Latest Results of Landslide Monitoring Project in Harbor of Ambarli Region

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Key words: Landslide, Deformation Monitoring, Geodetic Techniques, GPS

SUMMARY

Landslide is an important problem occurring and causing natural catastrophes frequently. Landslide may cause considerable damage on the engineering structures such as buildings, roads, dams, subways and harbors etc. Therefore, monitoring and solving the mechanism of landslides are very important for preventing and reducing their negative effects. Deformation monitoring techniques measured by several methods such as periodical conventional geodetic surveying methods or by the use of electronic sensors have been used successfully in monitoring of the landslides. Recent developments in Global Positioning System (GPS) provide reliable and precise monitoring at the millimeter level in 3D positioning.
In this study, the landslide monitoring project performed in the Harbor of Ambarli region, between October 1999 and October 2010, is introduced. The region is a custom and also includes several industrial buildings.
Aim of the project is to monitor horizontal and vertical movements of the region periodically using GPS technique. The deformation network is measured periodically every 3 months via dual frequency GPS receivers. In addition to the geodetic methods, geotechnical studies are also performed in many drilling wells, which have inclinometers, piezometers and settlement gauges. Geotechnical measurements are performed every month. Adjusted 3D coordinates are obtained for every period by means of the post-processing of the GPS data. Then, the displacement vectors are calculated by comparing the last period with reference period for the position and height. The results show that, there have been significant movements on some deformation points in horizontal as well height. The results agree with the geotechnical measurements.

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1. INTRODUCTION

Monitoring, identifying and defining the geometric changes are very important for engineering structures. Results of deformations directly concern with the human life and safety (Kalkan, 2007, Kalkan and Alkan, 2006). Concerning of monitoring issue is increasing recently.

The measurements for determining both the crustal movements and geometric changes on engineering structures are called deformation measurements. Evaluation and interpretation of these measurements to determine deformations are referred deformation analysis. Deformations are monitored by geodetic and non-geodetic methods. Geodetic deformation monitoring method is based on the evaluation of the classical or satellite-based measurements on the control networks.

Photogrammetric method (remote sensing methods) and geotechnical methods using some special tools (inclinometer, Piezometer, settlement column, strangage, extensometer, etc.) are the examples for non-geodetic techniques. Similar analysis techniques are used in all of these methods.

Landslide is defined as "the movement of mass of rock, debris or earth down a slope" (Cruden and Varnes, 1996). They are also referred as mass movements, slope failures, slope-instability and terrain instability. Landslides are natural events leading to significant loss of life and property. Monitoring the landslides is one of the deformation monitoring types that used different surveying techniques (Kalkan et al., 2002).

Many studies are been carried out in many parts of the world for monitoring of landslides and possible prevention or reduction in line losses (Ahmad et al.,1999; Barberalla et al.,1988; Çelik et al.,1999; Glowacka et al., 2001; Hartinger et al.,2000; Kalkan et al., 2005; Kalkan et al., 2001, Vichas et al.,2001).

In this study, landslides and landslide monitoring and application techniques are mentioned briefly. Also the landslide monitoring project on harbor of Ambarli region which carried out since 1999 and the results are outlined.

2. GPS TECHNIQUE

Nowadays, Global Positioning System (GPS) is the most commonly used satellite-based positioning system (Alkan et al., 2005). The purpose of GPS measurements is to determine the coordinates of object points selected to represent the landslide in the region and calculate the displacement vectors for each point by special analysis methods using the differences between the periods. GPS method is successfully used for high accuracy monitoring of the continental movements, amount of horizontal and vertical movements of major engineering structures such as viaducts, dams, bridges, high buildings. Therefore, GPS method was chosen for the landslide monitoring project for taking into consideration issues such as of ease of use, working independent of weather conditions and day light, not requiring of viewing the points each other and meeting the required accuracy of the measurements.

