DEFORMATION MONITORING of ATATÜRK DAM

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Keywords

Atatürk Dam, Deformation Monitoring, Geodetic Techniques, Non-geodetic Techniques.

Abstract

The importance of water and water structures are increasing recently. This situation is more considerable for such countries like Turkey which has location in middle zone of the world. The dams are one of the important engineering structures that used for water supply, flood control, agricultural uses, drinking and hydroelectric power. Turkey has about 550 large dams. Dams are very large and critical structures and they demand application of precise monitoring methods at regular intervals. Monitoring is an essential component of the dams.

In this study, brief information is given about Atatürk Dam. In addition, methods of geodetic and non-geodetic monitoring measurements is mentioned. Especially geodetic monitoring methods are emphasized and also some of new measuring techniques recommended.

Atatürk Dam is one of the five dams constructed on Fırat River. The dam has great importance including especially irrigation and hydroelectric power.

1. Introduction

Necessity to water is increasing day by day with respect to the World population, rising of living standards and destruction of nature. This situation is more considerable for such countries like Turkey which has location in the middle zone of World, also having limited water sources.

One of the important 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. But this situation also brought great risks to public safety living near to the dam in case of natural hazards (earthquakes, floods …etc.). In order to provide safety, well planned and implemented geodetic and non-geodetic monitoring is very essential for such structures.

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). More than 150.000 dams exist in World according to the literature (Akarun, 1983). Especially after the Second World War, higher and larger capacity dams are constructed. Nowadays, dams can be constructed with more than 300 meters embankment and more than 200 million m^3 capacity.

Today, highest dam is Rogun Dam/Tajikistan with 335 m height and largest capacity dam is Synrude Tailings Dam/Canada with 540 billion m^3 in World. Itaipu Dam has the biggest hydroelectricity power in Brazil and Paraguay boundary (URL 1). But in near future Three

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Gorges Dam will be the biggest dam in World for hydroelectricity power. There are about 550 big dams in Turkey having International criteria (URL 2 and URL 3).
In this study, brief information is given about the dams and monitoring techniques are mentioned. Especially the geodetic monitoring of the dam and the results are mentioned which has been measured by Istanbul Technical University (ITU), Department of Geodesy and Photogrammetry Engineering, Division of Surveying Technique from May 2006 with cooperation of Turkish General Directorate of State Hydraulic Works (DSI).

2. Deformation Monitoring of Dams

Dams are critical engineering structures which are loaded with different factors. Deformations can be 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 be cause geometric 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 are increased.

2.1 Deformation Monitoring Methods

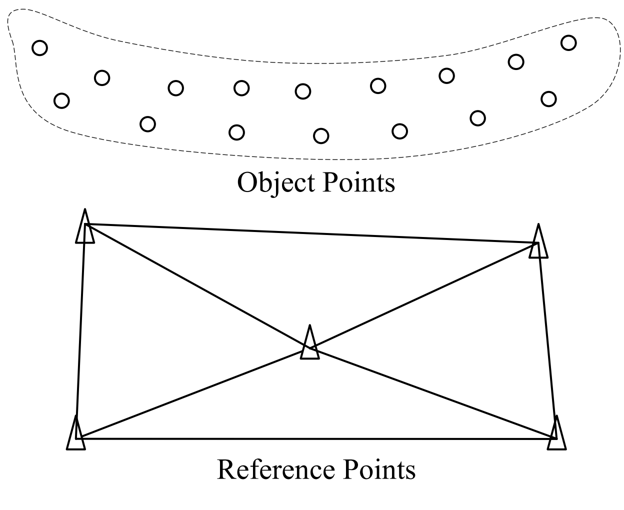
Geodetic and non-geodetic methods are used for monitoring the deformations. Geodetic method includes many surveying techniques listed on table 1.

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 Tech.	• Processing of SAR Satellite Images

Generally, deformation networks are used for monitoring horizontal and vertical deformations. Position changes on dam embankment and surroundings are defined relatively, due to the reference points. These points are established on the areas which expected no deformation. Deformation networks include Objects/Deformation Points and Reference Points usually (Figure 1).

Figure 1. 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 (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
• 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

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. Piezometers are used for monitoring groundwater level or pore water pressure in fully or partly saturated soils (Figure 2a, 2b,2c).

