STABILITY SURVEY OF BOOSTAN EARTH DAMS USING INSTRUMENTATION DATA

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ABSTRACT

Behavior analysis of the earthen dams is performed to study the dam performance with respect to the safety issues, and to compare the real and predicted behaviors; it also seems to be important and necessary for future planning during construction, drainage, and operation periods. The behavior analysis of the dams is facilitated by installing instrumentations in the sensitive points, and by measuring different parameters such as pore pressures, and deformations such as sitting, and displacements, and by the technical inspections. In this study, also, the stability of Golestan province dams has been investigated by using instrumentation data. Firstly, the recorded data of instrumentation were collected. Then, by using the data, the stability of the dams was controlled. The obtained results indicate that Golestan dams are in a normal and favorable condition.

1. INTRODUCTION

Protecting, maintaining and controlling the dam behavior not only preserves the national wealth and capital, and increases its life span, but also it is very significant with respect to the safety, and preserving human's lives and the environment. Generally, one of the most important problems that occur after constructing and implementing major constructions such as dams are protecting, maintaining, security and efficiency of the construction. Hence, due to the highly cost, and the longtime of constructing the dams, it is inevitable to perform their measurements, behavior control, protecting, and operating. To analyze the behavior of a dam during the periods of construction, drainage, and operations, it is necessary to really measure some parameters such as displacement, pore water pressure, leakage, etc., which with the help from their measuring, we can control the designing data, the dam behavioral performance, and finally the dam stability. For this reason, some instrumental equipment are used under the instrumentation.

Instrumentation is used for a wide spectra of measuring instruments for measuring the variation of the physical and mechanical quantities that are implemented in the area of geotechnical and constructing projects, especially the dams. The variations of the quantities such as displacement, force, water pressure, and so on. Are measured and controlled by using instrumentation data. Instrumentation and behavior analysis hold a high place in the geotechnical projects, especially in the dams as one of the hugest geotechnical constructions. Today, tooling has gained a significant importance in controlling the stability and safety of the dams. Predicting and appliance of instrumentation in the major and sensitive points, on-time and continuous reading at the required time intervals and periods, and exact and comprehensive evaluations of the data and results acquired from these instruments seem to be as important and sensitive as the instruments themselves. In many dams by using the results obtained from behavior-analysis instruments, an issue or risk has been identified in time; so, there has been enough time to perform in-time treatment; and, consequently, the occurrence of an irrecoverable incidence has been mitigated.

Controlling the behavior and performance of the dams, especially during operation times, is of high significance so that it is necessary from the very drainage phase, to perform their behavior-analysis with acute sensitivity. To do so, after each period of performing interval readings of the instruments, the dam performance should be assessed from different behavioral aspects (such as pore water pressures, tensions, displacements, and other controlling parameters). The results from these assessments and interpretations should be regularly published in the form of analytical reports. Added to the regular reports, on special time intervals, and in the case of the emergencies (flood, earthquake), special and case reports should also be prepared.

The behavior analysis of the dam has two major advantages: Firstly since the dam behavior during construction can indicate its future behavior; so, it makes it easier to understand the principle aspects of the dam planning. Secondly, during the dam operation periods, the behavior analysis gives the necessary information for the dam safety, and effective operation to the employers and controlling authority to cover the dam behavior. By examining the measurement data during operation, the previous behavior of the dam can be studied, too. The dam safety, preserving integrity, and dam performance are important to make sure of the absence of possible unacceptable hazards or risks to individuals' lives, assets, and the environment. Safety control is, in fact, the examination of the status of the dam safety by the regular inspections of the construction, the continuous monitoring of the behavior, and analysis of its performance, and also reviewing the documentaries of the initial planning and construction of the dam in order to make sure that the safety criteria have been met.

Protecting, maintain, and controlling the dam behavior not only preserves the national wealth and capital, and increases its life span; but also, it is very significant with respect to safety, and preserving human's lives, and the environment. Generally, one of the significant problems that occur after the construction and implementing major constructions such as the dams, are protecting, maintaining, security, and efficiency of the construction. Hence, due to the highly cost, and longtime of constructing the dams, it is necessary and important to regard their measurement, behavior control, protection, and operations. To monitor a dam behavior during periods of construction, drainage, and operations, it is necessary to really measure some parameters, such as displacement, pore water pressure, leakage, etc., with the help of their measurement, we can control the planning data, the behavioral performance of the dam, and finally, the stability of the dam. To do so, the instruments and equipment are used under instrumentation. Annually, to expand the possibility of more acute behavior analysis, the diversity and accuracy of instrumentation gains an increase. The behavior analysis warns against the possible issues arisen in the dams in order to neutralize them. So, we can summarize the causes of the dam behavior analysis in terms of examining the safety problems of dams, making a comparison between the real performance, and the predicted planning, and gaining experiment for future planning of dams.

2. LITERATURE REVIEW

The outbreak of the incremental trend of planning and constructing the dams, and the water preservation construction dates back to many centuries. Eye inspections and live inspections were a part of the implementing process of the early projects from the earliest embankments to the years after implementation and operation [1]. Afterwards, instrumentation and measuring instruments were employed. For example, we can refer to the readings obtained from topographic levels that are said were obtained from the Gross Bois dam crown in France in 1853 [2]. The dam was constructed from 1830 to 1838; there were carried out some readings to measure the displacement of the dam crown. During next years, level measurement by using surveys were among the most important considerations to perform behavior analysis of such dams. During late 19th century, the open-pipe piezometers were used in India to study the leakage water running under the dams specialized for irrigation, constructed on alluvial areas [3].

In 1907, this kind of instrumentation was employed by the British engineers to determine the free level of water table in the earthen dams. In the USA, the observational wills, water level counters, and the hydrostatic level gauges were initially employed in the Rehabilitation office of the earthen dams to measure and record the water level or pore water pressures. Simultaneous with employing the water level, counters, the hydrostatic pressure gauges were designed, and employed in several dams. Installation of the hydrostatic pressure gauges in 1938, and 1939 for COBOL dam in the state of New Mexico, USA, was an example of installation of this kind of instrumentation at that time [4]. In the USA, Roy Karlson designed an instrument that measured the pressure by a sensor involving a stretched wire, in the concrete and earthen dams. This measuring instrument of the wire resistance stretch was first commercialized in 1932, and was later completed by piezometers, concrete stress cell, earth pressure cell, and seam detectors. Also, in 1930's, in the USA, the reconstruction office began to make use of the controlled measurements for the harmonic performance of the complete dam constructions with planning data, and the construction methods. This attempt leads to the design of the water level counters, and two-piped hydraulic piezometers for measuring the pore pressure [5].