Double frequency GPS receivers were used in the project. GPS measurements were performed by the faculty members of Department of Geomatics Engineering adhering to the GPS surveying plan which applied on earlier periods. The measurements were performed in separate time periods on the main reference network, the deformation network and on the connection points of these two networks. Data were obtained from the satellites over 10 degrees and recorded in 5 seconds epoch. Static method was applied for the measurements. Figure 1 shows the main network canvas and figure 2 shows the canvas including all points.

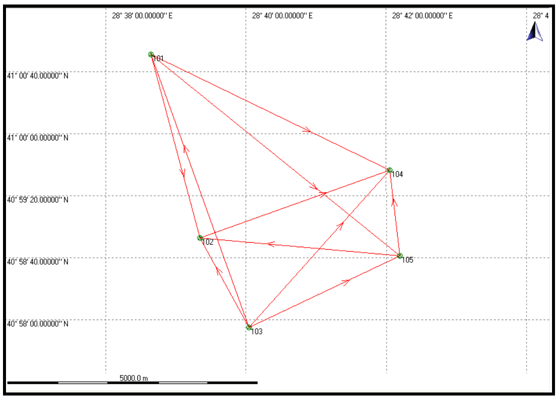


Figure 1. Main network canvas

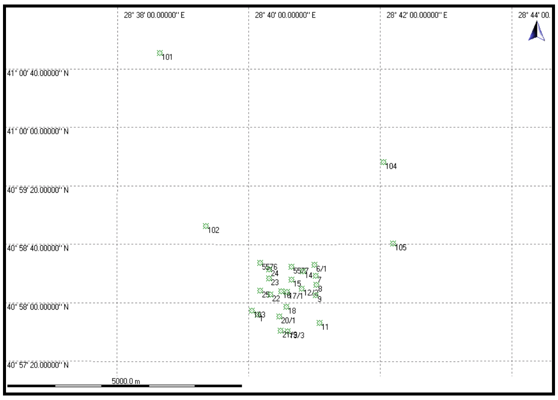


Figure 2. Main network and deformation points

3. LANDSLIDE MONITORING METHODS AND SURVEYING INSTRUMENTS

Landslide is a geological phenomenon and includes the movement of soil, debris, stone or rocks down on a surface. Landslides are classified and given specific names due to the speed of movement and type of material (Figure 3) (URL1).

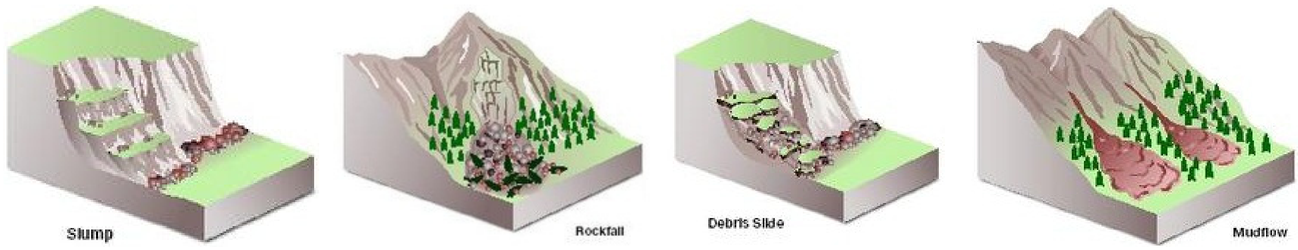


Figure 3. Examples of landslide types

Table 1. Geodetic deformation monitoring methods and surveying instruments & equipments

Geodetic Methods	Instruments and Equipments
Alignment Surveys	Theodolite, Laser Optic, Invar Wires…etc.
Conventional Surveys	Total Station, Theodolite and Electronic Distance Measurement Instruments (EDM)
Satellite Base Surveys	GPS, GLONASS and GALILEO Receivers
Precise Trigonometric Leveling	Precise Total Station, Theodolite and EDM
Precise Geometric Leveling	Precision Leveling Equipment
Laser Scanner Technique	Laser Scanner
Interferometry SAR Image Technique	Processing of SAR Satellite Images

Geodetic and non-geodetic methods are used for monitoring the deformations. Geodetic method includes many surveying techniques listed on table 1.

