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FEM Simulation of Earth Dam and Comparison of Results with Field Monitoring (Case Study: Doroodzan Dam)

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Abstract: *Based on the importance of the dam construction industry as well as the large investments made in this regard, the location of these dams, which is sometimes located in the vicinity of cities or infrastructure, is necessary to ensure the safety and sustainability of these structures more than before. In this paper, various sections of the tools and tools used in these sections are mentioned. In the following, the performance of the instrument system in the earth's dam has been studied and a comparison and interpretation of the results of various instrumental readings has been undertaken. Also, the comparison between the field test results of the instrument and the FEM simulation has been implemented. Based on the results, it is observed that the difference in the numerical modeling results and the field observations of the instrument is negligible and is about 2%. Differences in the results of total tensions are significant. The results of the numerical analysis are much larger than the actual results of the instrumentation. Assuming that the tensile instrument has functional accuracy, the interpretation of this difference is due to the phenomenon of arc in the core. The tensions are transmitted to the lateral embankment and the reading rate is reduced. Finally, the performance of the tool in determining the pore water pressure has also been somewhat acceptable.*

Keywords: Instrumentation, Numerical Modeling, Vertical Stress, Settlement, Pore Water Pressure

INTRODUCTION

Doroodzan Dam is an earth dam in Fars Province, Iran (Figure 1) which has been completed in 1974 and built mainly for irrigation water storage, flood control, and municipal water storage. The general information about Doroodzan dam is presented in Table 1. (Moayedi et al., 2010)

Figure 1: Location of study area

Table 1. General information about Doroodzan dam (Moayedi et al., 2010)

Type	Homogeneous embankment with riprap protection	units
Height	57	m
Volume	993	m.c.m.
Surface at normal water level	55	km^2
Dead storage	133	m.c.m.
Catchment's area	4372	km^2
Mean annual inflow to the reservoir	1192	m.c.m.
Mean annual evaporation from the reservoir	64	m.c.m.
Mean Annual Precipitation	485	mm

The increasing need for dams, and the need to construct them at different locations with different geomechanical and hydrological conditions, possibly unfavorable, has led to the construction of each of these dams containing a new experience. Behavioral review and long-term dams monitoring are of particular importance. Many dams are located in the upper reaches of villages or densely populated cities, whose lack of safety will lead to irreparable dangers and losses. Otherwise, due to the strong dependence of society and industry on water, it is important to guarantee the possibility of regular and long-term exploitation of the land, and any action to maintain their sustainability and efficiency is inevitable because failure of a dam, not only destroys the capital spent on its construction, but a large amount of water is also abandoned, with no financial losses or casualties. Therefore, if the prediction of the dam behavior can reveal some of the possible events before it occurs, it can play an important role in preventing the failure of the dam and its consequences. Considering the importance of the issue, a more comprehensive study is needed to examine and predict the behavior of soil dams. (Duncliff and Green, 2017)

Main threats for dam safety are seismic activity (Elgamal et al., 1990; Pelecanos et al., 2013, 2015 & 2016) internal deterioration (Bridle and Fell, 2013; Shire and Sullivan, 2013; Shire and O'Sullivan, 2016), faulting, climate change (Pytharouli and Stiros, 2005; Gikas and Sakellariou, 2008).

hydraulic fracture etc.

In the past, for the lack of knowledge from earth dams' behavior, the height of these dams were limited, but today, by the development of soil mechanics science and the existence of advanced soft wares for the modeling and analysis of earth dams, the height of theses dams has been increased and therefore earth dams are more common than other type of dams in the world. (Saeedinia et al., 2012)

Many earth dams are used as water supply, irrigation or hydroelectric power infrastructure. Considering high cost of construction of Dams and extensive damages caused by their unsafety, dams' sustainability control is of great importance. In order to evaluate Dam's behavior, return analysis method can be utilized. Earth Dams having various parts include: core, crust, filter, drainage, Rock-fill cover (Rip Rap). In designing any structure such as an earth dam, in addition to considering a series of assumptions and criteria for examining and controlling its behavior during the construction, dewatering and exploitation periods, the actual measurement of some of the parameters that can be assisted by design and It also controls the behavior of the dam, performed by a device known as instrumentation. Control of the behavior of dams is important because if we have an understanding of these, we can largely avoid the occurrence of unforeseen situations and circumstances. (USACE, 2009)

Measurement is to evaluate the performance of a structure during the construction phase and exploitation phase and compare it with design predictions. Considering the importance and the intended purpose of the designers, the measurements made for the conduct of the structure are divided into two categories. (Belyakov, 2012; Fell et al., 1999)

- **During construction and first dewatering**

Measurements of the first stage are carried out in order to ensure the dam and safety of the dam during construction and to achieve the points that due to the complexity of these structures may not be considered during design.