Figure 2a, 2b, 2c. Non-geodetic Surveying Instruments

(a) Inclinometer (b) Settlement Column (c) Piezometer

3. Atatürk Dam and Deformation Monitoring

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 3). Type of the dam is rockfill. The height from the river bed is 169 m (from the foundation is 184 m). The power station is started in 1993; its capacity is 8.9 billion KWh per year (URL 2). Some characteristics of Atatürk Dam are given in Table 3.

Figure 3. Location of Atatürk Dam in Turkey and a Satellite Image

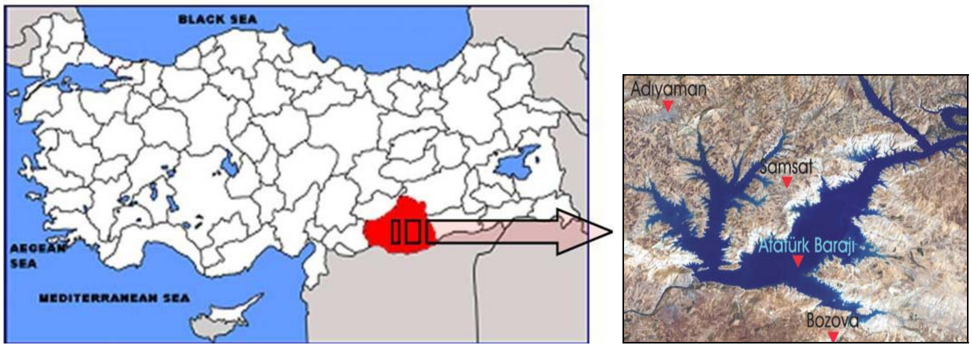


Table 3. Some characteristics of Atatürk Dam

Location	Şanlıurfa
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 Atatürk Dam, has been maintaining since 1990. Points and some equipments are placed on dam foundation, embankment, concrete structures, side berms, power station and galleries. Recent geodetic measurements has been performed by Istanbul Technical University (ITU), Department of Geodesy and Photogrammetry Engineering, Division of Surveying Technique from May 2006 with cooperation of Turkish General Directorate of State Hydraulic Works (DSI). Either geodetic measurements, pore water, temperature, slope, displacement, strain and crack measurements are maintained also (Kalkan, 2007 and Bilgi, 2006).

3.1 Geodetic Monitoring of Deformations on Atatürk Dam

Reference network was created with 32 triangulation points (survey pillars) on surrounding area. 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 measurements, GPS measurements are performed on the geodetic monitoring network which is formed in the beginning of the monitoring project. 7 benchmarks located outer of reference network form the GPS network. These points are established on far surrounding area and on strong ground. These benchmarks are scattered into 7x9 km area (Figure 4a).