Deformation networks are used for monitoring horizontal and vertical deformations. Position changes on the deformation and surrounding area are defined relatively, due to the reference points. These points are established on the areas which expected no deformation. Deformation networks include deformation (objects) points and reference points (Figure 4).

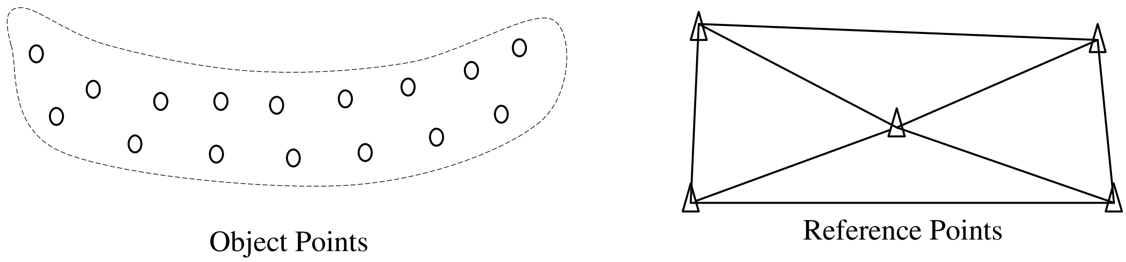


Figure 4. Geodetic deformation monitoring networks

Surveying type, surveying period and related standards of geodetic method differs due to the type and character of the expected deformation (USACE, 2002). Not only horizontal and vertical deformations, but also, mass changes, groundwater level changes, strains, temperature changes are monitored by using several instruments on non-geodetic methods (Table 2).

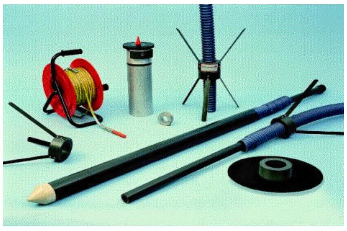
Table 2. Non-geodetic Methods and Surveying Instruments

Non-Geodetic Methods	Instruments
Slope Measurement	Inclinometer
Movement Measurement	Settlement Column
Pore Water Measurement	Piezometer

Those listed above are known as standpipe and wired instruments. Most important advantages of these instruments are easy to read, easy to automate and reliable to collecting data in remote centers.

Inclinometers are widely used for monitoring slope and landslide movements. Settlement columns are used to measure the settlement of one or more points at different depth along the vertical line. Piezometer is used for monitoring groundwater level or pore water pressure in fully or partly saturated soils (Figure 5a, 5b, 5c) (URL-2).


(a) Inclinometer


(b) Settlement Column

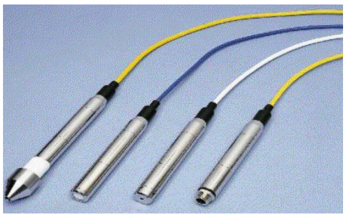

(c) Piezometer

Figure 5a, 5b, 5c. Surveying instruments for non-geodetic method

4. AMBARLI HARBOR and MONITORING PROJECT

The monitoring of landslide project was applied in Ambarli Harbor region in Beylikduzu district of Istanbul city, Turkey. (Figure 6-7).


Figure 6. Ambarli Harbor region and reference network


Figure 7. Deformation (object) network

Geodetic and non-geodetic measurements of the project have been performed by Istanbul Technical University (ITU), Department of Geomatics Engineering and Department of Civil Engineering from September 1999. The project is carried out with cooperation of Turkish General Directorate of Disaster Affairs and supported by Altas Ambarli Harbor Management

Inc. Solving the mechanism of landslide and defining the potential risk of landslides in the port area are aimed in the project.

The reference network on the solid grounds including 5 points (Figure 6) and the deformation network in the region including 23 points (Figure 7-8) were established in the project.

