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Deformation Monitoring in Dam, Using Geodetic Measuring (Case Study-Koman, Albania)

Msc. Marpol Koço

General Directory of Planning and Development Territory, Tirana Municipality, Albania
E-mail: *marpol.koco[at]tirana.al*

Abstract: ***The world we live in is constantly changing and nothing is static. Managing this change is essential to economic and social progress. Monitoring should be able to detect damages, constructive deficiencies and security threats so that a sudden event can be detected and prevented. Detection of deformation size is a very difficult challenge for engineering geodesy. The difference between the points coordinates (between two consecutive epochs) considered, can occur for two main reasons: as a result of point movement, and as a result of errors we may do during the field measurement process. To solve this problem different monitoring methods are combined. This combination consists of switching from manual and electronic methods to online monitoring or geomonitoring. Analyzing and measuring the deformations of an object with geodetic methods is one of the biggest challenges of monitoring teams. This analysis has the final purpose of calculating the deformation of each point and the numerical size of the displacement vector as well as the error ellipse. The paper concludes with conclusions and recommendation for the future actions.***

Keywords: Dam, Koman, Deformation Monitoring, Geodetic Measuring, Displacements

1. Introduction

Construction work on the Koman HPP began in 1980. The dam built forms a lake with a total volume of 430 million m^3 of water. The dam is 115 m high. In HEC Koman since 2012 the Swiss company BSF Swissphoto AG has implemented a geodetic monitoring system for the Koman dam.

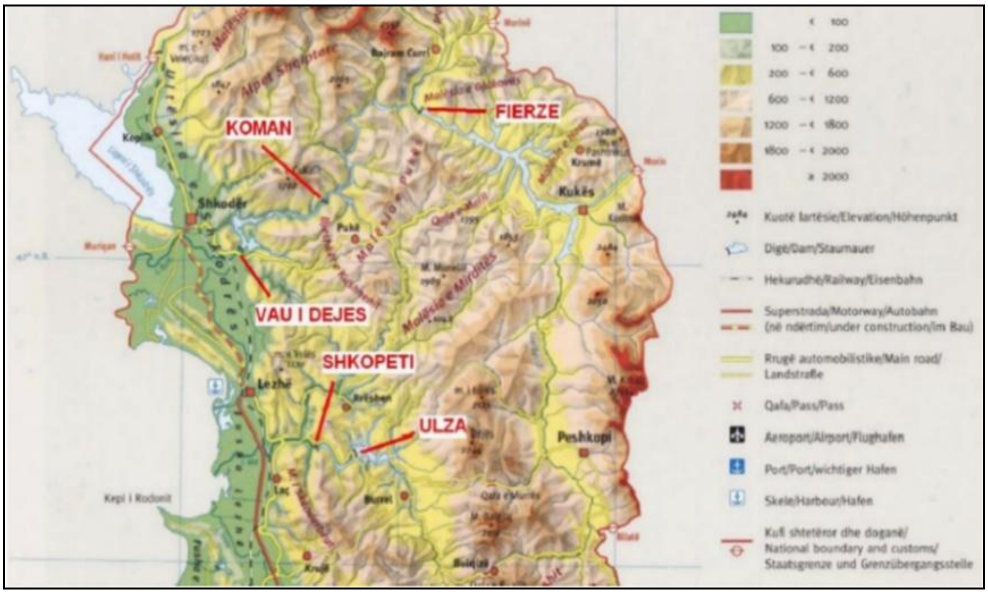

Figure 1: Location of dams in Albania

The monitoring system consists of 9 Pillars, 18 Concrete Monuments, 14 Leveling Bolts, 13 Reflector Bolts, 4Permanent Reflectors and 8 Target Plates (for detailed description of the installed points see “As Built Documentation”). Measurements in epoch 0 (zero) for the geodetic network was taken on October 10th 2012. The water level of the reservoir was at 172.04 m. Measurement in epoch 1 for the geodetic networks were taken on April 15th and 16th 2013. The water level of the reservoir was at 173.72 m, which is close to maximum. Measurements in epoch 2 for the geodetic network were taken on April 20th and 25th April 2018. The water level of the reservoir was at 172.38 m resp.172.46m.

