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RIGIDITY CONTROL OF A THIN REINFORCED CONCRETE DAM

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Abstract

A 40 years old geodetic monitoring record consisting of horizontal deflections from a straight line and spirit leveling of six control stations from the crest axis of the Ladhon Dam, SW Greece, was analyzed. This dam is made of reinforced concrete, is founded on limestone and shale and is 101.5m long and 56m high. The available geodetic data indicate that the displacements do not exceed the amount of 7mm, and that they seem to be slightly dependent on ambient temperature and the reservoir level. They also indicate that the Ladhon Dam, despite its age (more than 40 years old), is very rigid, a result consistent with visual measurement of its structural health (absence of traces of leakage and of structural or foundation failure).

1. Introduction

The vast majority of dams till approximately 1960 were of thin-cell or gravity (triangular vertical cross-section) type. Such structures proved very vulnerable to foundation instability (Malpasset dam, Marinos 1994) and to seismic loading (Pacoima), and occasionally a threat for thousands of people (Malpasset, Marinos 1994; Vaiont, Marinos 1994). For this reason the systematic monitoring of their deformation represents a major contribution towards their structural health and reduction or even avoidance of disasters. Yet, for various reasons (confidentiality etc.) detailed reports for long-term monitoring of such dams are very rare in the literature, and the effects of the fluctuations of ambient temperature or of reservoir level on the dam geometry are problems poorly understood. In this article we present the results of a 40-year long geodetic monitoring system of the Ladhon Dam in SW Greece and try to contribute to answering such problems.

2. The Ladhon dam

The Ladhon dam, on Ladhon River, is a medium size (101,5m crest length and 56m high above river bed) dam. It was constructed between 1950 and 1955, by an Italian company, as a part of compensation from the Italian government for 2nd World War damage in Greece. It is a concrete hollow gravity dam with a slant upstream face and a vertical top, close to the village Tropaia in central-western Peloponnese, approximately 250 km SW from Athens. Its geometrical characteristics are shown in Table 1.

The reservoir of the Ladhon River dam was formed in a meander-type valley, the geological background of which consists mainly of limestone and shale. The reservoir characteristics are shown in Table 2. During the function period, no serious leakage or stability problems have been reported for this dam. In particular, it suffered no damage from earthquakes which affected the wider area, mainly from 1966, Ms = 6.0 Megalopoli earthquake (Papazachos and Papazachou , 1989) (max intensity VIII-MMKS)

Table 1 Main characteristics of the dam

Height above river bed	56m
Crest elevation above sea - level	422.4m
Crest width	3.4m
Crest length	101.5m
Maximum width at base	50m
Total volume	34000m^3

Table 2 Main characteristics of the reservoir

Top of flood control storage above sea – level	422m
Top of maximum usable storage above sea – level	420m
Reservoir depth	31m
Reservoir length	15km
Area at maximum water level	4km^2
Area at minimum water level	0.05km^2
Gross storage	57.6×10^6m^3
Flood control storage	8.6×10^6m^3
Usable storage	46.2×10^6m^3
Dead storage	2.8×10^6m^6

3. The geodetic monitoring system

The aim of the geodetic monitoring system of the Ladhon dam is to control possible horizontal deflection from the dam axis and vertical displacements of the crest of the dam. All measurements refer to 6 control stations on the crest of the dam, and reference stations close to its abutments.

(1) Horizontal Deflections

Two control stations at the abutments of the dam (R1 and R2 in Fig. 1) define an axis, along which 6 monitoring stations (C1 to C6 in Fig. 1) were established on the crest of the dam. During each period of measurements, a high precision theodolite was placed at the control point, R1, aiming at control station R2, and hence defining a fixed reference axis.