Furthermore, 15 exploration wells were drilled at the appropriate places ranging between 20 m and 50 m depths in order to solve the mechanism of the landslide, to define the soil profile and the geometry of the landslide region. 9 inclinometers, 3 piezometers and 3 magnetic settlement columns were located to these wells and the measurements were performed at monthly periods. 29 periods of measurement (0, 1, 2, ... 28, 29) were carried out on the GPS network till March 2011.

The results of 0 period performed in October 1999 and 1st period performed in February 2000 were compared statistically for reference network and some movements are detected. No significant move was identified for the points on reference network on the later periods. This movement was related to the Duzce-Kaynasli earthquake with 7.2 magnitudes and Istanbul earthquake with 5.8 magnitudes. For this reason 1st period was accepted as the base period instead of 0 period for comparing.

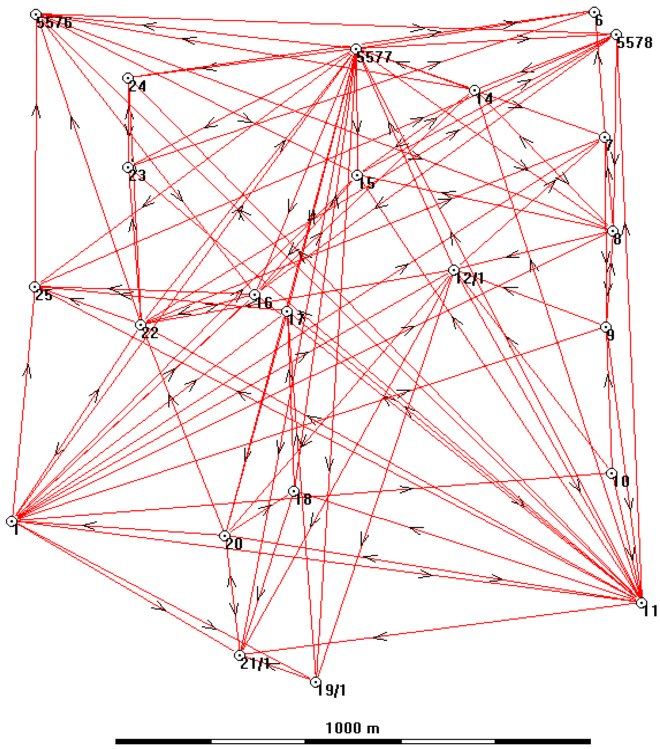


Figure 8. Deformation network formed by deformation points

In this study the results of 1st period and 29th period were compared and displacement vectors were created. In this way, significant movements on deformation points were investigated by comparing the results of the periods. The results are summarized on figure 9, figure 10 and table 3. Also some specific samples including significant movements were given from the results of earlier periods.

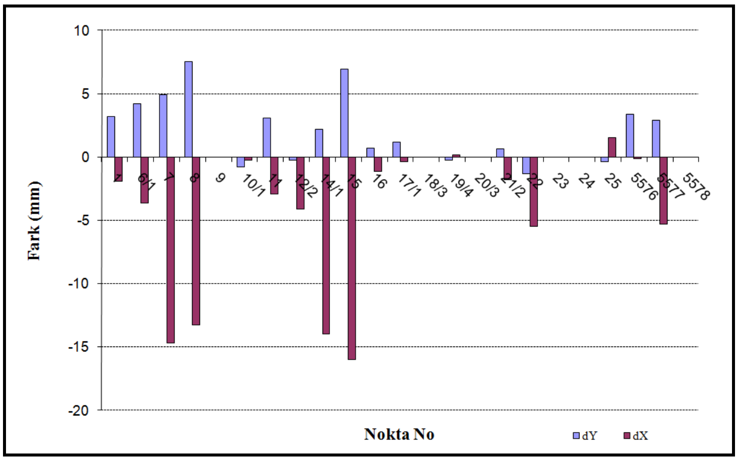


Figure 9. Displacement vectors in X and Y direction for deformation points (October 2010 results)

