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Behavioral Assessment of Karaj Dam Using Instrumentation Data

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ABSTRACT: One of the many uses of applying Instrumentation and monitoring dams and concrete dams in particular is using their results in order to expand our knowledge of the real behavior of the dams. In other words, each dam can be considered a major experimental model that can properly answer lot of questions about the performance of the dam and foundation against real forces, both fixed and variable forces. However, with the passage of time, there will be changes in the behavior of the dam, foundation and abutments due to fixed and variable tensions; the only way to be informed of these changes is recording the dams' behavior in various stages of construction and operation. Using the Instrumentation and monitoring can make the real situation of stability assessment possible based on the existing realities and recorded responses of the rock mass and structure. Using the results of monitoring and study of the changes of instrumentation data in many cases it is possible to discover the phenomenon that lead to erosion and destruction of the dam and avoid them or reduce their effects or finally minimized the potential damage caused to the residents and facilities of the downstream through on time actions.

Keywords: Direct pendulum, Embankment Dams, Instrumentation, Pneumatic piezometers

INTRODUCTION

Dam construction projects are among the most important and costliest major construction projects. Due to economics, water resources, agriculture, energy production and job creation reasons, dams are of outmost importance. However, geotechnical, hydrological, meteorological and other unknown parameters constantly threaten the stability and safety of dams. Therefore, monitoring is a step towards identifying the problems the dams are facing with and taking reasonable and right measures to maintain the stability and safety of them (Seraj, 2010).

Unlike concrete gravity dams that only has cantilever performance; concrete arch dams have both arch and cantilever performances and can transfer the loads to the side using arch function and eventually to the foundation according to the cantilever function. Therefore concrete arch dams with less thickness are able to withstand far more loads than concrete gravity dams. Due to the designing and operation complexity of concrete arch dams, monitoring them is of great importance. And various tools are used to monitor them (Bagherzadeh 2006).

One of the many uses of applying Instrumentation and monitoring dams and concrete dams in particular is using their results in order to expand our knowledge of the real behavior of the dams. In other words, each dam can be considered a major experimental model that can properly answer lot of questions about the performance of the dam and foundation against real forces, both fixed and variable forces. However, with the passage of time, there will be changes in the behavior of the dam, foundation and abutments due to fixed and variable tensions; the only way to be informed of these changes is recording the dams' behavior in various stages of construction and operation (Turner *et al.,* 2011). In general geotechnical instrumentation can be divided into two categories. The first group to determine the parameters of rock and soil, such as compressive strength, shear strength parameters, in situ stress, deformation modulus, permeability, etc., which is used in study and design phase. The second group for monitoring of structures such as the pendulum, extensometer, thermometers, leak detector, etc.; which is used in the period of implementation and operation (Durability, 2012).

Tavakol and Farhang (2013) studied restoring instrumentation of Latiyan dam and preliminary results from it. In the above research, a summary of the results of monitoring by means of the mentioned instrumentations such as displacement of the pendulum, the inclinometer and leakage detectors was presented and the inclinometer and pendulum performances. Emadalli (2014) examined the non-geodetic and geotechnical methods for the measurement of displacement (Case study of instrumentation analysis related to Maroon Behbahan reservoir dam. In the above study, the results of geodetic measurements (micro geodesy observations) such as precise measurements of length, angle and height have been compared to the results of non-geodetic observations for Maroon reservoir dam.

Tayeb *et al.*, (2011) studied the behavior of the Maroon dam body using network analysis of instrumentation during construction and filling. In the above study, the results and interpretation of monitoring devices installed in the core of the dam were studied and interpreted and based on these results, the behavior of the dam body was controlled and evaluated during filling and operation.

Seraj and Hezarkhani (2003) did thermal analysis of double-arch concrete under construction Karun 3 dam and compared it with the results of instrumentation. In Karun 3 Project, the results of the mentioned program are compared with the measurement results of dam body done by instrumentation including seam gauges and inclinometers and these results were consistent with each other.