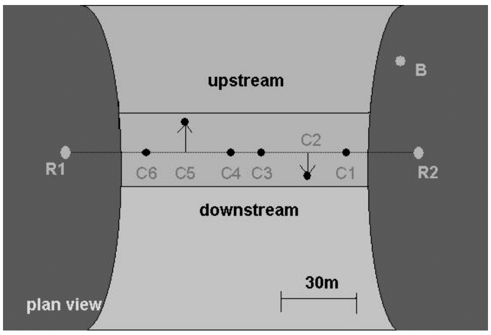

Fig. 1 Principle of measurements of deflections of the dam crest from a straight line. Deviation of each one of the control stations is measured along a rule using a high accuracy theodolite in reference station R1 and pointing to the reference station R2. Deflection is defined as the difference of the corresponding ruler readings between a specific survey and the initial survey for a certain control point.

(2) Vertical Displacements

The relative vertical displacement of the control stations on the crest of the dam was measured using high accuracy spirit levelling relative to a fixed benchmark, on the left abutment of the dam (for location see shown in Fig. 2). Relative elevation changes for each benchmark and each survey period was measured. Vertical displacements (negative for uplifts) were then computed as the difference between values of a specific survey and the initial survey.

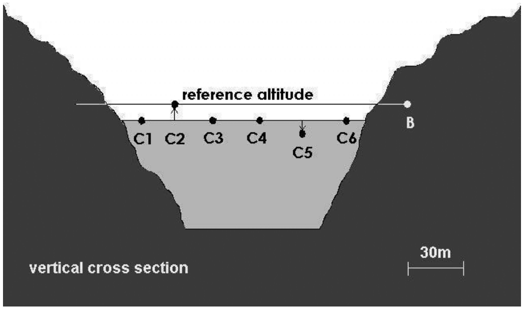

Fig. 2 Relative elevations of each control station is measured relative to reference station B using high accuracy spirit leveling. Vertical displacement in epoch i is defined on the difference between the elevation of a certain point in period j and an initial value at epoch 0.

At each monitoring station a millimetre ruler was placed vertical to the dam axis and the reading of the theodolite axis on the ruler was recorded. Deflection of each epoch and station were computed as the difference of the corresponding ruler readings between a specific survey and the initial survey,

$$d_{ik} = R_{ik} - R_{0k}$$

where, d_{ik} = deflection of epoch i and station k, R_{ik} = reading of epoch i and station k, R_{0k} = initial reading of station k

Readings at the side of the lake were taken to be negative.

4. Accuracy of measurements

The accuracy of the measurements of the horizontal deformations and the vertical displacements depends on the accuracy of the instruments used.

(a) Horizontal Deformations

The accuracy of the theodolite, used for horizontal deformation monitoring, is of the order of 1" – 2". This means that for a 100m long dam the accuracies of deflection measurements for each period can be estimated from the formula

$$s \approx r\vartheta$$

where,

ϑ is the accuracy of the theodolite in rad

For r = 100m at maximum, the accuracy of each deflection means is better than 0.48mm. For horizontal displacements computed as deflection changes,

$$d_{ik} = R_{ik} - R_{0k}$$

the corresponding accuracy is

$$\sigma_f^2 = \sigma_{ik}^2 + \sigma_{0k}^2 = 2\sigma_{ik}^2$$

(since the various epoch measurements are considered uncorrelated)

or better than 0.68mm

$$\sigma_f = \sqrt{2}\sigma_k = 0.68\text{mm}$$

This means that computed horizontal displacements above this threshold are significant against random errors.

(b) Vertical Displacements

In this case the accuracy of the measurement is the accuracy of the spirit leveling, about 0.5mm/km, Stiros and Rondogianni (1985) which is fine for the purpose we use it. For the short lines discussed here, observed relative elevation differences between reference and control stations are better than 0.5mm, and follows the previous analysis, observed elevation changes are accurate to with 0.7mm.

5. Available Data

The available original deformation control data include information for the date, the temperature and the reservoir level during the measurement, as well as the horizontal deflection and the vertical displacement of each one of the six control stations. The measurements cover the period 1960 and 2001, start several years after the completion of the dam, but there are systematic after 1968 (Table 3). For this reason, there is no control of deformation of the dam during the reservoir filling period.
Because measurements showed little, if any deformation, spacing between surveys was irregular and sparse. The measuring process however, was totally uniform as far as the method, instrumentation and survey parties are concerned.