Vibration wire sensor has a long life span, and enjoys high accuracy and stability. It has been proved to be an appropriate instrument for special and severe environmental conditions. Its exit signal frequency makes it to be less sensitive to the disadvantages and deficiencies in the conducting current than other sensors. Today, the vibration wire sensor is the most applicable among the implemented instrumentation. During 1930's, and 1940's, the use of vibration wire sensors for behavior analysis gained popularity worldwide [6]. From 1930's to 1970's, the use of modern dam instrumentation extended, and dam instrumentation with constructing new dams was widely employed. The instrumentation, over recent years, has gone under considerable changes that are indebted to the advancements of Electronics, and micro-computer technology. The advancements in this field made it easier to collect and process the data; this has caused to change the nature of the instrumentation results. Recently, this has been made possible to receive the information from dams' instrumentation in the remotest areas of the world via satellites and to transmit it to offices in other countries. The information can immediately be simplified by the computer, and be put into a format that makes it possible to instantly recognize the performance deviations of the construction (by the engineers) [7].

3. THE SIGNIFICANCE ANALYSIS AND PROTECTION CONSIDERATION OF EARTHEN DAMS

The dam behavior analysis has two major advantages: Firstly since the dam behavior during construction can indicate its future behavior; so, it makes it easier to understand the principle aspects of the dam planning. Secondly, during the dam operation periods, the behavior analysis gives the necessary information for the dam safety, and effective operation to the employers and controlling authority to cover the dam behavior. By examining the measurement data during operation, the previous behavior of the dam can be studied, too. The dam safety, preserving integrity, and dam performance are important to make sure of the absence of possible unacceptable hazards or risks to individuals' lives, assets, and the environment. According to the statistics and reports published by ICOLD (1983), which result from the investigation of 14700 dams, it was noticed that 7% (1105 dams) were being destroyed, and 0.7% (107 dams) were already destroyed. According to the report, a major part of the constructed dams was of earthen and/or trench type; and, that these dams, compared to concrete dams, had a very higher percentage of destruction (74%). This clearly represents the necessity of the behavior analysis, and protecting the earthen dams [8].

The main failures of the earthen dams are due to the vein phenomenon, and leakage from the dam body, foundation problems, and water overflow over the dam, which these problems can be identified by proper behavior analysis, and can take timely actions. According to the historical investigations, the higher the dam, the less the destruction. This issue can be related to the cause that in high and huge dams, the destruction rate would be less due to that the operations of tooling and behavior analysis have been carried out with more accuracy and in a wider area. In a dam construction project, the tooling and behavior analysis could be divided in four phases: planning, construction, initial drainage, and operation. In each of the phases, the controlling parameters such as leakage, displacement, water pressure, etc. are measured, evaluated, and controlled. According to the variations of water level in the pool during the dam operation, the behavior analysis will gain high importance. The rapid decrease/increase of the pool water can lead to dangerous problems; so, the issue should always be under continuous control and evaluation. Added to the general cases mentioned, the dam behavior after earth quake, and after huge floods should be investigated specifically and separately for each kind of dams [9].

With regard to the destruction of the earthen dams, and the major problems arising from the destructions, their evaluations have shown that the following phenomena can put their safety at risk [10]:

1- Inappropriate sealing of the foundation

2- Cracking in the sedimentary core part

3- Cracking in the common wall where aggregates change

4- Solubility of foundation rock

5- Deteriorations of impenetrable building coverings

6- Drying of sedimentary embankments, and the resulted cracking

7- Steep slopes and susceptibility to slip instability

8- Heterogeneous rock masses and heterogeneous subsidence problem

9- Inappropriate involvement between the dam and the surrounding constructs

10- Doing embankments with inappropriate aggregates

11- Sensitivity to earthquake lubrication conditions

4. METHODS AND MATERIALS

4.1 Instrumentation

A set of equipment used for behavior measurement or behavior analysis of a construct are called instrumentation. The instrumentation can be divided into two groups: Mechanical instruments, and electrical instruments [11]:

(a) Mechanical instruments:

They are the instruments that are mainly made of the mechanical elements. Their reading system may be manual or mechanical. The main system of these instruments is in such a way that may measure the phenomena directly, and there will be little need to change the reading measurement into a target parameter. For example, the ground water level is measured by a vertical-wire piezometer, and the water stop level is measured from the entrance tube part of the piezometer. The obtained value directly shows the groundwater level. Some mechanical instruments have many advantages; because, in addition to the ease of their installation, they will be removed with greater ease in case of any failures. Fabrication of this set of instruments does not involve using complicated technologies, so that many of them can even be fabricated in small workshops. Also, for the matter of their costs, in some cases, they are more cost-effective. But, in several cases, it is not possible to apply the mechanical instruments, or they may fail to meet the measurement for a specific purpose. So, where high accuracy is demanded, the electrical instrument will gain priority.

(b) Electrical instruments:

The electrical instrumentation is the instruments that work with electricity, and their main measurement factor is mainly resistive or vibrational. Today, the use of the electrical instruments such as the vibration wire system in the measurement equipment, has several advantages: the electrical instruments, in fact, measure the phenomena indirectly, and their reading results should be converted to the parameters via some formulas. For example, if we consider an electrical piezometer of vibration wire type, the pore water pressure reading cannot be directly obtained, rather the reading would give us the frequency of the wire vibration. The value of the pore water pressure is obtained when the read digit is put in the related formula. Of course, the new reading instruments will do this operation, and they directly measure the pressure. Today, with the technological advancements in the measurement equipment, many of the electrical reading instruments enjoy the suitable sensitivity, and are rivals for the mechanical instruments in terms of perdurability and costs. The technology of fabricating the electrical instruments are much more complicated than that of the mechanical instruments. Due to their instant response to the variations in the target parameters, the appliance of these instruments has replaced other instruments such as the mechanical ones.

4.2 Advantages of employing instrumentation

(a) Aiding assessment

Design assessment: The designer usually cannot design the project from safety or economic aspects. To do so, the observational methods are employed in which the constructing design is completed. In this regard, the instrumentation plays an essential role in the construction, and enables the engineers to design the project with appropriate safety and economic considerations. Assessment of the technology of constructing the new constructions: often, the modified and new construction technology, or even the engineer's claim cannot be accepted unless they are proved in practice. Therefore, the obtained data from the instruments can help assess effectively the new construction by using the modified technology.

