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Numerical modeling of sealing curtain design performance in earth-dams implemented on layered soils (Case study: Abbasabad dam)

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ABSTRACT

In the design and operation of earthen dams, leakage control and permeability of the bed can be considered as one of the most important geotechnical and hydraulic issues of the dam. Studies have shown that the optimal implementation and functional control of the sealing curtain significantly plays a significant role in reducing leakage flow and also the stability of the dam. In this regard, in the present study, an attempt has been made to pay attention to this issue and to evaluate the leakage and permeability conditions to evaluate the performance of the sealing curtain for Abbasabad earthen dams based on layered bed sediments. To take. For this purpose, the finite element numerical approach and Plaxis software have been used. Methodologically, two modeling groups were implemented for the dam state without sealing the curtain and with the sealing curtain, and then the dam was dewatered and the hydraulic behavior was measured. The results of the simulation show that when the sealing curtain was not implemented, these elements had limited changes in the range of the dam core, which has become more widespread with the implementation of the sealing curtain. This issue indicates the movement and effect of the current resulting from the implementation of the sealing curtain in the area of the dam core. However, the stress drop in the dam area indicates the activity of the drains in order to relieve the pore water pressure. On the other hand, the strain expansion in the core range reflects the phenomenon of fine-grained plastic behavior resulting from in-situ stress and pore-water pressure.

1. Introduction

The importance of dams and the role of these large structures in the improvement of human life are reduced by the number of towers, as expected, given the importance of these structures and much research is being done and will be done in this area (Weaver, 1991). Many knowledges and specialties are used in the construction of this structure and many groups are involved in its design and construction. Knowledge of the behavior of different layers of land at the dam site, after dewatering the dam due to the variety of conditions and the number of effective parameters, has increased the importance and necessity of geological and geotechnical studies that control the seepage of dam foundations is one of the important tasks Geotechnics is the foundation for many of these dams (Park and Oh, 2018). In general, in dam construction projects, to prevent water from leaking from under the dam body, the foundation of the dam should be permeable to water to an acceptable

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level. This is usually done by injecting cement slurry into the sub-dam layers under the clay core, commonly referred to as grouting or sealing (Fell et al., 2017). So far, many methods and strategies have been implemented for injecting sealing curtains, in which a number of well-known countries have conducted many studies and researches related to this technology (Guyer, 2017). The creation of sealing curtains plays an important role in the improvement of dams. These important structures, which are used as a restraint to control seepage in the soil of earthen dam bed, are implemented with the aim of improving the engineering properties of the dam bed, thus preventing water from escaping and reducing water leakage through the foundation. The barrier prevents internal erosion and leaching of fine particles from the core into the seam and gap of the foundation, as well as reducing the hydrostatic pressure in the lower part of the foundation (Rawlings et al., 2000). The construction of this curtain is done before the construction of the main body of the dam, by performing the injection operation. The most common method for creating this curtain is to dig one or more rows of vertical boreholes and inject cement slurry in these boreholes, but this way of designing and constructing the curtain does not guarantee its optimal performance (Jansen, 2011). Therefore, the injection operation will be successful and best performed if there is a complete knowledge of the situation and characteristics of the area based on the geotechnical characteristics obtained from local explorations. Knowing the properties of different types of slurries and how to use them will also be very effective in this process (Ewert and Hungsberg, 2018).

In general, all dams usually have some leakage when water is stored behind them, and this amount of leakage should be controlled so that it does not exceed the allowable limit. Experience has shown that most damages to dams and water facilities have been due to problems, with 10% of such breakdowns leading to extensive damage and loss due to leaks. It is also possible that after spending exorbitant costs for the construction of the dam, the desired result will not be achieved due to water leakage from the dam (Zhang et al., 2020). So, for the implementation of any dam construction project, checking the condition of the construction site is one of the most important parts of identification, implementation and operation. The problem of water permeability of dams is strongly dependent on the geological characteristics of the region and since these properties are unique in each site, so the proposed model for each site is determined according to the local conditions (Ashrafi et al., 2020).

Sealing walls are often as impermeable surfaces under the dam, which are implemented by various methods to prevent negative outflow depletion in the dam, especially earthen dams. Performance and ability of sealing curtain on different levels of dam bed conditions such as slurry penetration depth, sediment conditions, impermeable bed depth, bed quality, hydraulic conductivity coefficients of sediments and bed, mechanical density and sediment consolidation conditions of dam bed; It is completely dependent (Rawlings et al., 2000). So, in the design of a suitable sealing curtain, these items must be fully considered. Generally, some of these indicators are selected according to the sealing criteria and using the results of geotechnical and permeability tests; But some of these indicators should be determined in the field and the implementation of modeling methods or with the help of empirical relationships. Of course, it should be noted that changes in the geological conditions of the dam environment have caused different conditions in the construction site and this issue has a significant impact on the sealing model (Shi et al., 2020).

Today, with the advancement of water and hydraulic engineering sciences; it is easily possible to develop software and hardware facilities, evaluate various leakage conditions in the body of dams, as well as check the performance of sealing curtains in dams, and the results of evaluations have always been remarkable. Among these, we can mention analytical methods (Dou et al., 2020), numerical approaches (Refaiy et al., 2021), hybrid methods (Zhang et al., 2021) which have been able to do well in Apply analyzes of dams and massive geotechnical structures (Azarafza et al., 2018). Among these, the use of numerical approaches, especially finite element method (FEM), has received more attention due to its significant ability to analyze and simulate leakage conditions in the body and bed of earth dams (Brinkgreve et al., 2011).

