Monitoring Temporal Behavior of the Yamula Dam

Temel BAYRAK, Turkey

Key words: dam deformation, reservoir water level rising, and dynamic modeling

SUMMARY

Temporal behaviors of the Yamula dam (on Kızılırmak River and far 35 km from Kayseri city in Turkey) were monitored by using geodetic measurements covering four periods of 1,5 years. A developed deformation analysis technique was used to determine whether there was a relation between dam subsidence and reservoir water level rising. Investigations indicated that there was an apparent linear relation between dam subsidence and reservoir water level rising. In addition, there was evidence of reservoir water level rising in the amplitude of displacement. So, reservoir water level rising was regarded as a causative force in the formulation of the model. The analysis of reservoir water level rising by the dynamic model clearly indicated that large water level rising on the reservoir were an important triggering factor for the dam deformations. The developed model was capable of determining relations between vertical displacements and reservoir water level rising in addition to displacements, velocities and accelerations of displacements. The model allowed interpretation of measured displacements including geodetic and reservoir water level relationship.

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1. INTRODUCTION

In 2003, The Ayen Energy Joint-Stock Company that is a Turkish company started construction of an earthfill dam called the Yamula with a water storage capacity of nearly 3.4 billion cubic meters of water. The dam, located near Kayseri city, about 320 km SE from Ankara (Capital city), was designed to secure water supply, to store water to be used for generation of electricity, and to control river flooding for about 0.6 million inhabitants. The dam reservoir, about 40 km long and more than 1 km wide, covered over 92 km^2 of land. The storage water is supplied from the Kızılırmak River. In 2005, the construction work was finished and the dam was put into service. Due to the bigness of the dam reservoir and due to the seismicity and frequent earthquakes (average magnitude 4.8 from 1908 to 1994) in the area, a considerable effort has been put into designing an efficient and reliable system for monitoring deformation of the dams and of surrounding area (Fig.1).

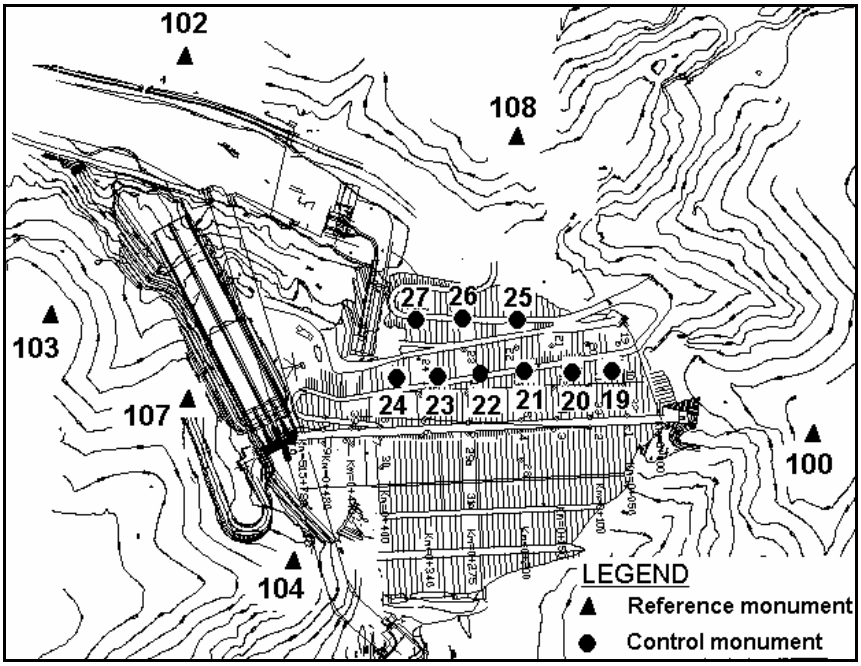

Figure 1. Geodetic network monuments for The Yamula Dam

Both geodetic and geo-technical instrumentation were used in the monitoring scheme. But this paper discusses only vertical geodetic data results. For this, a geodetic surveying network was designed to detect displacements of points larger than 10 mm at 95% confidence level using a high accuracy Total station (Sokkia 530R) that offers standard deviation of distance measurements of 2mm ±2ppm and angle measurements (one set in average atmospheric conditions) with a standard deviation of 1.5” or better. The dam deformation-monitoring scheme consist of 6 reference stations (100, 102, 103, 104, 107, 108) established surroundings of the dam and of 9 control stations (19, 20, 21, 22, 23, 24, 25, 26, 27) located on surface of the dam at the side of downstream face. The first campaign was carried out in December 2003, the second in March 2004, the third in November 2004 and the last one in April 2005. Available measurements were made during the first filling period of the dam.