Figure 4(a,b). Atatürk Dam Reference Network

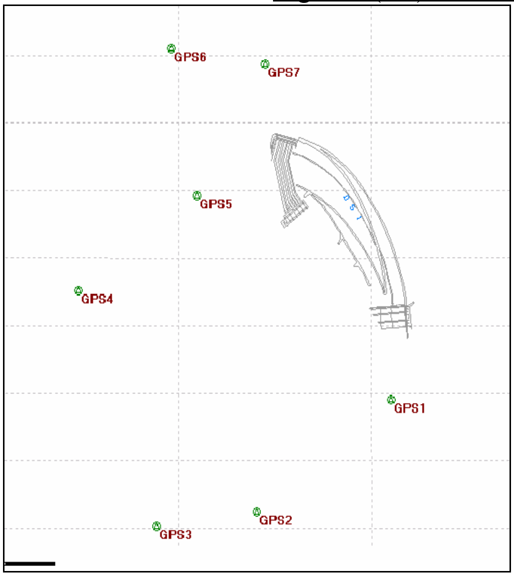


Figure 4 (a): GPS Network

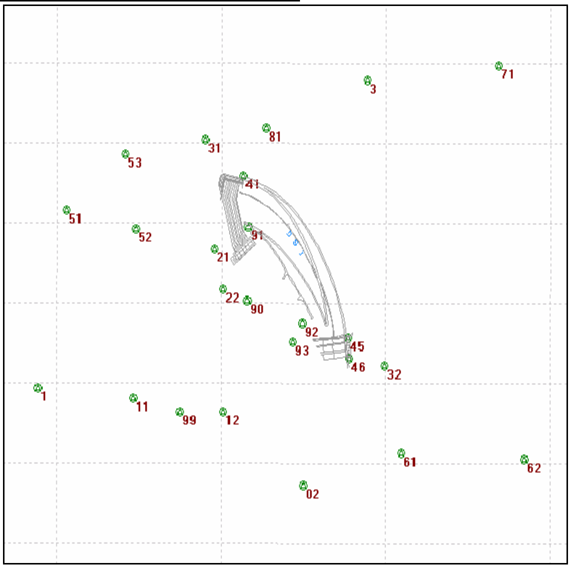
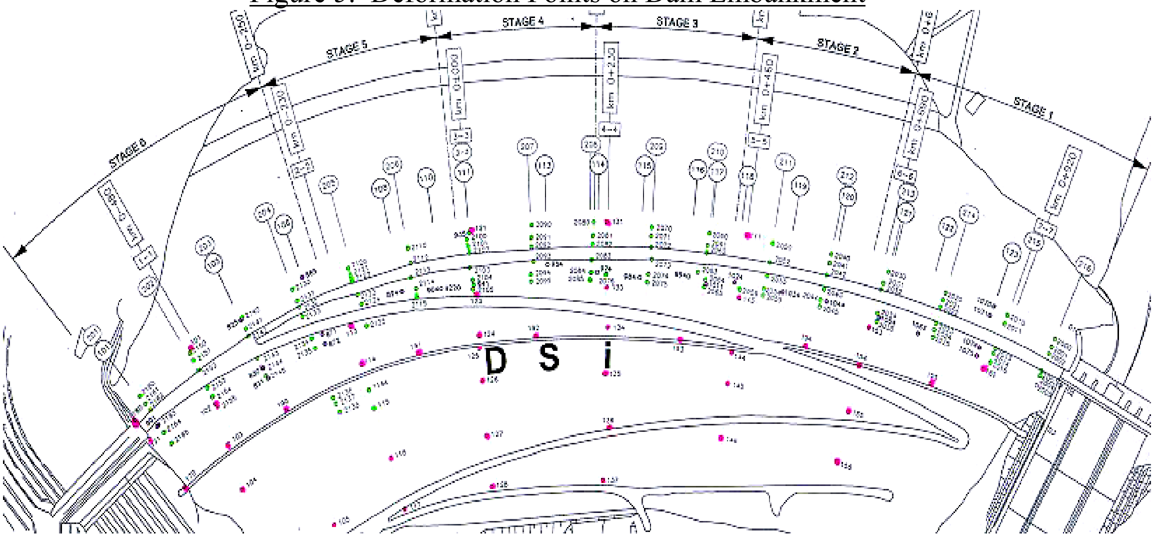


Figure 4 (b): Conventional Network

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 4b). Some of these benchmarks are also used for measuring of deformation points on dam embankment and surrounding area.

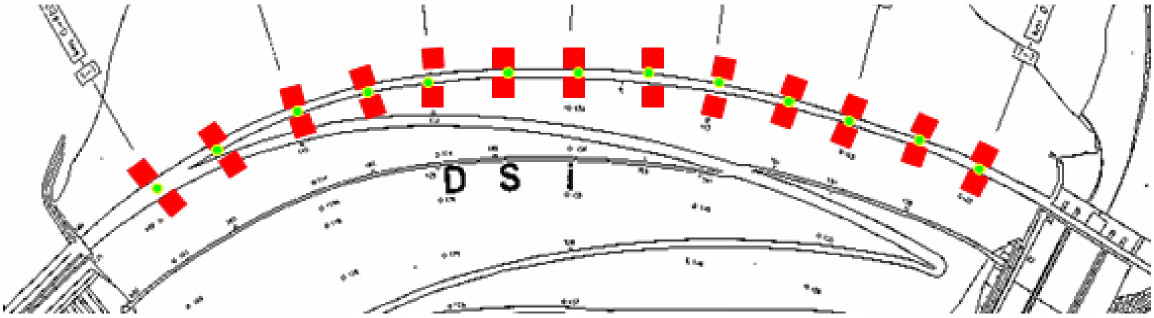
Deformation Network (Formed with Object Points): Object network with 400 benchmarks are designed for monitoring dam embankment, side berms and galleries (Technical Report, 2004). There are more than 200 benchmarks on dam embankment (Figure 5).