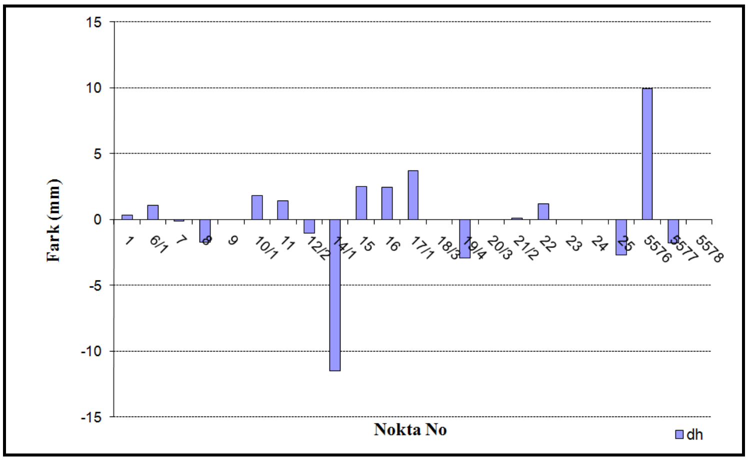


Figure 10. Displacement vectors for GPS height for deformation points (October 2010 results)

Since the beginning of the project, the largest horizontal and vertical movements were determined on 23rd and 24th points. But these movements were nearly stopped after 14th period (Figure 11). Landslide prevention structures built before the 14th period have been supposed as the major reason for stopping of these significant movements.

The measurements of the 9 inclinometers established on pre-defined areas were performed monthly and collected and stored by data collectors in order to determine the mechanism of landslide movement in the region.

Table 3. Displacement vectors for each point and limit values (October 2010 results)

Point	*Location*		Movement	*Height*		Movement
	Displacement Vector $d_p(*)$ (cm)	Limit Value D_p (cm)		Displacement Vector $d_h(*)$ (cm)	Limit Value D_h (cm)	
1	3.7	0.4	**Yes**	0.3	0.5	**-**
6/1	5.6	1.4	**Yes**	1.1	2.4	**-**
7	15.5	1.0	**Yes**	-0.1	1.2	**-**
8	15.3	0.6	**Yes**	-1.7	0.9	**Yes**
9	-	-	**-**	-	-	**-**
10/1	0.8	1.2	**-**	1.8	1.6	**Yes**
11	4.2	0.5	**Yes**	1.4	0.7	**Yes**
12/2	4.1	0.6	**Yes**	-1.0	1.0	**-**
14/1	14.1	6.4	**Yes**	-11.5	10.6	**Yes**
15	17.4	0.6	**Yes**	2.5	1.1	**Yes**
16	1.3	0.6	**Yes**	2.5	1.1	**Yes**
17/1	1.2	7.0	**-**	3.7	11.1	**-**
18/3	-	-	**-**	-	-	**--**
19/4	0.3	9.7	**-**	-2.9	14.5	**-**
20/3	-	-	**-**	-	-	**--**
21/2	1.9	1.0	**Yes**	0.1	1.8	**-**
22	5.7	0.7	**Yes**	1.2	0.8	**Yes**
23/1	-	-	**-**	-	-	**-**
24	-	-	**-**	-	-	**-**
25	1.6	0.8	**Yes**	-2.7	1.0	**Yes**
5576	3.4	0.4	**Yes**	9.9	0.7	**Yes**
5577	6.0	0.6	**Yes**	-1.8	0.7	**Yes**
5578	-	-	**-**	-	-	**-**