In this paper we summarize geodetic data results describing 1.5 years deformation of the Yamula dam and present causative relationship between reservoir level and dam deformation in vertical dimension.

2. GEOMETRIC MODELING CAUSATIVE RELATIONSHIP BETWEEN RESERVOIR WATER LEVEL RISING AND VERTICAL DEFORMATIONS

Analysis of deformations of any type of a deformable body includes geometrical analysis and physical interpretation. Geometric analysis describes the change in shape and dimensions of the monitored object. Physical interpretation is to establish the relationship between the causative factors (loads) and the deformations. This can be determined by statistical methods (Chrzanowski A. S., Chrzanowski A, Massiera M. 2005).

This presented statistical model investigates causative relationship between dam deformations in vertical dimension and water level rising during the first filling period of the Yamula dam. In order to be found causative relationship, values of reservoir level rising and computed vertical displacements from static deformation model were drawn in a graphic for each control points. Because any deformation weren’t found by static model in point 19 and 20, these points weren’t included establishing relationship (Bayrak 2006). This relationship can be shown in Figure 2 for point 21 and in Table 1 for all control points.

R^2 in Fig. 2 is the coefficient of determination. R^2 gives the proportion of sample variety in dependent variable (vertical displacements) that is explained by independent variable (reservoir level rising).

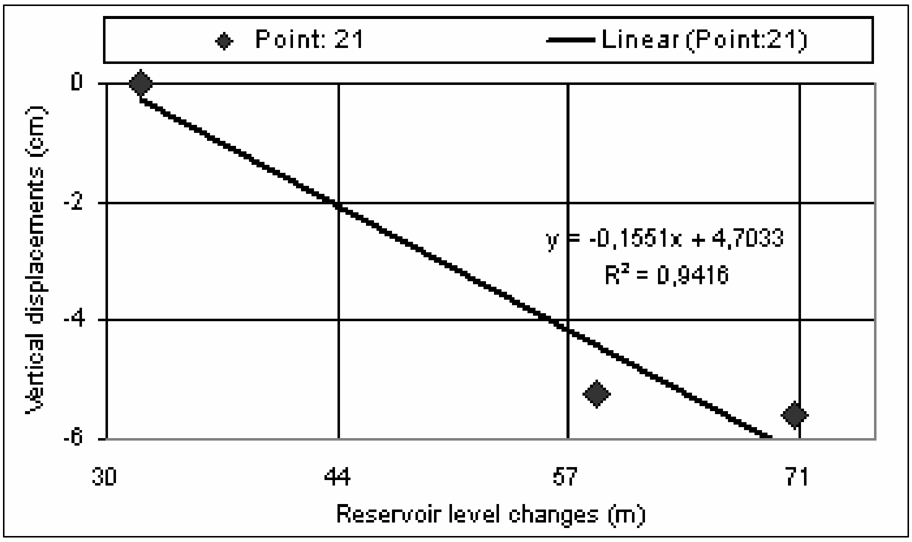

Figure 2. Relationship between reservoir level rising and vertical displacements at point 21

For point 21, R^2 means that 94.16% of the variability in the dependent variable is explained by the independent variable and 5.84% is unexplained. For all control point, values of coefficient of determination were determined. Results can be seen from Table 1. It can be realized from Table 1 that there is a linear relation between vertical displacements and reservoir level rising. Average R^2 means that 81% of the variability in the vertical displacements can be explained by the reservoir water level rising.

Table 1. Coefficient of determination for control points

Point Number	Coefficient of Determination
21	0.94
22	0.99
23	0.99
24	0.97
25	0.58
26	0.71
27	0.51
Average	**0.81**

So, in this investigation, it was assumed that the effect of water level rising on vertical displacements was linear. Adding the cause of vertical movements to a kinematical approach can form causative relationship (Yalçınkaya and Bayrak 2005, 2005, 2003, Pelzer 1985). So, formation of causative relationship can be built as follows for one-dimensional leveling network.

$$x_j^{(i)} = x_j^{(i\text{-}1)} + (t_i - t_{i\text{-}1})\, v_{xj} + \tfrac{1}{2}\,(t_i - t_{i\text{-}1})^2\, a_{xj} - (h_i - h_{i-1})\, b_{xj} \tag{1}$$

