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Polyphyton Dam: Monitoring of the Right Abutment Slide

Spyridon Raftopoulos[1]

s.raftopoulos@dei.com.gr

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ABSTRACT

Polyphyton Hydroelectric Dam is a rockfill Dam with central inclined core, 105 m. tall, with a crest length of 297 m., located 26 km south of the town of Kozani, in the Region of Western Macedonia, Greece. Construction completed in 1974.

An unstable area located in the right abutment, upstream of and in the vicinity of the Dam is critical for the Dam safety. This particular area could potentially affect all supplementary parts of the project, such as the Inlet of the Power Intake and Spillway etc. It covers an area of 0,66 km^2, with a volume of approximately 30x10^6 m^3 and came up during the process of excavations within the borrow area on the right abutment, which provided rock materials for the Dam construction.

This paper discusses the monitoring of the slide on the right abutment of the Dam through geodetic methods, supported by a Total Station, located on the opposite side on the left abutment. Additionally, monitoring includes; a crack meter system founded on the bottom of an adit on the right abutment at a certain position, where a serious volume of deformations is expected, which gives depth information regarding the moving area.

Nevertheless, although the above mentioned system has changed the previous routine of topographic measurements in the area, some of them still proceed in being carried out. Therefore, a correlation between former and current status of measurements is attempted, so that their improvement, as well as the information of the ongoing stability of the specific area emerge.

I. INTRODUCTION

Monitoring big infrastructures, as well as the geological environment around them, sometimes is something more than the typical measurements routine regarding the Project's safety. More or less, great Hydroelectric projects like Dams, are almost always related with geological problems, some great other minor, either in the vicinity around them or at the reservoir area.

This is a matter of disturbance caused at the Project's area during construction and the subsequent changes to the preexisted local geological conditions.

Polyphyton Hydroelectric Dam is located south of the town of Kozani, in the region of Western Macedonia, Greece. Its construction spanned from the year 1971 to 1974.

An **unstable area** (Alexis area Fig 1), located in the

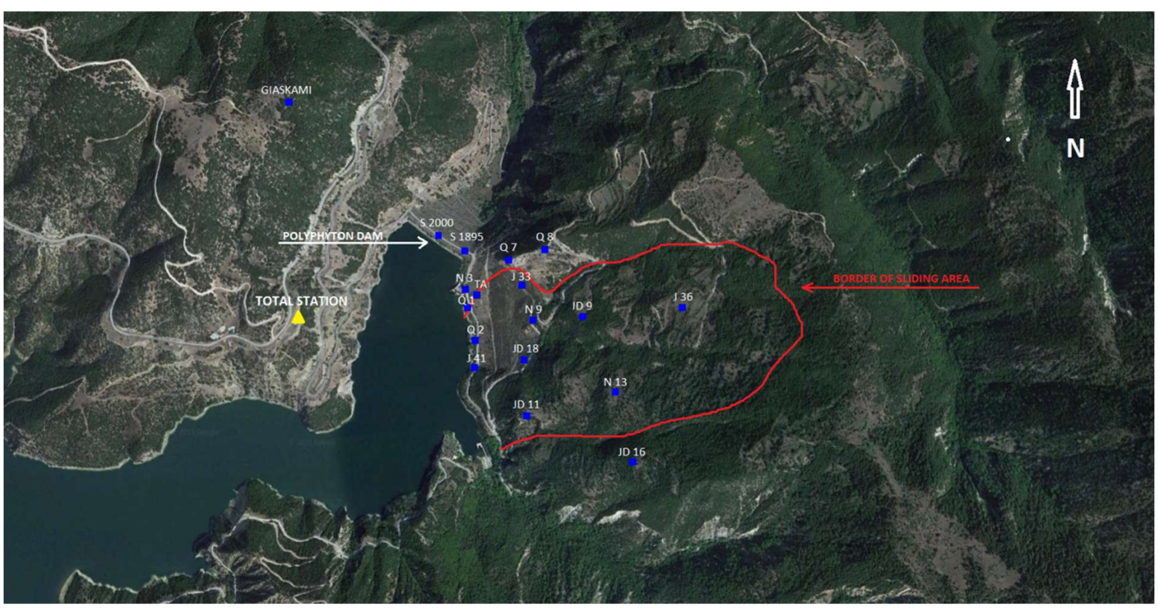

Figure 1. Polyphyton Dam border area. Alexis slide

right abutment, upstream of and in the vicinity of the Dam is critical for the Dam safety. This particular area could potentially affect all supplementary parts of the project, such as the Inlet of Power Intake and Spillway, as well as the upstream shell of the Dam.