Identification of the special nature of an unexpected: If a rupture is observed in the construction or a concern (possibility of risk) in the project place occurs, the data from the instrumentation can help identify and assess the unexpected events. In addition, the instrumentation can represent the construction conditions before and after restorations (the corrective works). Continuity check of acceptable execution: the instrumentation system continuously shows the results of information in the dam or construction. The information may not be in urgent demand during the initial phases, but it can show the possible problems in the future.

(b) Aiding in forecasting

Using the instrumentation information is of high importance to predict the future behavior of the dam. The observations might require taking instant reactions to resolve possible future problems. The instrumentation installed inside or over the dam, is not to protect the dam against harsh events or its destruction. The main role of the instrumentation is do behavior-analysis, and to provide the information that introduce the abnormal or unnatural cases of the dam behavior to warn the risk prior to the incidence. Therefore, by continuous reading of the applied instrumentation in different parts of the dam, its behavior is analyzed and interpreted by using the acquired data; and, based on the results from the measuring parameters, we can predict the dam behavior during different phases.

To gain correct, accurate, and timely knowledge of the dam behavior, the necessary instruments according to the designer's view, are installed in critical and analyzed sections; and, the dam behavior is controlled and investigated during different periods such as constructing time, the initial drainage, the completed construction, operation times, after each huge flood, after each earthquake and the quick evacuation. The valuated analysis along with the construction planning and control analyses should usually lead to desirable quality and the dam security. Even if all these requirements are considered, for all the huge dams, the behavior-analysis should be done in order to compare their performance during construction, drainage, operations, and special conditions such as the occurrence of earthquake, and possible floods to the predicted behavior during planning. The behavior-analysis of the dams is of special importance for their initial period of dam filling lake.

(c) Aiding verification

The correct information of the instrumentation can be used to make inferences in several cases. For example, to prove the structural performance of the construction during temporary project delivery, to control the allowance of the embankment real displacement values to the predicted values, and establishing a database to predict the possible dangers, and proving the claim of the occurrence of danger and/or unexpected event after construction requires spending high prices. The instrumentation can help us make decisions during unexpected events to pass sound judgments.

(d) Aiding the researches

Aligned with the advancement of executing dam operation, the information from the instrumentation makes it possible to understand the complicated behavior of the forces on the dam; and, the future planning is always indebted to the quality of the former information. In other words, to make new dams, the instrumentation data are analyzed in the following cases:

- Proof or disproof of the planning hypotheses
- Determining the primary comparison model of the dam behavior
- controlling the executive methods, and their modification if necessary
- Indirect controlling of the aggregates
- Testimonials (preparing legal documentations)
- Scientific research and development

4.3 Reading, processing and recording the instrumentation data

The timing of reading the installed instrumentation should be in accordance with the instructions determined by the project instrumentation engineer. Since, the assessment of the status of stability, and also rooting of the factors of any kind of instability requires having enough information of the way the changes occur in measuring instrumentation, the timing needs to be dynamically set with the tone of the predicted or recorded variations. Also, the recording of any executing activity on the project site that is somehow related to the stability and performance of the dam and its related facilities should be mentioned in detail.

During operation, most of the variations observed or recorded are related to the variations of the pool water level and the climate conditions (environmental temperature, amounts of rainfall). Therefore, all the parameters should be recorded together with these two parameters and the measuring hour. Processing the read data is carried out by applying the corrections of the predictable errors, and the necessary corrections related to the necessity of synchronous instrumentation readings in a station (or section).

Drawing behavior-analysis carves, as it is usual, is in the form of the measurement variation curves over time or other effective parameters. For example, drawing the variation curve of the parameters such as dam body and foundation deformation, pore water pressure on the dam body or foundation, etc., to the variation of pool water level can make it possible to assess the main causes of the variation. Also in the case where the measurements are not consistently carried out, and its variation curve over time is too interrupted, it is recommended to draw the recorded variations curve related to the pool water level. General and numerical specifications of Boostan Dam.

4.4 General characteristics of Boostan Dam

The Boostan Dam sit in Golestan province is located about 35kms northeast of Gonbad Kavus city and 23 KMs upstream of Golestan Dam. The dam is located on the Gorganrood River, in a location with coordination of 33° 25′ 30″ east longitude, and 55° 25′ north latitude [12]. The following figure shows a satellite image of Boostan Dam. The general specifications of the Boostan Dam and its associated structures have been presented in Table1.

Figure 1 : The satellite image of Boostan Dam and its associated structures

Figure 2 : View of Boostan Dam Lake

Table 1 : General Specifications of Boostan Dam

Deviation system and bottom discharger		Overflow specifications		Reservoir specifications		Body specifications	
Dam body	Location	Free	Overflow type	5Hm3	Reservoir volume in the crown overflow level	Homogenous Earthen	Dam type
2 metal pipes	Number	40m	Overflow length	18Mm3	Flood control volume	35m	Height from foundation
1600 mm	Pipe diameter	100m	Crown overflow level	4.1km	Normal Number width	25m	Height from floor
280 m	Pipe length	PFM	Designing flood	96 m	Normal numeric	105m	Clam crown level
296 m	Total system length	Right stand	Overflow location	28 Mm3 per year	Profitable volume of water for agriculture	642 m	Dam crown length
45 m3/s	Deviation capacity	785 m3/s	Maximum Debby	Design principles		10 m	Dam crown width
25 years spreader in the reservoir	Designing flood			0.15g	Horizontal quake acceleration	265 m	Foundation thickness
				50 years	Dam life span		

5. INSTRUMENTATION

The installed instruments in Boostan Dam include Casagrande Piezometers, vibrational Piezometers, total pressure cell, and sitting gauge-diversion meter. The data of these instruments are read monthly. After evaluating and sieving the data, the curves are drawn to study the stability and leakage status, and then they are analyzed.

5.1 Piezometers

Studying the pore water pressure, and its variations in the earthen dam is of high significance, so that the increase in the pore water pressure leads to the decrease of shear stress, and the effective soil stress, and endangers the dam stability. For this reason, in the earthen dams, the pore water pressure variations have always been considered; by taking necessary actions its overflow is controlled.

The pore pressured while stable and steady leakage during the dam construction are affected by the leakage force from the water flow in to the dam. The necessary time of saturating the dam downstream, and creating stable leakage is more related to the soil type constituting the dam body, and to the water behind the dam body. While it is possible that for penetrable aggregates the creation of saturation status, and the current line in the dam take one year to complete, it takes 2 to 3 years for impenetrable aggregates, and in some dams, even after many years, the condition has not been created due to the water level variations in the reservoir, and the type and characteristics of the aggregates. With regard to the continuous variations of reservoir water level in Boostan Dam, the case has not been created yet. In the homogenous earthen dams, Like Boostan dam, the stokehole and drainage blanket are very effective, and can make the current lines be vertical. Finally, due to the presence of the drainage blanket, it reduces pore pressured to a great extent.

