

Deformation Monitoring Studies at Atatürk Dam

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Key words: Atatürk Dam, Deformation Monitoring, Geodetic and Non-geodetic Techniques

SUMMARY

The importance of water and water structures are increasing recently. This situation is more considerable for such countries like Turkey that are located within the middle zone of the world. The dams are one of the most important engineering structures that used for water supply, flood control, agricultural uses, drinking and hydroelectric power. Turkey has approximately 550 large dams. Dams are very large and critical structures and they demand application of precise monitoring surveying at regular intervals. Monitoring is an essential component of the dam after construction and during operation and must enable the timely detection of any behavior that could deteriorate the dam, potentially result in its shutdown or failure. Considering the time and labor consumed by long-term measurements, processing and analysis of measured data, importance of the horizontal and vertical small structural motions at regular intervals could be comprehended. In this study, brief information is given about Atatürk Dam. Moreover, methods of geodetic and non-geodetic monitoring measurements are mentioned. Especially geodetic monitoring methods are emphasized and also some of new measuring techniques are recommended. The study generates several important results. One of them, which have been subject to this paper, is to determine whether, the deformation of the dam embankment is caused by the level of reservoir water or not.

ÖZET

Suyun önemi her geçen gün daha da artmaktadır. Özellikle, Türkiye gibi orta kuşakta bulunan ülkeler için bu durum daha da önemlidir. Barajlar, suyun biriktirilmesi, taşkın koruma, sulama, içme ve enerji üretimi amacıyla kullanılan en önemli mühendislik projelerinden bir tanesidir. Ülkemizde yaklaşık 550 adet büyük baraj bulunmaktadır. Barajlar büyük ve kritik yapılardır ve bu yapıların düzenli aralıklarla presizyonlu deformasyon izleme yöntemleri ile izlenmesi gerekmektedir. Barajın yıkılmasına yol açabilecek herhangi bir hareketin tespit edilebilmesi amacıyla, barajın inşasından işletilme sürecine kadar deformasyonların izlenmesi gereklidir. Uzun dönem ölçmeler için harcanan emek ve zaman, ölçülen verilerin değerlendirilmesi ve analizi göz önüne alındığında ufak çaplı yatay ve düşey yapısal hareketlerin önemi daha iyi anlaşılabilir. Bu çalışmada, Atatürk Barajı hakkında özet bilgi verilmiş, jeodezik ve jeodezik olmayan deformasyon izleme yöntemlerinden bahsedilmiştir. Özellikle jeodezik izleme yöntemleri vurgulanarak yeni bir takım ölçme teknikleri önerilmiştir. Çalışma birkaç önemli sonuca değinmektedir. Bu çalışmanın da konusu olan sonuçlardan bir tanesi, baraj rezervuarındaki suyun seviyesinde meydana gelen değişimlerin baraj gövdesindeki deformasyona etkisinin olup olmadığıdır.

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1. INTRODUCTION

Necessity to water is increasing day by day with respect to the World population, rising of living standards and destruction of nature. Mission of the water structures is controlling of water and producing energy. The dams are one of the important engineering structures which are used for water supply, flood control, agricultural uses, drinking and industrial purposes like hydroelectric.

Due to increasing energy requirement, higher dams are built. This situation also brought great risks to public safety living near to the dam in case of natural hazards. In order to provide safety, well planned and implemented geodetic and non-geodetic monitoring is very essential for such engineering structures.

Dams can be constructed having more than 300 meters crest height and more than 200 million m³ reservoir capacity, today. Highest dam is Rogun Dam in Tajikistan with 335 m crest height. Synrude Tailings Dam in Canada has the largest reservoir capacity with 540 billion m³. Itaipu Dam, on the boundary of Brazil and Paraguay, has the biggest hydroelectricity power capacity (URL 1). However, Three Gorges Dam in China will be the biggest dam in World in near future having the biggest hydroelectricity power capacity. There are about 550 dams in Turkey having International criteria (URL 3 and URL 4). World's largest and highest dams are shown on Table 1.

