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Full Length Research Paper

Determination of strain accumulation in landslide areas with GPS measurements

Mustafa Acar

Department of Geomatics Engineering, Faculty of Engineering, Aksaray University, 68100 Aksaray, Turkey.
E-mail: acarmusta@gmail.com. Tel: +90 382 280 13 22. Fax: +90 382 280 13 65.

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People have suffered from past to present from natural events such as earthquakes, landslides, avalanches and floods that are called disasters. It is necessary to monitor ground movements in areas where disasters like landslides may occur in order to reduce and mitigate effects of such disasters which put people's lives at risk. Space-based positioning technologies including the global positioning system (GPS), which have been very popular in geodetic studies in recent years, and was used effectively in projects involving determination of strains such as the movements of the earth's crust and landslides thanks to the high precision, speed of measurement and comfort that they offer. The present study evaluated the GPS measurements that were carried out in the Gurpinar landslide area between 1996 and 1998 and intended to determine the horizontal movements of earth's crust and accumulation of strain using these data.

Key words: Landslides, strain, GPS, Gurpinar landslide area.

INTRODUCTION

It is necessary to monitor ground movements in areas where disasters like landslides may occur in order to mitigate and remove the effects of such disasters which put people's lives at risk. Therefore, this subject forms a significant area of study in geomatics engineering. Geodetic control networks that are established in the area of study and in places that may characterize the movements in the area are utilized in order to determine the crustal movements geodetically (Brunner et al., 1981; Tzenkov and Gospodinov, 2002; 2003). Geodetic control networks are established in areas that are seismologically active in order to monitor local movements of the earth's crust (Xu and Grafarend, 1995).

The measurements performed by the geodetic control networks that are established in the area are repeated at different times in order to determine strains. Repeated geodetic measurements are commonly used in determination of strain values of the earth's crust (Brunner et al., 1981). Moreover, the time intervals between the measurement periods are determined on the basis of the magnitude of the possible strains or the change in the forces that affects the structure. Developments experienced in measurements and calculations have made efforts of strain monitoring one of the prominent practices in geodesy. Today, space-based positioning technologies, especially the global positioning system (GPS), are used effectively in projects involving determination of the movements of the earth's crust, monitoring of landslides, controlling of the movements of the earth in mine enterprises and large-scale excavations and determining strains in engineering projects such as dams, bridges, highways, railways, ports etc.

Strain analysis is one of the methods employed in measurements of strain to determine geodetic data. Thanks to the strain calculations in areas of strain, and through determination of strain amounts and strain discharge time periods, it will be possible to determine how and what kind of strain and what these strains may cause and measures can be taken before hand in the case of various disasters. Losses of life and property can be prevented through knowledge of strain amounts and predictions that cause disasters such as earthquakes and landslides through strain analyses that are conducted in this manner (Kiranlioglu, 2006).

Despite the many advantages that the GPS technique provides users with, due to the geometrical weakness of the satellite system, inefficiencies of atmospheric modeling that is used during the evaluation process and sources of error that can not be eliminated, and the accuracy of the vertical component of the 3-dimensional (3D) positioning information is lower than that of the horizontal component (Featherstone et al., 1998; Denli, 1998; Krauter, 1999; Çelik et al., 2001, Erol, 2008). Therefore, two-dimensional (2D) strain tensors must be determined instead of 3D strain tensors and the vertical component must be handled separately (Denli, 1998). The present study evaluated the GPS measurements that were taken in the Gurpinar landslide area between 1996 and 1998 and aimed at determining the horizontal movements of the crustal and strain parameters using these data.

STRAIN ANALYSIS

Strain of objects can be expressed using the stress field that is applied on them. Accordingly, the subject of strain constitutes an important area of interest in geophysics and geodesy in order to obtain information about the stress fields on earth in terms of studies concerning strains of earth's crust, earthquakes, landslides, movements of deep masses etc. (Brunner, 1979). The concept of strain is closely related with the concept of displacement. To explain it in terms of coordinate change, we can say that, it is the proportion of transformations of coordinates in the direction of axes to those of the initial coordinates. Since, it is without a unit and basically expresses a ratio, it is also known as unit strain (Acar et al., 2008a; Url-1).

The strain that accumulates on the earth's crust can be determined using two methods, namely; using the seismic data and geodetic data. The expectation is that the results obtained from the methods should be in harmony with one another. The basic assumptions from geodetic data regarding the studies aimed at determining strains are as follows:

(i) Geodetic network points or geodynamic traverse stations characterize the area,
(ii) The displacements that occur in the area and the time period are linear and that strain accumulation is uniform (Deniz, 2007; Denli, 1998).