First derivate of Eq. (1) according to time parameter:

$$v_{xj}^{(i)} = v_{xj} + (t_i - t_{i\text{-}1})\, a_{xj} \tag{2}$$

Second derivate of Eq. (1) according to time parameter:

$$a_{xj}^{(i)} = a_{xj} \tag{3}$$

First derivate of Eq. (1) according to difference of reservoir water level:

$$b_{xj}^{(i)} = b_{xj} \tag{4}$$

Where $x_j^{(i)}$=coordinate of point *j* at period (*i*); $x_j^{(i\text{-}1)}$=coordinate of point *j* at period (*i*-1); v_{xj}=velocity of *X* coordinate of point *j*; a_{xj}=acceleration of *x* coordinate of point *j*; $t_i = (i)$ measurement period time; $t_{i-1} = (i-1)$ measurement period time; *i*=1,2,...,*k*=(*k*=measurement period number); and *j*=1,2,...,*n*=(*n*=number of points). In addition, Where h_i and h_{i-1}=reservoir water levels in periods (*i*) and (*i-1*), respectively; and b_{xj}= water coefficients of point *j* that have vertical coordinate in period (*i-1*).

Eq. (1) is the functional model of the model. The model was solved with least-square adjustment (Koch 1999). The parameters of position, velocity, acceleration and water level were included in this process. It is necessary to measure deformation network at least seven times to compute unknown parameter. The computation of unknown parameters was done using a Kalman-Filter with a-four measurements periods. In Kalman-filter process, the Hannover approximation was applied using four steps to compute the unknown parameters (Bayrak 2006; Yalçınkaya and Bayrak 2005, 2003).

Results computed from four periodic measurements made in December 2003, March 2004, November 2004, and April 2005 of the model in the application network (Fig.1) were statistically investigated, and relationship between vertical displacements and water level parameter were given in Fig. 3.

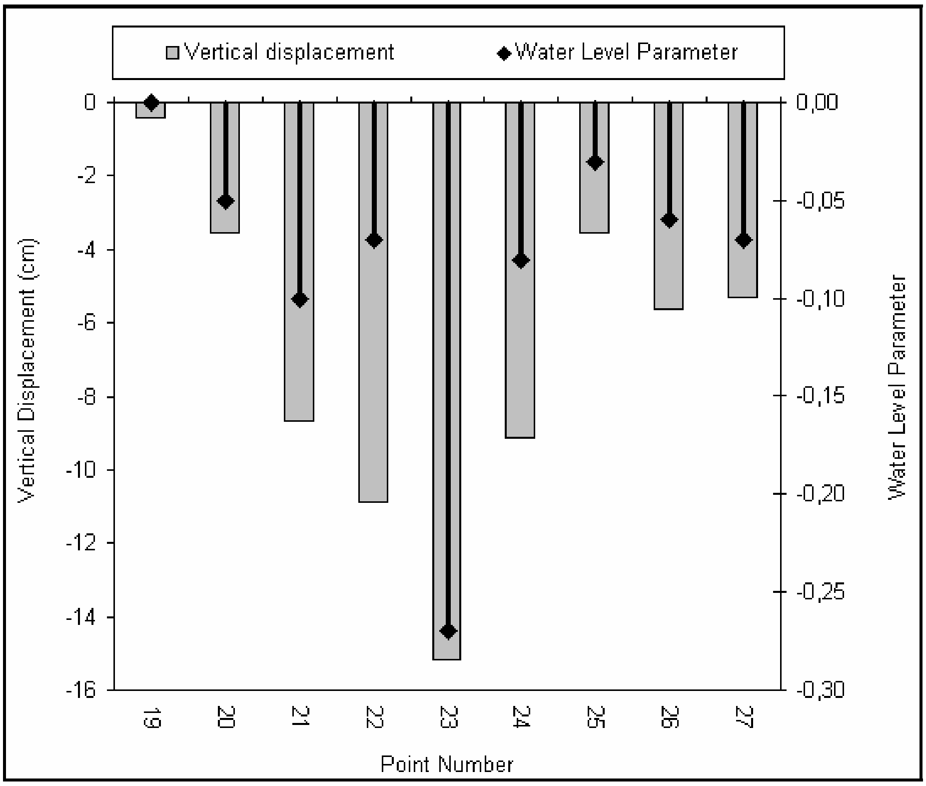

Figure 3. Relationship between vertical displacements and water level parameter

R^2 for relationship between vertical displacements and water level parameter were determined. This value was 76%. It means that 76% of the variability in the vertical dam deformations can be explained by the reservoir water level rising and 24% was unexplained. The 24% is due to other causative factors of the dam.

3. CONCLUSIONS

The presented case study demonstrates the usefulness of monitoring surveys in solving water level fluctuations problems in dam monitoring studies. Thus the proposed deformation model serves not only the purpose of giving information on geometrical changes (vertical displacements, velocities, and accelerations of network points) at the surface of the Yamula dam but become a tool for physical interpretation of the vertical deformations related water level rising during the first filling period of the dam.

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