- **At the time of operation**

The measurements of this stage provide an overview of the behavior of all structures or specific sections of it. In addition, these results can be used in scientific analysis as well as control the accuracy of the assumptions that were considered during design.

These behaviors include collecting the results of measurements of the precise instruments in the dam and setting the statistics in a way, along with objective observations and other direct measurements, such as dandruff and so on. Behavioralism is one of the most important pillars of the long-term assessment of the safety and sustainability of dams, which in many cases can be used to identify the weaknesses and stability of these structures. Depending on the type of dam, a series of parameters are considered for the characterization and continuity of the structure. The control and stability of the dam foundation, ensuring non-permeability and the absence of internal erosion, permeability between the foundation and the surroundings of the reservoir, the wall or seal of the seal, the performance of the downstream drainage network, the deformation and examination of the horizontal and vertical movement of the dam are parameters that the kidneys Dams and especially dams and dirt are threatened. In all large dams, by installing necessary tools for soil pressure and deformation values at construction time, the first dewatering and operating time, and the performance of the dam is evaluated and analyzed. Behavioral history can also be an experience in designing other dams in the future. (Foster and Spannagle, 2016; Hunter et al., 2010; Nobari and Duncan, 2014; Pagano et al., 2016)

Maleki and Alavifer (2005) have assessed behavior of Masjed Soleiman 's Dam with numerical modelling using FLAC 4.0 software and showed that first watering of reservoir has led to changes in total stress and threaten dam's stability. Nikkhah (2007) evaluated the precise instrument installed on Molla Sadra earth Dam's body and in view of the rate arching ratio, he showed that Molla Sadra Dam is at satisfactory situation. Aflaki (2009) evaluated Shirin Darreh earth dam and expressed that regarding Dam subsidence, stress testers and subsidence testers are in accordance with the result of software. Niroomand et al., (2011) used the results of precise instruments to study the function of Karkhe Dam. Return analysis have been implemented by CA2 software that regarding measured vertical pressure, there is a great consistency among the precise instruments results and the software. Mokrami and Mir Ghassemi (2013) have evaluated Dam's behavior during construction by using piezometers' results and applying stress testers in clay core of Gelabar Dam. In their study return analysis have been executed using ABAQUS software, eventually they have stated that throughout construction, the total and effective stress changes as well as pore water pressure values in core have been at acceptable range.

In brief, the above discussion demonstrates the importance of measurements to evaluate the behavior of dams and comparison of the results with the results of numerical simulations. This paper presents the results of FEM simulation of Doroodzan earth dam. Moreover, dam performance has been measured through the assessment of the results obtained from precise instruments used on Dam's body and was compared to the result of FEM simulation.

Numerical Simulations

Engineers have used different numerical methods, including the finite element method (FEM), finite difference method (FDM), and distinct element method (DEM) for flow fluid simulation. Finite Element Method (FFM) is advantageous as can be used to solve various types of engineering problems in the stable, transient, linear or nonlinear cases

In order to achieve the objectives of this study, FEM is used. The material properties used in this study are presented in Table 1 and Table 2. The schematic view of doroodzan dam and the location of instrumentations is shown in figure 2.

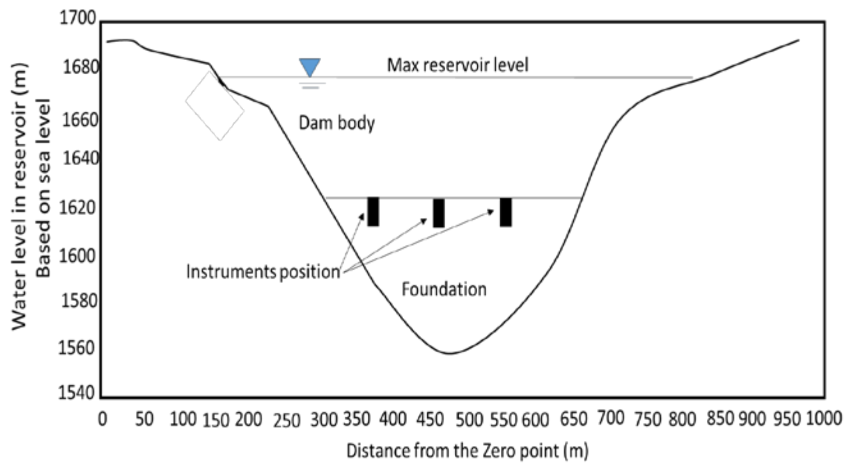

Figure 2: Schematic view of Doroodzan dam and the location of dam equipments

Modelling strategy which has been used in this paper is:

- Creating the geometric model of dam
- Applying the boundary conditions
- Applying the relevant forces
- Mesh generating
- Running
- conclusion

Table 2. Material properties of the foundation of the dam (Doroodzan Dam Geotechnical database, 2017)

Density [kg/m3]	1*10
Poisson's ratio	0.17
Elastic modulus [MPa]	26000
Rayleigh mass damping factor (α)[1/sec]	1.429732
Rayleigh stiffness damping factor (β) [sec]	0.0011331

Table 3. Material properties of the dam body (Doroodzan Dam Geotechnical database, 2017)

Density [kg/m3]	2400	2400
Poisson's ratio	0.167	0.167
Elastic modulus [MPa]	2795	32500
Rayleigh mass damping factor (α)[1/T]	1.4297	1.4297
Rayleigh stiffness damping factor (β) [T]	0.0011331	0.0011331
Allowable compressive strength [Mpa]	10.07	13.48
Allowable tensile strength [Mpa]	0.805	1.078

Comparison of the Results of Numerical and Field Analysis

In the following, a summary and comparison of the results of FEM modeling and instrumental field observations of the earth's dam is presented.

These cases are evaluated in three subcategories of maximum sum of values, total vertical tension and pore water pressure.

- **Comparison of Different Models in FEM Simulation**

The results obtained from two instruments of tensile and piezoelectric instruments were selected as two main tools during operation. In the presented form, the results of the instrumentation of the tensile meter are compared with the FEM modeling (in two cases, with the Mohr-Coulomb model and the plastic model). Figures 3 and 4 show the comparison of the results of instrumentation tensile meter No. 3 and No. 8, respectively, and the results of FEM modeling for different water levels. As it can be seen, the instruments on the right-hand side of the nucleus, where the pressure drop in water is greater than those of the pisometer, the behavioral model of Mohr Coulomb has shown more results than the behavioral model of plasticity, given that the Mohr Coulomb model for more deformation. It is expected to exhibit more stress than plastic, but in other tools where their installation is where the pore pressure is higher or deformations are less, the plastic model shows a higher result. As can be seen in the tensile tool No. 8, the difference in the amount shown in the instrument with miss-instalation is higher than other tools used at higher barrier levels, this difference can be due to the greater effect of pore water pressure on this tool which is due to the complex changes in the water surface behind the dam and the time lag of its impact on precision instruments.

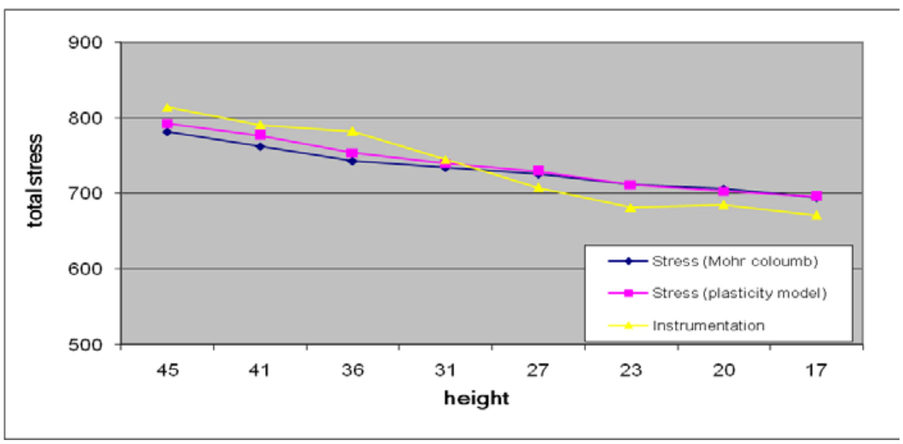

Figure 3. Comparison of the results of instrumentation tensile meter No. 3 and the results of FEM modeling for different water levels