In this regard, we can use the work of Fatemiaghda (2012) to evaluate the quality of the sealing curtain of Salmanfarsi Dam using the secondary permeability index (SPI) in designing and evaluating the quality of the sealing curtain, after injection and Logan test. Asadi et al. (2014) in investigating the effect of sealing curtain wall conditions on leakage of Karkheh clay core dam from Seep/w software which showed that the best position of the shear wall is about 0.4-0.6 of the dam width from the heel. Noroozi Sarkarabad et al. (2017) in investigating the effect of sealing wall on hydraulic gradient and leakage in Sabalan gravel dam by numerical simulation of finite element in different situations with different depths and permeability values after the dam they paid. The results of this study showed that the maximum hydraulic gradient occurs behind the Sabalan Dam in the sealing wall. Changes in the position of the dam sealing wall to achieve the minimum hydraulic gradient showed that the optimal location in terms of the minimum hydraulic gradient is the core toe and in terms of reducing the leakage flow at the heel of the core. Shabani et al. (2019) used numerical analysis of the effect of clay blanket and sealing wall on the reduction of leakage from the soil barrier using Seep/w software. The results of this study showed that the combination of blanket and sealing wall with full height to the end of the permeable layer in contrast to the blank form had little effect and the percentage of leakage reduction is almost the same in both cases, but in contrast to the incomplete sealing wall. Used with blanket, the leakage reduction rate will be doubled compared to the blank form.

Ganjalipour and Esmailzadeh (2019) used finite element numerical modeling by Seep/w to evaluate the depth of slurry curtain tried to present a new method to calculate the performance of the curtain based on the position of the piezometer and a model of an earthen dam with a height of 180 meters Considered. These researchers have analyzed more than 200 different models and constantly changing conditions; Determine the rate of change in depth versus performance for both types of sealing curtains and determine the optimal position and characteristics of the sealing curtain. The results of this study have been used to provide leakage measurement and design strategies for earthen dams. Kamasi and Biranvand (2020) in the study of leakage flow and sealing performance of Ayoshan earthen dam using numerical analysis by Geostudio and Plaxis software stated that the measurement of seepage of Ayoshan dam based on numerical approaches is consistent with the results of instruments and field tests It is very good that this issue shows the remarkable ability of numerical method in the analysis and design of sealing curtains. Shakouri and Mir Mohammadi (2020) in evaluating the penetration depth for sealing walls in earthen dams that have been implemented on a case-by-case basis for Anbaran Dam; it has used a set of numerical approaches of elements and finite differences. GeoStudio, FLAC2D and Plaxis software have been used in this regard. The results of the numerical model showed that with increasing the penetration depth, the stresses and displacements of the bed and dam area during the dewatering stages have increased. This increases the hydraulic slope and seepage in the bed area and the concentration of leakage in the area below the dam's core (sealing curtain) and the implementation of the sealing curtain reduces the hydraulic gradient and decreases the displacement (uplift) in the core area. Poursalim and Alizadeh (2020) used numerical modeling and Plaxis software to measure the performance of the sealing curtain and seepage conditions from the dam bed to two groups of dam modeling before and after the implementation of the sealing curtain in the core dam Clay and showed that the sealing curtain was able to control the strain and seepage behavior in the core of the dam. Mashkabadia and Zandib (2021) conducted studies based on measuring the effect of changes in different positions of the sealing wall and horizontal drainage of Gulfaraj Dam in order to select the best location for drainage and sealing curtains by GeoStudio software. The results showed that for the sealing wall located above the core, an angle of 20 degrees and for the sealing wall located downstream of the core, an angle of 100 degrees is suitable. Increasing the distance between the two walls of the vertical seal increases the lifting pressure and decreases the maximum output gradient. Increasing the horizontal drainage length of the gradient reduces the maximum output, while having little effect on the upward pressure.

Looking at the presented achievements, it can be said that the application of numerical methods, especially finite element methods, has been able to pay attention to functional analysis and sealing curtain design in earthen dams. Also, the results of these simulations have been able to show the seepage and flow conditions in the dewatering stages of dams and estimate the state of plastic strain in the core of the dam. Due to this issue, in the present study, using numerical models of leakage conditions and performance of sealing curtains for clay core earthen dams built on multilayer soils; the Plaxis software has been used for this purpose.

2. Case Study

2.1. Location and Geological Setting

Abbasabad Dam in the southeast of Baneh city is located on one of the tributaries of Nanour River with geographical coordinates of 45 degrees and 59 minutes and 20 seconds east longitude and 35 degrees and 51 minutes and 44 seconds north latitude. Abbas Abad Reservoir Dam is located about 270 km northwest of Sanandaj and about 20 km southeast of Baneh. The location of the dam and the location of the study area are shown in Fig. 1. Access to the site is possible through Saqez Baneh asphalt road and Baneh Nanor asphalt road between Pahlavi Dej, Hong Jal and Koleh villages. This dam has been constructed in order to supply drinking water to the city of Baneh and the cities of Buin, Armardeh and Kani Sur. Nanour River is one of the tributaries of Choman River. At the beginning of its catchment area, this tributary originates from the two main tributaries, both of which originate from the southeast of the poor cell mountain and flow to the northwest. Kani intersects with each other and changes its direction to the west in the area of Sartzan and the side of the fort, and redirects again to the northwest around the branch of Hong Jal and leaves the dam site and the basin. The highest point of the basin is located at Dizbadr mountain tops at a height of 2765 meters located in the southeast of the basin. The castle at an altitude of 2035 meters above sea level has formed the southwestern border and Kalgam Mountain at an altitude of about 2150 meters above sea level has formed the southern boundary of the basin (Darvishzadeh, 2017).

