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Evaluation of leakage performance and deformation of Dehgolan's Sural Dam using numerical methods and comparing them with instrumentation results

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ABSTRACT

Dams account for a large part of the investment related to basic infrastructures. Considering the fact that increasing safety factor in the project is proportionally followed by an upward increase in costs, it is very essential to ensure the stability of dams in all stages of designing, implementation and commissioning. In the case study of Sural Dam, the performance of instrumentation used in this dam was investigated. For this, the behavior of the dam was investigated by reviewing the documents and technical reports of dam construction as well as the theoretical behavior from numerical analysis and the actual behavior resulting from reading instrumentation as well as comparing those findings. In order to investigate the distribution conditions of displacement, stress and water pressure in the body of the Sural Dam, such instrumentation including: leakage indicator, electric pressure cell and electrical piezometers was used. To analyze the stress-deformation of the Sural Dam in the final stage of construction and (water) intake, the analysis was done using FLAC 3D software and via solving both deformation and water flow. The behavioral model applied is the full Elastoplast model with the Mohr–Coulomb rupture cap. After completing the analysis of the final stage of construction, the values of displacement, stress and pore water pressure obtained from the analyses were compared with the values recorded from instrumentation of the Sural Dam with the efficiency of numerical modeling in predicting the behavior of the dam being examined.

Keywords: *Embankment dam, Arching phenomenon, Leakage indicator, Mohr–Coulomb rupture*

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1. INTRODUCTION

Dams are significant structures in terms of economic, social and political aspects. Dams contribute greatly to agricultural development, rural and urban development, drinking water supply, hydroelectric energy production, control and regulation of water flow in rivers, etc. Because constructing dams incurs high costs and severe consequences from the instability of dams requires protecting, maintaining and evaluating the stability of dams quite constantly, using instrumentation and behavioral measurement factors in geo-mechanical projects can lead to evaluating the actual situation of stability in addition to continuously controlling of the project implementation process and optimizing of the implementation method, in line with the existing rock mass and recorded rock mass and structure reactions. Iran has long been among the dam-building countries as it has enjoyed an ancient history of dams built by ancient Iranians. According to the available credible statistics, there are currently more than 40 dams under operation, more than 35 dams under construction and more than 30 dams under study in the country (ASCE Task Committee, 2000).

Many of the dams have been constructed upstream of rural areas or densely populated cities which will lead to irreparable losses should safety measures are not observed. Otherwise, given the strong dependence of society and industry on water, it is quite important to ensure the feasibility of regular and long-term operation of dams as any measures to maintain their stability and efficiency is inevitable. Despite the astonishing progress made in engineering sciences and the critical role of dams in the advancement of human civilization and the urgent need for these large structures, the heterogeneity and unpredictability of the complete rock mass in nature as well as mistakes or insufficient human attention in designing, implementing and operating the dams properly have caused adverse consequences such as loss of lives and and breaking of dams. A general conclusion from the adverse experiences of dam instability and related life and economic losses as well as a review of observations and measurements before instability indicated that many of these instabilities could be predicted and avoided through the factors leading to to the incidents. The importance of maintaining dams, from the point of view of studying their interaction with the rock mass, which involves identifying and evaluating the factors affecting instability, is increasingly becoming obvious. Therefore, considering the need to control the stability and safety of dams, one should make use of experiences in similar cases and the behavior of the dam during operation to the maximum level in all stages of design, implementation and operation.

According to the International Committee Statistics on Large Dams, large dams alone have accounted for about 18,000 casualties and severe economic damage over the past hundred years. Every catastrophe has been faced with public despair and the extensive efforts of official assemblies to investigate the causes of the disaster. Currently, a great number of dams across the world will entail catastrophic and irreparable consequences if they break apart. Studies demonstrated that most of these structures were not commissioned as they were designed to be constructed. Consequences of Malpasset concrete two-arch Dam (1959), Vaiont two-arch Dam (1963) and Earth Dam of Titan (1976) are clear examples of the severe consequences of dam failure.

Dam instability statistics indicate that the highest number of failures were related to earth-fill, gravity, rock-fill, multi-arch and arched dams, respectively. According to these statistics and other published reports, one may argue that the effective factors in dam failure can be classified as follows:

- **Hydrology**: The incidence of unexpected flooding more than the discharge capacity of overflows and other dam outlets.
- **Geotechnical**: Inadequate foundations and walls of dams and reservoirs, both in terms of strength and stability.
- **Construction materials**: Specifications of construction materials, including strength, permeability, erosion.
- **Launching the dam**: Failure to comply with design and implementation criteria.
- **Operation (commissioning):** Failure to comply with water intake and operation criteria.