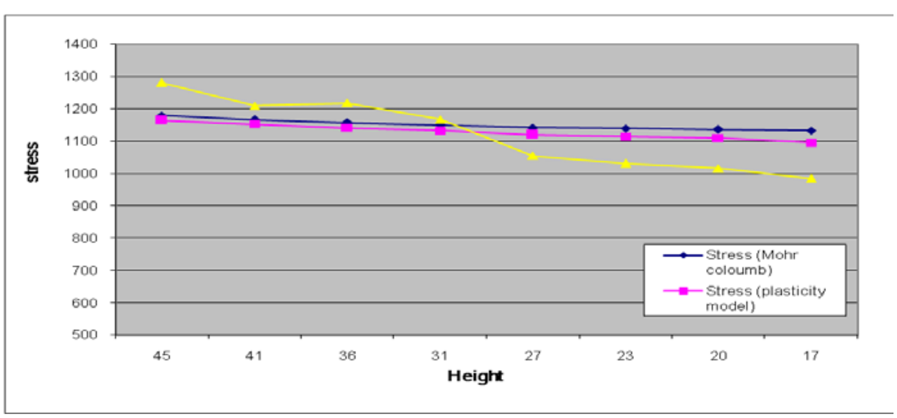

Figure 4. Comparison of the results of instrumentation of tensile meter No. 8 and the results of FEM modeling for different water levels

Figures 5 and 6 show the results of the piezometric tool and the software modeling in different levels of water. Of the 7 worked out instruments, the results are related to the two piezometer 1 and 2, which have the greatest difference with the precision instrument results. These differences are due to the unmanageable latency of the effects of water change in analytical modeling. In piezometer 1 and 2, due to the low permeability, we will encounter delays due to the lack of precision in the modeling.

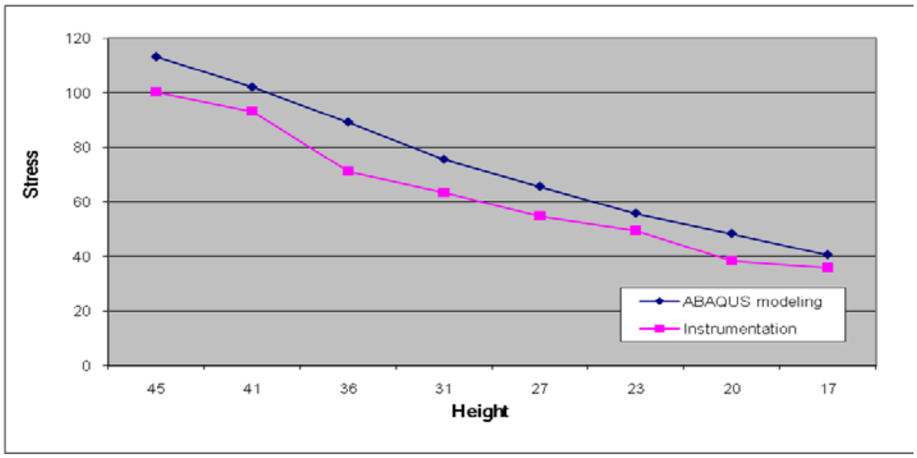

Figure 5. Comparison of the results of the piezometer No. 1 and the results of FEM modeling for different water levels

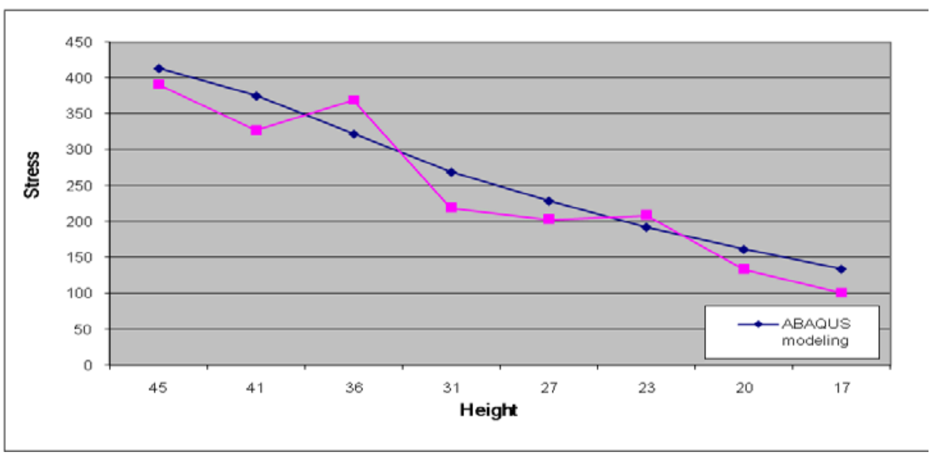

Figure 6. Comparison of results of instrumentation piezometer No. 2 and FEM modeling results for different water levels

In the figures 7 and 8, the horizontal and vertical stresses in the dam obtained from the results of the instrumentation of tensile gauges 1 and 2 are compared with the main stresses. As can be seen in these figures, the difference between the main stresses and stresses related to the directions of the axes x and y in the dam are insignificant. As it is evident in the figure, the difference between the main stresses and the stresses of the x and y directions is higher at higher water levels. This difference is predictable due to the existing pore water pressure or the flow of water inside the dam. In the following figures, the main tensions are obtained by the FEM models and tensions in two directions x and y by instrument readings.

