KINEMATICS OF A LANDSLIDE OVER THE POLYPHYTON RESERVOIR (GREECE)

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Abstract

A geodetic monitoring system was established about 20 years ago to survey a slow sliding rock mass with a volume of $10^7 m^3$ along the rim of the Polyphyton Reservoir, 1km from the Polyphyton dam, north Greece. An analysis of the distance changes of a number of control points from a stable point, as well of spirit levelling data covering these control points indicate that the distance change record of a selected control station is representative of the kinematics of the landslide. The velocity of the latter is gradually diminishing during the last 20 years, an indication of its stabilization. However, anomalies in this movement do exist, indicating that earthquakes as well as precipitation and lake level fluctuations are factors controlling to a certain degree the kinematics of this slow moving rockmass.

1. Introduction

The Polyphyton Reservoir was formed in 1974 with the construction of the 105m high, 297m long rockfill dam of Aliakmon River at Polyphyton (Fig. 1), north-central Greece, 80km SW of Thessaloniki. Two other smaller dams and reservoirs have been constructed downstream. The Polyphyton Reservoir covers an area of about $2km^2$, contains about $2x10^9 m^3$ of water and runs a hydroelectric power plant with a capacity of 360MW. Two major landslides, in the form of slow creep (average velocity 10-15cm/year, but with peaks of the order of 1cm/day; Riemer et al., 1996) represent an important problem for the stability of this reservoir: the "Alexis" landslide, next to the spillway of the dam (Riemer et al., 1996) and the "Beta" landslide, about 1km upstream. Both landslides affect rock masses much smaller than the mass which produced the Vaiont (North Italy) disaster in 1963 (Petley, 2000). Yet, the Polyphyton Reservoir landslides are active (Figs. 2, 3) and close to the rockfill Polyphyton Dam. For this reason these landslides have been systematically studied using geodetic techniques for about 20 years. The aim of this monitoring geodetic system was to identify accelerations in the movement of the landslide and call for emergency measures. The results of the study of the kinematics of the "Beta" landslide are the subject of this article.

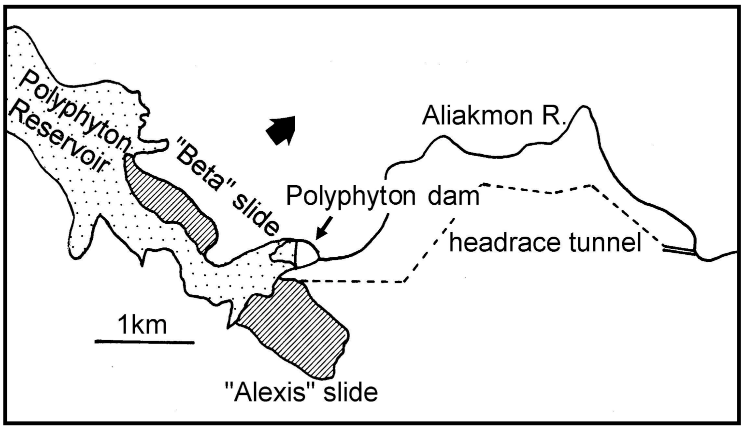

Figure 1: The Polyphyton dam and the ''Alexis'' and ''Beta'' landslides, location map.

Figure 2: The ‘‘Beta’’ landslide, view from south. The road is shown in fig. 4.

Figure 3: A ground rupture of the ‘‘Beta’’ landslide.

2. Geometry of landslide “Beta”

The sliding mass represents intensively tectonized gneiss and covers an area about 750m long and 450m wide with a mass of 10^7m^3 in a rather steep (average value 44%) slope. The top of the landslide is at the height of 380masl, about 90m above the maximum reservoir level, and its toe at the height of 230m, about 40m below the minimum function reservoir level; 60% of the landslide mass is above the water level. The sliding mass has a roughly semicircular shape and is cut by numerous micro-graben structures (Figs. 3, 4) and cracks. The basal shear failure plane is estimated to be at a maximum depth of 35m.