Table 1: World's Largest and Highest Dams

Dam	Location	Volume (1000x) cu m	Dam	Location	Structural height (m)
Three Gorges	China	39,300,000	Rogun	Tajikistan	335
Synrude Tailings	Canada	540,000	Nurek	Tajikistan	300
Chapetón	Argentina	296,200	Xiaowan	China	292
Pati	Argentina	238,180	Grande Dixence	Switzerland	285
New Cornelia Tailings	United States	209,500	Inguri	Georgia	272
Tarbela	Pakistan	121,720	Vaiont	Italy	262
Kambaratinsk	Kyrgyzstan	112,200	Manuel M. Torres	Mexico	261
Fort Peck	Montana	96,049	Tehri	India	261
Lower Usuma	Nigeria	93,000	Álvaro Obregón	Mexico	260
Cipasang	Indonesia	90,000	Mauvoisin	Switzerland	250
Atatürk	Turkey	84,500	Alberto Lleras	Colombia	243

Source: URL 2

Deformation measurements have an important status among various engineering surveying. Results of deformations directly concern with the human life and safety (Kalkan and Alkan, 2006, Kalkan, 2007). Earthfill dams are subject to external loads that induce deformations to the structure and the foundations. The self-weight of a dam and the reservoir water pressure are primarily responsible for the increase of stresses within the dam body, which in time result

in horizontal and vertical displacements, mostly of a permanent character (Gikas and Sakellariou, 2008).

In this study, brief information is given about Atatürk Dam and methods of geodetic and non-geodetic monitoring surveying, which have been measured by Istanbul Technical University (ITU), Department of Geomatics from May 2006 with cooperation of Turkish General Directorate of State Hydraulic Works (DSI), are mentioned. Especially geodetic monitoring methods are emphasized and also some of new measuring techniques are recommended.

2. ATATÜRK DAM

Atatürk Dam is the biggest dam in Turkey. The dam is a part of GAP Project (South-East Anatolian Project) and built at Şanlıurfa city, located on Fırat River (Figure 1). It is one of the five dams constructed on the river. The dam has great importance including especially irrigation and hydroelectric power. Atatürk is an earth-rockfill dam. Some characteristics of the dam are given in Table 2.



Figure 1. Location of Atatürk Dam in Turkey

Table 2. Some Characteristics of Atatürk Dam

Location	Şanlıurfa/Turkey
River	Fırat
Construction year	1983 - 1992
Dam volume	84500 hm ³
Height (from river bed)	169 m
Reservoir volume	48700 hm ³
Reservoir area	817 km ²
Irrigation Area	872385 ha
Capacity	2400 MW
Annual Generation	8.9 billion KWh



Geodetic monitoring of the dam, has been maintaining since 1990. Points and some equipment are placed on dam foundation, embankment, concrete structures, side berms, power station and galleries. Recent geodetic surveying have been performed by Istanbul Technical University (ITU), Department of Geomatics from May 2006 with cooperation of Turkish General Directorate of State Hydraulic Works (DSI). Either geodetic measurements, non-geodetic measurements like pore water, temperature, slope, displacement, strain and crack measurements are maintained also (Kalkan, 2009, Kalkan, 2007 and Bilgi, 2006).

3. DEFORMATION MONITORING

Dams are loaded with different factors. Deformations can exist both on dam and near area. Structure of dam, weight of embankment and water, water pressure, temperature changes, crustal movements are the reasons of deformations. These factors can cause geometric changes by the way of horizontal and vertical small structural displacements and physical changes. These geometric and physical changes have to be monitored and defined whether significant or not. Thus, safety, efficiency and life of the structure can be increased.

3.1 Deformation Monitoring Methods

Geodetic and non-geodetic methods are used for monitoring the deformations. Geodetic method includes many surveying techniques listed on Table 3.

Table 3. Geodetic Deformation Monitoring Methods and Surveying Instruments & Equipments

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

Generally, deformation networks are used for monitoring horizontal and vertical deformations. Position changes on dam embankment and surroundings are defined relatively to the reference points. These points are established on the areas which expected no deformation. Deformation networks include reference points and object/deformation points usually (Figure 2).