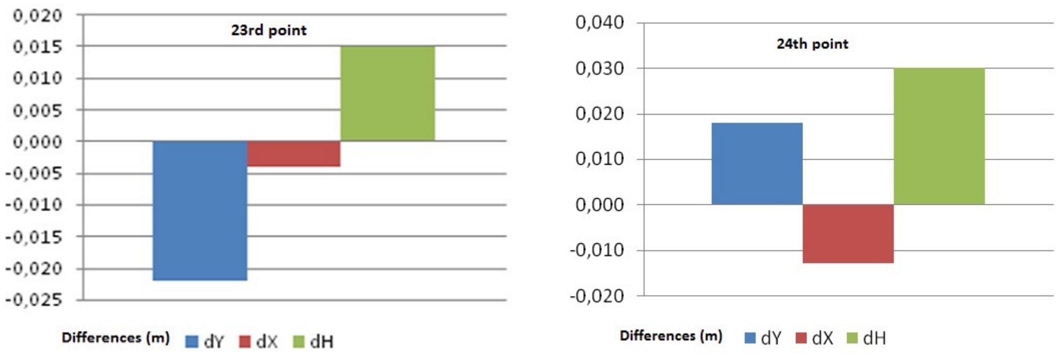
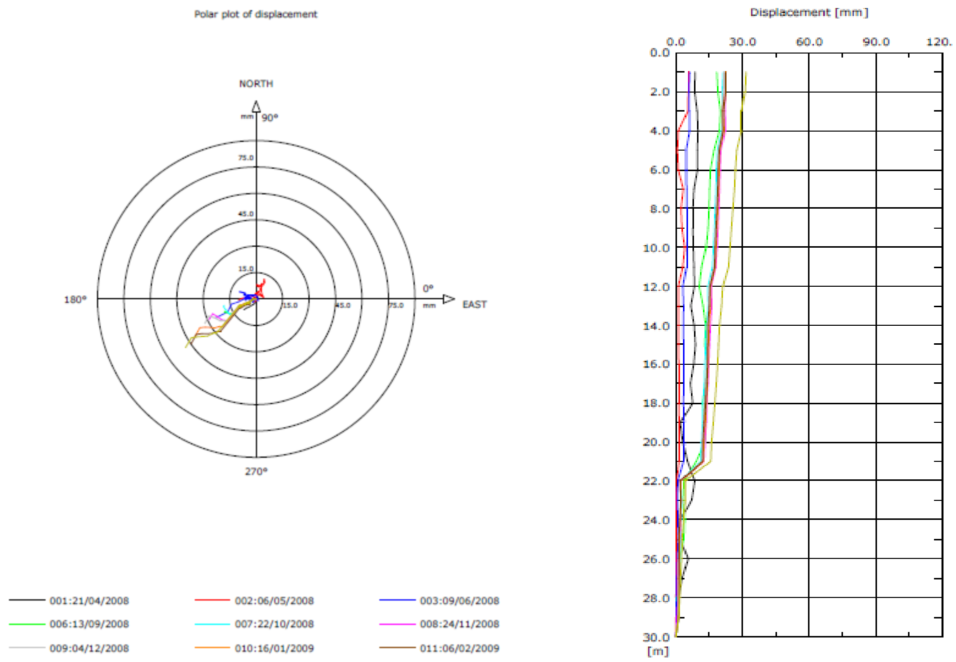


Figure 11. The differences between 25^{th} and 14^{th} periods for the points 23 and 24

The slope changes measured were processed by computer software and the results were converted to horizontal deformation values. At the end of this process, the direction and amount of movements on polar diagram, movements in the direction of the Y and X axes, total resultant movements and the slip angles were obtained and drawn as a special form of diagrams. Total motion and polar motion diagrams of the Altas 22 well inclinometer measurements occurred between April 2008 and February 2009 were given as a sample output in figure 12 and 13. 22 mm deformation has occurred on this inclinometer in February 2009. Increasing of this movement was detected from 22 m towards to upper level of the well. Amount of the movement was more than 30 mm in March 2009.