As we know the drainpipes in the earthen dams are required to ensure that the dam main body aggregates are not washed off, and to prevent the endangerment of the stability due to the inside water pressures, and they are used to control the leakage. In the Boostan Dam, the horizontal drainage blanket has been used as a supplement along with the vertical chimney drainpipe; and, considering that the chimney drainpipe has been implemented in the vicinity of the dam central line, so, the critical conditions of the leakage forces will be considerably reduced. The instruments installed in the dam body and foundation of Boostan dam to screen the piezometric level fluctuations involve the cascade and vibrational piezometers. The locating map of these instruments on the section No.2 is displayed in the following figure.

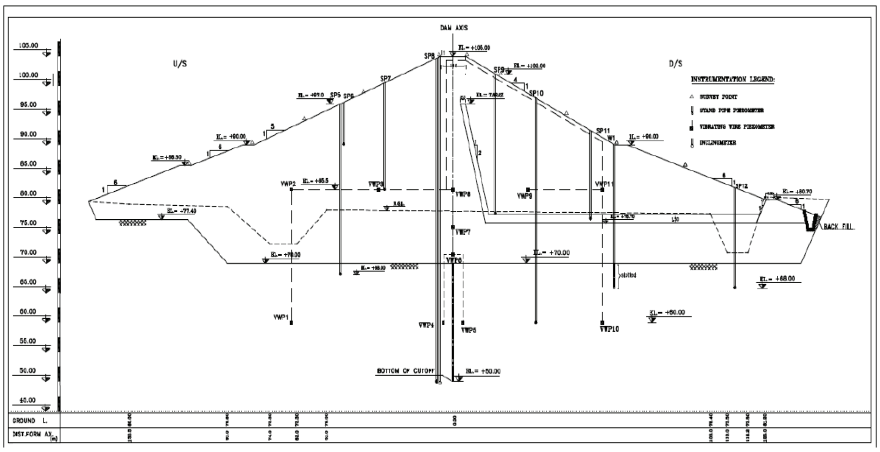

Figure 3 : Instrumentation map of Boostan Dam in section No.2

The simple or Casagrande Piezometer is a simple and economical instrument of measuring the water pressure. It involves a plastic porous pipe at the bottom of the bore, and, PVC pipe to read the water level. Reading the water level in the pipe is carried out via a water bathometer that includes a scaled cable which is inside a probe. When the probe is entered into the pipe, upon its contact with water level, a continuous vocal signal is produced. By doing so, the water depth can be read. The upstream level of the piezometer pipes in elongation is determined through survey operations, based on which the level and water height (total head) calculations are performed. By total head or the piezometric level, it is meant the expression $Z + U/Y_w$, where Z is the level of the piezometer installation, U is the water pressure, and h is the height shown by the piezometer. The following shows the schematic picture of the instrument.

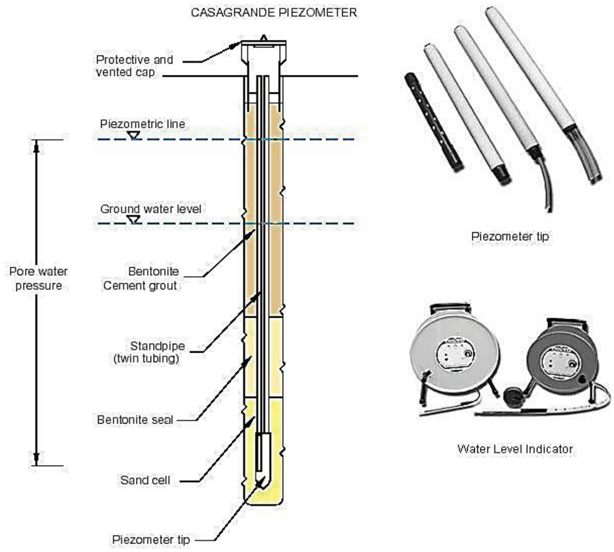

Figure 4 : The schematic figure of Casagrande Piezometer, piezometer tip, and the reading gauge

To screen the fluctuations of each parameter and the present conditions of the dam, the acquired values of piezometric level (h) and pore pressure (U) are drawn in the form of a curve. The fluctuations of the curves over time, and with respect to the reservoir level variations are screened and analyzed. In the equilibrium, it should be noted that due to the presence of water stop wall on the dam axis, it is expected that in this area, a considerable drop be observed. Also, the available data of the hydraulic drop values are calculated, and their curve has been drawn. The drawn curves for section No.2 tooled in Boostan Dam have been represented in the Figures 5-7.

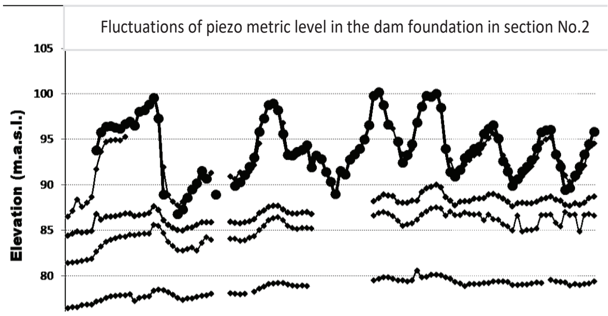

Figure 5. The curves of piezometric level fluctuations over time in the dam foundation in section No.2

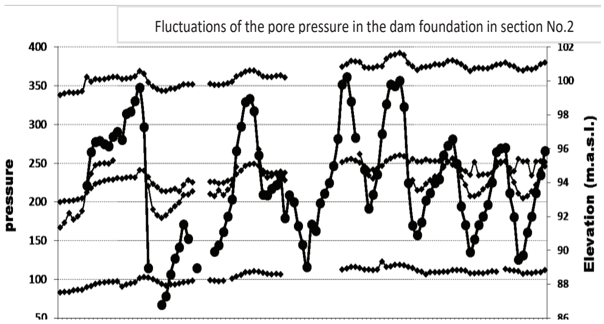

Figure 6. The curves of the pore pressure fluctuations per time in the dam foundation section No.2