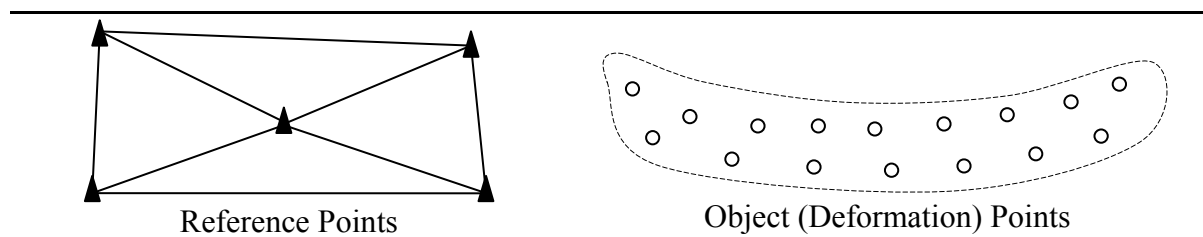


Figure 2. Geodetic Deformation Monitoring Network

Surveying type, surveying period and related standards of geodetic method differs due to the type of the dam, character of the expected deformation amount (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 4). Those listed below are known as standpipe and wired instruments.

Table 4. Non-geodetic Methods and Surveying Instruments

Non-Geodetic Methods	Instruments
Slope Measurement	Inclinometer
Displacement Measurement	Settlement Column
Length Change Measurement	Extensometer
Pore Water Measurement	Piezometer
Vertical Displacement Measurement	Reversed Pendulum
Grouting Measurement	Joint meter
Crack Measurement	Crack meter

4. GEODETIC MONITORING of DEFORMATIONS

Reference network was created on the surrounding area of the dam with 32 triangulation points (survey pillars). Deformation network has 360 benchmarks. Moreover, two leveling network exist on dam crest (36 benchmarks) and power station (45 benchmarks).

GPS Network: As a supplement to the conventional geodetic surveying, GPS surveying is performed on the geodetic monitoring network which is formed in the beginning of the monitoring project. 7 benchmarks forms the GPS network located outer area of reference network. These points are established on far surrounding area of the dam and on strong ground. These benchmarks are scattered into 7x9 km area (Figure 3a). Other 25 benchmarks were designed for conventional surveying. These are scattered to 4x5 km area and located as properly surrounding the dam embankment and near surrounding area (Figure 3b). Some of these benchmarks are also used for measuring of object points on dam embankment and surrounding area.

Deformation Network (formed with object points): Deformation network with 400 benchmarks are designed for monitoring dam embankment, side berms and galleries (Technical Report, 2004). There are more than 200 benchmarks on embankment (Figure4).