A general way to prevent damages to dams, the main factors of which were mentioned above, is to accurately investigate each of the factors and seek logical and justifiable solutions (both technical and economic solutions) to prevent failure caused by those factors. By reviewing the rainfall and flooding statistics in the area where the dam s constructed, one can calculate the maximum likely flood rate and the reasonable flood rate for designing (or correcting the overflow) via updated statistical methods, thereby increasing the overflow capacity using modern technologies. It is very essential to conduct continuous behavior measurement of the dam to prevent the dam from failing due to various factors. For this, one can predict the cause of instability and take necessary measures to counter it using instrumentation at appropriate places, periodic reading and interpretation of behavioral data along with data back analysis. In many cases, phenomena that are likely to erode, weaken, and destroy the dam can be recognized and avoided before they happen, or their impact can be reduced using behavioral results and surveying an instrumental data changes trend. In sum, when appropriate, possible damages to the residents and downstream structures of the dam can be minimized via taking the necessary measures (ASCE Task Committee, 2000; Hasani and Rasti Ardakani, 2003; US Army Corps of Engineers, 1995; Rahimi, 2014; Kharghani and Fakhari, 2005).

On the other hand, as a result of increased height of dams and reduced quality of embankment and foundation materials in many of the places, it has become common to observe and record the behavior of dams using measuring instruments. At present, all large dams under construction are instrumented to measure surface and internal movement and pore pressures and (in many cases) to measure stresses, as the behavior of the dam under different stages of construction, i.e., intake and operation of the dam is recorded utilizing these instruments. The cost incurred by instrumentation is about half to one percentage point of the cost from building the dam, however, it is considered a valuable investment in evaluating the performance of the dam. On the other hand, so far a survey of instrumented dams has led to an understanding of important aspects of the behavior of earth dams.

In order to examine the instrumentation installed in the body, the available information of the instrument must be investigated and organized. In order to sort out the incorrect information from the correct information, engineering judgment, adjustment relations and available information on the way the dam is constructed are utilized. Moreover, based on the behavior surveys performed in different dams across the world, a process for the operation of the instrument is expected by incorrect information can be sorted out.

An investigation in to the appropriate operation of the dam can be achieved by ensuring the correct numerical analysis. As a result, the results from the dam analysis should be compared and validated by the parameters recorded by the instrument. If the data obtained from reading the instrument is found to be consistent with the analysis findings, the analysis findings can be viewed as suggesting the actual behavior of the dam and it can be used for different sections of the dam. In this dam, validation is performed on three important parameters: subsidence, pore water pressure and water stress.

During the operation stage of earth dams, the pore water pressure in impermeable materials increases when the height of the embankment rises, the weight forces the upper layers, the volume of soil decreases, and the air inside them gets compacted. When the soil is exposed to the additional pore water pressure, water flows into the empty space inside the soil. These empty spaces may be relatively large, such as that found in rock-fill soils, or they may be very small and microscopic, such as the those in clay particles.

As the soil saturates and the pore water pressure rises, a sharp a decrease occurs in the shear strength of the soil and may cause instability and damage to the dam under a critical state. In cases where behavior-graph has been performed for dams, the pore water pressure is investigated along with other behavioral cases. There may be many articles in recent research which have only assessed the pore water pressure.

Rashidi and Haeri evaluated the behavior of earth and rock-fill dams during initial construction and intake using instrumentation and numerical modeling. In this study, the behavior of Gavoshan dam was examined. Based on this, a two-dimensional analysis using FLAC software via finite difference method was performed on the largest section of the dam as instrumentation and numerical modeling were applied. The elastoplastic model used by Mohr-Coulomb was selected.

The phenomenon of subsidence captured the attention of many researchers when dealing on a laboratory work scale. Most of the experiments were directed at odometric and triaxial paths. In an odometric experiment, if a sample of dry rock-fill is placed under a load and that an increase in subsidence ceases, the rocks will undergo significant subsidence if they get wet. This is attributed to the effect of water lubrication (reduced friction), resulting in new slip and arrangement of gravels inside the rock mass, as they create a more stable state (Deng et al., 2018).

Therefore, evaluating rock-fill dam behaviors should be performed by considering the subsidence phenomenon. In the numerical simulation of the dam behavior in the first intake, this issue has to be focused attention and its effect be taken into account.

This comparison also shows that the values of pore water pressure and stresses differ in two- and three-dimensional analysis. The common method for designing an earth dam seepage is to carry out a two-dimensional seepage analysis for the maximum section or section of the dam type and generalizing the results to the third dimension. It is natural for the impacts of valley's shape and also the changes of the problem features in a third-dimension direction not to be considered in such an analysis, (Ghorbani et al., 2015; Pereira and Nogueira, 2019).

In this study, the findings obtained from instrumenting the Sural Dam were focused attention. Sural Dam is a rock-fill dam with a clay core which is 41 meters high from the riverbed. The Sural Dam is situated in Kurdistan Province, about 80 km southeast of Sanandaj, 22 km southwest of Dehgolan. The dam is located at the confluence of the Gazgazareh and Ramul rivers. These two branches, after joining each other, lead to the Sural Plain after passing through the Sanjarkhan Strait, which is 2 km long from Sanjar Khan Strait to Sural village (Sural Dam Studies Guide- Water Power Consulting Engineers).

2. MATERIALS AND METHODS

Geographical location of the area under study

Sural Dam is situated in Kurdistan province, between Qorveh and Dehgolan cities and was completed in 2014. The length of the dam crest is 250 meters, the width of the dam crest is 7 meters and the height of the dam up to the foundation is 41 meters. The volume of the dam reservoir is 10 million cubic meters and the maximum usable water volume is 7.5 million cubic meters.