Strain analysis is the last stage in interpretation of in the crustal deformations. Homogeneous strain parameters can be obtained from the strain vectors calculated for the points of a geodetic network established in the research area or from the differences of the repeated observations made in these points (Deniz, 1997).

Since the geodetic network is evaluated according to the coordinate system, strain is determined in accordance with this coordinate system. To determine the strain tensor components, the measurements were carried out in the geodetic control network in the first and second periods are adjusted separately. The linear extension of a baseline between the two points of the network is expressed as;

$$\varepsilon = \frac{S' - S}{\Delta t . S} \qquad (1).$$

Here, S' expresses the length that has changed at the end of the Δt period while S expresses the unchanged length. On the other hand, the linear extension of a baseline whose azimuth is t is given as

$$\varepsilon = e_{xx} \cos^2 t + e_{xy} \sin 2t + e_{yy} \sin^2 t \qquad (2).$$

Here,
e_{xx} , is the change in the unit length in the direction of the x axis
e_{yy} , is the change in the unit length in the y axis and
e_{xy} , is the shear strain.

Components of the strain tensor are calculated using this basic correlation. There are two different applications for this purpose. The first concerns the division of the geodetic network into triangles and calculation of the components of the strain tensor for the area that each triangle covers (Figure 1). Three equations (2) are established for the three baselines of the triangle and e_{xx}, e_{xy} and e_{yy} are calculated.

The strain tensor components calculated for each triangle will be valid for equilibration of the triangle. The second method used in determining the strain tensor components using equation (2) concerns measurement from one point and creating of the basic equation to the other points and, if the baseline is more than three, there were calculation of strain tensor components through adjustment. Subsequently, strain parameters shown below could be calculated from the parameters of strain tensor (Deniz, 1997; Deniz and Ozener, 2008; Poyraz and Aydin, 2009).

$\Delta = e_{xx} + e_{yy}$ Dilatancy (3)

$\gamma_1 = e_{xx} - e_{yy}$ Principal shear strain (4)

$\gamma_2 = 2e_{xy}$ Engineering shear strain (5)

$\gamma = \gamma_1 + \gamma_2$ Total shear strain (6)

Principal strain parameters are calculated equations in below,

$E_1 = \Delta + \gamma$ Maximum principal shear strain (7)

$E_2 = \Delta - \gamma$ Minimum principal shear strain (8)

$\beta = \arctan\left(\frac{e_{xy}}{E_1 - e_{xy}}\right)$ Direction of maximum principal

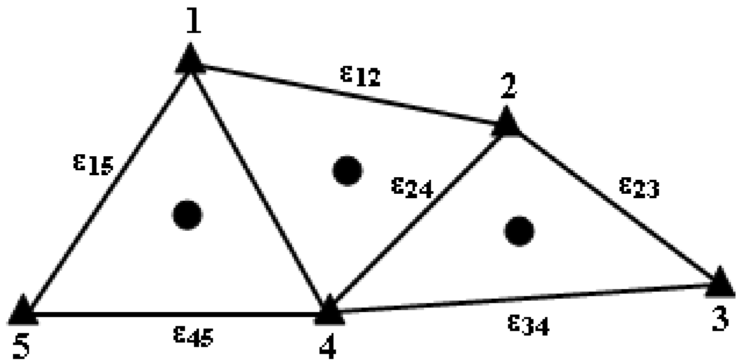

Figure 1. Sample network for calculating strain tensors.