3. Geodetic monitoring system and results

The geodetic monitoring system of landslide “Beta” was established in 1978, a few years after that of the “Alexis” Slide. Planning and surveys were made by the Dam Control and Safety Section of the Public Power Corporation of Greece. Because of the limitations imposed by the topography of the area and the available instrumentation, personnel and budget, the monitoring system was at a first step limited to repeated measurements of the quasi-horizontal

EDM distance change between a number of selected stations in the sliding mass (stations B1-B9) and a single stable station on the opposite cliff (station K, see Fig. 4). In a second step, repeated spirit leveling surveys between the control points and stable points beyond the sliding mass were also made.

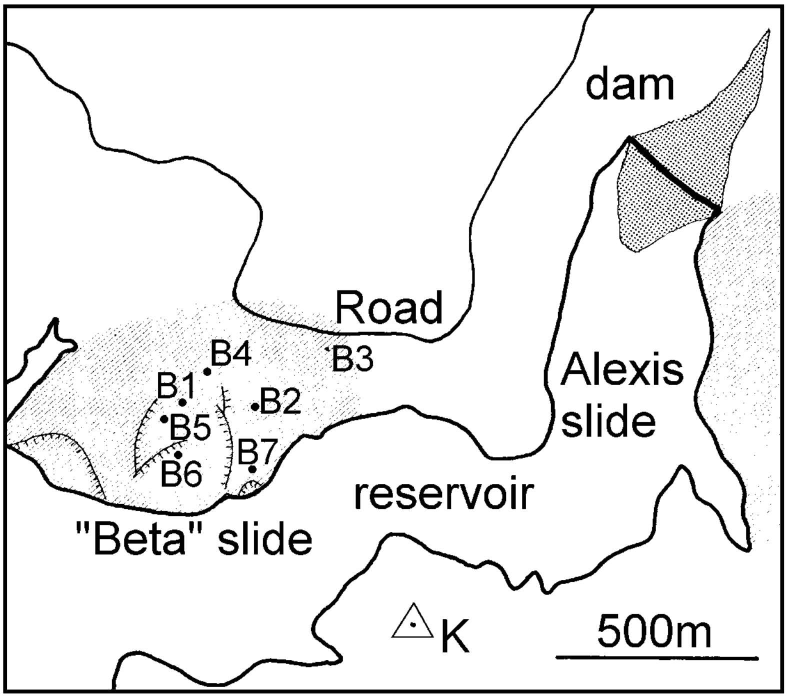

Figure 4: Control and reference points for the monitoring of the ‘‘Beta’’ slide, location map. Main ground ruptures (thin lines with ticks) are also shown.

Between 1978.11.10-1998.09.07, 480 epochs of distance measurements, and between 1983.08.03-1998.07.07, 15 epochs of leveling surveys have been completed and are available for this study. The primary aim of the leveling surveys was to provide a control to the EDM measurements. Both records are nearly complete and nearly uniformly distributed, with the exception of two main intervals, about 3 and 0.5 years long, for which data are missing (see below, Figs. 5,6). The frequency of observations was also increased after periods of observed acceleration of the landslide movement, as well as after the 1995 earthquake of surface magnitude 6.5.

Table 1 shows the cumulative results of observed length changes between the control points “B” and the stable point “K”, as well as of the observed elevation changes of the control stations. This Table indicates that in a 15-year long period an up to 0.5m subsidence of the control stations is observed, while in a 20-year long period an up to 2.6m contraction of the distance between the fixed station and the control stations occurred. Figures 5 and 6 show the plot of observed distance changes and of vertical displacements versus time of the control stations, respectively.