Horizontal

Vertical

Figure 12. Polar and displacement diagrams obtained from inclinometer measurements

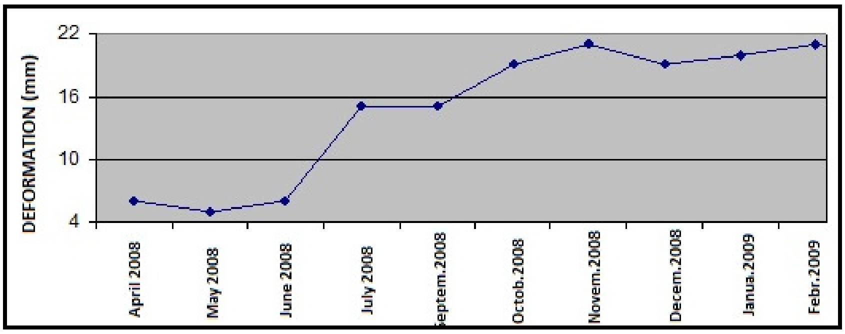


Figure 13. The monthly deformations in Altas 22 well between 2008 and 2009

The changes on the pressure of pore water were measured by 4 sensors on each 3 piezometers located in several depth wells. Results show that the pressure of pore water was changing due to the rains and drainage of the ground. These pressure change amounts were big on the levels near to the surface and small at the bottom levels.

Magnetic settlement columns for monitoring vertical movements on the ground were measured at monthly periods and obtained the results of ground settlements at different levels. The measurements obtained from 4 different depths at each wells were processed and the settlement-time graphs were drawn. The ring depth for 1^{st} magnetic settlement column is ring-1 is 3.2 m, ring-2 is 9.1 m, ring-3 is 15.7 m and ring-4 is 19.4 m. The vertical movements for the ring-2 between March 2008 and March 2009 were given graphically on figure 14 as a sample output. A decreasing settlement 2 cm between March and June, an instant increasing by 2 cm between June and July, an instant settlement by 2 cm on August, a increasing by 1 cm on September, a settlement by 1 cm on January, a increasing by more than 2 cm between January and February and decreasing to the same level of January on March can be seen by evaluating the graph.

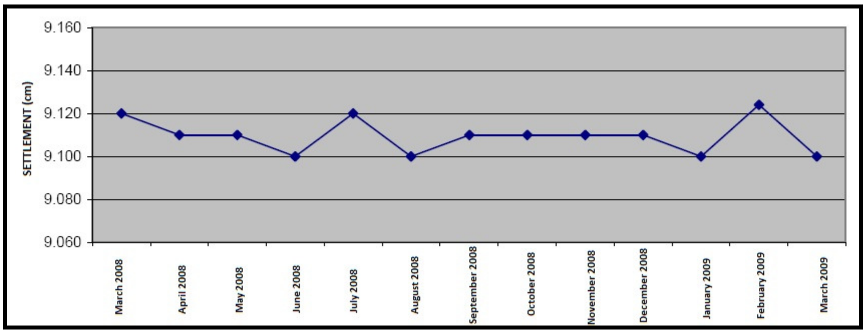


Figure 14. Settlement-time graph occurred in ring-2 for the 1st magnetic settlement column

5. RESULTS

The monitoring of deformations using GPS has widely used like conventional techniques in geodetic methods. Furthermore inclinometer, strangage, extensometer, magnetometer, laser line measurement tools...etc is used for monitoring the landslide deformations especially. In order to provide safety, well planned and implemented geodetic and non-geodetic monitoring is very essential for landslide deformations.

In this study, the results of Ambarli Harbor region landslide monitoring project which carried out since 1999 were outlined including 29 periods. The biggest movements are 134 cm horizontal and 29 cm vertical movement on the deformation point 24. But these movements were nearly stopped after 14th period by preventing structures. The biggest movement in horizontal direction is 2.2 cm and in vertical direction is 3 cm on the same deformation point obtained on later periods. Similar results for same directions are obtained using the inclinometer measurements in parallel with the GPS results.

Solving the landslide mechanism is very important for the settlement areas. Otherwise, unsuitable projects are constructed on these sliding grounds. Some sliding levels were defined on the wells which had 30 m depths in the deformation project region. Also 20 m pile foundations and retaining walls were proposed for some parts of the region. It has determined that these deformation preventing structures could be prevent the landslide using the long term results.

At the end of 29th period measurements and evaluations, local seasonal movements in the region have been continued in some places, depending on the load changes and the movement reaches to nearly dm unit at several points.