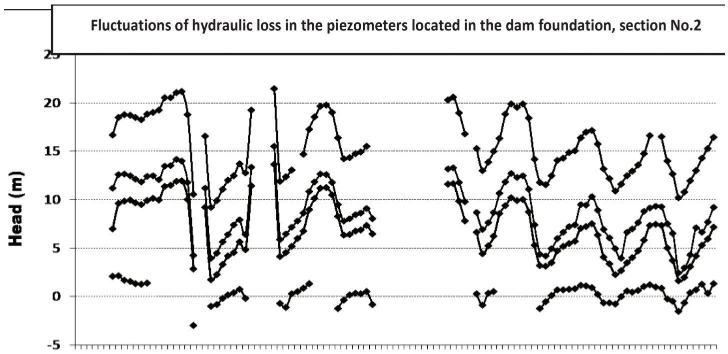

Figure 7. The curves of hydraulic loss fluctuations per time in dam foundation section No.2

Analysis of hydraulic loss fluctuations

Appropriate to the tooling map, 4 casagrande piezometers have been installed in the foundation. Of these, 2 piezometers SP5 and SP8 have been installed in the upstream, and, 2 piezometers SP10 and SP12 have been installed in the downstream of the dam element. Screening the total trend of the piezometric level fluctuations indicates the parameter decrease due to its passing through the foundation layers. Based on the figure, the piezometric level fluctuations in SP5 is in close concordance with the reservoir water level, and it is completely affected by the reservoir water level, which seems, with respect to its location (set at level of 69.5m, dam upstream), to be logical. Since the upper level of the piezometer pipe is 97m, it will dive in the water, and cannot be read while the reservoir level reaches more than 97m.

SP8 piezometer which has been installed in the upstream dam element and close to the extreme depth of the wall, is less affected by the water level fluctuations; this can be a result of its location (+50m). SP10 and SP12 piezometers which are located in the dam downstream, affected by the performance of the element show a more logical hydraulic loss than the reservoir level. In 2015, in SP10 curve some skips are observable, that seem to be caused by the error in reading and recording the data. Also, in SP12 the trend of hydraulic loss is valid and mentionable. As it is expected, the piezometeric level in this instrument shows a considerable difference with regard to the reservoir water level. The fluctuations of the reservoir water level, also, are effective on the piezometer behavior. According to the fluctuations of the hydraulic loss, it is observed that the greater the distance from the reservoir, the grater the water level loss in the piezometers. Piezometer No.12 has shown the utmost loss with respect to the reservoir level, which, due to its location, seems to be logical.

In general, it can be said that the water passing conditions, and the water pressure in the dam foundation in this section have acceptable conditions. The vibrational piezometers are a reliable and stable instrument of measuring the pore water pressure. The output of the piezometers includes a signal that is independent from impedance and the contact resistance, and can transmit the signal to a great distance. The principle behind the function of this type of piezometer is the vibrational frequency of a stretched wire, so that at the time of the instrument fabrication, the wire stretch value is definite. The sensor includes a porous tip piece, often of ceramic materials, and a diaphragm.

This diaphragm at one end is attached to a tip, and from the other to a pre-stressed piece. When the change in the pore pressure is induced, the diaphragm moves, and the tension of its attached warp changes. Since the frequency of the normal vibration wire is a function of the stress imposed on it, upon knowing the frequency in the new state, the logger equipment reads a digit proportionate to the mentioned frequency (proportionate to the imposed pressure). The pore pressure is calculated by using the read digit, and with respect to the equipment calibration coefficient. These piezometers are shown in Figure (8).

Figure 8. Type of vibration wire piezometer

Similar to the way of screening the casagrande piezometers, the curves of the piezo metric level fluctuations, the pore pressure, and hydraulic loss in the dam body and foundation piezometers in section NO.2 are drawn and screened.

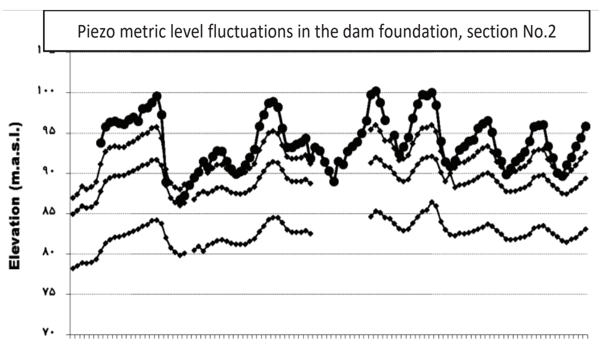

Figure 9 : Curves of piezometric level fluctuations per time in the dam foundation, section No.2

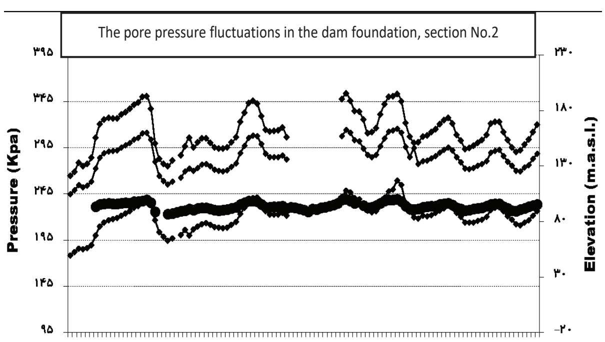

Figure 10 : The curves of pore pressure fluctuations in the dam foundation, section No.2

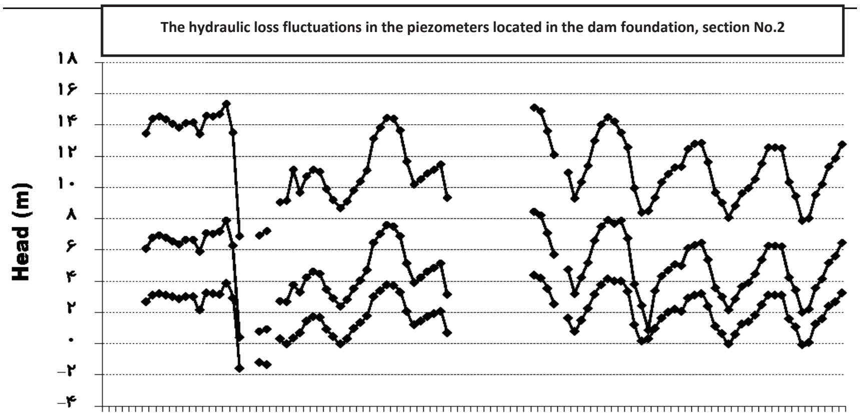

Figure 11 : The curves of the hydraulic loss fluctuations based on time in the dam foundation, section No.2

5.3 Analysis of pore pressure fluctuations

Based on the locating map of the tools, EPF1 and EPF4 piezometers, and EPF5 and EPF10 piezometers were installed in the upstream, and downstream dam elements on the dam foundation, respectively. As it can be noticed from the curves of the piezometric level fluctuations in the piezometers, the parameters follows the fluctuations of the reservoir water level in the upstream. According to the curves, the piezometric levels in EPF1 and EPF4 piezometers are close to the reservoir level, and are affected by the reservoir level. Also, due to the height of the ground water when the reservoir level exceeds 95m, the piezometric level changes under its effect. Similar to the results of Casagrande piezometers, the same phenomenon is observable in the electrical piezometers.