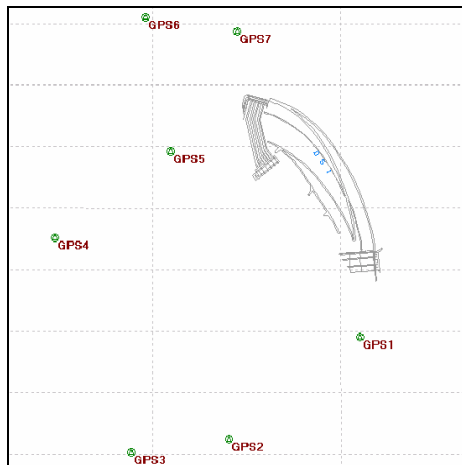


Figure 3a. GPS Network

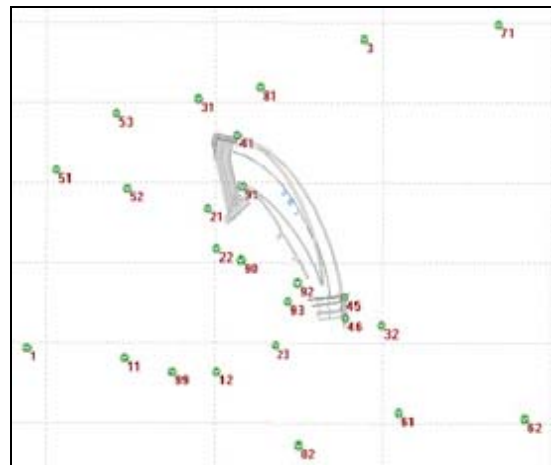


Figure 3b. Conventional Network

Figure 3(a,b). Reference Network of Atatürk Dam

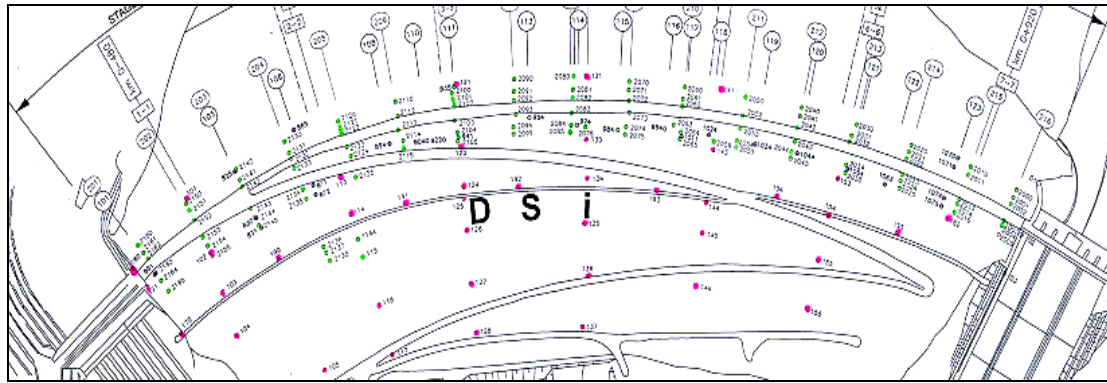
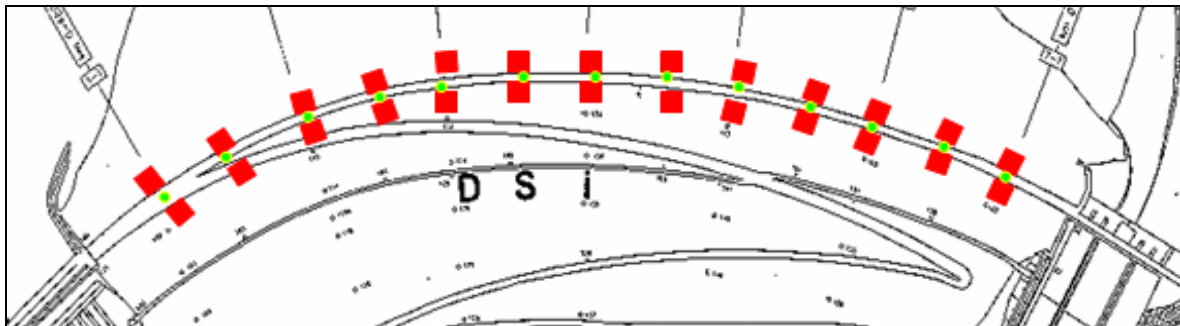
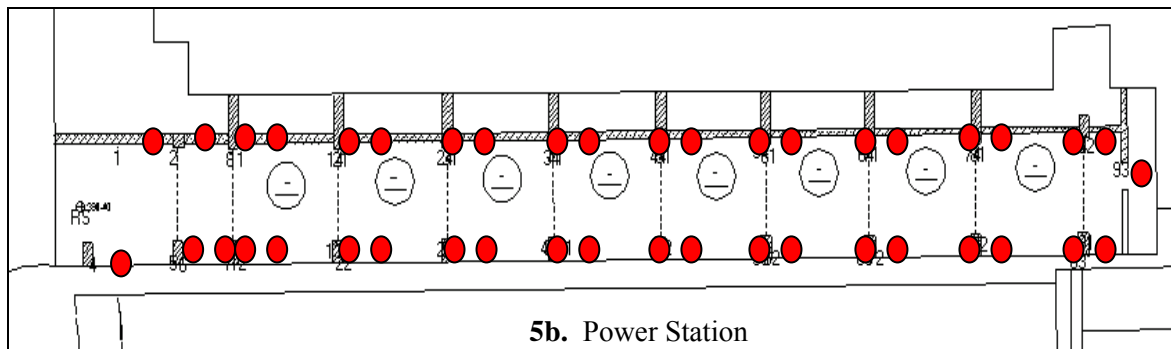