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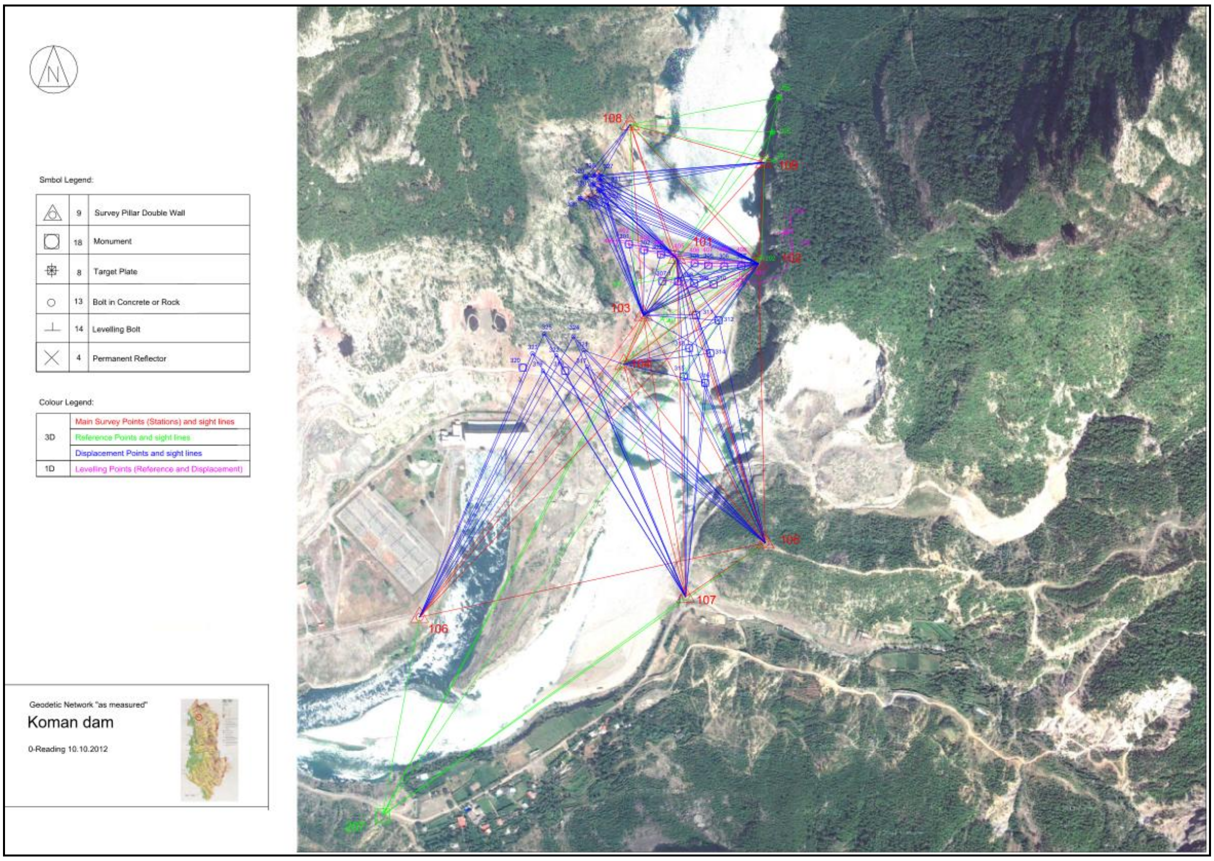

Figure 2 Geodetic Network for Koman HPP

The Geodetic Network consists of **Total Station (TPS)-** measurements and **Levelling**.