The particular unstable area is being monitored through geodetic methods, supported by a Total Station and additionally a crack meter system, founded on the bottom of an adit on the right abutment at a certain position, where a serious volume of deformations is expected.

The aim of this paper is to describe the procedures of measurements and the combination between them. In addition, on top of this, its scope is to carry out some conclusions about the deformations of the unstable area.

II. TECHNICAL DATA

Reservoir:
Top of flood control area, **El.293 m.**
Area at maximum water level , **74 km^2.**
Gross storage, **1939 millions m^3.**
Dam:
Type, **Rockfill with central inclined core.**
Max. height over the foundation, **105 m.**
Crest length, **297 m.**
Total volume, **3,4 millions m^3.**
DIVERSION TUNNEL:
Total length, **634 m.**
Diameter, **9,7 m.**
Accommodated flow, **1.600 m^3/sec.**
Spillway:
Intake structure, **Three 12,9 m. wide bays, with flap gates.**
Max. capacity, **1375 m^3/sec.**
Power Intake:
Total length, **4,5 Km.**
Diameter, **8,5 ÷7,0 m.**
Accommodated flow, **345 m^3/sec.**
Power Station:
Type, **Underground.**
Units, **3 Francis.**
Installed capacity, **3 × 120 MW.**
Total mean annual energy, **420 GWh.**

III. GEOLOGY

The bedrock formations of the Dam site broader area, are members of the Pelagonian Massif, a geotectonic zone extending from Serbia via Greece to Turkey. This is partly covered by younger sediments of Plio-Pleistocene age. The geological formations, which prevail, are crystalline rocks like biotite gneiss interspread with amphibolites, quartz diorite, mica schist, phyllite, and marble. Transitions to meta quartz diorite also occur, as well as aplitic veins are extremely frequent in such transitions. These rocks are considered to be metamorphic sediments of young Paleozoic to Jurassic age. Slope deposits are frequently covering the bed rock, in both abutments.

Dipping varies, as well as the direction of schistosity. Important shear zones are a respectively often phenomenon. They occur in varying thickness, as a result of the local orientation of schistosity , when it is favorable for instabilities. Shear zones are induced from the weathering of the mica layers. This is the main reason for shear zones creation, when it is favorable in combination with the schistosity dipping.

The **Alexis unstable area** is a result of the above mentioned geological conditions.

IV. ALEXIS AREA

A. *Background information*

The construction of the Polyphyton Dam started in the year 1971. During preliminary site investigation before the Dam construction, a slide on the right abutment just upstream of the Dam axis, had been detected. The depth and the volume of the sliding mass was a matter under consideration, but in no case was it estimated to be as great as it was revealed next, during the Dam construction. In order for that moving area to be controlled, it was decided to be removed and placed on the Dam site as part of the construction materials. The site should be the *Quarry II*. Thus, stability problems could be eliminated from the Dam vicinity.

On November of 1972, during excavations at Quarry II, the extent of the actual unstable area begun to reveal, while deep shear zones in the rockmass were found. On July of 1973, an investigative program was carried out and also geodetic methods applied so as this area is controlled. 16 boreholes were drilled where numerus of geotechnical instruments were installed. Later in the year 1981 a 274 m long adit was excavated, for exploration purposes as well as to relieve the rockmass of the internal water pore pressures. After the above mentioned investigation took place, it was found out that the Alexis slide was an **old as well as extensive instability**. Additionally, due to the multitudinous shear zones, the slide did not have a unique, clear basic failure plane. The whole sliding mass is consisted of a quantity of lesser slides corresponding to the several shear zones (Fig 2). Thus, the main slide is a rather interactive model, with a lot of individual slides which affect each other. This is the reason for different moving rates from place to place within it.

Coming up against instability, prompt measures applied. Slopes of excavations were properly improved, being more gentle. Furthermore a toe berm was constructed down from the river bed up to a certain elevation. On the other hand, later (on 1981) after the Alexis adit construction, the area was somewhat drained.