Olapoor *et al.* (2011) studied the analysis of failure risk of instrumentations in Maroon earth filled dam. Mohammad Sharifi *et al* (1393) analyzed 15 Khordad dam leakages during operation using the instrumentation and signing. In the above study, 15 Khordad dam vertical deformation were examined using tools installed (slump magnetic plates) and the signs. The studies of 15 Khorded dam slump results represent logical behavior of the dam regarding vertical displacements but according to given results, dam has had horizontal displacement so it is necessary to resolve the problem of deviation chime and their reading. Beirami *et al* (2012) investigated the instrumentation and monitoring earth filled dams and water permeability of the support, body and foundation were examined. In this survey, the model used in the installation of instrumentation and the obtained results of Mollasadra reservoir dam was presented along with introduction of the instruments used in earth filled dams.

Kazemi *et al* (2014) evaluated the leakage monitoring data from Jiroft double arch concrete dam foundation and supports. In this study, the results of piezometers and drains installed in Jiroft double arch concrete dam foundation and supports used for monitoring leakage were evaluated.

Bazyar *et al* (2013) evaluated numerical three-dimensional instrument system of earth filled dams (Case Study of Azadi dam). The results of comparison show closeness of measured values in real samples obtained from the numerical model in this study.

Rezai Hajiani Bushehrian (2014) analyzed the leak and percolation monitoring of Molasadra earth filled dam. In this study, the numerical simulation of percolation and force parameter entered to the dam have been done in two dimensional mode in the range of body using seep/w software in persistent and temporary cases, on Molasadra dam; and the obtained results were measured and compared with real values.

Kyvanlou and Faghfur Maghrebi (2009) monitored Kamayestan concrete gravity dam with ANSYS software and compared it with the results of the instrumentations. The comparison of the results of the analysis in different levels of water and data from reading devices in different parts of the dam showed that most of the displacement of dam has occurred aligned with water force and at normal level of the water surface in the middle block of dam towards down; and most of the vertical displacement of the dam occurred in wide area from middle block to the crest; and finally studying the charts obtained from reading instruments, analysis and different levels of water determined that the instruments which showed vertical displacement of the dam have great difference with analytical results.

Hemmati and Barkhordari (2014) monitored Shirin Dare dam at the last phases of construction suing instrumentation. The studies show that Plaxis software has very well modeled the dam behavior, the slump and the cavity pressure coefficients and arcs created at the last phase of construction are all in the permitted range which guarantees the safety of the dam in the due time. In between, unequal slump of the section, postulates a new dam monitoring to prevent occurrence of possible hazards. Also observing non-compliance of cavity pressure in intermediate levels of core, abnormal data readings were observed.

To monitor the body of dam, a variety of instruments are usually used. In this research instrumentations that measure the movement of Karaj dam directly and indirectly will be surveyed.

The purpose of above study is monitoring Karaj dam during operation by exact tools. In this study, temperature variations with reservoir level, dam crest displacement along with reservoir water level, displacement changes, strain gauges changes with the reservoir level, the drainage rate changes, the total inflow rate and water leaking along with tank water level in the dam are all studied at the time of operation.

MATERIALS AND METHODS

A. Karaj Dam location Amir (Amir Kabir)

Amirkabir dam which is as well called Karaj Dam is located in north of Karaj and in 25 km of Karaj Chaloos road. This dam is the first multipurpose dam of Iran, and a source of Tehran water supply. Amir Kabir dam is a multipurpose dam. Among these purposes we can point to the Tehran piped water supply and development of agriculture and water supply of 50 thousand hectares of Karaj. With more than forty-six years of experience, the dam's hydroelectric power plant is connected to country's power network and is capable of producing 90 megawatts of electricity. However based on the catchment basin and its output rate, this amount of electricity generation is considered to be very low and defects in dam engineering are blamed for it. Fig. 1 shows Karaj Dam.

Fig. 1. Location of Amir Kabir Dam.

Table 1: General characteristics of Karaj Dam.