Figure 4. Object Points on Dam Embankment

Precise Leveling Network: One leveling network exists on dam embankment with 36 benchmarks, along the dam crest. Other leveling network is positioned inner and outer of the power station and includes 45 benchmarks (Figure 5a and 5b). Precision leveling (geometric) method was applied for determining the height differences between the benchmarks in the power station. These surveys have been performed in monthly periods. The benchmarks in the power station are designed as wall points and located on bearing columns. The surveying on wall points has been performed two times per year with precise leveling method.



5a. Dam Embankment



5b. Power Station

Figure 5 (a,b). Precise Leveling Network on Dam Crest and in Power Station

High precision theodolites and EDMs for conventional surveying, double frequency GPS receivers for GPS surveying and digital precise level for leveling measurement are used in monitoring project. Used instruments and equipments are given on Table 5a and 5b.

Table 5a. Surveying and GPS Instruments

Instrument	Number	Model	Institute
High Precision Theodolites	3	Leica T2002 Leica T3000	ITU DSI
Electronic Distance Measure (EDM) Instruments	2	Leica DI 3000	ITU and DSI
High Precision Digital Level	1	Leica DNA 03	DSI
GPS Receiver	3	Ashtech Z-Xtreme	ITU
GPS Receiver	3	Thales Z-Max	ITU
GPS Receiver	7	Topcon Hiper GGD&PLUS	ITU and DSI
GPS Antenna	3	Ashtech Z-Xtreme Geodetic Antenna IV	ITU
GPS Antenna	3	Thales Z-Max Antenna	ITU

Table 5b. Other Equipments

Equipment	Number	Institute
Barcoded Invar Rod	2	ITU and DSI
Orange Formed Circular Target for Survey Pillars	36	ITU and DSI
Observation Plaque	25	DSI
Single Prism	12	ITU
Three-Prism	8	ITU

4.1 GPS Surveying

GPS technology is used many engineering applications efficiently today (Kalkan et al, 2002, Kalkan et al, 2003). It can be used for measuring the surface deformations associated with earthquakes, steady flow of huge masses of ice, in weather forecasting, measuring the slow and rapid deformations of the Earth's crust (URL 5). The Global Positioning System (GPS) provides a valuable tool for monitoring geospatial deformations, and thereby aids in understanding the complex structural and tectonic mechanisms related to the interaction of the water reservoir and the body of the dam (Gikas et al., 2005). High accuracies can be achieved with relatively little effort, unlike conventional terrestrial techniques (URL 6).

Supplementary to the conventional geodetic surveying, GPS surveying are performed from May 2007. The first campaign is performed in between DOYs 125-130. GPS surveying is performed in six days at six stages in six consecutive days. For combining six stages, some stations were measured more than one times in order to link the daily measurements. The duration of measurement in each day was about 8 hours with an interval of 5 seconds. Each station was observed at least one day. Data sampling of 5 seconds and elevation mask of 10° are used throughout the campaign. In order to get precise antenna heights, four height measurements are performed at each station. The GPS instruments and equipments used in the project are determined in detail in Table 5a. Some pictures of GPS surveying and surveying plan are shown on Figure 6.

After the process and adjustment of GPS surveying, a few mm internal accuracy values were obtained for the coordinate components of WGS 84 Ellipsoid.

Static method GPS surveying is observed on 55 different points of the dam embankment for testing whether GPS method can be used or not. As a result, convenient outcomes were

obtained. Static method GPS surveying due to 4 fixed pillars is performed on nearly all points on the embankment for the following periods (Figure 7).