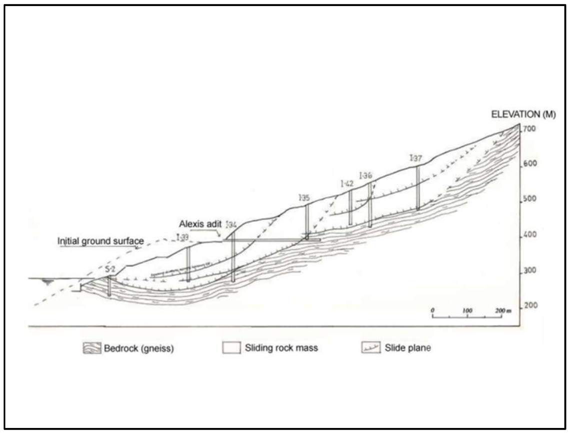

Figure 2. Polyphyton HEP. Geological section of the right abutment upstream dam (Alexis area)

B. *Displacement characteristics*

Deformation rate just after the excavation procedure in the year of 1972 was at maximum 1,5 mm per day. After all stability measures had been taken, deformations were on progressive degradation. Consequently after two years (in 1974), movements did not surpass 0,5 mm per day, while after the year of 1982 they fluctuated between 0,1 and 0,2 mm per day, respectively. Nowadays, deformations at the Alexis region are a few up to 10 millimeters per year in the majority of the places, as well as locally. The South part of the slide movements slightly exceed 2 cm at maximum per year. Total displacements at characteristic spots of the Alexis area for period 1974-2015 are depicted on Figure 3.

Precipitation appears to be the main factor affecting the stability of the area as well, less than the reservoir level fluctuation during May and June.

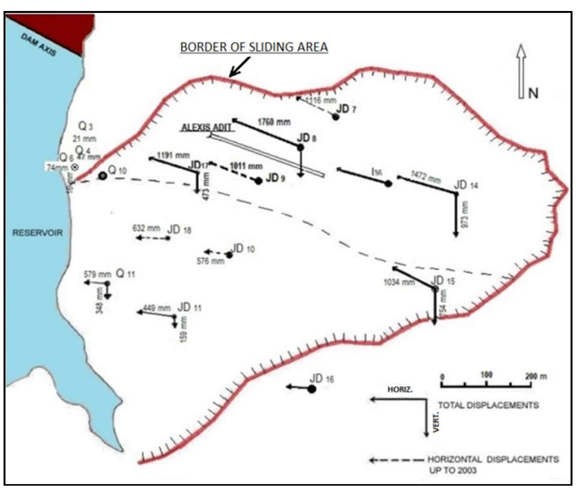

Figure 3. Alexis area. Displacements of monuments. Period 1974-2015

V. Slide Monitoring

A. *Superficial procedures*

During Dam construction and after that, a schedule of Alexis slide was carried out in order for the movements to be controlled. That schedule included geotechnical instrumentation as well as topographic measurements.

Regarding the topographic control a lot of procedures were applied. Thus 45 and more topographic monuments were interspersed into the slide area, and a numerous monuments founded on four sub horizontal cross sections at certain altitudes above the reservoir level.

The measurement program included:

- Monthly police measurements from left abutment to the Alexis area.
- Monthly vertical measurements (levelings) on certain sub horizontal routs on the Alexis area.
- Monthly vertical measurements on the floor into the internal of the Alexis adit.
- Annual geodetic measurements to all existing topographic monuments.

Of course interstitial measurements had to be done when unusual facts were occurring or were on progress, such as extreme measurement values, seismic events or outrageous pool level fluctuation etc. Using the Total station monitoring after the year 2015, some of the previous routine and especially police measurements, were repealed.

A robotic instrument is set in a concrete mount (Figure 4) founded on the stable bedrock at the opposite side of the Alexis area, on the left abutment.

Figure 4. Total Station on left Abutment

Instrument's hardware unit is been kept in a small building constructed in touch with the concrete mount on the back. 14 selected spots at certain representative points in the Alexis slide are being used for checking and measuring. These spots are among the preexisted ones on the area, which are now exclusively used for the total station. In addition topographic reflectors have been set on them.
Additionally two monuments are constructed on the Dam crest in the sight of the Total Station instrument, as well as two benchmark monuments.