The lowest point of the basin in the riverbed is located in the construction site, which according to the topographic map is 1: 50,000, 1560 meters above sea level and the height difference between the highest point and the lowest point in the basin is 1205 meters (Geological Survey of Iran, 2011). The oldest catchment rocks are low-grade metamorphic rocks, probably Ordovician to Carboniferous, volcanic rocks, slightly metamorphic andesite with acidic metapyroclastic rocks, crystalline limestone that begins in the basin and begins to form. They cover half of the basin. Permian and Jurassic rocks have not been reported in the basin. In the lower half of the bed, low-grade metamorphic rocks, mostly phyllite with a little limestone and Cretaceous-Paleocene volcanic rocks, which is the boundary of the recent complex with the Ordovician to

Carboniferous fault, and southwest of the flysch-type flysch basin with turbidite Has also been reported. In the lower half of the bed, Quaternary deposits include alluvial barracks, slope deposits, slope deposits, and alluvial deposits, and river bed filling alluviums and tributaries. From the point of view of structural division, the study area of the project is located in Sanandaj-Sirjan zone and in terms of tectonic-sedimentary divisions in Esfahan-Marivan zone; it is related to Sanandaj-Sirjan zone (Aghanbati, 2016).

Figure 1. Location of Abbasabad earth reservoir dam

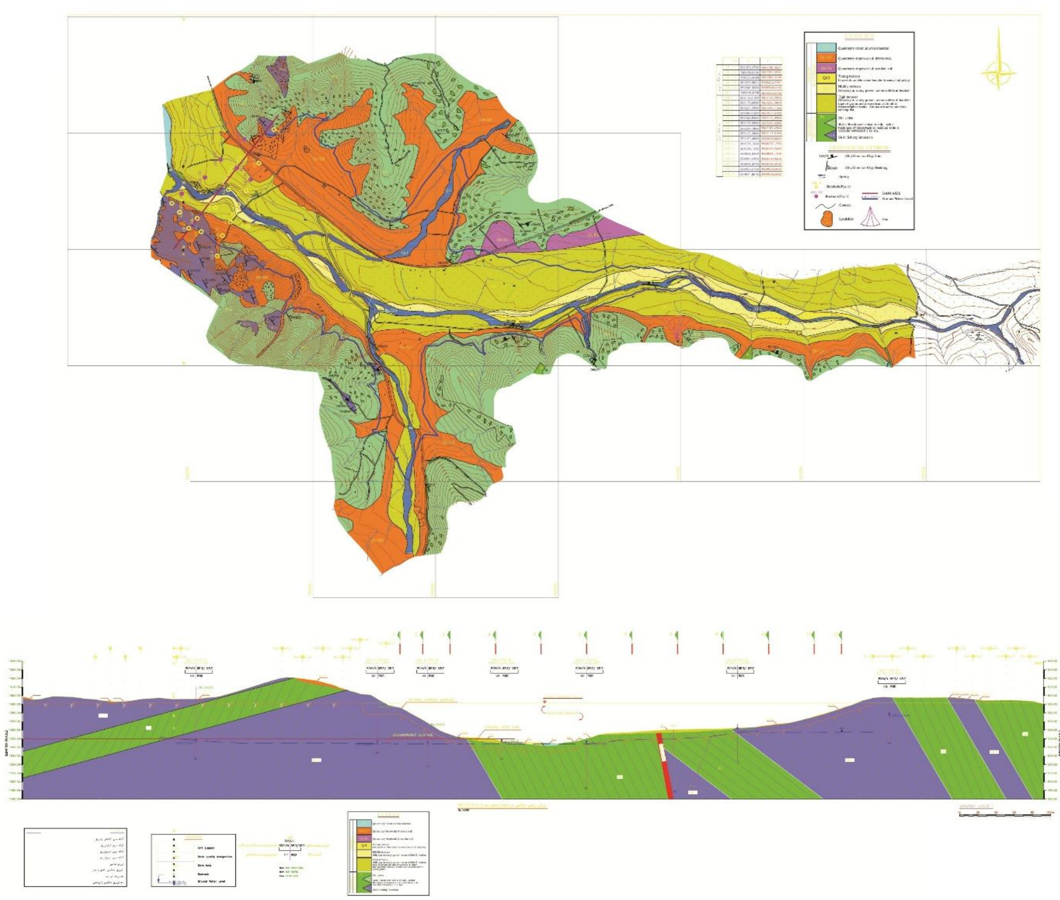

Figure 2. Geological map and section of Abbasabad dam (Geological Survey of Iran, 2011)

The main trend of faults and folds is northwest-southeast, which is in the same direction with the Zagros range. Post-Cretaceous tectonic movements have caused folds and deformation of Cretaceous sediments with alteration in the green schist fascia. These endeavors are equivalent to the orogenic phase of laramin in the Cenozoic Mesozoic. It is thought that the interactions of the Late Alpine (Pliocene) and Pasarren (Quaternary) orogenic movements have led to the current formation of the study area. The general trend of faults as well as the axis of folds is northwest-southeast. In pre-Cretaceous rocks, faults with northeast-southwest trend can also be seen. Piranshahr active fault passes about 4.5 km southwest of the site (Aghanbati, 2016). The geological map of the study area and the geological section of the dam area are given in Fig. 2 (Geological Survey of Iran, 2011).