1.1. Total Station (TPS Network)

Stations: The TPS-Measurements are taken from the 9 pillars upstream and downstream of the dam. *Reference Points:* The Pillars are backed up with 7 additional reference points. The reference points are metal dowels protected with a screw, target plates and one concrete monument. The dowels take a reflector bolt type SBB. *Deformation Points:* The deformation points are 17 concrete monuments (plus pillar 101) in 5 rows along the height of the dam. In the rock face above the intake 4 permanent reflectors and 8 target plates are installed and to be measured.7 deformation points are situated in large boulders in the hillside above the powerhouse. With the measurement in epoch 2, 4 additional bolts were installed. Two new points were installed at the equilibrium towers and two points at the dam toe. During the construction work for the dam rehabilitation the 6 monuments in the lower part of the dam (points 311 – 316) were replaced. The current measurement represents a new measurement in epoch 0 for these points. Points 323 and 333 have been destroyed. Points 318 and 320 aren't measurable anymore due to roadwork in progress.

1.2. Leveling Network

Reference Points: The reference points for the levelling are situated in the tunnel on the left side of the dam. In front of the tunnel one additional reference point is installed to allow change to the smaller 2m invar staff. *Deformation Points*: The 10 deformation points for the leveling are integrated into the foundations of the monuments and the pillar along the dam crest. Two additional bolts are fixed to the concrete structures on both sides of the dam crest. Point 401 got destroyed during the dam rehabilitation.

2. Material and methods

2.1. Measurement Data Processing

2.1.1. Measurement in epoch 0 and epoch 2: Monitoring of engineering facilities begins with observations of age 0. In the case of dams as the initial time for the commencement of geomatic observations should be the period without beginning the accumulation of water in it. Based on the measurements of epoch 0, all measurements of other epochs will be made and a comparison will be made between this epoch and subsequent epochs. Measurements for the next season (season 2) are made in autumn or spring depending on the measurement of season 0, time when temperatures are normal and the water level in the dam is very close to the minimum or maximum. In this case we can make an obvious comparison between epoch 0 and epoch 2. This difference should be obvious because in the case of season 0 the weight of water in the dam is maximum and in the case of season 2 both temperature and air pressures are stored in the memory of the instrument. To increase accuracy, we perform measurements with a minimum of 3 series (we can measure more series). If for some reason the measurements are not accurate then we repeat the measurements until we reach the required accuracy. The measurements for the measurement in epoch 2 were taken on April 20th (levelling) and April 25th ($^{($}Total Station) 2018. The measurement was combined with training for the TPS and digital Level. The conditions during the measurements were good, clear sky and between 23 and 27°C.

***2.1.2. Total Station (TPS) Measurements*:** 9 Stations were measured with a Leica TM30 1". For each Station at least 2 sets of angles in both faces were measured. Temperature and pressure were measured on site for each station and corrected on the TPS. The lines between the pillars were measured from both sides. The whole network was measured force centered. Each deformation point was measured from at least three individual Stations to ensure the accuracy and the reliability.

2.1.3. Levelling: The levelling was divided into 3 separated lines, one over the dam crest, one from the dam crest to the tunnel entrance and one through the tunnel to the reference points. The aim is to break down the levelling into short sections to be able to check the quality of the lines on site. Each line was measured forth and back with a Leica DNA10 and invar staffs**.**

2.2. Total Station (TPS) Adjustment

The network is adjusted with CAPLAN as a spatial 3d network for the TPS measurements and as a 1-dimensional network for the levelling. The whole network is set on local coordinates. The Y-axis for the coordinate system is defined through two points on the dam crest (301 – 307). This means that further coordinate changes for the Northing values represent a movement downstream or upstream whilst changes in the Easting values represent movements towards the right or left abutment (for the deformation points in the dam face). For the adjustment the following a priori values were taken (Table 1):

Table 1: Technical parameters with Total Station

Parameter	A priori Value
σDist	1mm + lppm
σHz:	0.7" + 0.5mm / Station
σDH:	0.5mm + 1" x dist. [km] + 4.7mm x dist. [km] x dist. [km]
σz:	1"

First a free network adjustment was calculated to check the quality of the data collected. In a second step the measurement in epoch 0 coordinates of the reference points were introduced into the adjustment with an a priori accuracy of 1mm.