B. *Rockmass internal control (Alexis adit)*

On the other hand, a crack meter is installed on the floor into Alexis adit (Fig. 5), in order to control movements from the inside of the sliding mass. In that sense, concerning the data coming from the internal of the adit they are more representative than the superficial measurements.
For this purpose, choosing the most outstanding fracture was an important point, since the adit crossing the whole sliding mass cuts at least four important shear zones up to solid rock. Consequently, in every shear zone there are two main fractures in their beginning and at the end, except for some subordinate or minor ones spread within them. Thus, the most kinetically important fracture, regarding its geometric characteristics like gap, jump etc. is the fracture which is located to the most external point towards the adit inlet side. This fracture was chosen

Figure 5. Alexis adit crack meter

for the crack meter installation. Of course, a full system consisted of numerous crack meters installed on each fracture of the sliding rockmass could potentially be the most integrated and adequate option, but at this primary stage of this application, the single crack meter is a pilot procedure for further evolution of this system in the future. In this case of a potential scheme of fully instrumentation deriving from crack meters on every fracture in the adit, the results by summing up all the individual deformation could be more comparable to those from the total station. Of course these numerous shear zones crossing the adit having more or less their peculiar mechanism, could potentially differentiate the conditions regarding the geometry of the moving parts. Consequently, it could be possible that some parts of the fractured rockmass are slightly raised rather than move down. Nevertheless, as it is shown on the related graph (Figure 8) the fracture on which the crack meter is installed, coincides with the limit of the majority of the great displacements. So even using only one crack meter in the adit, it is quite representative for the total displacements that could be detected in its internal. In any case the reasoning for this choice up to now, except for the pilot usage of them is, to actually be a **reliable alarm** for the stability of the region, providing a reference point to depth data.

VI. Slide deformations

A. *Total station measurements*

Measurements during the past years using the Total station, overall ascertain the previous classical topographical methods at a significant degree.
Referring to the period of the past four years (2015-2018), horizontal deformations of the fourteen

Table 1. Total station measurements (2015-2018) of Alexis area

Displacement Monuments	Horizontal Displacements (mm)*	Vertical Displacements (mm)
N3	6.6	3.1
Q1	31.6	8.5
J41	33.1	9.1
JD18	31.6	7.0
TA	6.1	1.8
Q2	25.7	6.3
JD11	60.4	12.2
N9	31.0	9.8
J33**	24.4	4.7
JD9	34.7	9.9
N13	23.4	5.8
Q7	4.7	3.0
JD36	33.3	7.8
JD16	24.2	7.5

** Horizontal Displacement Component towards the reservoir*
*** Period 2015-2017*

displacement monuments, fluctuated in general from 24 mm to 34 mm in total (Table 1). Two of these monuments point to their being of very low moving rates, fluctuated between 5 mm and 7 mm in total within the above mentioned reference period. On the contrary, the only case of rather greater deformations derives from a monument located at the lower Southern part of the slide. This monument indicates a movement of 60 mm respectively. The rate of the movement progress is smooth without roughness or gaps. Vertical displacements fluctuate around 8 mm concerning the reference period, and it is fully agreed with the results from the corresponding measurements through the crossing sections into the Alexis area, as it is going to be mentioned in the following paragraph.

B. *Alexis adit data*

Crack meter in the internal of the Alexis adit controls a part of the total possible moves of the sliding mass as it has been installed on just one crack-shear zone within it. Although, as this crack is the most kinetically important, the rates of its measurements are expected to be mildly different, tending to be lower than the respective superficial data. During the reference period of the four past years, the results of this particular instrument revealed deformations of 9,7 mm along the axis of the adit (A Axis), towards the inlet, 10,5 mm across (B Axis) toward the right looking from the internal the adit to the inlet and 8,7 mm vertically (Z Axis, Figure 6). According to the topographic measurements regarding the vertical movements (leveling) that were carried out on the floor of the adit, there is total agreement between the results obtained from the crackmeter and the two nearest monuments besides it. It is underlined, that the measurements for vertical displacements in the internal of the Alexis adit are correlated to the sound rock at the end of it. For the reference period, these topographic measurements indicate a vertical deformation of 10 mm, between the nearest measured monuments on the adit floor. All of this provide an indication about the correctness of the installation of the crack meter in regard to the decision for the exact position and the technically right way of installation.