The Sural Dam is situated in the geographical position (38S 701359.094 m E 3893608.64 m N). The altitude of this area is 1995 meters above the sea level. According to Figure (1), this dam is of earth type and composed of rocks.

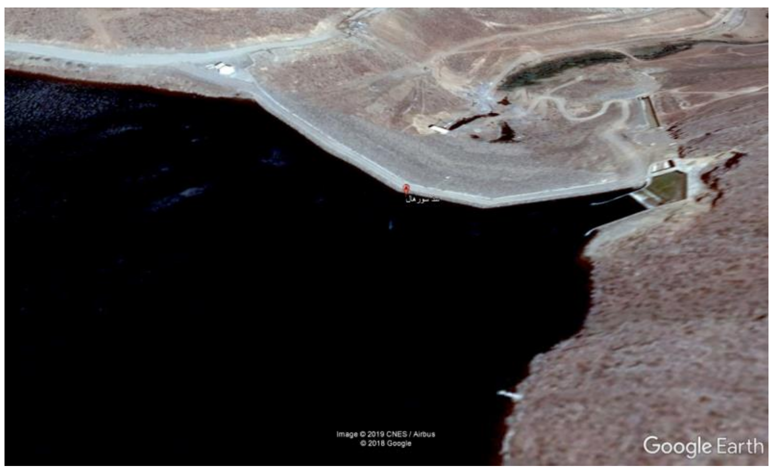

Figure 1: 3D view of earth Sural dam using google earth software

In Sural Dam, soil piezometer instruments were used for behavior-graph in order to study the pore water pressure in the body and the dam foundation, while pressure cell instruments were used to measure stresses in the body while deviation-gauge was used to study displacements in the dam body.

Numerical finite difference method

The finite difference method is one of the most important and oldest numerical methods used in continuous environments, which is applied in most engineering projects, including modeling and analyzing earth structures (such as earth dams). Any mechanical problem defined by differential equations can be solved using the numerical finite difference method (introducing initial and boundary values) (Cividini, 2014; Itasca, FLAC 3D). Flac 2D and Flac 3D softwares are the most important numerical finite
difference software for solving geo-technical problems both under static and dynamic conditions.

Numerical model

In this research, FLAC 3D software was used to model the construction and intake period of the earth Sural dam numerically. In numerical modeling, the main section of the dam is used. Figure 3-7 illustrates the section of the dam. In order to minimize the effects of lateral boundaries on stress and displacement changes, the distance from the lateral boundaries to the center of the model should be appropriately selected. As well, the meshed network must have appropriate dimensions in order to increase the accuracy in the areas close to the place where stresses change. Selecting the optimal dimensions of the numerical model has a significant effect on problem solving time. This is while as dimensions of the model increase, the problem solving time increases exponentially; hence, considering that in this study, embankment modeling was done in form of layers to increase the accuracy of the layers and via solving the water flow in saturated areas, the most optimal dimensions were selected. Figure 2 illustrates the finite element network with the model used being the numerical modeling.

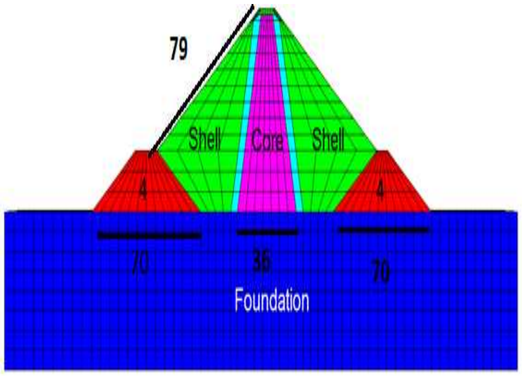

Figure 2: Geometry of the model and meshed network used in numerical analysis

Material features

Considering the behavior of geotechnical materials and soil, the behavioral model selected to numerically solve the problem is a complete elastoplastic behavioral model with Mohr-Coulomb rupture. To determine the strength parameters of body and foundation materials, three-axial tests, permeability and density experiments were performed and the values of the parameters were derived.

The general experiment procedure is that a soil sample, often whose height is twice its diameter, is placed inside a chamber and then subjected to an all-out pressure, where in this case the outlet valves are not made open if we intend to stabilize the sample. The sample is stabilized and the pore pressure reaches zero. After this stage, the sample reaches rupture by applying an upright load. In this case, the discrepancy between the upright load and all-out load, known as deviation stress, causes the sample to rupture. If the ample is intended to be drained, the water valves are made open.