2.2. Engineering Geological and Geotechnical Features

At the Abbasabad Reservoir Dam site, the Nanour River flows from the northwest to the southeast, creating a relatively wide and asymmetric valley of schist rocks and schist limestones. Schist limestones have formed low areas due to higher resistance to erosion, heights and schists, so that the topographic slope on the left side is about 32 degrees to the level of 1607.5 in this level, the topographic slope is about 10 meters wide, It decreases and forms the top of the abutment, the left abutment to the northwest forms a snout that has a slope of about 15 degrees. This situation is due to the existence of a valley that is formed parallel to the valley of the construction site on its south side. On the right side of the valley there is a wide platform up to the level of 1560, from the mentioned level the slope of the right side is about 6 degrees to the level of 1570 and from the mentioned level to 1610 where it becomes almost horizontal, it is about 20 degrees. A very small drift occurred in the river at the edge of the Jeep Valley. The bed level is about 1545 meters above sea level. The width of the bed in the river section is about 20 meters and in the crown level is about 510 meters. Fig. 3 shows the engineering geology section of the route leading to the dam. The bedrock mass is related to the axis of the dam is highly folded and fragmented and consists of a series of inverted folds whose southern edge has a steeper slope than the northern edge and is turned to indicate the application of tectonic force from the northeast to It has been to the southwest. The slope of the layers on the left side is 15-75 in the direction of the largest slope of 030 to 095 degrees and 78 to 227 degrees. On the right bank of the river, the layers have a slope of 75 degrees to the direction of the largest slope of 220 degrees. In the right support, the layers have a slope of 34 to 55 degrees towards the direction of the largest slope is 012 to 090 degrees and 55-72 degrees to 202-195 degrees. This structural condition is due to the fine folds, which have been corroded by the tectonic force from the north fold.

In order to identify the subsurface status and integrate the surface geological data with the subsurface, in the dam site and its related structures, 21 boreholes with a total area of 785.5 m, of which 47.5 m in the river and 738 m in the rock In addition, 96 Lefran tests, 113 water pressure tests and 32 impact and standard penetration tests have been performed. Based on the results obtained from these subsurface excavations, the overburden is mainly composed of clay and layered sand up to 5 m thick and is based on the Unified classification in SC, SC-SM, SW, ML and CL categories, which indicates the presence of a lens. Some of the sand, silt and clay are also thin. These materials have low permeability and high density, but due to their low thickness, it is recommended to remove them from under the core and body of the dam. This is the case for bedrock, which consists of the alternation of shale and shale lime with medium to high strength, 2 sheets to medium layer, and schistos with interlayer of metamorphic crystalline lime. Weathering of schist rock mass has been reported between 1.3 to 16 meters. Due to the extensive changes in the condition and quality of the rock mass, the quality index of the rock mass has been estimated. The quality index of rock mass varies between 0 and 100%. The weighted quality index during the boreholes drilled in the shale limestones varies between 16 to 72% and their weighted average is 55%. The weighted quality index of airborne zone and their micro is 5%, and the schist is 15%. The very poor to moderate quality of the bedrock mass may be due to the laminating of the bedrock and the fragmentation due to tectonic action in the area, but it is mostly due to its laminating. The water level in the exploratory boreholes was measured and recorded 4 times a day during drilling, before the start of drilling, before the start of the in-borehole test, after the test and after the end of the drilling. After drilling each borehole, the water table is measured and recorded almost weekly. According to the obtained results, the water table in different boreholes does not show many fluctuations, which indicates the natural state of groundwater in the valley of the construction site on the right side. For the engineering classification of bedrock mass, the GSI geological strength index classification is used, which has a GSI value for seam of relatively healthy 35-40, which indicates a medium bedrock mass with smooth, relatively aerated, folded fracture surfaces with angular blocks. Which has been cut by several cracks, and for 50-60 lime, it is estimated that very block bedrock with fastening, locally disintegrated, one of the angular blocks cut by 4 cracks, Composed. For fault zones, especially fault zones, the distance between the exploratory boreholes of EX22-24 injection, GSI and at a distance of about 5-6 meters, is equal to 15-20, which indicates a rock mass that eats with weak and severe fastening (Fig. 3). Also, by conducting field operations and surveying the dam area, samples were taken to evaluate the geomechanical and geological characteristics of the area engineering. The samples transfer to the laboratory and have been subjected to physical and mechanical tests.