The only discordance of the measurements between the crack meter and topographical process is the variation in vertical deformations. Measurements from the crack meter have more or less a very smooth variation at any dimension. However, a significant gap arose on 30/1/2018, when the part of the adit floor located towards to the inlet was rapidly and at once settled down for 8,5 mm. This rate practically represents the whole vertical displacement of the sliding area within the reference period of the past four years. A proportional gap was also found during the topographic vertical measurements, between January and June of 2016, approximately one year and a half earlier than the crack meter's specific indication. Moreover, there was a slight difference regarding the crack meter indicated value and the displacement rate. It has to be underlined that the topographic measurement points besides the crack meter (monuments R 13 and R 15, Fig.6) are 13 m and 6,5 m far from it. The internal sliding parts of the whole sliding mass, are moving independently, tilting while raising their back side, before they are deformed. In that sense, it could be a reasonable justification for the rate discordance between the crack meter and the other measurements regarding the vertical deformations. All of this aside, the specific behavior of the unstable mass, may be an indication of the sliding mechanism, as the first deformation occurs on its external body as a bending. Consequently, the accumulative stress is burdening the existing shear zones, and after exceeding the sliding surfaces residual strength, it rapidly slips within them.

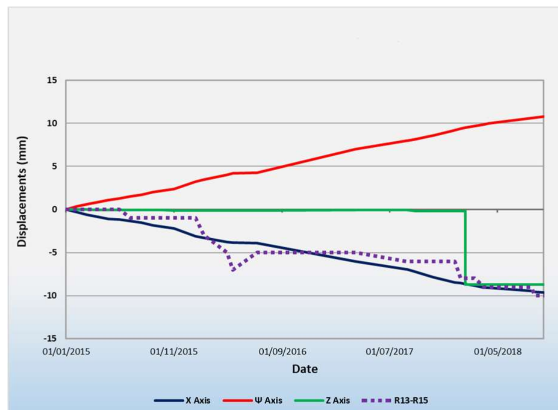

Figure 6. Alexis adit. Traxial rock meter vs Topographic vertical displacement measurements

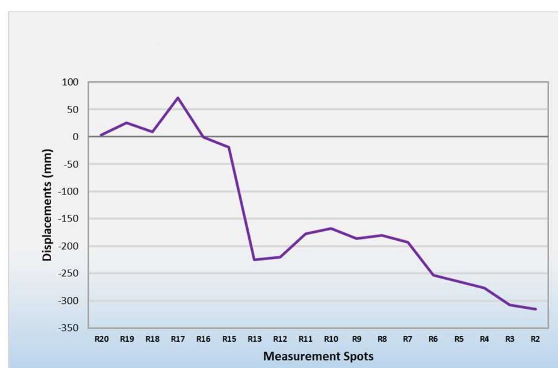

Figure 7. Alexis adit. Total vertical displacements during 1984-2018

VII. COMMENTS AND REMARKS

Regarding the compatibility between deformation data from the surface and the internal of the rockmass, a deviance is always to be expected. The main reason for this is that the slope surface tends to move superficially in a strictly local or wider scale so that it is appertained to skin deformations. These potential deformations are totally unrelated to the actual rockmass moves. Thus, in any case, superficial deformations are always equal or greater than those from the inside rockmass. Even so, it appears that the results from all available measurements that were quoted above there is a strong correlation between. Additionally, small differences lead to an approximate diagnosis about the complicated mechanism, due to broader rockmass failures.

VIII. Conclusions

Superficial and underground measurements are in general compatible, insomuch as it is taken into consideration that although the crack meter has been installed on the main fracture in the internal of the adit, it reflects a (main) part of the anticipated deformation. Moreover, a differential behavior between them is expected, due to the peculiar deformation mechanism that occurs among the sheared parts of the boarder sliding mass. This provides a motivation for further equipment improvement in the internal of the adit, enhancing the existing instruments with supplementary ones installed on the cracks of the rest respective shear zones.

Measurements derived from different sources, superficial or underground, carried out by topographical or geotechnical instruments (crack meters, etc.) could give important information about instability mechanisms.

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