TABLE 3. Measurements that took place the years 1960 – 2001
(The asterisk indicates which measurements were made in a particular date)

Date	Horizontal measurements	Vertical measurements	Reservoir height	Temperature
10/9/1960	*	*	*	*
1/4/1968	*	*	*	*
19/5/1968	*	*	*	*
9/6/1968	*	*	*	*
27/7/1968	*	*	*	*
22/9/1968	*	*	*	*
19/2/1969	*	*	*	*
9/7/1969	*	*	*	*
21/3/1970	*	*	*	*
4/9/1970	*	*	*	*
5/2/1971	*	*	*	*
27/6/1971	*	*	*	*
16/2/1972	*	*	*	*
10/1/1973		*	*	
23/7/1973	*	*	*	*
9/2/1974	*	*	*	*
31/10/1974	*	*	*	*
28/5/1975	*	*	*	*
21/11/1975	*	*	*	*
22/5/1976	*	*	*	*
9/11/1976	*	*	*	*
27/4/1977	*	*	*	*
15/10/1977	*	*	*	*
3/2/1978	*	*	*	*
26/5/1982	*	*		
24/1/1984	*	*		
30/10/1984	*	*		
8/8/1985	*	*		
23/1/1986	*	*	*	
3/2/1987	*	*	*	
26/5/1988	*	*		
11/5/1989	*	*	*	
23/4/1991	*	*	*	
13/6/1996	*	*	*	
3/6/1997	*	*		
29/3/2001	*	*	*	
12/10/2001	*	*	*	