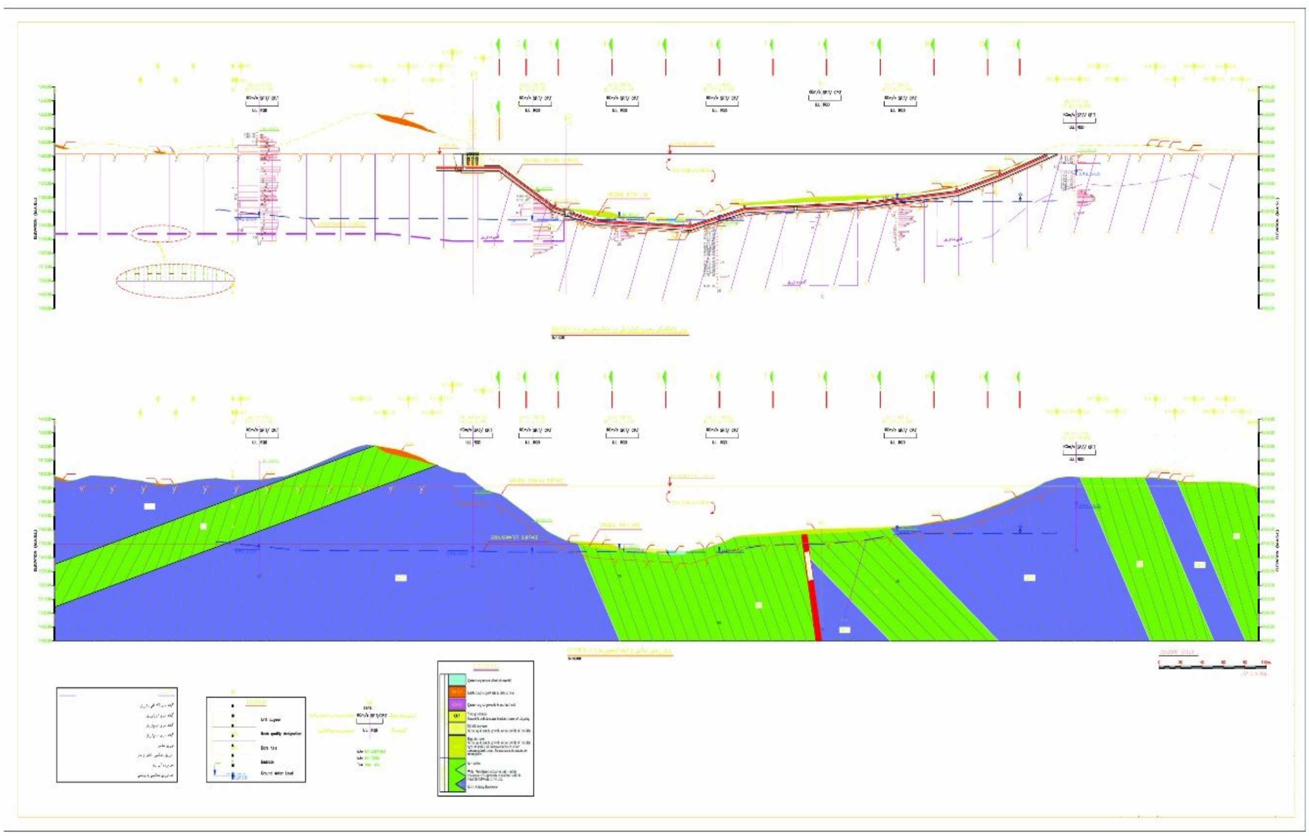

Figure 3. Engineering geological cross-section of dam

Table 1. Results of geotechnical experiments on samples taken in the dam area

Parameters	Sediments 1	Sediments 1	Shear zone	Fine-grained body	Core	Drainage	Seal
Dry density (t/m^3)	26.77	26.28	23.53	20.60	18.50	18.70	23.53
Saturation density (t/m^3)	26.96	26.57	24.51	21.00	19.30	20.70	23.53
Elastic modulus (MPa)	1409000	2793000	3000000	330000	330000	30000	1200000
Poisson ratio	0.30	0.33	0.35	0.30	0.35	0.25	0.20
Cohesion (MPa)	200	400	269	13	78	0.01	100
Friction (degree)	36	37	25	20	22	38	43
Dilation (degree)	0	0	0	0	0	0	0
Bulk coefficient	7-10	6-10	4-10	7-10	8-10	1-10	-

Relevant tests are common geotechnical tests such as uniaxial test, direct shear, density, specific gravity, porosity, etc., which have been performed according to the instructions provided by ASTM. Table 1 presents the results of geotechnical experiments performed on the studied samples. The results of these experiments are used in the numerical analysis of this research.

3. Material and Methods

In order to evaluate the performance of sealing curtains in the design or implementation stages to measure hydraulic changes that affect the geomechanical properties and engineering geology of the dam area and bed, recursive analysis is used. The purpose of applying this approach is to provide a logical answer to what the dam and sealing curtain function after the dewatering operation and during the conditions of the steady flow of the dam. For this purpose, static (and sometimes dynamic) analysis methods are generally used. In water resources engineering, approaches proposed for recursive evaluation are generally considered to be effective for long-term states and structural analyzes. As some of the deformations (due to the in situ stress field) are within the dam, they change with the implementation of the sealing curtain and take on a new nature. Such behavior refers to the plastic strain of the environment, which is caused by the water factor, which appears as surface flow (water behind the dam) and pore-water pressure. By performing recursive analysis, it is possible to estimate the stress-strain conditions, which are aimed at knowing the behavior of the dam in different construction and operation conditions, and to analyze the amount of deformations before and after the sealing curtain in the dam. Also, by using these results, the performance of the sealing curtain can be examined. One of the most widely used approaches to evaluate the performance of the sealing curtain and measure its performance is the use of numerical methods, especially the finite element approach, which is used to measure the seepage conditions in the dam bed. Relying on numerical methods, it is possible to evaluate total and partial deformations before and after the implementation of the sealing curtain, in situ stress and strain field changes and the stress-strain relationship for the dam area in the critical section of the dam before and after Implementation of sealing curtain, changes in porous water pressure at the moment of dewatering and long-term analysis of the dam to evaluate the seepage status, calculation of hydraulic gradient in the dam core and flow focal points, changes of hydraulic head and water flow below and dam before and after curtain implementation Sealed well and used the results to evaluate performance.

In this study, FEM method and Plaxis software have been used to evaluate the characteristics of seal design and return analysis to investigate the amount of permeability and deformations due to the stress-strain field distribution in the dam bed at its critical point. For this purpose, two simulation groups have been performed for different hydraulic conditions, including dam dewatering for situations without and with a sealing curtain. In each of the modeling groups, environmental changes for the dam body and bed have been estimated. For this purpose, three stages of modeling have been described, including geometric modeling and presentation of model boundary conditions, property allocation and presentation of model behavioral model, mechanical modeling and seepage analysis. In the geometric modeling stage, using the design data for the critical section of the dam (ABAS-II, III-408), the geometric properties of the dam and the alluvial bed that have been estimated by conducting engineering geological experiments and surveys with Observance of scale enters the model. For this purpose, by determining the appropriate scale in the evaluations, the amount of analysis nodes is determined. Then, considering the boundary conditions, these properties are defined to the model. After constructing the geometric model in the first stage, using the results of geotechnical experiments (laboratory and on-site), the properties and properties of the properties are assigned to the model and the behavioral model is defined depending on the type of rupture (valid rupture criterion in the environment). At this stage, the model is ready to perform the analysis operation and according to the type of analysis (long-term), pore-water conditions, drop and initial and final level are entered in each group of simulations. In the final stage, the model under deformation cycles under plastic environment conditions is solved in 300 cycles by considering the intermediate changes in the first stage and eliminating the intermediate changes in the second stage. The simulation results are evaluated for the analysis of the performance of the sealing curtain and the results are interpreted. Boundary conditions occur in the form of closing infinite boundaries in order not to prevent the reflection or refraction of the deformation and the stress field in the environment.