Figure 6. GPS Surveying and Surveying Plan

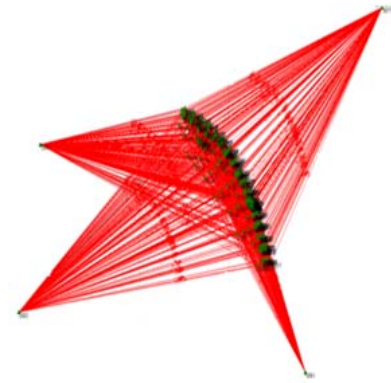
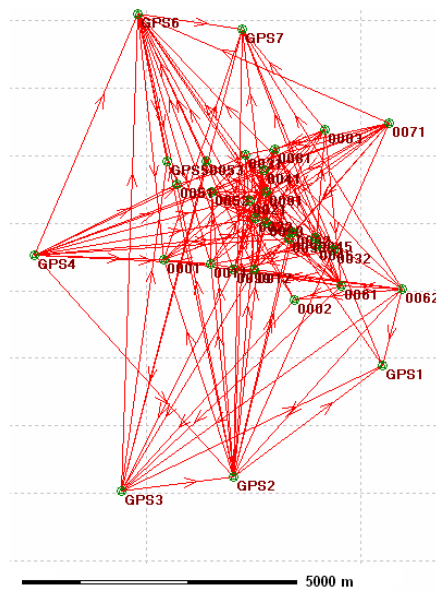


Figure 7. GPS Surveying Plan for Embankment Points

4.2 Conventional Surveying

Precise horizontal and vertical angle and distance measurements were performed to more than 200 object points using 9 pillars for relating the object and reference points. A few mm point position accuracy was obtained after the adjustment of each period measurements with appropriate stochastic model. Point position accuracy is less than 1 cm for the deformation points on the dam embankment.

Measurement results of six periods performed by ITU were compared. Stochastic model test was applied at first for double period comparing for the evaluation of the results, whether in a same set or not. m_1 and m_2 are mean square values of unit measure belong to the first and second period. Test value ($f = m_1^2/m_2^2$) due to Fisher Distribution was calculated with 0.05 probability. Whether F is table value ($f_N < F_N$) for triangulation network and ($f_T < F_T$) for all network were calculated. Compared two periods in a same set was tested. An accuracy criterion of displacement vectors was calculated by double period analysis between the periods in the case of evaluation in a same set. The value ($dP_i > T_i$ or $dR_i > T_i$) derived from test value $T_i = 2,5 * (2)^{0,5} * (Mp_i)$ was used for the differences obtained whether significant or not. The displacement vectors drawn for the all points on embankment are given on Figure 8. GPS results between 3rd period (May 2007) and 5th period (Nov 2008) were compared with each other, for nearly all embankment points. The results for position changes are given graphically on Figure 9.

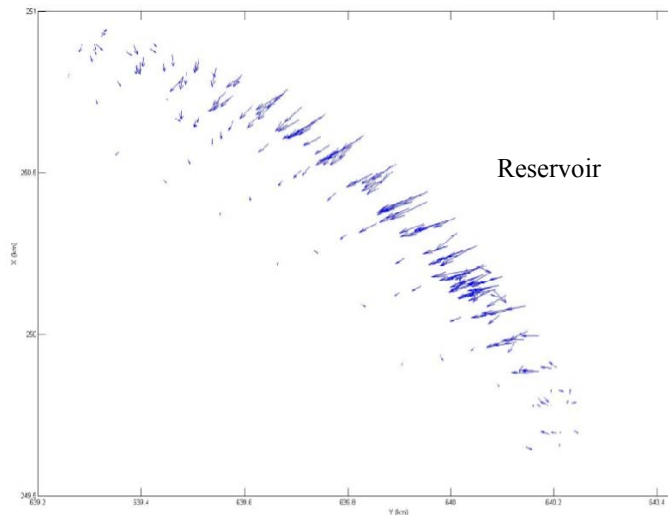


Figure 8. Displacement Vectors for the Points on Embankment Between May 2006-November 2008

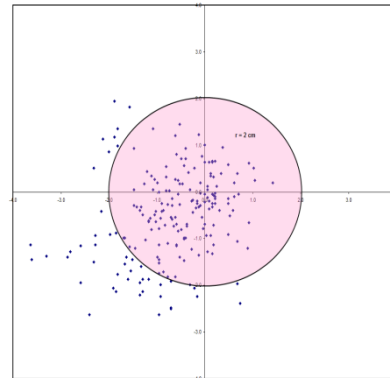


Figure 9. The Comparison of Point Positions Obtained From GPS on the Embankment (May 2007-Nov 2008)

4.3 Precision Leveling Measurement

The results of precision leveling measurement on dam crest performed monthly periods are shown graphically on Figure 10 for every six periods.