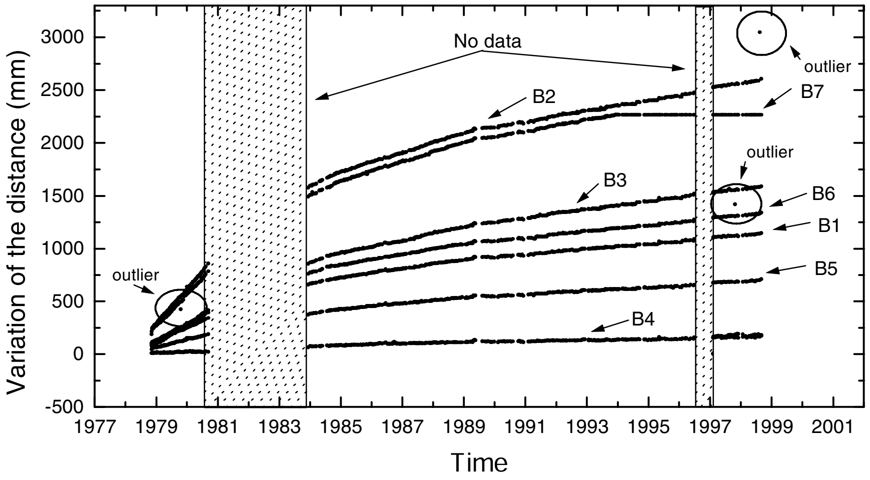

Figure 5: Variation of the distance of control station from stable station ''K''; EDM measurements. Some outliers are shown.

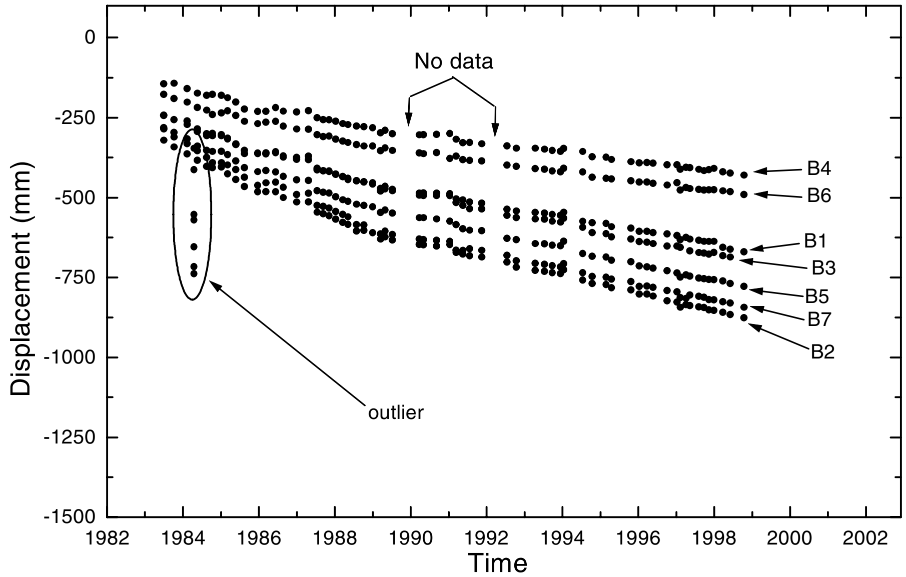

Figure 6: Vertical displacements of control station, spirit leveling data. Outliers, subsequently removed are shown.

Control station	B1	B2	B3	B4	B5	B6	B7
Cumulative distance change (mm) (1978.11.10-1998.09.07/ 480 epochs)	1144	2604	1587	172	706	1338	2265
Cumulative elevation change (mm) (1983.08.03-1998.07.07/ 15 epochs)	418	546	443	280	488	304	545

Table 1: Statistics of cumulative displacements of control points.

4. Assessment of the results

The various parts (or lobes) of a landslide move in different ways- this is exactly what Table 1 reveals; on the other hand, the available record of distance changes is not *directly* reflecting the landslide kinematics. For this reason, the aim of the present study was first, to evaluate the accuracy and precision of the available data and identify outliers, second, to correlate the available two types of data and identify a set of observations representative of the landslide kinematics.

4.1 Outliers

A very small number of small-wavelength (single observations), large-amplitude (>2sigma) deviations from the overall trend (defined by neighbouring observations) have been identified and regarded as outliers (Figs 5, 6), and were subsequently removed from the observation records.