This experiment is also done under different lateral pressures. Then, the Mohr circles governing each of the experiments are drawn in a coordinate system and the criterion of these circles is specified. The slope of this line is the angle of soil's internal friction and the intercept is the soil adhesion. As stated in the direct shear test description, this experiment is also based on Mohr-Coulomb theory, with the difference being this experiment is very similar to the behavior of the soil in place and rupture occurs at the weakest level. In this experiment, the all-out pressure represents the lateral soil pressure at its actual location and is usually chosen to equal to the approximate value of K0γz, where K0 is the coefficient of the lateral soil pressure under a stagnant condition and γ is the specified soil element with z being the element depth in this experiment. In this experiment, a sample of soil with standard specifications is extracted, a thin strip is drawn around it, and then placed inside a cylindrical chamber made of plastic or glass, which is usually filled with water or glycerin in order that the sample is subjected to rupture shearing. An axial stress is applied to the sample through a vertical arm installed to apply the load. After performing the experiment with different lateral pressures and drawing Mohr circles, the values of adhesion and soil's friction angle can be calculated (Motamedi and Hosseini, 2008). Large-scale experimentation is made possible for coarse-grained materials. The specifications of the materials that constitute the body and the foundation are provided in Table 1.

Table 1: Features of materials used in numerical modeling

Material	Specified weight (Kg/m3)	Elastic modulus (MPa)	Adhesion(KPa)	Internal friction angle	Poisson's ratio	Impermeability (cm/s)
Core	1750	18	40	23	0.32	3×10^{-8}
Crust	2200	30	0	45	0.3	1×10^{-3}
Filter	1900	20	0	33	0.3	1×10^{-3}
Area 4	2030	25	21	33	0.35	3×10^{-4}
Foundation	2450	1000	170	21	0.2	3×10^{-8}

Loading

To control the way pore water pressure and stress are distributed in the body of the dam and also to compare these values with the instruments installed, a history of changes to these parameters in parts of the body where the instrument is installed is reviewed during the embankment process along with water flow solution. As well, numerical modeling was performed under full reservoir conditions along with loading water on the slope of upstream dam (1: 1.5) and the effect of dam intake on displacement, stress, pore water pressure, etc. was investigated.

3. RESULTS

Investigating the effect of elastic modulus on modeling results

As stated, the Mohr-Coulomb behavioral model assumes the elastic behavior of the soil to be linear, whereas most soil materials have a nonlinear behavior with their elastic modulus changing during loading. Therefore, in this study, the sensitivity of dam stress-deformation changes was investigated in proportion to the elastic modulus parameter. For this, in addition to the initial elastic modulus of the core material (18 MPa), modeling the final construction stage with all the above-mentioned features was done and with the elastic modulus of the core material equal to 10, 15 and 25 MPa (Figure 3).

Figures 4a to 4d illustrate the changes in vertical and horizontal displacement, pore water stress and pressure relative to changes in the elastic modulus of the core material, respectively. As seen, as the elastic modulus increases, the vertical displacement values decreases from 537 mm to 337 mm with the pore water pressure declining from 53.2 to 28.3 kPa. This is to suggest the rate of vertical displacement has declined by 37% by changing the modulus from 10 to 25 MPa and the level of pore water pressure by 46%. As well, the values of stress and horizontal displacement have slightly increased as elasticity modulus has increased. The horizontal displacement has increased from 80 to 85 mm and the vertical stress has increased from 306 to 17346 kPa. This implies the level of horizontal displacement has declined by 6% by changing the modulus from 10 to 25 MPa and the amount of vertical stress by 12%. The obtained results indicated the effect of the elasticity modulus parameter on the results obtained from modeling. Therefore, this suggests that choosing ab appropriate behavioral model and accurate parameters can provided a significant effect on the numerical modeling results.

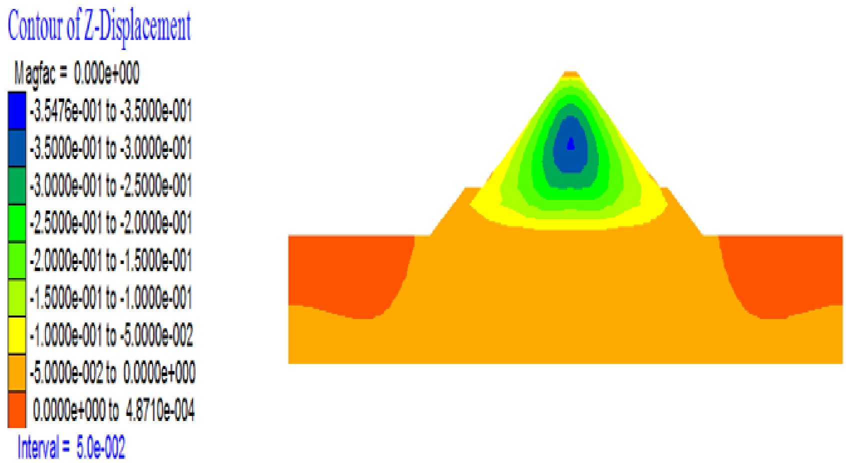

Figure 3: Distribution of vertical displacement in the body and foundation of the dam at the end of construction with an elastic modulus of the core equal to 25 MPa