REFERENCES

1. Ahmad, R., McCalpin, J.P., 1999. Landslide Susceptibility Maps for Kingston Metropolitan Area, Jamaica, Publication No.5, Unit for Disaster Studies, University of the West Indies, Mona, Kingston 7, Jamaica.
2. Alkan, R.M., Kalkan, Y., Bilgi, S., 2005. Forming The Geodetic Infrastructure of Engineering Projects by GPS and Different Leveling Methods, International Symposium on Modern Technologies, Education and Professional Practice in Geodesy And Related Fields, Sofia, Bulgaria.
3. Barbarella, M., Bitelli,G., Folloni,G., 1988. Deformation Surveys of Landslides Using Terrestrial Measurements and Space Techniques, 5. International (FIG) Symposium on Deformation Measurement and 5. Canadian Symposium on Mining Surveying and Rock Deformation Measurements. Proceedings 6-9, Frederiction, New Brunswick, Canada.
4. Cruden D.M., Varnes D. J., 1996. Landslide types and processes. In: Turner A.K.; Shuster R.L. (eds) Landslides: Investigation and Mitigation. Transp Res Board, Spec Rep 247, pp 36-75.
5. Çelik,R.N., Ayan,T., Denli H.H., Ozludemir T., 1999. Land Sliding Monitoring Using GPS and Conventional Techniques in Gurpınar, Third Turkish-German Joint Geodetic Days, pp. 839-848, İstanbul/Turkey.
6. Glowacka, E., Gonzalez, J.J., Nava F.A. Farfan F., Díaz de Cossio G, 2001. Monitoring Surface Deformation in the Mexicali Valley, B.C., Mexico. 10. FIG International Symposium on Deformation Measurements, pp. 175-179, California, USA.
7. Hartinger, H. Brunner, F. K., 2000. Development of a Monitoring System of Lanslide Motions Using GPS, Proc. of 9th FIG International Symposium on Deformation Measurements, pp.29-38, Olsztyn, Poland.
8. Kalkan, Y., 2007. "Atatürk Barajında Jeodezik Yöntemlerle Deformasyonların İzlenmesi", Technical Report, General Directorate of DSI, Ankara.
9. Kalkan, Y., Alkan, R.M., 2006. Mühendislik Yapılarında Deformasyon Ölçmeleri, 2nd Natinoal Engineering Surveying Symposium, 23-25 Kasım 2006, pp. 64-74, İstanbul.
10. Kalkan, Y., Alkan, R. M., Yanalak, M. Erden, T. ve Bilgi, S., 2005-2009. Landslide Monitoring Project of Ambarli Harbor with Geodetic and Geotechnic Methods, Technical Report, Istanbul Technical University Foundation, Istanbul.
11. Kalkan, Y., Baykal, O. Alkan, R. M. Yanalak M. ve Erden, T., 2002. Deformation Monitoring with Geodetic and Geotechnical Methods: Case Study in Ambarli Region, Proc. of the International Symposium on Geographic Information Systems, pp. 354-364, Istanbul, Turkey.
12. Kalkan, Y., Alkan, R.M., Yanalak, M., Tari, E. and Erden, T., 2001. Landslide Monitoring Project of Ambarli Harbor with Geodestic and Geotechnic Methods, Technical Report, Istanbul Technical University Foundation, Istanbul.
13. USACE, 2002. Engineering and Design Structural Deformation Surveying (EM 110-2-1009) Department of the Army US Army Corps of Engineers, Washington, DC 20314-1000.
14. Vichas,C., Skourtis,C., Stiros,S., 2001. Kinematics of Landslide Over the Polyphyton

Reservoir (Greece), 10. FIG International Symposium on Deformation Measurements, pp. 71-76, California, USA.
15. URL1, http://www.scienceclarified.com, visited: March-2011
16. URL2, http://www.sisgeo.com, Sisgeo Inc. web page, visited: March-2011

BIOGRAPHICAL NOTES

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