. The change in position is known as displacement. Strain is known as the change in shape. In general, strain is used for the determination of deformation.

4.1. Strain Analysis with Geodetic Methods

Strain analysis are commonly used for determination of the deformation. The main geodetic methods that are used for strain accumulation are;

– adjusted measurements that is; length, angle and azimuth differences,
– coordinate differences,
– determination of strain parameters in an adjustment model.

Table 2: Strain parameters that are defined by repeated geodetic observations

Parameters	Length	Azimuth	Angle	GPS
Area Deformation (Δ)	+			+
Shear Strain (γ)	+	+	+	+
Eigenvalues (ε_1 , ε_2)	+			+
Rotation Angle (φ)	+	+	+	+
Angular Strain (ω)		+		+

4.2. Strain Tensor

Strain tensor can be defined by below matrix;

$$E=\begin{bmatrix} e_{xx} e_{xy} \\ e_{xy} e_{yy} \end{bmatrix} \quad (1)$$

The diagonal elements of strain tensor ($e_{xx} e_{xy}$) shows extension through the coordinate axes. The other elements (e_{xy}) show the angular deformation that is a result from deformation according to coordinate axes.
Strain tensor parameters are determined with least square adjustment method. For strain parameters the below formulas are used:

Pure shear:

$$\gamma_2 = 2e_{xy} \quad (2)$$

$$\varphi = 0.5 * \tan^{-1}\left(\gamma_2 / \gamma_1\right) \quad (3)$$

Maximum strain direction:

$$\varphi = 0.5 * \tan^{-1}\left(\gamma_2 / \gamma_1\right) \quad (4)$$

The infinitesimal strain-displacement relationships can be summarized as,

$$\varepsilon_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) \quad (5)$$

Shear strain parameters (γ_1, γ_2) show the angular deformation (Figure 4.). Pure shear (γ_1) is the augmentation of the angle that is between two perpendicular northwest-northeast directions. (γ_2) defines decrement between two perpendicular the north and east directions (Feigl, 1990).

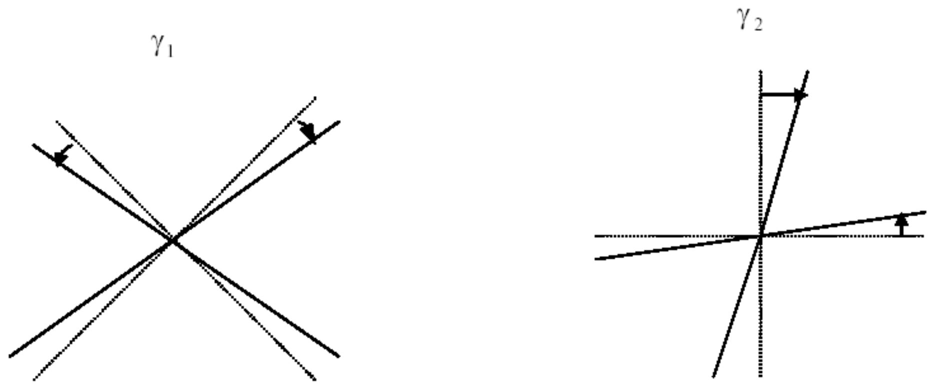

Figure 4: Shear strain parameters (γ_1, γ_2).

5. DETERMINATION OF STRAIN FIELD IN THE WESTERN PART OF NORTH ANATOLIAN FAULT ZONE

5.1. Computation of Strain Parameters with Triangulation

For this method the field was separated to six triangles and strain fields of all triangles assumed s homogeneous and the strain parameters of each triangle was calculated (Table 3).

Table 3: Strain triangles

Regions	Point Names
Whole area	AVCT, BAD1, ULUT, BOZT, KART, MER1, MADT
Triangle 1	BAD1-BOZT-ULUT
Triangle 2	BAD1-BOZT-AVCT
Triangle 3	BOZT-ULUT-KART
Triangle 4	BOZT-AVCT-KART
Triangle 5	MER1-AVCT-KART
Triangle 6	MER1-MADT-KART

Triangles in the network are taken as "unit particle" of finite element method. By combining unit particles continuous parameter in the network (solution area), continuous parameters are found. For each baseline of a triangle, three general equations are created. Thus, are found.

$$e_{xx},\ e_{xy},\ e_{yy}$$

Strain parameters which were calculated with this method are independent from datum parameters. Calculated strain parameters for the points of equilibration of triangles show scale differences in the network. It is required to provide the continuity for the network among the parameters which are calculated for points of equilibration.

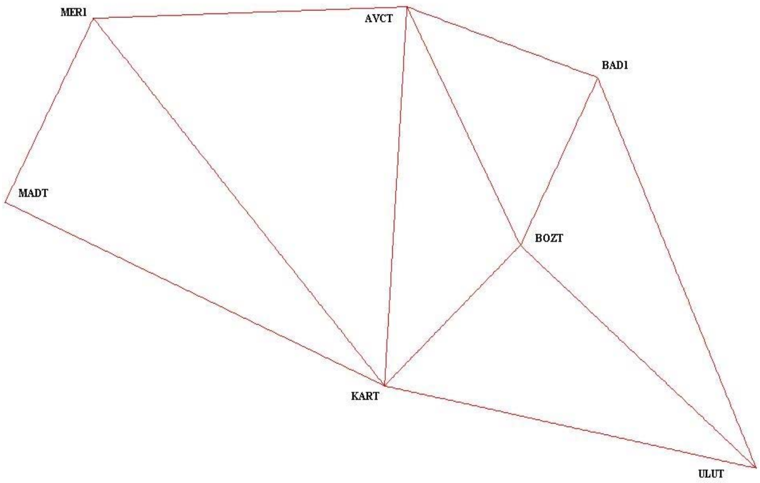

Figure 5: Triangles of the field

Calculated strain parameters are shown in Table 4 and extensions or compressions for the whole are is shown in Figure 6.