Figs.4 and 5 show the geometric models prepared for both simulation groups with defined boundary conditions for these groups. As can be seen, the boundaries of the model are closed in one or both directions depending on the position. Table 1 shows the properties of the materials used in the model. As can be seen in this table, the main characteristics of the elastoplastic behavioral model are presented. Elastoplastic behavioral models are the most important behavioral models in soil and rock environment that are acceptable in the analysis. This table should be defined individually for each of the materials in the geometric model, which is presented in Figs. 6 and 7.

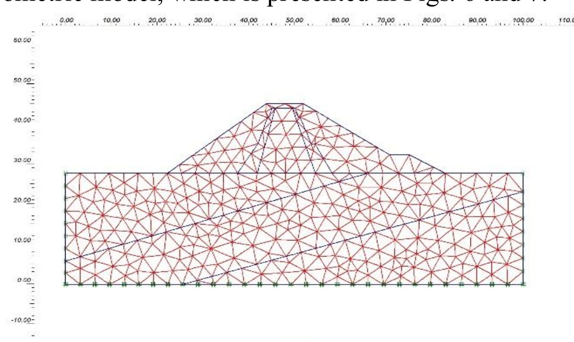

Figure 4. Geometric model of the dam without sealing

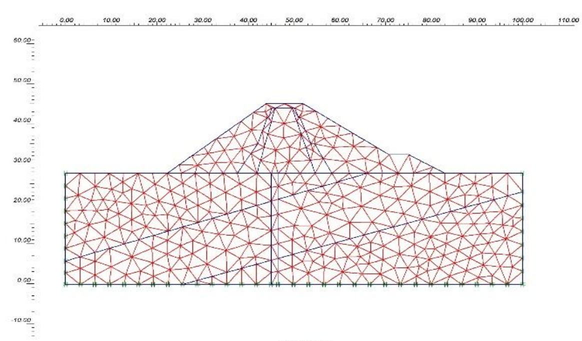

Figure 5. Geometric model of the dam with sealing

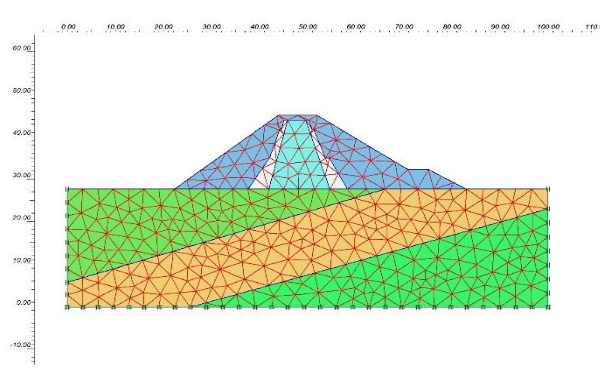

Figure 6. Define the behavioral model and assign properties to the model before sealing

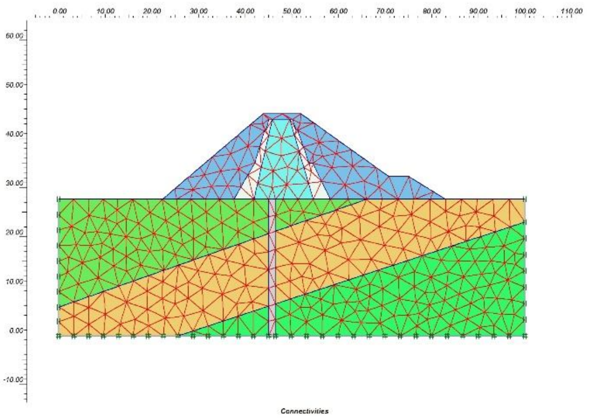

Figure 7. Define the behavioral model and assign properties to the model after sealing

4. Results and Discussions

After preparing the model, the model was implemented and the results related to the behavior and permeability of the dam for both cases was investigated. For this purpose, the model is solved (calculated) under specific plastic behavior during specific cycles and the output of the analysis is examined and interpreted. In mechanical modeling, the deformations created in the dam and the environment from the initial conditions to the conditions after the dam is dewatered and the construction of the sealing curtain are calculated and the amount of changes and displacements in the analysis nodes is estimated. . This information is used in the assessment of seepage from the body and bed of the dam during the stages before and after the construction of the sealing curtain and during the dewatering of the dam (long-term analysis). Figs. 8 to 17 present the results of solving the mechanical model to simulate the performance of the dam sealing curtain. In seepage analysis in the dam area, it is necessary to present the flow status and distribution of both potential and flow lines. As is well known, flow lines and potentials are perpendicular to each other. Estimating the condition of potential lines in the dam body when the sealing curtain is applied can be very effective in estimating the location of flow lines. This issue also has an effect on estimating the flow status in the body and bed of the dam. Fig. 18 shows the condition of the estimated potential lines for the final area of the dam after the construction of the sealing curtain and Fig. 19 shows the distribution and movement (flow) status in the area of the dam. As can be seen in these figures, the presence of a sealing curtain causes the potential lines to act perpendicular to the sealing curtain and direct the flow to the core of the dam. This issue is also observable in field conditions and is considered in dam stability designs. It is also focused on the transmission current in the dam core and downstream of the body. This issue also justifies the position of co-potential lines in modeling and shows the efficiency of analysis.