Crest length	390m
Crest width	87.5 m
Width at the bottom of the river	30 m
Height from the river bottom	163 m
Height from the foundation	180 m
Total water discharge valves	6
Total capacity of water discharge valves	1550 m^3 / sec
Discharge overflow capacity	1450 m^3 / sec
Type of spillway	Radial

Table 2: Specifications Hydro mechanical equipment's of Karaj Dam.

Row	Name of Equipment	Count	Dimensions in meter	Emplacement
1	Spillway	2	10 * 10	At 1755 level
2	Main valve	3	5.35 * 2.63	Plant units
3	valve	2	2.2Diameter	Plant units
4	Draft hatch tube	6	2.95 * 2.45	Plant units
5	Discharge Hatch	2	1.43 * 2.9	Drain valve
6	Discharge valve	2	1.3Diameter	

Table 3: Building details of Karaj dam.

Dam name	Karaj Dam (Amir Kabir)
Dam situation	In operation
Dam Type	Double-arch concrete
Foundation material	The combination of rock and alluvial
The height of the dam from foundation	180 meters
The height of the dam from riverbed	163 meters
Crest length	390 meters
The volume of the dam body	750,000 m Cube
The total volume of the tank	205 million M
The dead volume of the tank	10 million M
Lake surface elevation utmost normal	4 km Square
The total volume of annual water regulation	472 million M
Cultivation area	21,000 acres
Nominal power Capacity	90 MW
Type of main spillway	Free
The maximum discharge capacity of the flood spillway	1450 m On Second

Table 4: Specifications of Hydro mechanical equipment's of Karaj regulatory dam.

Row	Name of Equipment	quantity	Dimensions in meter	Emplacement
1	Spillway	2	10 * 10	
2	Hatch	1	1.43 * 2.9	Drain valve
3	valve	2	1.22 * 1.52	Drain valve

Table 5: Installed instrumentation in Karaj main dam.

Row	Name of Equipment	Count
1	Numerical indicators of lake level	1
2	Index trail at the dam crest	1
3	Drainage boreholes	66
4	Strain gauges	486
5	"Strain gage " Without Tension	50
6	Thermometer	170
7	Joint meter	58
8	Transformation gauge	17

Table 6: Installed Instrumentation in Karaj regulatory dam.

Row	Name of Equipment	Count
1	Numerical indicators of lake level	1
2	Thermometer	17
3	Joint meter	30

RESULT AND DISCUSSIONS

One of the major loads applied to the concrete arch dams and causes significant changes in the locations of the dams is thermal loads. To control the temperature of concrete dams, thermometers and thermocouples are used. In Karaj dam the weather temperature is measured daily; water and dam body temperature are measured and recorded based on the schedule. Basically, an increase in temperature moves the dam towards up and low temperature will cause the dam body to move down. The thermal analysis of the concrete dam needs reservoir temperature at different levels. To determine the water temperature at different levels in the presence of monitoring data, they can be used. To do this, the results of thermometers and thermocouples that are close to the tank are used as the tank temperature at different levels. Locating the thermometers in Karaj dam body is shown in Figure (25). Another method that is generally used in primary designs or when monitoring data is not available is using experimental formulas predicted for this reason.

In this study in addition to monitoring, Bofang experimental method has also been used to compare the results of thermometers and show the differences between these two methods. According to this method, the temperature of the lake at a depth of y and at the time of t is obtained through the following equation:

$$T_{(x,y)} = T_{m(y)} + A_{(y)} \times \cos\left[\omega(t - t_0 - \varepsilon)\right] \quad (1)$$

$$T_{m(y)} = C + (T_s - C)e^{-0.04g} \quad (2)$$

$$C = \frac{(T_b - gT_s)}{(1-g)} \quad (3)$$

$$T_S = T_0 + \Delta b \quad (4)$$

In the above equations:

y: is the height of the tank at the ideal time (in meter)

t and t 0 : Number of day with the highest temperature and the number of the desired days.

Ta: The average annual air temperature (in degrees Celsius)

T min and tmax: minimum and maximum average air temperature during the year.