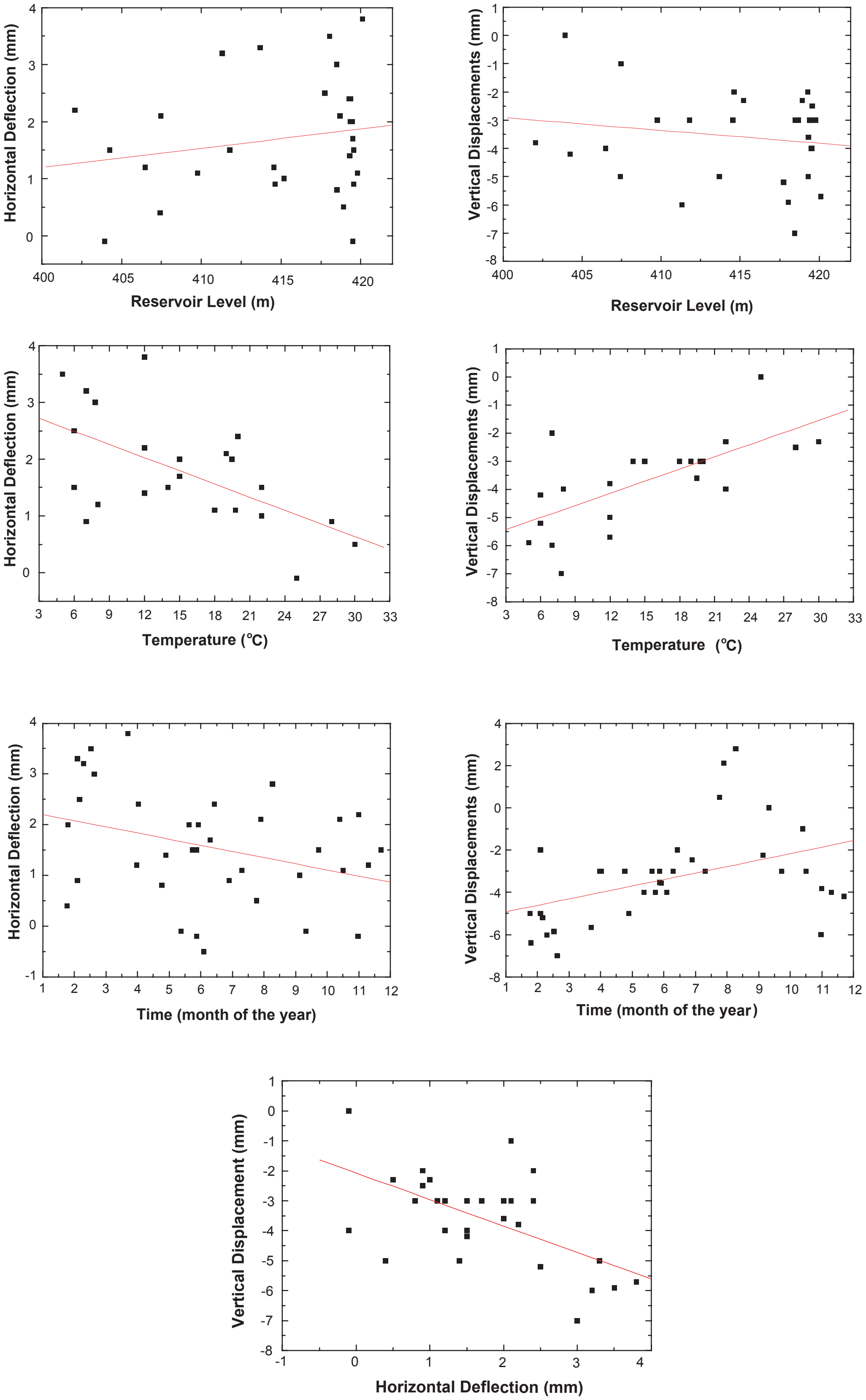

Fig. 3 Diagramms of Horizontal Deflection and Vertical Displacement of Monitoring Station C3 vs Reservoir Level, Temperature and Time. There is no significant linear correlation between these parameters which means that the Ladhon Dam, inspite of its age (> 40 years) is perfectly rigid.

6. Data analysis

Initially, the data was checked and cleaned from possible blunders. Then, they were grouped in months. The maximum horizontal deflection and vertical displacement have been found at the monitoring stations C3 and C4. This indicates that the central part of the dam is more sensitive than the rest of it. A next step was to search for a possible correlation between the reservoir level, the temperature, the time period, the horizontal deflections and the vertical displacements.

For this reason diagrams shown the relationship between Horizontal Deflection - Vertical Displacement, Horizontal Deflection – Reservoir Level, Vertical Displacement Reservoir Level, Horizontal Deflection – Temperature, Vertical Displacement – Temperature, Horizontal Deflection – Time, Vertical Displacement – Time of monitoring station C3 (which is the most vulnerable) were compiled (Fig. 3). The coefficients of linear correlation between the two variables in each diagram vary between 0.168 to 0.676. This indicates that there is no evidence of a strong linear correlation between the above variables. Given also that displacements were small, less than 8mm, no further analysis was made.

7. Discussion

Measurements have been taken in irregular interval of time, between a few months to eight years. Most of the measurements have been taken place in February and May. Maximum measured horizontal deflection, 5.7mm, was measured at monitoring station C4 on 19/02/1969. This particular date has no connection with the maximum reservoir level or the maximum or minimum temperature. Minimum horizontal deflection were measured at monitoring stations C1 and C6, which are close to the abutments of the dam, a very reasonable result. The monitoring station C3 has the maximum vertical displacement. Its value is 8mm and was measured on 30/10/1984. There is no data about the temperature and the reservoir level for this date. The minimum vertical displacement refers to monitoring station C1.

8. Conclusion

Our data analysis shows that (1) observed deformation of the crest of the dam are significant against random error, and small, less than 6mm and (2) there is no significant linear correlation between temperature, reservoir height, horizontal deflection, vertical displacement versus time for any of the six control stations on the crest of the dam. The maximum value for the coefficient of linear correlation between the parameters “horizontal deflection” and “time (month)” refers to monitoring station C3 and is equal to 0.676. These results indicate that the Ladhon Dam, inspite of its age (> 40 years) is perfectly rigid.

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