Figure 5. Deformation Points on Dam Embankment

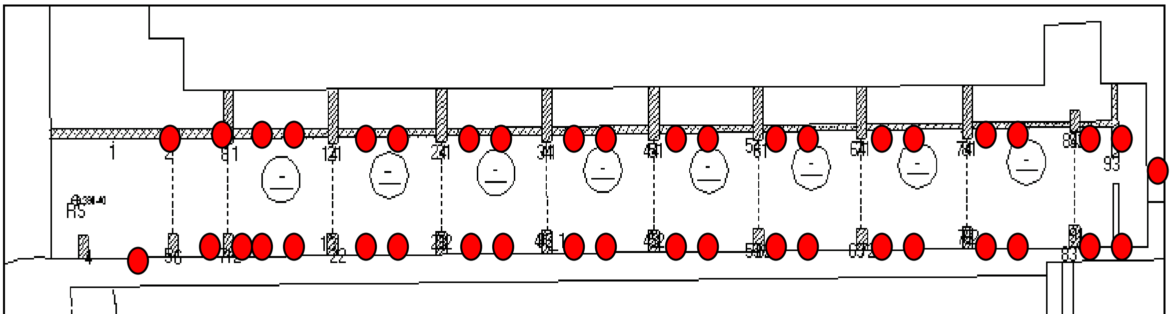


Leveling Network: One leveling network exists on dam embankment with 36 benchmarks, along the dam crest. Other leveling network includes 45 benchmarks inner and outer of the power station (Figure 6 a,b). Precision Leveling (geometric) method was applied for determining the height differences between 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 surveys on wall points have been performed two times per year with precise leveling method.

Figure 6 (a,b). Precise Leveling Points on Dam Crest and in Power Station



a) Dam Embankment



b) Power Station

Surveying Instruments and Other Equipments: High precision theodolites and EDMs for conventional surveying, double frequency GPS receivers for GPS surveying and digital precise level for leveling surveying are used in monitoring project. Used instruments and equipments are given on Table 4a and 4b.

Table 4a. Surveying and GPS Instruments

Instrument	Number	Model	Institute
High Precision Theodolite	2	Leica T2002 Leica T3000	ITU and DSI
Electronic Distance Measure (EDM) Instrument	2	Topcon GPT 7003 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 4b. 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

3.1.1 GPS Surveying

GPS technology is used many engineering applications efficiently today. Civilian applications, both commercial and scientific, already abound. Some of these applications are;

- Navigation for cars and cabs, trucks and trains, sailing boats and ships, airplanes and even other satellites.
- Vehicle tracking, emergency and rescue, deformation for potentially hazardous structures such as bridges, roads and dams. Also 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).

It has many advantages according to conventional surveying (Roberts, 2000, Pretorius, 2001, Kalkan, 2002, 2003, 2007). Some of the advantages are;

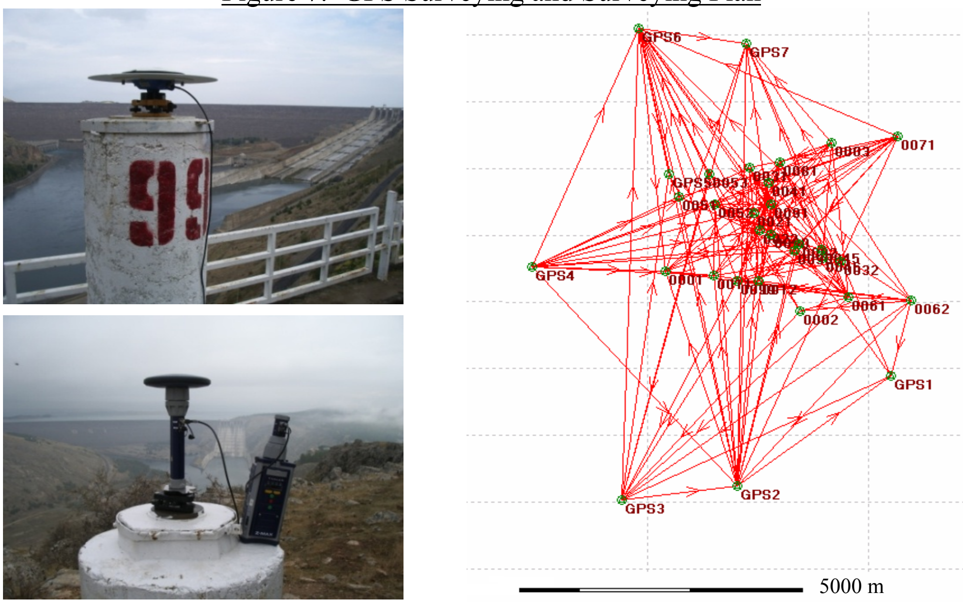
- Intervisibility among the stations is not necessary.
- Independent of weather conditions.
- Accuracy is largely a function of interstation distance, and not of network "shape" or "geometry".
- GPS surveying is more efficient, more flexible and less time consuming a positioning technique than using terrestrial survey technologies.
- High accuracies can be achieved with relatively little effort, unlike conventional terrestrial techniques (URL 4).