Based on Figure (11), the headwater loss in the piezometers increases with the greater distance from the reservoir, and the water passing the dam element. It should be mentioned that EPF10 piezometer has exited from the behavior-analysis circuit. This piezometers, from 2006 up to the present time, has not transmitted a digit to be read or recorded. Screening the pore pressure fluctuations in the piezometers confirm the above results. As it can be observed the trend of fluctuations in the pore pressured curves in these instruments are similar to the curves of piezometric level.

By using Figure (11), the range of the hydraulic head loss fluctuations in the mentioned instruments from 2005 to 2015 can be described as the following:

- EPF1 piezometer: 0-4.36 m; EPF4 piezometer: 0.42-8.49 m; EPF5 piezometer: 6.91-15.38 m.
- By comparing the water level loss values in 2005 to the previous years, the conditions are assessed to be normal.

5.4 Hysteresis curve of the foundation piezometers

The hysteresis curve is the fluctuation of the piezoelectric level of a piezometer with regard to the reservoir level fluctuations over different times. By using the curve, the status and behavior of the environment and the dam water passing, and the stability of the foundation in terms of the aggregate scouring, and the occurrence of midrib phenomenon can be screened. On the curves, the piezometric level values in the reservoir level with definite height are screened. For example, in level of 91.5 m, EPF23 piezometric levels have been 79.33 and 79.82 m in 2009, in 2014, respectively; which, the obtained results are approximate and acceptable. In addition, the drawn curve takes a roundabout path which shows the lack of scouring in the foundation particles. So, the efficiency of the dam element in this section is confirmed.

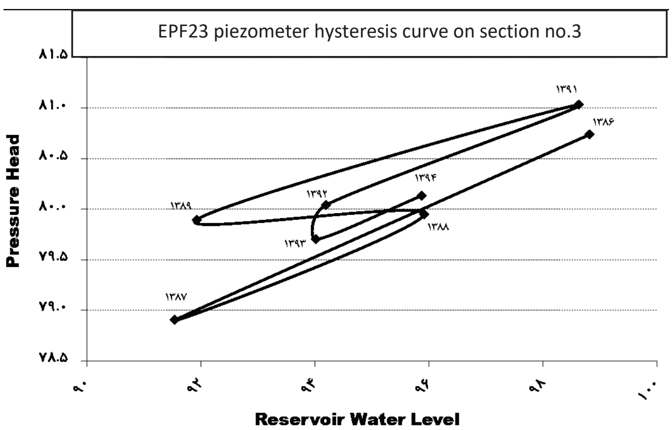

Figure 12 : GPF23 piezometer hysteresis curved

5.5 Pore over-pressure Ration

One of the parameters which its screening is of high significance in the earthen dams, is to determine the pore water pressure in the dam body and foundation. The parameter is calculated by dividing the pore water pressure of the piezometer (U) over soil overflow pressure (σ_v). The values of the pore pressure, the soil pressure, and the pore overpressure coefficient are calculated by the following equilibriums.

$$U = \gamma_w \times h_w$$
$$\sigma_v = \gamma_s \times h \qquad ...(1)$$
$$R_U = U/\sigma_v$$

Where U: Pore water pressure, γ_w is water density, h_w is water column height, σ_v is overflow soil pressure, γ_s is soil density and H is overflow soil height.

On the effect of the obtained value from this ratio regarding the screening of the performance of the dams, it can be said that when U exceeds σ_v, hydraulic failure occurs in the dam. When the water pressure is less than the soil overflow pressure, the status of the dam is determined with regard to the fact that the coefficient obtained from the division of the parameters falls in which of the following ranges:

– If $R_U < 0.4$ dam conditions are safe and favorable.
– If $0.4 < R_U < 0.6$ The possibility of danger exists, and the screened section should be rescreened with more accuracy. Also, if the ratio trend is increasing, necessary actions should be taken.
– If $R_U > 0.6$ The dam is in critical conditions. In this case, due to the overflow of the pore water pressure, the water tends to exit the soil. Therefore, the runaway water phenomenon is expected and it culminates in the dam failure.

In the Boostan Dam, the pore overpressure has been acquired from the electrical piezometers data; and its fluctuations over the screening period have been represented in the form of the following curves.

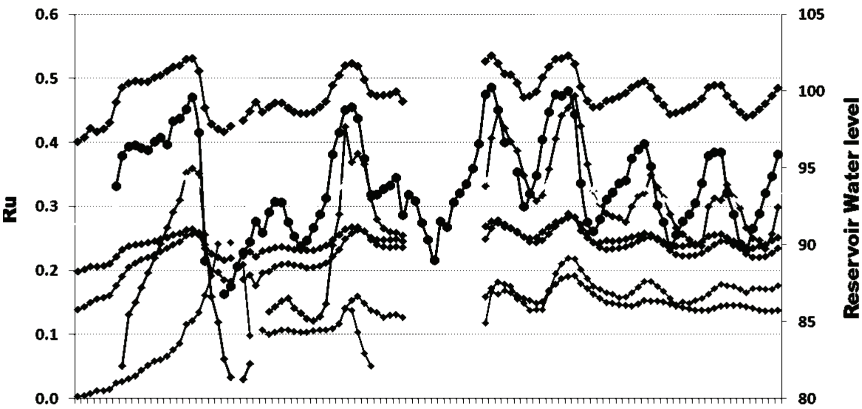

Figure 13. Curves of the pore overpressure ratio fluctuations in section No.2

5.6 Analysis of Pore over-pressure Ration

According to Figure (13), Run value obtained for most of the piezometers was less than 0.49 which shows that the dam status in location of these piezometers is normal and favorable, and there is no risk of uplift. EPF1 piezometer is in the closest distance from the dam reservoir and is more affected by the dam reservoir. The drawn curve for this piezometer shows that the pore overpressure ratio is >0.4. In some years, when the reservoir level has shown considerable increase, Ru value has exceeded 0.5. Of course, over recent years, due to the decrease of the reservoir eve** the ratio has always remained 0.4-0.5. Also, the observed fluctuations in the curves have been proportionate to the curves of the reservoir level fluctuations. Therefore, by reviewing the trend of Ru fluctuations in the piezometers on this section, the midrib phenomenon is not expected. But, it is recommended that in the future years the section be screened more thoroughly.