2.3. Levelling Adjustment

The reference height for the levelling adjustment is point 405 (leveling bolt in Pillar 101) with a freely chosen height of 100.00m not to confuse with the absolute heights for Koman. For the adjustment the following a priori values were taken:

Table 2: Technical parameters with Levelling

Parameter	A priori Value
σNiv:	0.1mm + 0.5mm x √ (dist. [km])

First a free network adjustment was calculated to check the quality of the data collected. In a second step the measurement in epoch 0 (zero) coordinates of the reference points were introduced into the adjustment with an a priori accuracy of 1mm.

3. Results

3.1 Measurements in 0 (zero) epoch

Within the adjustment the measurement in epoch 0 coordinates of the reference points were tested. Point 107 shows a significant movement and can therefore not be taken as reference point. Point 101 is a pillar on the dam crest and is not a reference point either. Point 105 shows a significant movement in height and is therefore only taken as a reference in plan.

Table 3: Reference Points and their movements compared to the 0 (zero) epoch (Significant movements in red)

Point	E [mm]	N [mm]	Plan Vector [mm]	Significance level Plan 95% [mm]	H [mm]	Significance level Height 95% [mm]
101	4	-3	5	3	-11	3
102	-1	2	2	3	-1	3
103	0	-2	2	3	0	3
104	0	-2	2	3	-2	3
105	-1	1	1	3	13	3
106	-1	-1	2	3	-1	3
107	-12	4	13	3	-3	3
108	1	3	3	3	-1	6
109	-1	0	1	3	1	3
201	2	0	2	3	4	6
202	1	0	1	3	3	6
203	0	-2	2	3	0	6
204	destroyed					
205	not measurable					
206	not measurable					
207	1	2	2	6	0	8

Within the adjustment the measurements in epoch 0 (zero) coordinates of the reference points were tested. Point 501 has moved significantly and can therefore not be taken as reference point.

Table 4: Reference Points and their movements compared to the 0 epoch (significant movements in red)

Point ID	Height [m]	Significance level Height 95% [mm]
501	-3	1
502	0	1
503	0	1
504	0	1

3.2 Final coordinates obtained from the compensations of the monitoring epochs in the Koman Dam

3D-Network adjustment Coordinate list. Total Station (TPS) Measurements taken 25.04.2018. All Coordinates are local coordinates only! In total 50 points (used as reference points colored in green).

Table 5: 3D-Network adjustment in 2 epoch

Point	E [m]	N [m]	H [m]	Accuracy Plan (1σ) [mm]	Accuracy Height (1σ) [mm]
101	1051.3705	2068.5464	101.3555	1	1
102	1186.9393	2062.9452	112.4055	1	1
103	1003.1343	1936.2765	94.0695	1	1
104	969.1738	1860.4423	84.2330	1	1
105	1274.6529	1571.2506	85.8804	1	1
106	663.1805	1320.9183	1.2327	1	1
107	1152.4067	1430.5081	1.1633	1	1
108	949.2072	2290.7474	121.0532	1	1
109	1185.6141	2255.2089	93.4086	1	1
201	1203.8972	2247.6409	93.4431	1	2
202	1192.3390	2070.0455	111.7645	1	2
203	988.3851	1954.7301	96.0950	1	2
204	1032.4796	1926.8710	77.9754	1	2
207	640.1763	938.5911	12.5107	2	3
301	980.7785	2053.0865	98.9477	2	2
302	1001.7785	2063.8087	99.9920	2	2
303	1022.3650	2068.2263	99.9576	2	2

1D-Network adjustment Coordinate list. Levelling Measurements taken 20.04.2018. All Coordinates are local coordinates only! In total 14 points (used as reference points colored with green).

Table 6: 1D-Network adjustment in 2 epoch

Point	E [m]	N [m]	H [m]	Accuracy Height (1σ) [mm]
410	1188	2068	100.8234	0.5
501	1189	2035	89.0962	0.5
502	1282	2165	89.8831	0.5
503	1254	2185	89.4308	0.5
504	1293	2212	89.4478	0.5

There was done a Coordinate Comparison of 0 epoch and 2 epochs.

3D-Network adjustment Coordinate Comparison. All coordinates are compared to their 0-epoch measurements.0-epoch measurements taken 10.10.2012 Level of Reservoir 172.04 m; 2-epoch measurements taken 25.04.2018 Level of Reservoir 172.46 m (Table 5). In total 50 points (significant movement colored in red).