ε : is phase difference between temperature of weather and the lake water in defined depth which is obtained through the following equation.

$$\varepsilon = \left(2.15 - 1.3e^{(-0.085\,y)}\right) \times 12 \quad (5)$$

tb: is the average of the water at the lake bottom and the weather frequency in a period of 365 days which is obtained through the following equation:

$$\omega = \frac{2\pi}{365} \quad (6)$$

The studied thermometers:

T95 and T98 in surface elevation upstream on 1710 level - water temperature

T96 and T99 in surface elevation downstream on 1710 level - weather temperature

T97 in the center of concrete on 1710 level - - internal concrete temperature

T126 and T128 in the center of concrete on 1738 level - internal concrete temperature

Fig. 2 shows schematic illustration of thermometer arrangements. Fig. 3 shows Change thermometers T95 & T98 in surface elevation upstream 1710m is associated with reservoir between the 1962 and 1971.

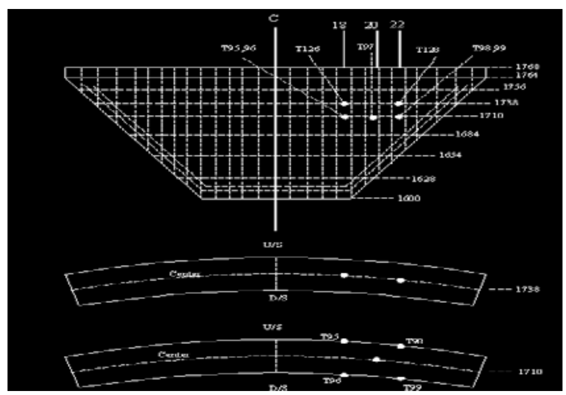

Fig. 2. Schematic Thermometer Arrangement.

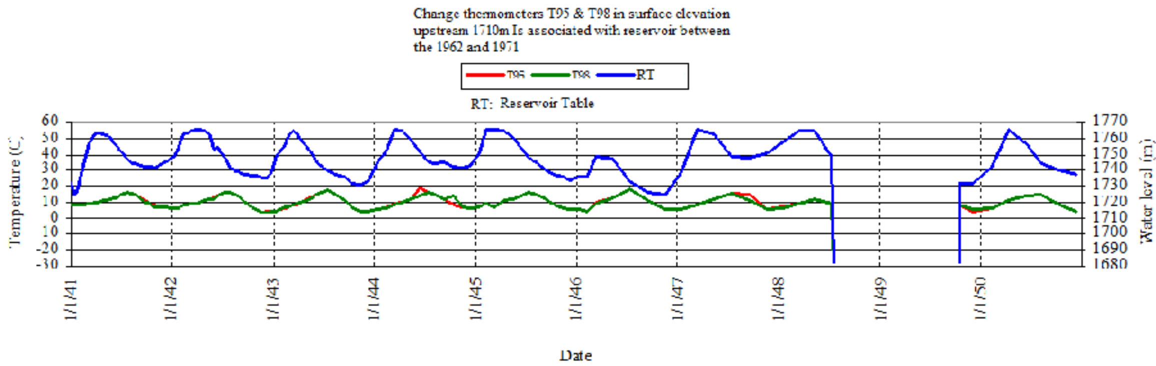

Fig. 3. Shows thermometers T95 & T98 Change in Surface elevation upstream 1710M Is associated with the reservoir between 1972 and 1981.