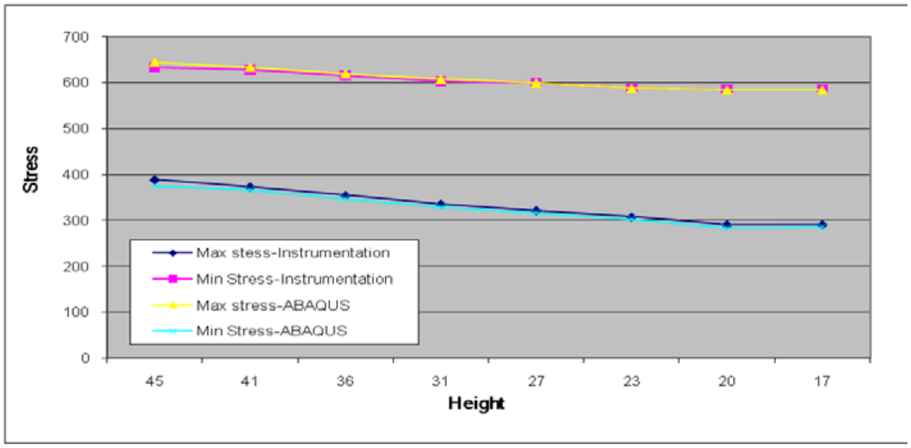

Figure 7. Comparison of the main and horizontal and vertical stresses in tension gauge No. 1 for different water levels

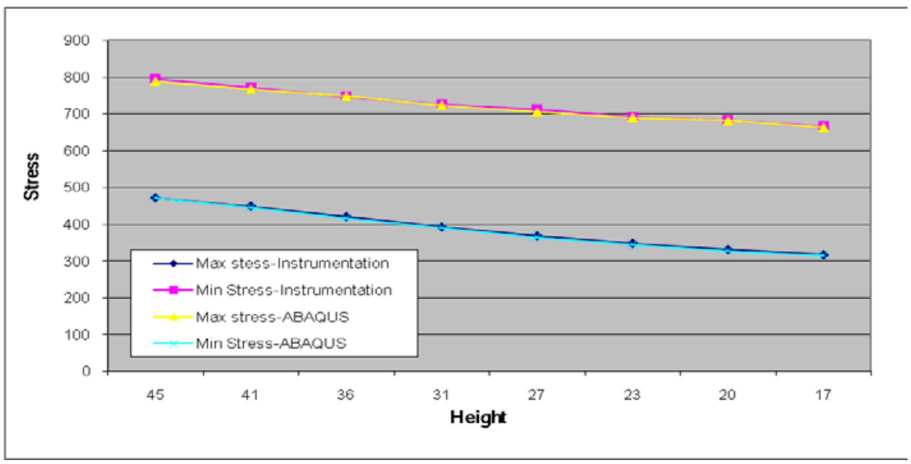

Figure 8. Comparison of main vertical and horizontal stresses in tension gauge No. 2 for different water levels

In the figure 9, the results of the settlement resulted from the consolidation of the construction period. As seen in the figure, sitting in the middle of the dam is slightly more than sitting at its edges, especially in lower layers. This heterogeneity is due to the arctic phenomenon, as well as the fact that the tensions in the middle of the dam are more normal and these two cases have caused more settling in the middle of the dam.