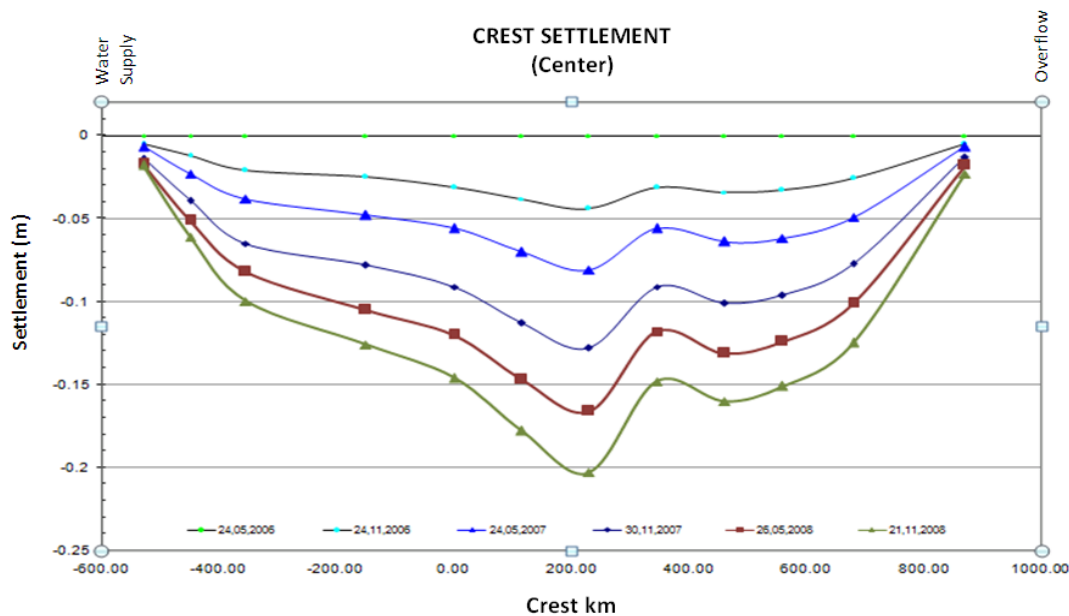


Figure 10. Settlement Graphic on Dam Crest Between May 2006 and November 2008

0+230 section has the biggest displacements. Dependent on the changes on water level, vertical displacement and the monthly average velocity on the dam crest are given on Table 6 and shown on Figure 11 graphically.

Table 6. Dependency to the Water Level on Reservoir, Vertical Displacement and Monthly Average Velocity on the Dam Crest (Section 0+230)

Period	Date Interval of Surveying	Changes on Water Level (m)	Vertical Displacement on Crest (mm)	Average Velocity on Crest (mm/month)
1 st Six Months	May 06 – Nov 06	-1.48	-44	7.3
2 nd Six Months	Nov 06 – May 07	+0.22	-37	6.2
3 rd Six Months	May 07 - Nov 07	-4.05	-47	7.8
4 th Six Months	Nov 07 – May 08	-0.53	-38	6.3
5 th Six Months	May 08 - Nov 08	-2.62	-37	6.2

Total vertical displacement and monthly average velocity dependent on the reservoir water level for 30 months is defined and shown below.