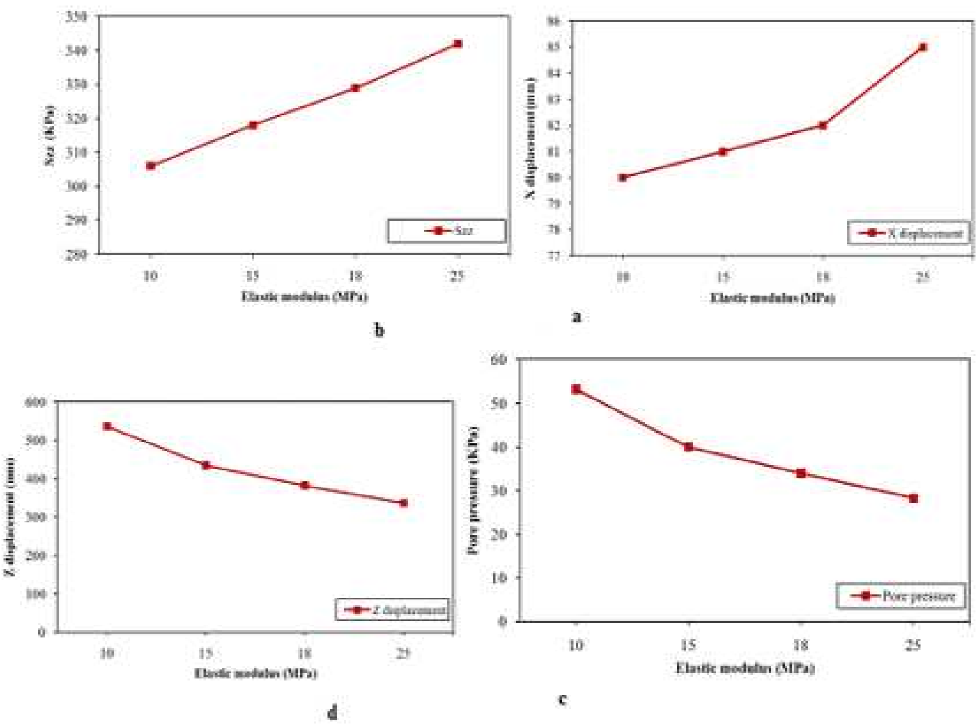

Figure 4: a) Changes in horizontal displacement relative to changes in elasticity modulus of clay core, b) Changes in vertical stress relative to changes in elastic modulus of clay core, c) Changes in pore water pressure relative to changes in elastic modulus of clay core, d) Changes in vertical displacement relative to changes in the elastic modulus of clay core

Full tank and stable seepage stage

As the water level increases to the maximum stress level, displacement and pore water pressure changes. Over time, the trend of changes stabilizes and stable conditions are made to the dam body. Under these conditions, the pore water pressure in the body and the foundation follows the reservoir. In order to simulate this step in FLAC 3D software, stress-deformation solution and water flow is performed with a duration of 15 years.

Changes to the figures

Figure 5a illustrates the changes in vertical displacements during the intake and the full tank and stable seepage stage. As seen, the force of water causes displacement in the body and after a period of time, it finally reaches a stable mode. Figure

5b illustrates the values of horizontal displacement (x) in the body of the dam in the long run. As observed, the displacement distribution pattern has fully changed since the construction ended, and the upstream water force has had a significant effect on the displacement of the body. As seen, the maximum overall displacement equals to 17 cm and the water force on upstream causes different parts of the dam to move downstream and upstream. As indicated, after a long time, no unusual and localized deformations are seen in the body of the dam, indicating the absence of rupture in the body.

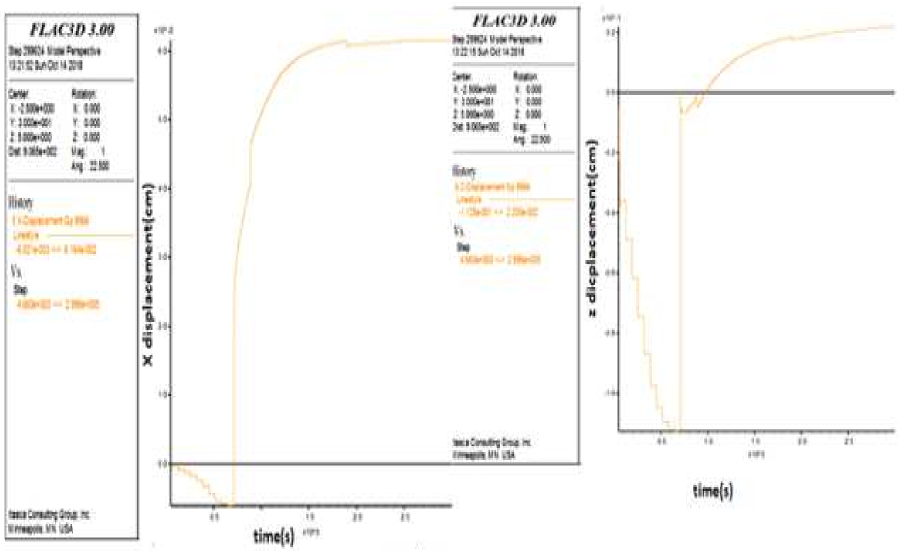

Figure 5: a) Vertical displacement changes in the lower part of the clay core during the full reservoir stage, b) Horizontal displacement changes in the lower part of the clay core during the reservoir phase

Stress distribution

At this stage, increasing the water level to the final level has increased the force on the upper crust of the dam and this changed the distribution of stress in the body. Figure 6a to c indicates the stress distributions σzz, σxx and σyy in the lower part of the core during the stable seepage stage. As seen, the stress values σzz, σxx and σyy are 620, 350 and 370, respectively.