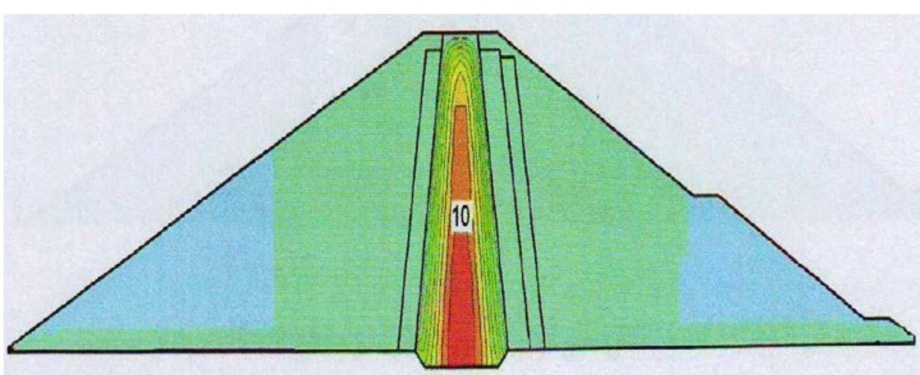

Figure 9. Vertical displacement resulting from consolidation for construction

In the following, the curve of the pore pressure change is plotted in the figure 10. As seen in the figure, the pressure of the pore water caused by the consolidation is first reduced and then increased with time. This decrease is due to the gradual expansion of the soil after saturation, which increases once again after consolidation.

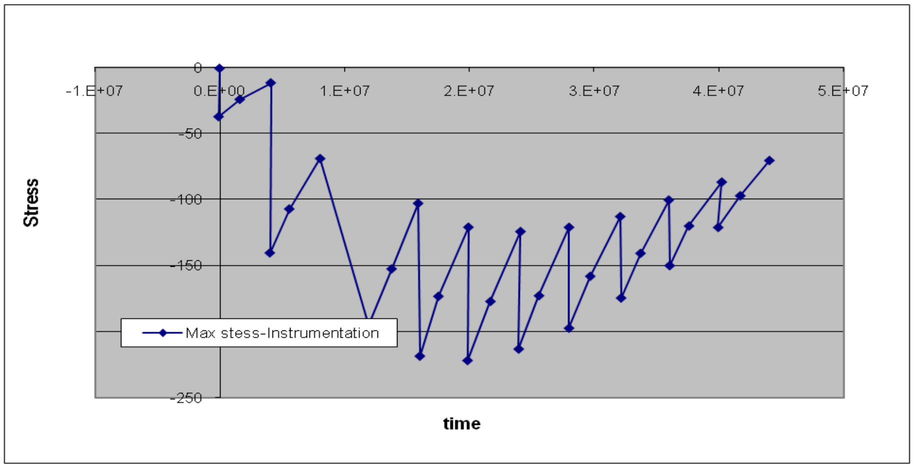

Figure 10. Pore pressure curve resulting from the consolidation in terms of time for construction time

- **Comparison of the maximum analytical and real-time settlement**

Comparison of the maximum analytical and real-time settlement and the results are presented in the following table :

Table 4. Comparison of Maximum Analytical and Real Settlement

Instrument readout results	Numerical analysis results	Variable
91 cm	89 cm	Vertical displacement

Based on the results, it is observed that the difference in the numerical modeling results and the field observations of the instrument is negligible and is about 2%.

- **Comparison of the maximum total analytical and actual stress**

The following table presents the comparison of the maximum total analytical and real tensions:

Table 5. Comparison of the maximum total analytical and actual stresses

Instrument readout results	Numerical analysis results	Variable
380KPa	1180KPa	Total stress

Differences in the results of total tensions are significant. The results of the numerical analysis are much larger than the actual results of the instrumentation. Assuming that the tensile instrument has functional accuracy, the interpretation of this difference is due to the phenomenon of arc in the core. The tensions are transmitted to the lateral embankment and the reading rate is reduced.

- **Comparison of the maximum water pressure in analytical and actual pore water**

The comparison of the results of the analytical and actual pore water pressure is shown in the table below.

Table 6. Comparison of the maximum water pressure in analytical and actual pore water

Instrument readout results	Numerical analysis results	Variable
30KPa	20KPa	Pore pressure

The function of the instrument in determining the pore water pressure is also somewhat acceptable. Although the difference is about 50%, however, the numerical difference is justifiable.

Conclusions

According to the surveys, it can be seen that among the three types of selected instruments, seismometers have the highest percentage of confidence. This is while pizometers are the most unreliable tools.
Pyrometers can be considered the most sensitive tool because about 24% of them have technical defects and are definitely disabled.
Compared to other sections, the performance of the 16-16 cross-sectional tools located on the support is much weaker. Also, the performance of section 4-4 is not justified due to the large number of tools used in it.
Determining the arch strength of the dam due to the high percentage of breakdowns of the pressure cells in the main sections 3-3 and 4-4 is not measurable.
Designing and implementing tools by a particular company could make the performance of the tools more acceptable.

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