Period	Date Interval of Surveying	Changes on Water Level (m)	Vertical Displacement on Crest (mm)	Average Velocity on Crest (mm/month)
30 Month	May 06 - Nov 08	-8.46 m	-203 mm	6.8 mm

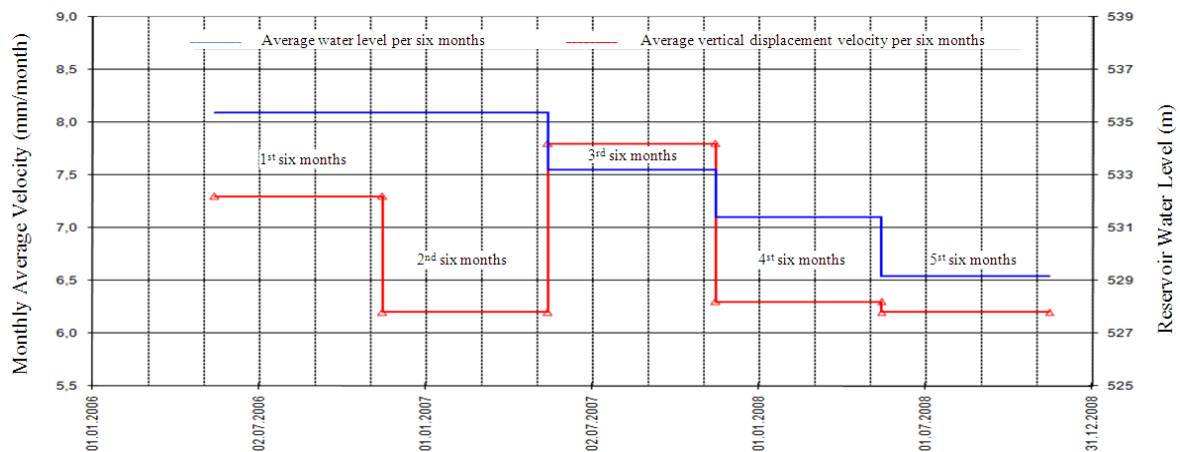


Figure 11. Average Water Level and Monthly Average Settlement Graphics Per Six Months, Between May 2006 and November 2008

5. CONCLUSION

Atatürk Dam, which has a strong substructure, has been monitored continuously using geodetic and non-geodetic techniques since 1990. According to the results of 6th period performed on November 2008, totally displacements were defined between May 2006 and November 2008. There are horizontal displacements on 63%, vertical displacements on 31% and radial displacement (perpendicular component to the crest axis) 59% on the deformation points. The biggest displacement on horizontal direction is 9.9 cm (radial direction is 9.8 cm) and vertical direction is 11.6 cm between May 2006 and November 2008. Biggest displacement vectors defined for the points on embankment is given on Table 7.

Three dimensional coordinates of the points could be defined accurately using GPS technique. The results obtained from conventional and GPS surveying were consistent with each other. GPS technique can be used instead of conventional surveying. For monitoring dam and near

surrounding, position accuracy **less than $\pm 1\text{cm}$** is sufficient for earth-rockfill dams such as Atatürk Dam. But it is difficult to say this situation for height accuracy yet.

Table 7. Displacement Vectors and Significance Test

Point Name	DY _i (cm)	DX _i (cm)	dP _i (cm)	Mp _i (cm)	Md _H (cm)	D _H (cm)	dH _i (dm)	dR _i (dm)	Bearing (grad)	Orientation (grad)	e+400 (grad)	dR _i (cm)	T _i (cm)
2082	-8.19	-5.47	9.85	1.56	1.27	4.48	-0.83	0.98	262.513	-4.49	395.513	9.82	5.51
2112	-6.18	-6.60	9.04	1.48	1.09	3.85	-0.51	0.90	247.909	-0.09	399.909	9.04	5.22
2056B	-8.53	-2.56	8.91	0.62	0.69	2.43	-0.78	0.89	281.438	6.44	6.438	8.86	2.20
4080	-4.84	-7.02	8.53	0.77	0.68	2.40	-0.65	0.85	238.427	-5.57	394.427	8.49	2.71
4050	-6.70	-5.05	8.39	1.00	1.05	3.71	-0.97	0.83	258.882	-8.12	391.882	8.32	3.52
4070	-4.49	-6.90	8.23	0.83	0.79	2.78	-0.66	0.80	236.726	-15.27	384.726	8.00	2.94

According to the results obtained from the measurements between May 2006 and November 2008 during three years, the vertical displacement (settlement) is not dependent to the water level on the reservoir. This important result will be supported also with new measurements on new periods during the monitoring project.

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BIOGRAPHICAL NOTES

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