4.2 Correlation of observations

Only a very small number (about 10) of observations of distance and of elevation change were completed during the same day. For this reason, for periods during which the changes of both parameters were nearly constant, we estimated the value of the elevation change corresponding to each specific value of distance change using a linear regression. However, if the time span between the two types of observations was up to 5 days, the two values were directly correlated. Using this procedure, approximately 50 pairs of data have been produced. A plot of the corresponding variables for stations B1-B7 is shown in Fig. 7. Obviously, the correlation between the two variables (distance change and elevation change) is excellent, and the corresponding linear regression coefficient ranges between -0.9973 and –0.9991. Similarly, the correlation coefficient between the elevation changes of the various control stations is ranging between 0.993 and 0.999, while for the distance changes this coefficient is ranging between 0.974 and 1.

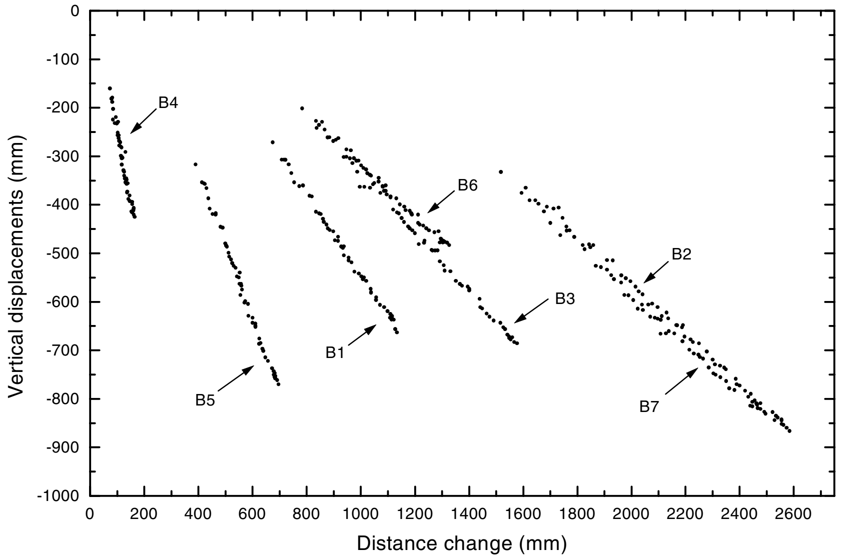

Figure 7: Correlation between observed vertical displacement (spirit leveling data) and EDM distance change from stable station ‘‘K’’. A nearly perfect correlation for all seven stations is evident.

5. Discussion

Elevation changes and distance changes from stable points represent independent observations. For this reason, their nearly absolute correlation indicates that the two variables and every control point are very sensitive to small changes in the kinematic status of this landslide or even perhaps to measuring errors. Consequently, any of these variables or the kinematic history of any of the control stations can describe with much detail every variation in the kinematic history of landslide “Beta”. We select the distance change record of station “B2” as representative of the landslide, on the base of the following criteria: (1) the highest correlation between distance change and elevation change as well as with the other control stations, (2) the highest amplitude of the displacement signal in the observations (see Table 1), and (3) longest record with very few discarded observations (outliers). The record of distance change of this station “B2” therefore records the complete history of movement of lansdslide “Beta”, i.e. the velocity of the landslide and the variations of its velocity. The latter are shown in Figures 8 and 9, respectively, and are based on the data of Fig. 5 slightly smoothed with a moving average filter with a dimension of 3.