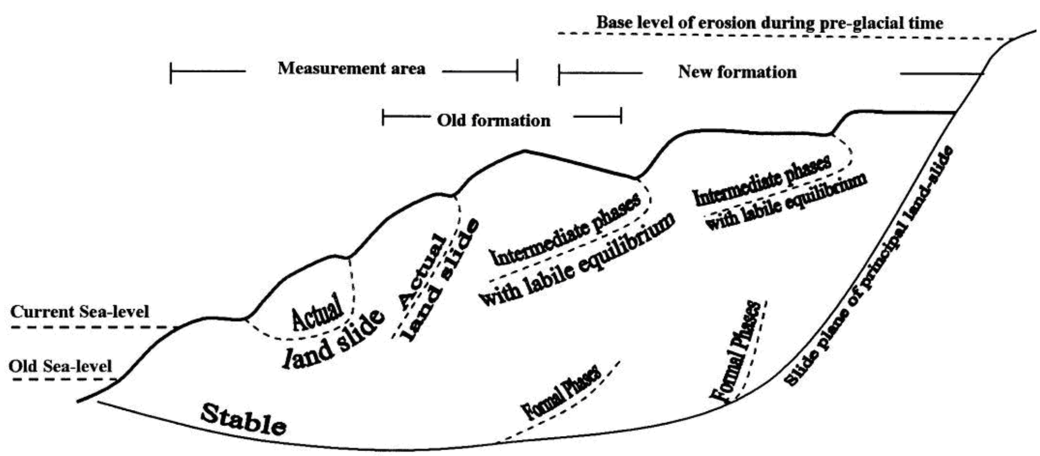

Figure 2. Landslide model for Buyukcekmece region (Altan et al., 1994).

shear strain arc

Application

The Gurpinar village landslide area in Buyukcekmece is an area where geological processes are continuing rapidly and therefore has become the subject of various studies. The area, which has an imposing view of the Marmara Sea, is a slope ending in the sea and an extremely appropriate area for housing construction. Accordingly, the area has undergone rapid development and many summer residences have been built. Therefore, studies have been conducted at different times and by different fields of science to determine the movements of earth that have occurred in the area due to landslides and to prevent landslides.

Geological characteristics of the area

The area where the study was conducted is a landslide area where an equilibrium slope is formed in a gradual manner. This equilibrium has been upset due to the small-scale particle shaped movements caused by surface waters and settlements in the area and as a result mass movements have occurred (Figure 2). Efforts have been spent in the area aimed at drainage in order to prevent movement of ground (Acar et al., 2008b; Acar et al., 2004; Altan et al., 1994).

The hillsides and slopes in areas especially in Gurpinar and Gungoren formations in Istanbul are potential sources of landslides (Siyahi et al., 2003). The Gurpinar Formation (GF), which exhibits outcrops in and around the settlement of Gurpinar constitutes the most problematic ground type in the greater Istanbul area. The outcrops of the area, which exhibits characteristics of a weak ground, extending along the banks of the Marmara Sea contain active mass movements of rotational slide type within a zone that is over 1 km in width. Construction of buildings must no way be allowed in the area and the area must be allocated as green space. Examples of large scale mass movements that have occurred in this zone area include the landslide zone to the south of the Buyuk Resit Pasa Farm, Fener landslides, Pekmez landslide (Gurpinar landslide zone), Pinarkent landslides

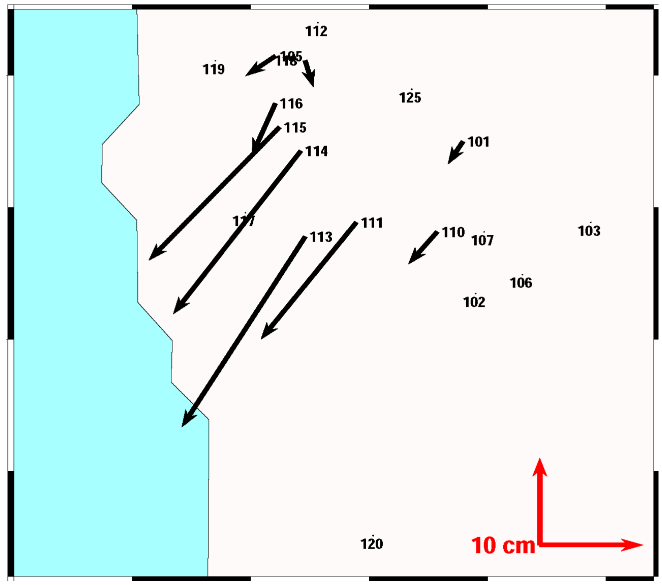

Figure 3. Horizontal displacements obtained by static model.

and lastly, Devebagirtan landslide. Due to the fact that these phenomena of geological origin, and the efforts aimed at improvement of the ground to establish stability will not be sufficient.

The clays and tuffs that form the unit in outcrops outside this zone are of benthonitic nature and hence, are highly plastic because they swell when they absorb water; therefore, it is inevitable that high rise buildings that will be constructed on them will be subjected to various degrees of damage due to different settlements. Considerable cracks and fractures are visible in the high rise buildings in the cooperatives area in the Gurpinar country that have occurred as a result of such events. Moreover, liquidation caused by a severe earthquake is a very important phenomenon that should be considered due to the fact that sand lens in the unit carry water (Url-2).