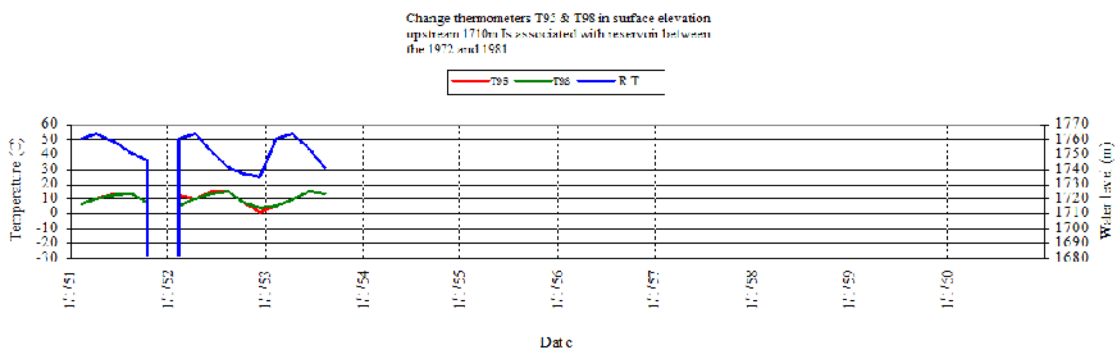

Fig. 4. Shows Change thermometers T95 & T98 in surface elevation upstream 1710m is associated with reservoir between the 1982 and 1991.

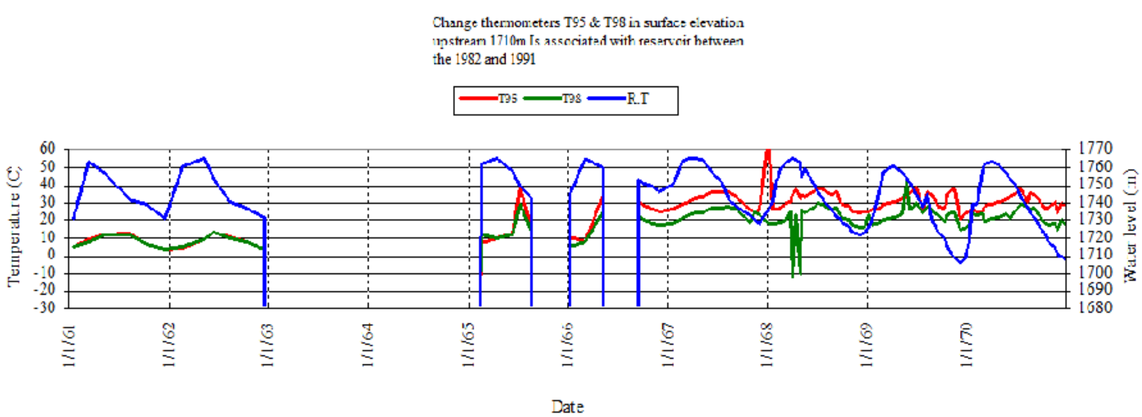

Fig. 5. Shows Change thermometers T95 & T98 in surface elevation upstream 1710m is associated with reservoir between the 1992 and 2001.

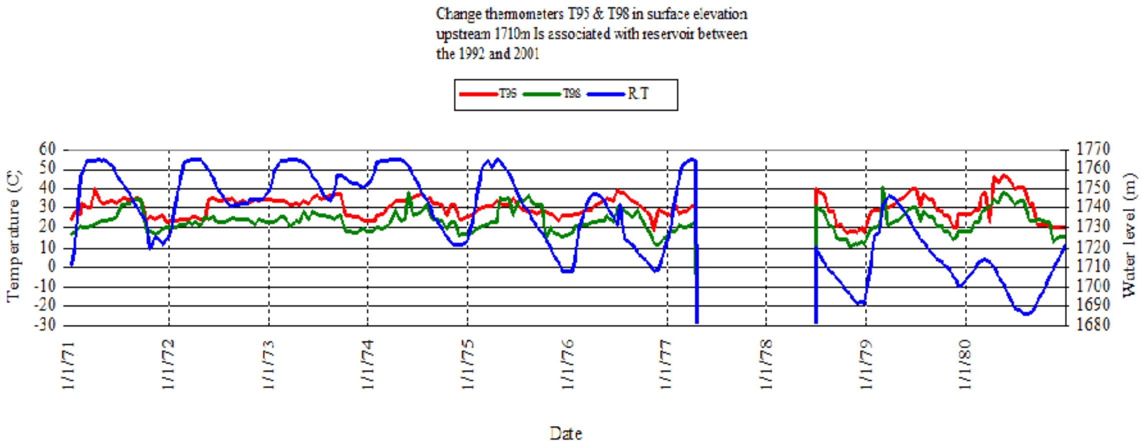

Fig. 6. Shows Change Thermometers T $_{126}$ & T $_{128}$ in Concrete Surface Center 1738M Is associated with reservoir between the 1962nd and 1971.