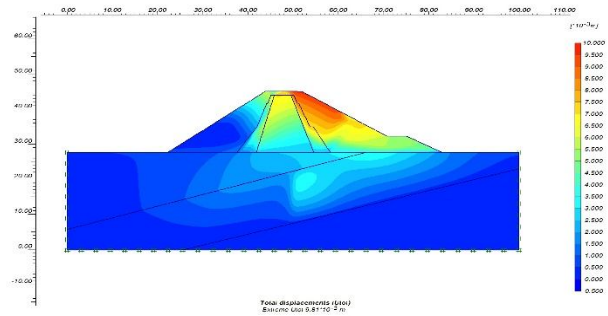

Figure 8. Deformation and displacement status in the dam area before sealing

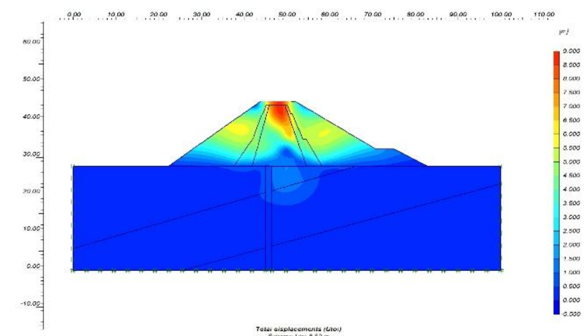

Figure 9. Deformation and displacement status in the dam area after sealing

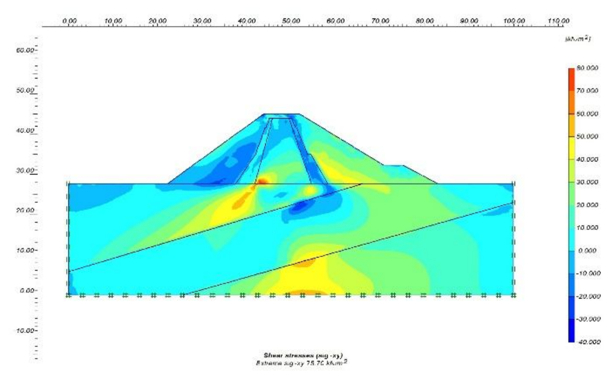

Figure 10. Condition of shear stress distribution after dewatering in the dam area before sealing

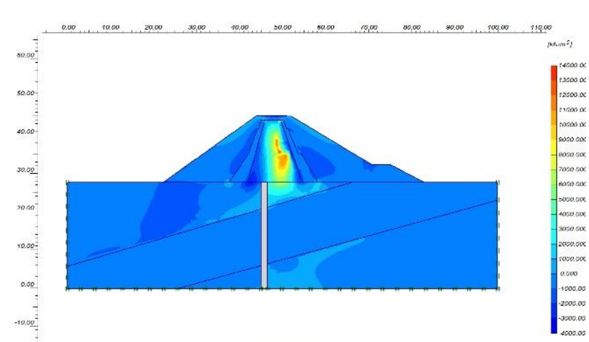

Figure 11. Condition of shear stress distribution after dewatering in the dam area after sealing