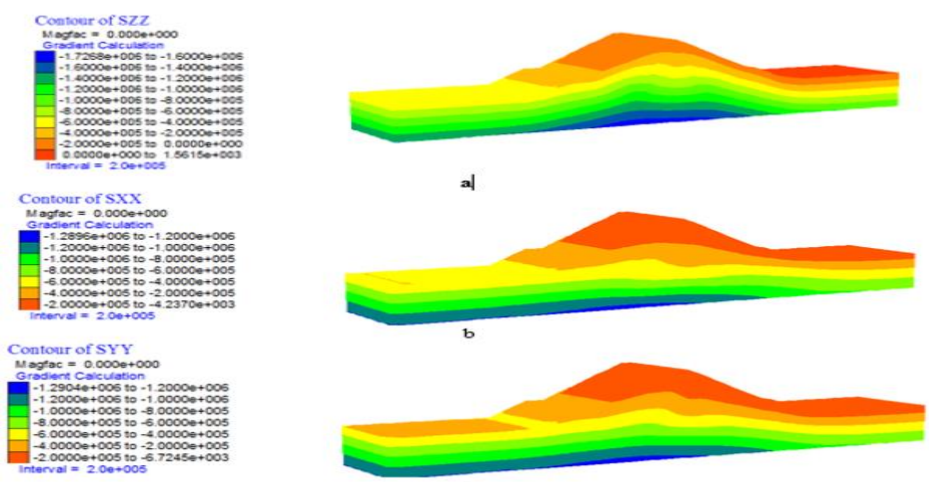

Figure 6: a) Distribution of vertical stress (Szz) in the body and foundation in the full tank stage b) Distribution of vertical stress (Sxx) in the body and foundation in the full tank stage, c) Distribution of vertical stress (Syy) in the body and foundation In the full tank stage

Porous water pressure distribution

After dam intake and gradual rise of the water level, the values of pore water pressure in the dam body vary. This change persists until conditions are stabilized and when the initial water pressure in the dam body is made proportional to the reservoir water level.

Figure 7 illustrates the conditions of stable seepage in the body and foundation of the Sural Dam. As seen, the water pressure in the body is fully balanced with the water reaching the core of the dam after passing through the upstream crust and is made permeable with a decline in the type of the material. In the end, it is removed from the lower part of the core.

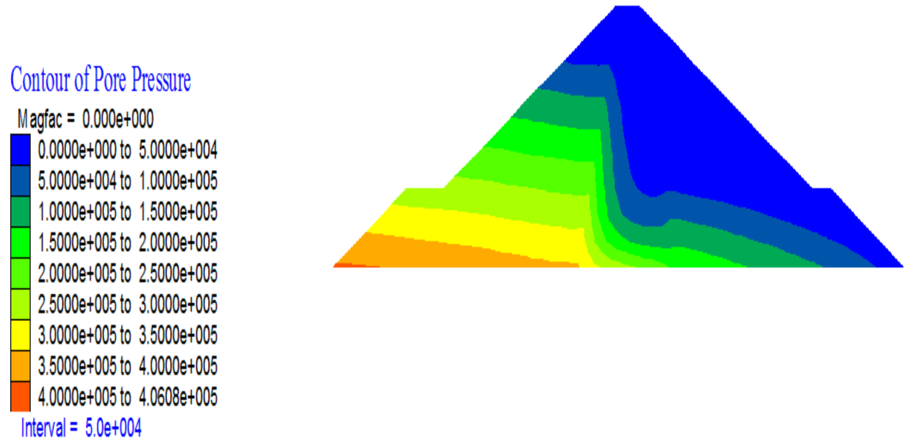

Figure 7: Distribution of pore water pressure in the body and the foundation at the full tank stage

The maximum pressure level at the beginning of the measurement decreases gradually at the bottom of the dam as time step increases.

Comparison of modeling results and reading of instrumentation at the end of construction stage

The values of displacement, stress and pore water pressure in the body of the Sural Dam during the construction time were measured by subsidence- gauge instruments, pressure cell and electrical piezometers. Using instrumental data and comparing them with the findings of numerical modeling can provide researchers with valuable information about the accuracy and capacity of behavioral models used in modeling earth dams while revealing the strengths and weaknesses of modeling. In this article, in numerical modeling, the values of displacement, stress and pore water pressure in the places where the instrument is installed in the body were measured and finally compared with the reading values of the instruments. Figure 8 illustrates the comparison between the subsidence values as measured by the subsidence meters and the values calculated in numerical modeling through FLAC 3D software. As shown, the maximum level of subsidence measured at the embankment center equals 37 cm and the maximum level of subsidence calculated in the modeling equals 39.2 cm, suggesting a discrepancy of 6%. This slight difference between the calculated and measured values demonstrates the appropriate consistency of the modeling and the instrumentation results as well as the ability of numerical modeling to calculate the displacement values in the body and foundation.