GPS MEASUREMENTS AND NUMERICAL EXAMPLE

The area where the landslide monitoring project was carried out were located in the Gurpinar village that is, to the Northwest of Istanbul. In the area, without doing proper geotechnical investigations of some buildings, mostly, where weekend houses had been built. But after the construction work had been completed, many damages on the constructions took place as a result of landslides. In order to investigate the effects of landslides in and around the settlement area, the project has been realized.

For this purpose, in the landslide area, a strain network consisting of 18 points was established. The point locations had been chosen to be stable and the landslide areas according to the geological structure of the ground. The geodetic measurements was used in the project were GPS measurements were carried out in four periods between July 1996 - March 1998. In this study, the measurements of the periods July 1996 - March 1997 have been evaluated.

The GPS data was collected in rapid static mode using 6 Leica SR399 and 4 Trimble SSI receivers. In all the periods, 2 sessions of GPS observations (10 min at each point) were realized (Acar et al., 2003). In addition, Figures in this study were drawn by Generic Mapping Tools (Wessel and Smith, 1991; 1995a; 1995b; 1998). By evaluating the adjusted coordinates and variance-covariance matrix, the static deformation analysis on the network points has been carried out. The horizontal displacements obtained through static deformation model are shown Figure 3. The control network in the research area was divided into 28 triangles using the Delaunay method to calculate strain parameters (Figure 4). Different strain parameter components of e_{xx}, e_{yy}, and e_{xy} were calculated for each triangle. The components that were calculated are given in Table 1.

Conclusion

Crustal movements and occurred deformation by their effects and strains are determined with geodetic and geological methods. Geodetic methods are preferred that strain parameters can be obtained in short time span with geodetic observations. In this study, strain analysis procedure has been applied using GPS data in a landslide

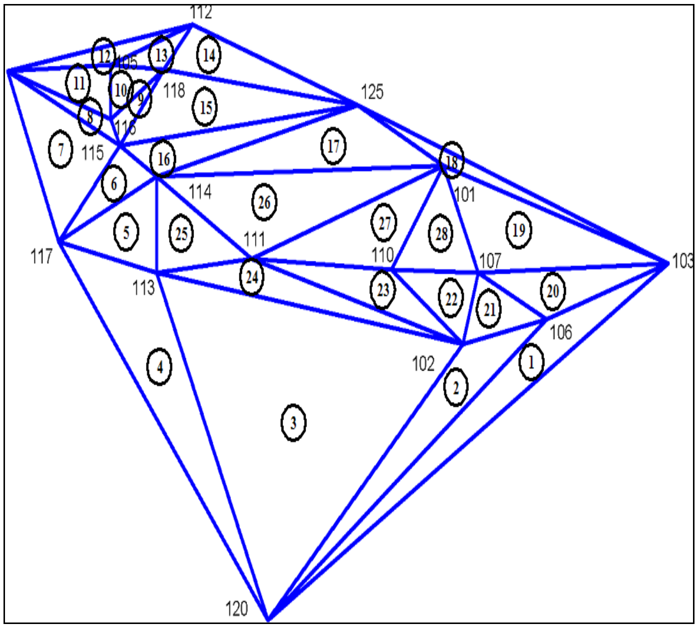

Figure 4. Triangle scheme of gurpinar landslide area.

Table 1. Calculated strain parameters in Gurpinar.

Number of triangle	$e_{xx}.10^{-6}$	$e_{yy}.10^{-6}$	$e_{xy}.10^{-6}$
1	-9.59	-132.45	32.32
2	9.38	71.39	-97.99
3	9.38	-453.44	252.53
4	108.75	2693.22	-618.69
5	21.39	1898.39	467.53
6	283.81	1474.01	223.33
7	108.75	2693.22	-618.69
8	-20.59	-3709.32	914.88
9	-1041.81	1381	1315.83
10	217.02	-97.59	-443.36
11	216.02	60.17	42.97
12	216.02	-836.45	-208.3
13	217.02	41.96	469.44
14	-158.76	-101.08	-165.48
15	-158.76	-1046	251.11
16	-877.37	284.24	-182.42
17	-877.37	20.31	152.57
18	39.18	-1388.99	34.89
19	26.56	-24.22	-64.84
20	48.7	-6.53	48.57
21	48.7	-72.66	19.5
22	-377.41	-25.35	132.81
23	-573.67	-168.66	-312.27
24	-826.58	173.1	30.88
25	-826.58	76.75	-7.64
26	-9.29	-532.04	-144.5
27	-573.67	5.39	225.02
28	26.56	-418.98	-21.2

area and 2D tectonic movements can be determined by strain analysis depending on the obtained results that, Gurpinar landslide area is still active and the intensive crustal movements occurs in the middle of slope area.

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