5.7 Total pressure cell

Total pressure cells are instruments of measuring the total pressure of soil (effective pressure, and water pressure). The instrument includes a flat cell filled with oil. The pressure imposed on the cell is imposed on the oil, and is transformed into some signals by a transducer. They are connected to a digital reading device via some cables. This device measures the pressure imposed on the cell. The device has been represented in Figure (14).

Figure 14 : Total pressure cell

5.8 Total pressure cell and stress screening in the dam body

To screen the values distribution and fluctuations with respect to the horizontal and vertical stresses in the Boostan Dam, 6 total pressure cells have been employed. The location of the instruments is in this order that on section No.4 (492.5 km) +0, and on 3 points (upstream, axis, and downstream) the total pressure cell tools have been installed juxtaposed in vertical and horizontal forms. Table 2 shows the instrument specifications and their location of installation. By using the data from reading the cells, the curve of the stress fluctuations over time has been drawn, which, i8s presented and discussed in the following.

Table (2) : specifications of total pressure cells installed in Boostan Dam

Sl.	Instrument name	Installation elevation (m)	Installation location	Installation Direction	A	L_0	T_0	Type of measurement system	Measurement
1	PC1	78.56	Bottom discharger	Horizontal	-6.07	9195.6	24.2	Vibration wire-manual	Total stress
2	PC2	77.6	Bottom discharger	Vertical	-5.94	9027.8	25.3	Vibration wire-manual	Total stress
3	PC3	77.1	Bottom discharger	Horizontal	-5.81	9196.8	30.1	Vibration wire-manual	Total stress
4	PC4	76.82	Bottom discharger	vertical	-6.01	9204	36.2	Vibration wire-manual	Total stress
5	PC5	76.97	Bottom discharger	Horizontal	-6.13	8933.3	27.2	Vibration wire-manual	Total stress
6	PC6	75.89	Bottom discharger	vertical	-6.11	9053.3	29.2	Vibration wire-manual	Total stress

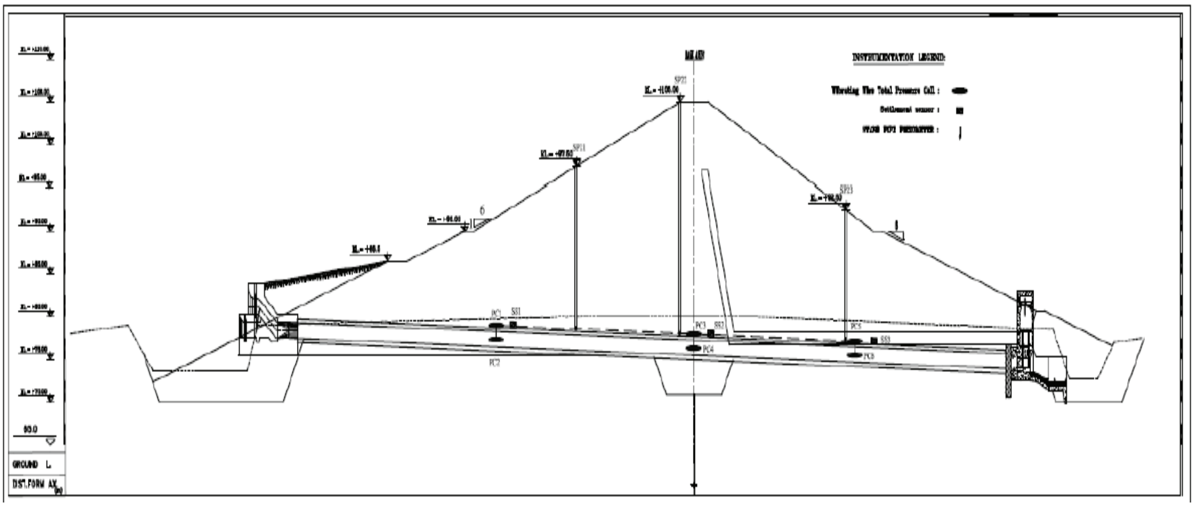

Figure 15 : Instrumentation plan of Boostan Dam, section No.4

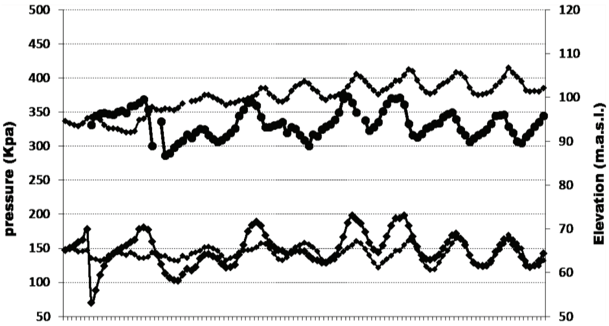

Figure 16 : Curves of reservoir water level fluctuations and vertical total pressure in section No.4

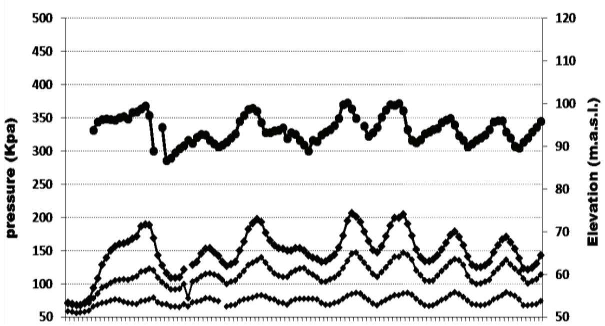

Figure 17 : Curves of reservoir water level fluctuations and horizontal total pressure in section No.4