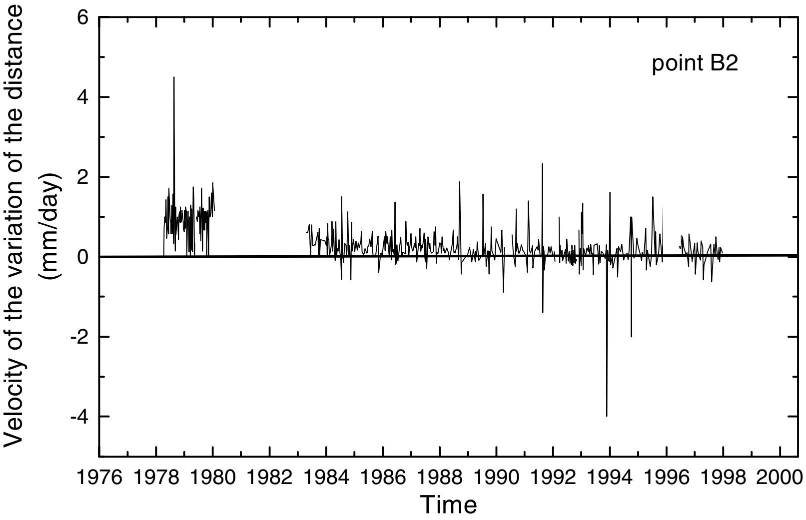

Figure 8: Velocity of station B2 (distance change data). A decrease in the landslide movement is evident. Data filtered with a moving average.

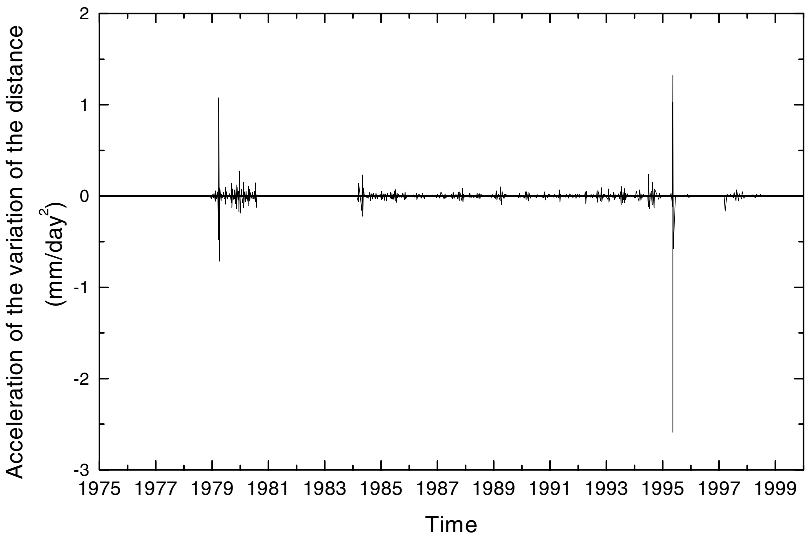

Figure 9: Acceleration of station B2 (distance change data). The 1995 peak anomaly was caused by the 1995 Kozani- Grevena earthquake. Data filtered with a moving average.

Some conclusions can be obtained from these two figures. First, that the “Beta” landslide is a slow, active landslide, and that its velocity is gradually diminishing, i.e. that it tends to stabilize, probably as a response to geotechnical, ground stabilization works which have been made in the last 20 years. Second, that the velocity and acceleration of the landslide movement show some anomalies, especially some peaks; the latter are probably real effects, and not artifacts of the measurements, since they are visible in the filtered data of Figs 8 and 9. Such anomalies represent a major threat in landslides, for they may represent premonitory phenomena of a total failure. Among these peaks, that of 1995 is associated with the 1995, Kozani- Grevena earthquake. This magnitude 6.5 earthquake proved that the wider region is not earthquake free, as was hitherto believed (Stiros, 1995), and that earthquakes represent another major threat for major works hitherto constructed with a very low earthquake resistance. Several other velocity and acceleration peaks can also be identified. Their correlation with the lake level fluctuations and with precipitation, factors which have been proved to control the kinematics of the Vaiont landslide (Petley, 2000) is a matter of ongoing research.

6. Conclusion

Two main conclusions can be obtained from the above data. First, that geodetic data which describe only one parameter, the distance from a fixed station in this case, can provide a complete and reliable record of the kinematics of a landslide. Second, that the available 20-years long detailed record of the landslide “Beta” indicates that such slow landslides are active and unstable, marked by anomalies (high acceleration episodes), which may represent premonitory phenomena of a final failure. Therefore, early identification of such events may provide an opportunity for prevention or mitigation of a disaster.

References

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