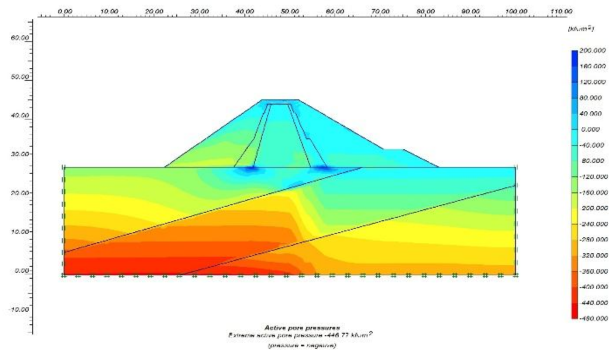

Figure 12. The pore water pressure status in the dam area before the sealing

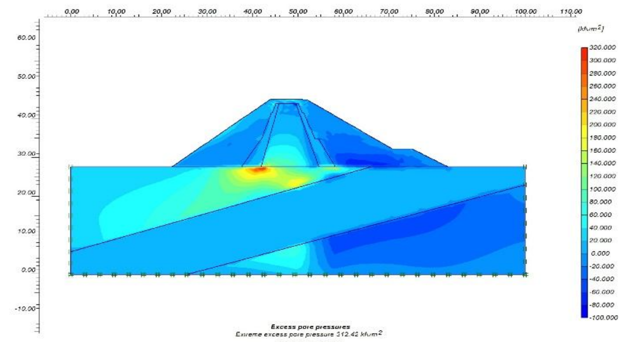

Figure 16. Double pore water pressure in the dam area before sealing

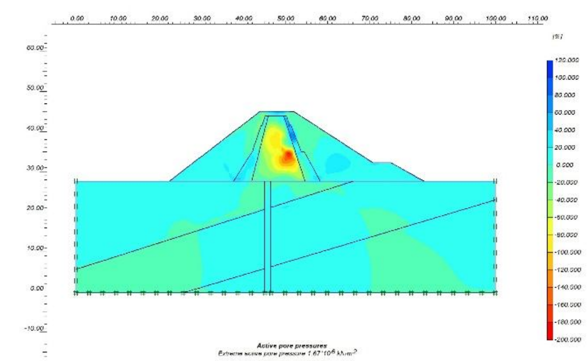

Figure 13. The pore water pressure status in the dam area after the sealing

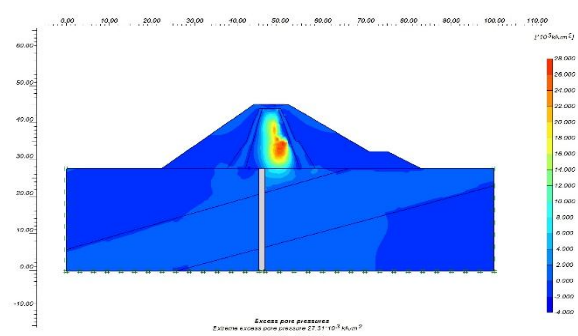

Figure 17. Double pore water pressure in the dam area after sealing

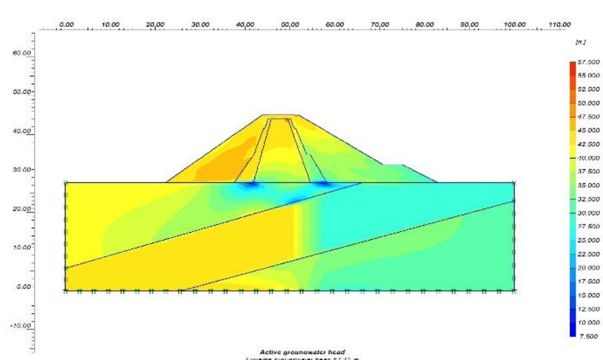

Figure 14. Active groundwater head in the dam area before sealing

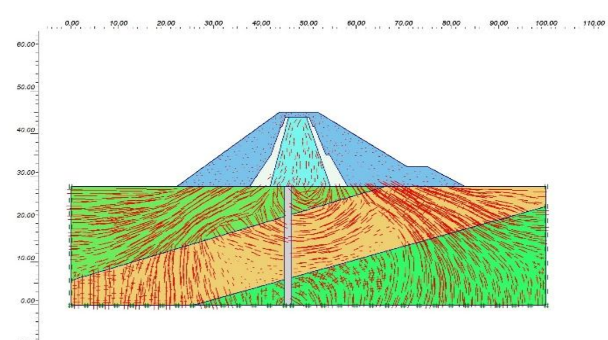

Figure 18. Distribution of potential lines in the area of the dam and sealing

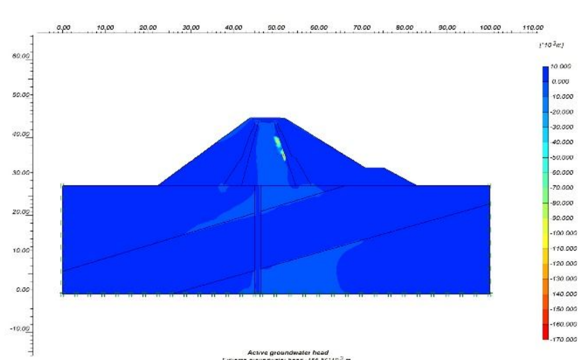

Figure 15. Active groundwater head in the dam area after sealing

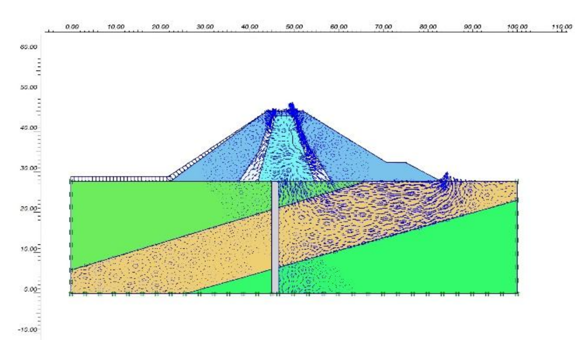

Figure 19. Flow contours in the dam and the sealing

In permeability analysis and sealing curtain design, the main problem facing the analysis is stress-strain-based deformations, stress field and the amount of pore water pressure changes.

5. Conclusion

According to the results of this study, the following can be mentioned:

A) Analyzes have shown that the vertical stresses and the main stresses are maximum in the range of the core and shell connection and have sudden changes. This is due to the difference in hardness in the shell and core of the dam, which is due to the fact that the ratio of existing stress to stress in a homogeneous dam is normal and expected.

B) In general, the results of analyzes confirm the appropriate behavior of the dam structure against different loading conditions. The displacements, stresses and pressures of the pores are acceptable and the seepage analysis performed by the numerical method shows the continuity in the steady flow and the distribution of the flow lines and the potential in a logical way.

C) Effective stress analysis has shown that the bottom-up sealing curtain implementation process has been successfully implemented in the dam design and its performance has been confirmed by reducing the deep stress and directing the flow to the dam area.

D) The presence of the sealing curtain has caused the potential lines to act perpendicular to the sealing curtain and direct the current to the core of the dam. This issue is also observable in field conditions and is considered in dam stability designs. It is also focused on the transmission current in the dam core and downstream of the body. This issue also justifies the position of co-potential lines in modeling and shows the efficiency of analysis.

E) According to the results of seepage analysis, it has been determined that the process of sealing the curtain has caused the shear stress in situ in the bed area to be reduced and its main focus is upstream and the core of the dam. Also, the effect of the downstream outflow caused an increase in the pore water pressure in the downstream part of the dam, which in turn has increased the shear stress in this area. The change of flow in the area of the sealing curtain has caused that a decrease in shear stress is observed and estimated in the upstream part of the dam and the reservoir part of the sealing curtain.

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