(-) Northing equals downstream movement
(+) Northing equals upstream movement
(-) Easting equals movement towards right abutment
(+) Easting equals movement towards left abutment

Table 7: Results in 3D Network adjustment between two epochs

Point	E [mm]	N [mm]	Plan Vector [mm]	Significance level Plan 95% [mm]	H [mm]	Significance level Height 95% [mm]
101	4	-3	5	3	-11	3
105	-1	1	1	3	13	3
107	-12	4	13	3	-3	3
303	7	3	7	6	-7	6
304	0	-2	2	6	-12	6
305	-3	2	3	6	-9	6
307	-2	-3	4	6	-6	6
307.1	3	-3	4	6	-8	6
308	1	-1	2	6	-7	6
317	10	-13	17	8	-3	8
319	0	-5	6	8	4	8
321	162	-374	407	8	-238	8
322	63	-295	302	8	-192	8
324	154	-359	391	8	-316	8
325	17	-153	154	8	-74	8
327	2	-2	3	8	5	11

Coordinate Comparison of 0 epoch and 2 epochs.

1D-Network adjustment Coordinate Comparison. All coordinates are compared to their 0-epoch measurements.0-epoch measurements 10.10.2012 Level of Reservoir 172.04 m; 2-epoch measurements taken 20.04.2018 Level of Reservoir 172.38 m (Table 8). In total 14 points (significant movement shaded in red). (-) Height equals settlement

Table 8: Results in 1D Network adjustment between two epochs

Point	H [m]	Significance level Height 95% [mm]
402	-10	1
403	-8	1
404	-11	1
405	-13	1
406	-14	1
407	-13	1
408	-11	1
409	-8	1
410	-2	1
501	-3	1
502	0	1
503	0	1
504	0	1

2D Displacements and 1D Height Displacements are presented in figure 3

Figura 3: (Left) Koman 2D Displacements; (Right) Koman Height Displacements

The monitoring study has considered two basic epochs in which we have performed factual measurements, the processing of which has resulted in shifting in the 2D horizontal plane it rotates around the value of 1mm-17mm and the 1D vertical plane it rotates around the value of 1mm-14mm with very high probability (95% reliability coefficient). Carrying out measurements in future epochs is necessary to verify whether these dams will maintain this stability.

In the 2D horizontal plane the points in the landslide area above the powerhouse have moved significantly. Especially the points in the higher levels (321-325) show large displacements of up to 40 cm. Compared to the 1. Sequence Reading the movement is now twice as fast.

4. Conclusions

Monitoring the sustainability of dams with geodetic measurements is generally valued as a service that approaches high cost, therefore and is often not required by dam managers. Companies specializing in such monitoring offer this service at a very high cost.

Monitoring should be carried out systematically at least 2 times a year. All data must be stored and processed with the new computer software. This monitoring should continue for a long period of time, as it could potentially threaten the safety of employees.

The calculation of the deformation of the points located on the entire surface of the dam (the size of the displacement in the plan, the size of the displacement in height and the displacement vector) made it possible to predict the risks that engineering works may have and to calculate the financial cost for constructive repairs or for partial maintenance works.

All objects that have deformation more than the tolerance provided in the project and all old and very old objects that have a great cultural, historical, archaeological importance should be monitored with the online method.

From the above work we note that the transition from the optical observation method to study the stability of objects to other methods such as the electronic method with Total Station (robotic or semi-robotic) or on-line monitoring with a combination of total station with GPS gives a result with higher accuracy and reduces time and cost for the monitoring process. At the same time data processing with new programs gives a higher security throughout this process.

5. Acknowledge

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Author Profile

Phd. Cand. Eng. Marpol KOÇO: Born in Tirana, 1987. Finished study as Mining Survey Engineer on 2011. He started PhD studies on 2012. His work experience includes: Geodetic engineer in private sector; External Lecture at University; Specialist in the Directorate of Policies and Mining Development; Head of Sector in Cadastral Directorate in Tirana Municipality. Expert real estate valuation.