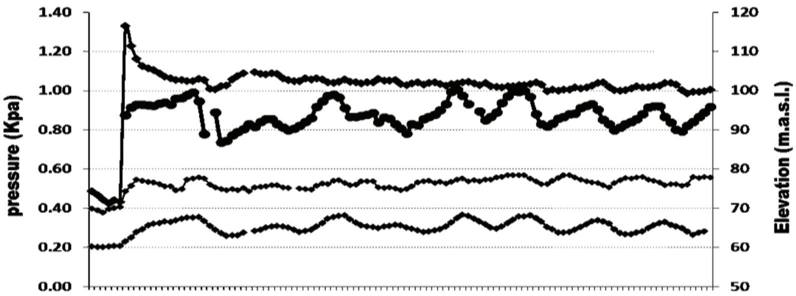

Figure 18 : Curves of the fluctuations of horizontal total pressure to vertical total pressure, and reservoir water level in section No.4

5.9 Analysis of total pressure

TPC-1 piezometer is located in the dam upstream. Synchronous with the reservoir water level fluctuations over the operational years from 2007, we can observe stress fluctuations in the TPC2 instrument. The measured horizontal stress by this instrument in 2006 was about 67 kPa, and it was less than half of the vertical stress value from the neighboring stress cell. While this instrument is indicating that the horizontal stress is about 67 KPa with a soft and descending trend, synchronously, TPC1 instrument, in which neighboring measures the vertical stress, shows that the vertical stress is more than 150 Kpa with an ascending trend. The instrument from the beginning of 2007 has experienced a stress loss from 178 Kpa to 70 Kpa. However, the vertical stress fluctuations in 2006 enjoyed an ascending trend due to the dam drainage. Based on the curves of the ratio of horizontal stress to the vertical stress, in 2006, the horizontal stress didn't show a fixed trend; but, afterwards, it shows a fixed stope and trend. From 2007 to 2010, the upstream total pressure cell instruments showed vertical and horizontal stresses close to each other. Therefore, the data of these two total pressure cells cannot be digitally much dependent; and, only their fluctuations can be employed for behavior-analysis.

If the accuracy of the data from the two instruments is accepted, the similarity of the tensions implies that we are in an environment with the hydraulic stress similar to a liquid, in which the stresses are equal to each other from different directions. However, the proximity of the surface of the horizontal stress to the vertical stress and the ratio of horizontal stress to the vertical stress close the unit is beyond expectation. It seems that the vertical stress has been measured to be less than the expected value. So, the related data of the total pressure cell cannot be valid enough. Perhaps, the sudden observed loss in the instrument can be a reason for the error, and deficiency of its data. The reduction of the horizontal stress to less than half (from 178 to 70 Kpa), which the vertical stress has an ascending trend, from the behavioral performance the stress conditions in the dam body cannot be justified. In this respect t, it can be mentioned that the stress failure in the total pressure cells in the dams can be due to stress eruption, rotation of the main stresses, or their deformation and displacement. If these cases have occurred in the Boostan dam, the horizontal stress tool should have recorded the sudden changes.

The curves show that the TPC4 horizontal pressure cell is more sensitive to the reservoir water level fluctuations; which, it is indicative of the water presence in that area. For the reliability of the data from the mentioned instruments, it should be noted that TPC4 instrument shows a reasonable horizontal stress, so that the recorded stress by the instrument is less than the recorded horizontal stress by the upstream total pressure cells, and is more than the recorded horizontal stresses by the downstream total pressure cell. This phenomenon is considered reasonable due to the decrease of the water effect, and the decrease of the hydraulic pressure in the location of the pressure cells TPC4 and TPC 6. Hence, the trend of the total pressure cells fluctuations installed dam axis is acceptable. The overhead of the pressure value in the TPC3 cell is related to the height of the dam body in the axis. Based on the figure, it can be seen that the instrument reacts very little to the reservoir level fluctuation with delay; which, due to its installation location, is reasonable.

As it was noted earlier, two total pressure cell has been installed in the dam downstream to measure the horizontal and vertical stresses (TPC5 and TPC6). As it is evident from the curve of the horizontal and vertical stress fluctuations of the mentioned instruments, and the reservoir water level, from 2008 on, the two instruments have been affected by the reservoir water level, and react to its fluctuations. Considering that this instrument pair (TPC5 and TPC6) together with the pair of TPC1 and TPC2 are symmetrical over the dam axis, the vertical stress fluctuations in both points show an identical trend, the only difference being their degree of being influenced by the reservoir water level. As it is evident from Figure (18), which shows the ratio of the horizontal total pressure to the vertical total pressure during operation, and the reservoir water pressure fluctuations, the ratio of horizontal to vertical pressure (TPC4 to TPC3) is in the range of 0.2-0.4, which is less than that of the upstream cells. However, the range of the stresses ratio fluctuations in the dam axis is greater than that of the fluctuations in the dam upstream (TPC2/TPC1) and the dam downstream (TPC6/TPC5).

5.10 Corresponding arc ratio

Figure (19) shows the curve of the corresponding arc ratio fluctuations by using the acquired parameters from these piezometers. The ratio is calculated by the division of the pressure value from the instruments data over the soil overflow pressure. As it can be seen, the obtained values the instruments of TPC1, TPC2, TPC3, and TPC5 range 0.3-0.7 that shows the conditions are normal and favorable. The curve related to the cells of TPC4 and TPC6, shows lesser digits; it seems that the plates of these instruments have exited from the horizontal coordination.

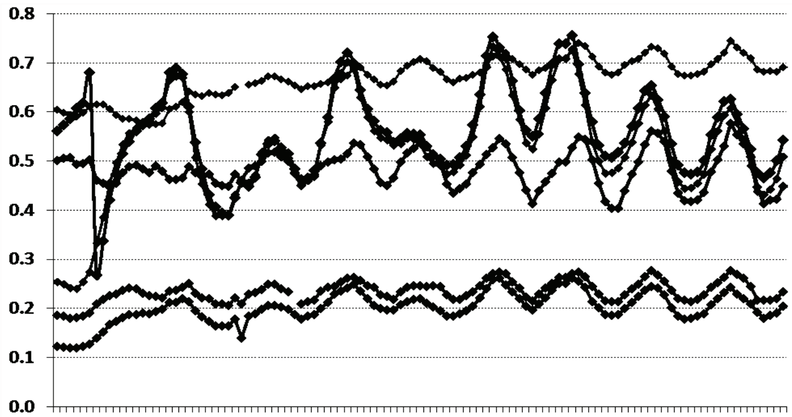

Figure 19 : The curve of the corresponding arc ratio fluctuations in the total pressure cells in section No.4

6. CONCLUSIONS

The assessment of the recorded data from the dam instrumentation shows that the Boostan Dam, after 10 years of operation, is in a rather normal condition. However, the dam should be under more control. Also, it is suggested that survey mapping to determine the dam status, and the elongation of the top pipe of the piezometers be surely carried out.

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