Supplementary to the conventional geodetic surveying, GPS surveying are performed. Monitoring studies by ITU were started in May 2006 and planned to re-observe each six months with a similar plan as mention below. The first campaign is performed in between DOYs 125-130. The use of receiver and antennas throughout the campaigns was homogeneous.

GPS measurements were 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 4a

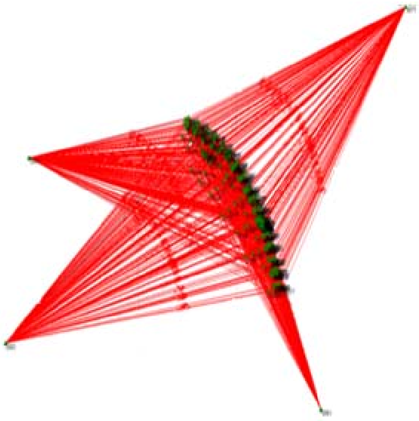
Some pictures of GPS surveying and surveying plan are shown in figure 7.

Figure 7. GPS Surveying and Surveying Plan



After the process and adjustment of GPS surveying, **a few mm** internal accuracy value was 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 are performed on nearly all points on the embankment for the following periods (Figure 8).

Figure 8. GPS surveying plan for the points on embankment and orange formed circular targets for conventional surveying

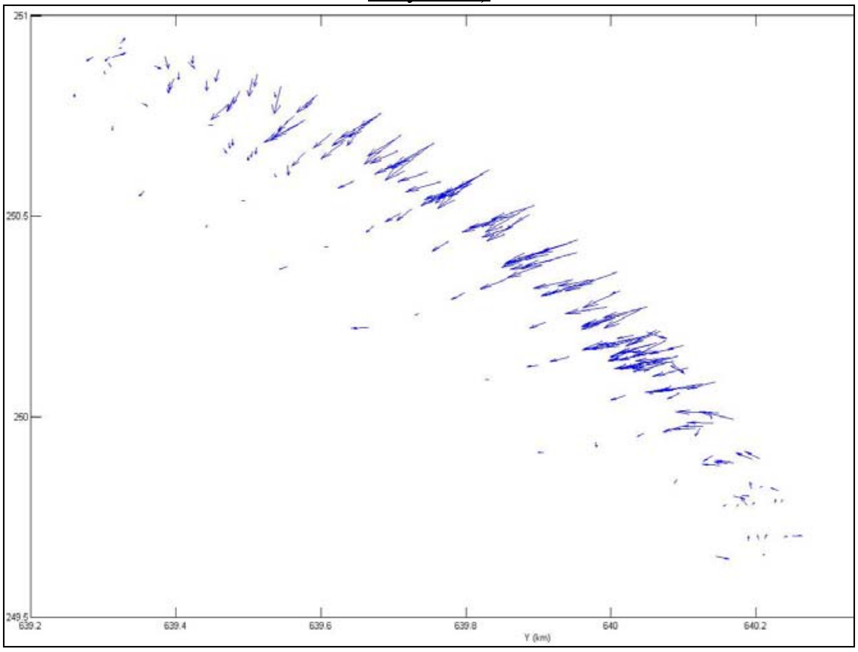


3.1.2 Conventional Surveying
Conventional surveying includes precise horizontal and vertical angle and distance measurements. These surveying were performed on 13 pillars of conventional network. Precise horizontal and vertical angle and distance measurements were performed to more than 200 object points using 9 pillars, for relating object points 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 (object) points on the dam embankment.
Measurement results of six periods performed by ITU were compared. At first, stochastic model test was applied for evaluation of the results, whether in a same set or not, for double period comparing.
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. Accuracy criteria 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. Due to the results of 5. Period which performed on May 2008, radial displacement (perpendicular component to the crest axis) were defined on 25% of object points. The biggest displacement from upstream to downstream was 5.6 cm in two years. A sample of displacement vectors defined for embankment points is given on Table 5, the graphics drawn for all is given figure 9.