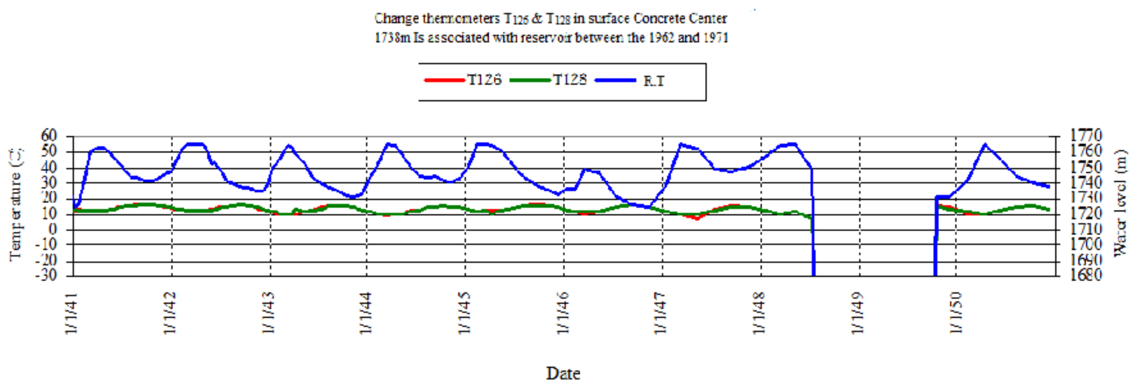

Fig. 7. Shows Change thermometers T_{126} & T_{128} in surface Concrete Center 1738m Is associated with reservoir between 1972 and 1981.

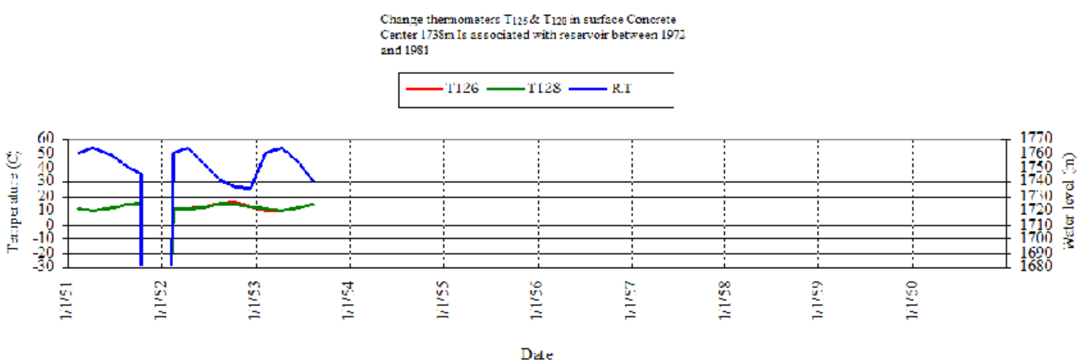

Fig. 8. Shows Change thermometers T_{126} & T_{128} in surface Concrete Center 1738m Is associated with reservoir between 1982 and 1991.