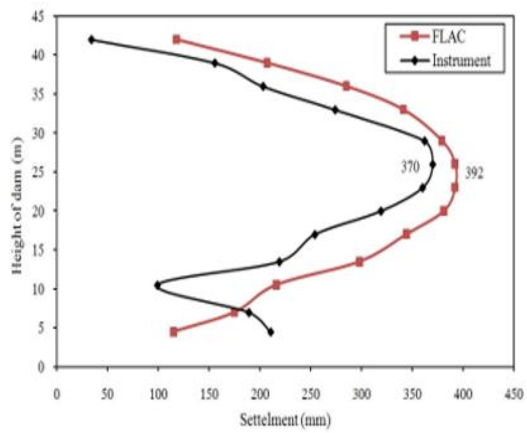

Figure 8: illustrates values measured by instrumentation and calculated based on numerical modeling

The reason behind these two diagrams is the presence of problems in the instrumentation, where Figure 9 illustrates the comparison between the measured stress values and the values calculated by numerical modeling as well as the expected theoretical stress value. As seen, the measured values differ from the calculated stress values and the theoretical stress because of the soil weight. Figure 10 illustrates the arching coefficient measured using instrument data and modeling results. Comparing the results of this section indicates that numerical modeling predicts the arching levels of 0.8 in the dam core; however, in practice, the measured value fluctuates between 0.3 and 0.8, which this interval is thought to be a high range for materials of the same type and instruments. A likelihood about the low level of arching in the pressure cell instruments can be due to the administration and installation of the instrument so that the materials on the instrument are not compacted, thus causing localized arches at the place where the instrument was installation. In sum, the values of arching calculated numerically suggest the proper distribution of stress in the body of the Sural dam.

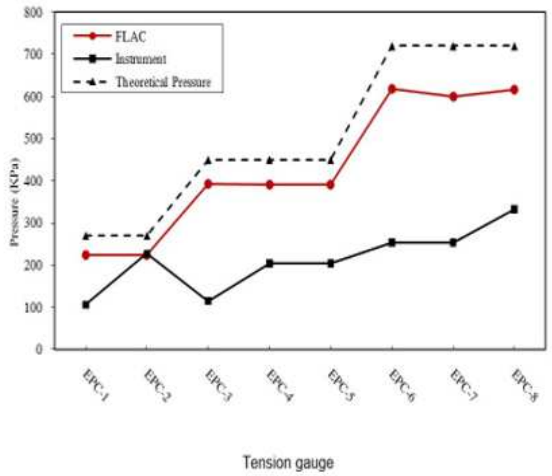

Figure 9: shows stress values measured by instrumentation and calculated based on numerical modeling.

EPC 1-8 are the number of stress gauge installed in the body of the dam. The way they work is such that they are made of two circular steel plates where the diameter of these plates is 20 to 30 cm and the distance is 2mm. The space between the plates is compacted by a compressible liquid which compresses the liquid due to the pressure on the plates and the compacted liquid causes the diaphragm to displace.

Pressure cell readings: total pressure
Electric piezometer reading: pore pressure
Pore pressure - total pressure = effective pressure

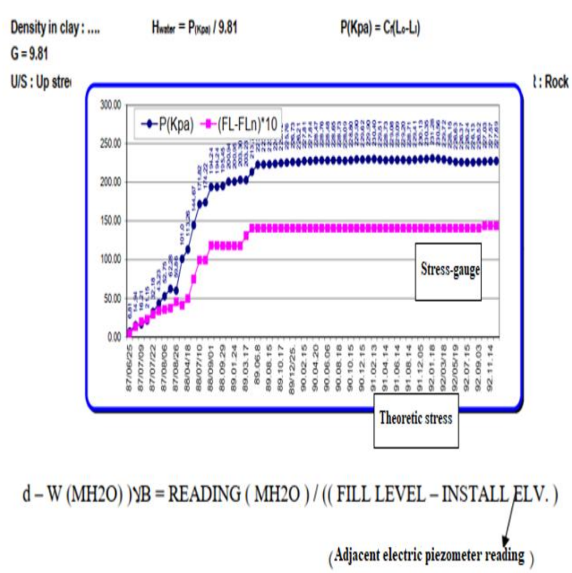

Figure 10 - Theoretical stress and stresses measured by EPC2 stress gauge

The red graph shows the theoretical stress and the blue graph shows the stress read from the instrument

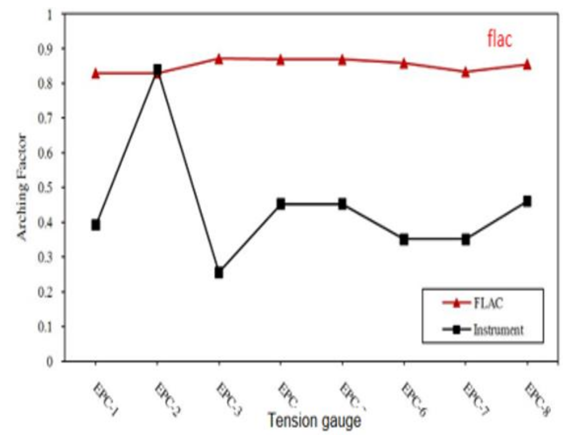

Figure 11: Arching coefficient values measured by instrumentation and calculated from numerical modeling