Table 4: Calculated strain parameters

TRIANGLE CORNER POINTS	**PRINCIPLE STRAIN COMPONENTS**		**Ψ (deg)**	**E_{INTER} (μs)**	**E_{SHEAR} (μs)**
	ε_1 (μs)	**ε_2 (μs)**			
BAD1-BOZT-ULUT	0.5828	-0,0859	6,9826	0,2485	0.3344
BAD1-BOZT-AVCT	0.7782	-0,3067	30,9725	0,2357	0,5425
BOZT-ULUT-KART	0,2189	-0,5221	-89,9999	-0,1516	0,3705
BOZT-AVCT-KART	0,4077	-1,395	47,9029	-0,4935	0,9012
MER1-AVCT-KART	0,4102	-0,075	54,0592	0,1676	0,2425
MER1-MADT-KART	0,5001	-0,0426	40,9145	0,2287	0,2714

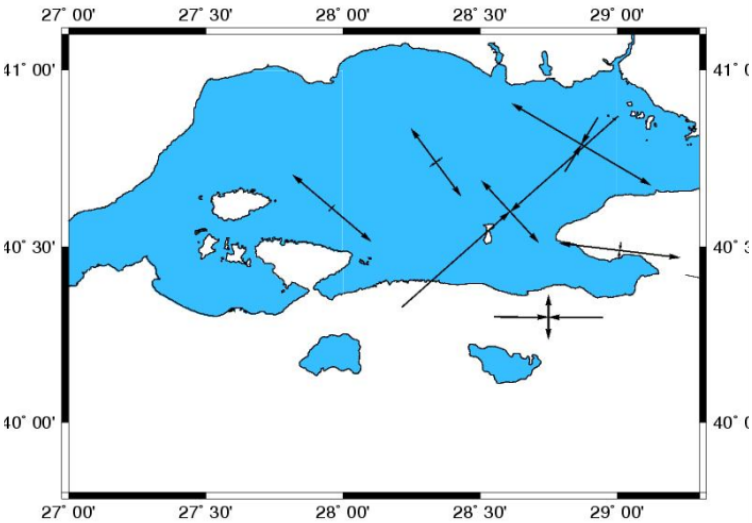

Figure 6: Extensions and compressions for whole region accepted as homogeneous

From the figure6, it can be seen that according to the calculations the compression at the BOZT-AVCT-KART triangle is very obvious.

5.2. Computation of Strain Parameters with Infinitesimal Method

This method is based on the measurements coordinate differences between a fixed point and its surroundings. Strain tensor parameters are calculated from adjusted coordinate differences. This method can be applied if the number of connections are more than three. dx and dy coordinate differences or deformation vector for each point can be measured from the general deformation equation.

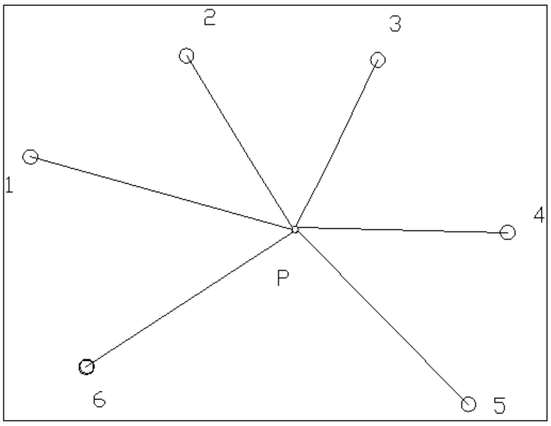

Figure 7: Point P and its surrounding points

$$dx_i = x_i e_{xx} + y_i e_{xy} + t_x \tag{6}$$

$$dy_i = x_i e_{yx} + y_i e_{yy} + t_y \tag{7}$$

With strain tensor parameters maksimum and minimum strain principle parameters and maksimum strain rotation can be calculated;

$$\varepsilon_1 = 0.5*(e_{xx} + e_{yy}) + \sqrt{(0.25*(e_{xx} + e_{yy})^2 + e_{xy}{}^2)} \tag{8}$$

$$\varepsilon_2 = 0.5*(e_{xx} + e_{yy}) - \sqrt{(0.25*(e_{xx} + e_{yy})^2 + e_{xy}{}^2)} \tag{9}$$

$$\beta = \arctan \frac{e_{xy}}{\varepsilon_1 - e_{xy}} \tag{10}$$

After all calculations were done for all points, the results are shown on table 5.

Table 5: Infinitesimal strain parameters

STATION ID	**Principle strain parameters**		**β (deg)**
	ε1 (μs)	**ε2 (μs)**	
KART	-0,16	-3,57	263,721
MER1	1,25	-0,48	648,121
AVCT	5,66	-0,31	413,968
BOZT	0,22	-0,08	603,227
ULUT	0,15	0,05	342,705
BAD1	0,70	-0,09	285,418

6. CONCLUSION

In this study, strain accumulation around the fault zones in western Marmara Region is calculated with two techniques as triangulation and infinitesimal strain model. Since the region has very complex tectonic characteristic, the strain parameters are calculated separately. ε_1 and ε_2 defines the principle strain parameters. Positive values of principle strain parameter refer extension, negative values refer compression. In Figure 6, the arrows show the extension and compression quantities. Additionaly, velocity of the stations at the northern branch of NAF at the Marmara Region have bigger displacements than the stations at the southern branch.

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