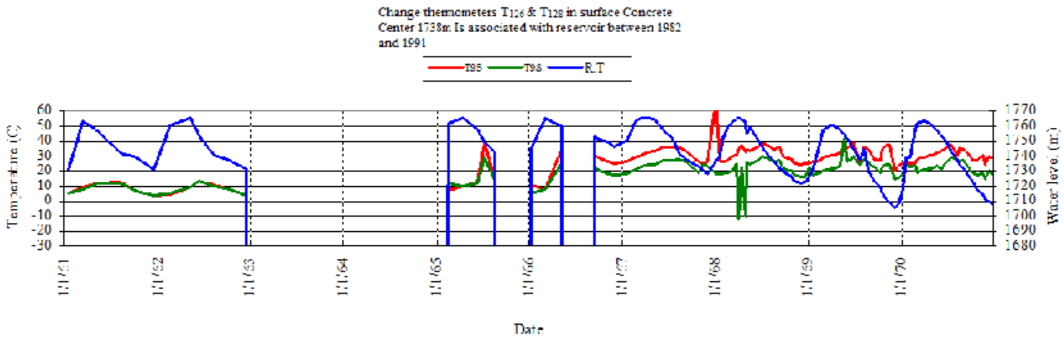

Fig. 9. Shows Change Thermometers T $_{126}$ & T $_{128}$ in Concrete Surface Center 1738M Is associated with reservoir between the 1,992th and in 2001.

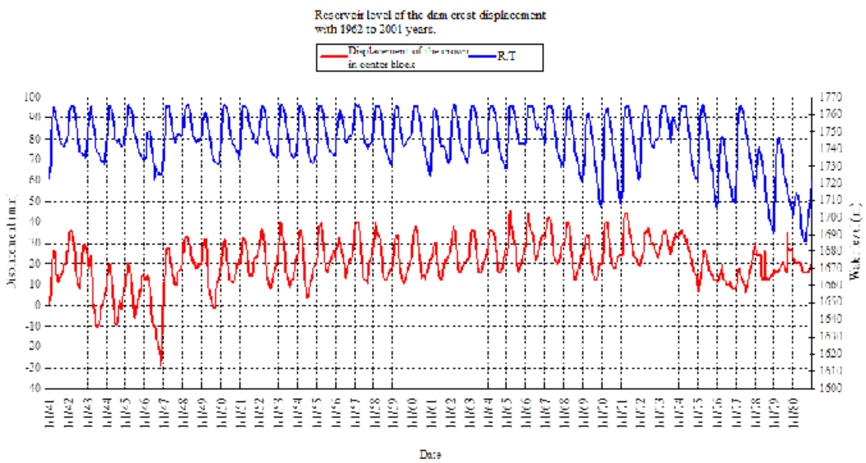

Fig. 10. Displacement of dam level in the reservoir.

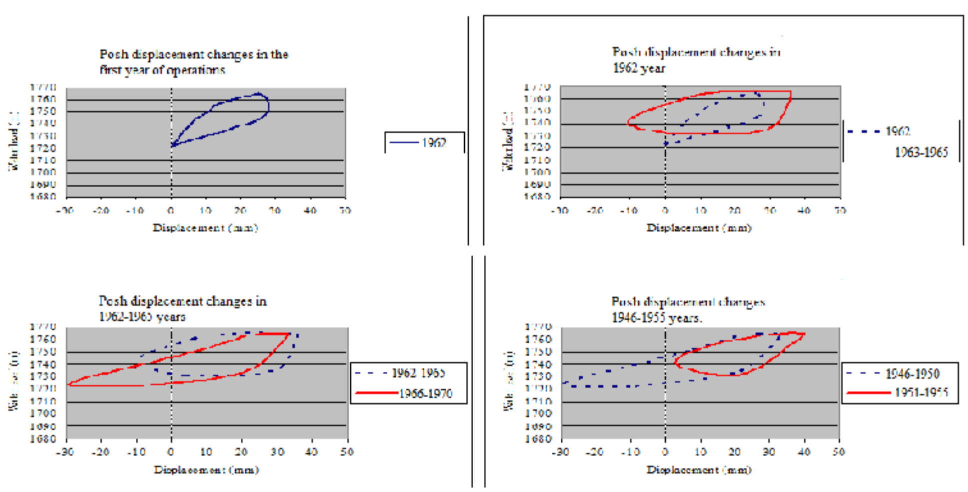

Fig. 11. Cover of the displacement changes.

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