Table 5. Displacement vectors and significance test

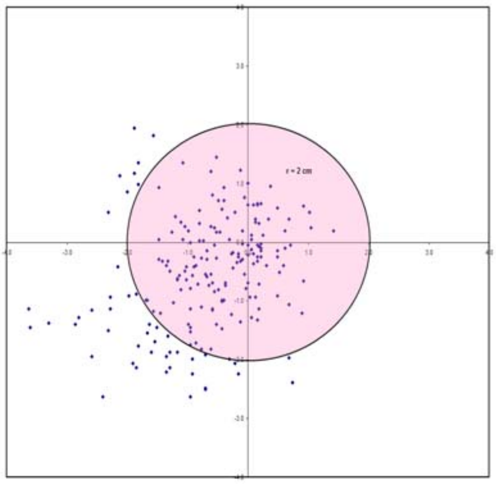
Point Name	DY (cm)	DX (cm)	dP (cm)	Mp (cm)	dH (dm)	dR_i (dm	FI Grad)	Bearing (grad)	Orientation (grad)	e+400 (grad)	dR_i (cm)	T_i (cm)
113	-2.21	-3.29	3.96	0.84	-0.10	-0.38	53.930	238.00	-184.07	215.930	**-3.84**	2.98
114	-1.57	-2.98	3.37	0.79	-0.17	-0.32	56.370	238.00	-181.63	218.370	**-3.23**	2.78

Figure 9. Displacement vectors defined for all embankment points for two years (May2006-May2008)



Moreover, GPS results, 3rd period (May 2007) and 5th period (May 2008) were compared each other, for nearly all embankment points. The results for position changes is given graphically on figure 10.

Figure 10. Displacements for the embankment points (May2007-May2008)



4. Conclusion

Atatürk Dam is the biggest dam in Turkey, also can be accepted one of the important dam among the others in World. It provides many benefits, including water supply for drinking, agricultural and industrial uses, flood control, hydroelectric power, recreation, etc. In order to provide safety, well planned and implemented geodetic monitoring is very essential for such structures. Atatürk Dam, which has a strong substructure, has been monitored continuously using geodetic and non-geodetic techniques since 1990.

For GPS and conventional surveying, reference network with 32 points and object network with 400 points were used to define the deformations periodically.

Significant radial displacements (perpendicular component to the crest axis) were defined on 25% of object points due to the results of conventional surveys between the periods of May 2006 and May 2008. The biggest radial displacements from upstream to downstream are given below.

872	2123	974	871	133	2103	922	2135	984	894	2125	964
-5.45	**-5.39**	**-5.29**	**-5.21**	**-4.67**	**-4.62**	**-4.54**	**-4.44**	**-4.32**	**-4.29**	**-4.27**	**-4.23**
cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm

Similarly, biggest vertical displacements are given below.

4060	2057	4030	2053A	2092	2163	2056A	4050	2082	4020	2059A	2059B
-6.5	**-6.4**	**-6.3**	**-5.9**	**-5.7**	**-5.7**	**-5.7**	**-5.6**	**-5.5**	**-5.4**	**-5.4**	**-5.4**
cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm

On the other hand, after the process and adjustment, 3 dimensional coordinates of the points could be defined accurately using GPS. The results obtained from conventional and GPS surveys were consistent with each other. GPS technique can be used instead of conventional surveying. For monitoring dam and near surrounding, position accuracy **less ± 1cm** is sufficient for rock fill dams such Atatürk Dam. But it is difficult to say this situation for height accuracy, yet.
Furthermore, using of Laser Scanner Technology for 3 dimensional modeling and Interferometric SAR Image Technology for monitoring vertical displacement of dam embankment are recommended.

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