Diagram interference is due to instrumentation error from non-calibration. Figure 11 illustrates the comparison of water pressure values measured by instrumentation and values calculated in modeling. As seen, the maximum level of pore water pressure read in the dam core is 95.28 and the maximum level of pore water pressure calculated in the modeling is 90. Appropriate consistency of values and position of the maximum water pressure would suggest a proper modeling capacity to calculate the pore water pressure in the dam core. This is while, in the lateral areas of the core and in the adjacency of the upper and lower filters, the measured pore water pressure values are found to be less than the calculated values. The reason for this can be the easy movement of water and change of permeability in these areas, so that it is possible to move water to the filters in practice. As well, in case embankment operations are delayed or stopped during the commissioning, the likelihood of draining water pressure in these areas, adjacent to the filter, is more than other areas.

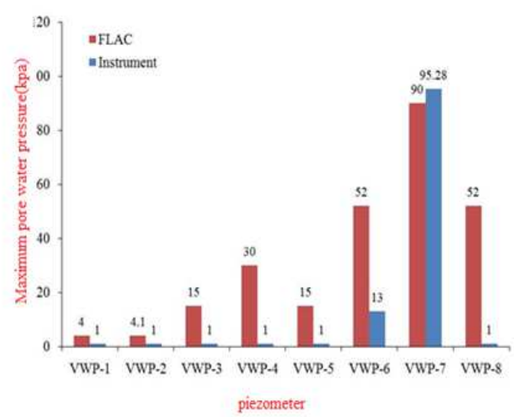

Figure 12: Values of pore water pressure measured by instrumentation and calculated based on numerical modeling

4. CONCLUSION

The final goal of this article was to numerically model the Sural Dam and to compare the results obtained from numerical modeling for the construction and intake period of the dam through the measured values of the instrument installed in the dam body as well as to compare the final results. A comparison of numerical modeling results and instrumentation results suggests the strengths and weaknesses of the behavioral model used in numerical modeling so as to accurately predict the values of stress and displacement and pore water pressure in the body and foundation. It is also likely to compare the impacts of stress and displacement during construction and intake changes and the effects of dam intake on these parameters. Hence, numerical modeling was carried out for the construction stage and the results were compared with the measured instrument values. The values of the pore water pressure were read from the piezometer, the subsidence from the subsidence-gauge and the stresses from the pressure cells installed on the dam body. In addition to comparing the results with the values recorded by instrumentation by changing the elastic modulus parameter, the core materials sensitive to the stress, displacement and pore water pressure to changes in this parameter were investigated. the findigs revealed that:

1. A comparison of the stress values obtained from numerical analysis and instrumentation indicates that the results are to some degree different from each other so that the stress values recorded by the instrument are found to be less than the those of numerical analysis. The large discrepancy between the stress recorded by the instrument with the theoretical stress from the weight of the soil has created doubts on whether the instrument is accurate; this can arise from a lack of proper transfer of soil pressure on the barometer plates due to improper installation of instruments and proper compactness on the plates.
2. The results obtained from numerical analyses in the final stage of construction suggest the proper stability of the Sural Dam in this stage.
3. In general, a comparison of the results obtained from numerical analyses and instrumentation readings has shown the appropriate ability of numerical analysis to calculate the behavioral parameters of the Sural Dam.
4. A study of changes in the elasticity modulus on the values of displacement, stress and pore water suggested that the behavior of the dam was highly dependent on this parameter.
5. Studies have shown that by changing the elasticity modulus from 18 to 25 MPa, the values of vertical displacement decreased from 537 to 337 mm, which indicates a drop of 37%.
6. Studies illustrated that by changing the elasticity modulus from 18 to 25 MPa, the values of the pore water pressure decreased from 53.2 to 28.3 kPa, denoting a decline of 46%.
7. Studies have demonstrated that by changing the elasticity modulus from 18 to 25 MPa, the values of vertical stress (Szz) increased from 306 to 342 kPa, suggesting an increase of 12%.
8. Studies have shown that by changing the elasticity modulus from 18 to 25 MPa, the horizontal displacement values increased from 80 to 85 mm, implying an increase of 6%.
9. Analyzing the full reservoir stage indicates the significant impacts of increased water level in the dam reservoir on displacements and stress distribution.
10. As the water level increases, the dam was seen move downstream and up to the upper level, so that the values of vertical displacement for the full reservoir stage equaled 5 and 8 cm, respectively.
11. The findings demonstrated that the horizontal displacement values for the full tank stage were 3.42 and 16.8 cm, respectively.
12. Analyzing the full reservoir stage illustrated that as time passes and water penetrates into the dam body, the values of pore water pressure varied and water reached the dam core upon entering the crust and then it faced a drop due to low permeability of the core.
13. Studying displacement and stress distributions values in the semi-full reservoir stage suggests a proper stability of the Sural Dam in these stages.

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