Journal of
Applied Research in Water and Wastewater
Journal homepage: www.arww.razi.ac.ir

Original paper

Monitoring and numerical analysis of pore water pressure changes Eyvashan dam during the first dewatering period

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ARTICLE INFO

Article history:
Received 3 November 2018
Received in revised form 5 February 2019
Accepted 9 February 2019

Keywords:
Pore water pressure
Dewatering
Eyvashan earth dam
Instrumentation
Cut off

ABSTRACT

The performance of dams due to high operating costs and irreparable damages caused by failures in the construction phase and during the dewatering and exploitation period should verified and monitored by proper behavioural analysis. Dewatering the dams will result in the saturation of the embankment and supports and, consequently, the reduction of the stability coefficient. Therefore, in order to allow an earth dam to tolerate the new conditions easily and without problems, the rate of dewatering should be within the range. In this study, pore water pressure in the body of Eyvashan earth dam was evaluated. The water level inside the clay core due to changes in the reservoir water level during the first dewatering and using the actual specifications of the materials by Geostudio and Plaxis software and compared with the results of the instrumentation in the dam body. In order to adapt the observed and predicted data, a multi-variable regression was used and the coefficient of determination was used and respectively the value of R^2=0.9834 and R^2=0.9863 was obtained which shows a very good agreement between the observed and predicted data. Indicating that the cache water pressure values and their occurrence are in good agreement with the initial design conditions and that the barrier behaviour is stable in terms of pore water pressure. Installed piezometers upstream of the core show a higher pressure than the downstream, due to the high saturation state of the phreatic line. Also, the height of pressure in the downstream of cut off in the results of numerical modelling and in the observed results has suddenly decreased, which indicates the correct function of the injection cut off.

1. Introduction

Geotechnical problems which earth dams could experience during their operational stages are mainly related to slope instability and internal erosion phenomena (Jannati et al. 2010). Updating dam safety and efficiency with regard to such concerns is becoming a crucial matter, especially for those structures that have been in operation for several decades. To accomplish this work, dam loading history should be preventively known; in addition, monitored physical quantities and results from periodical inspections should be suitably collected and interpreted during the diserent stages of the dam's life (Nayebzadeh et al.2000). The pore water pressure created of clay core in earth dams is very important in terms of soil mechanics and its increase can endanger the stability of the dam. Increasing pore water pressure may reduce effective stress, thus reduce the shear strength of core materials, and ultimately create cracks or ruptures in the dam body. Therefore, reducing the pore water pressure in the dam body during the construction and operation of the dam is a very important issue (Johansson et al. 1997). According to the ICOLD (International Commission on Large Dams), the majority of failed dams either did not have any monitoring system or had a system that was out of order. This finding therefore demonstrates the importance of inspection and an appropriate monitoring system for regular observation of dam performance. The objective of dam monitoring, which plays a significant role in the concept of dam safety, is to provide data in order to evaluate dam performances throughout its whole life cycle. In the analysis of the earth's dam in the conditions where the reservoir is full and permanent leakage is established, a conventional and simple method of using effective stress based on the pore pressure caused by gravity leakage from the dam. Usually the pore pressure distribution caused by gravity leakage from within the dam (Rahimi. 2011). The distribution of the pore pressure due to the gravity leakage is determined using the flow grid method, although the finite element method used in this field. The finite element method was first proposed for geotechnical problems by Woodward and Clough (1967), but the use of this method was presented to analyze large structures such as earth dams by Nobari and Duncan (1972). Since then finite element, method became a powerful tool for predicting the behavior of both earth and rock fill dams. Zienkiewicz (1977) presented General Reports for Static Analysis of earth Dams. Karoui et al. (2016) investigated numerical analysis of the behavior of Sidi El Barrak dam and compared it to the instrumentation data. Abhilasha et al. (2014) investigated the numerical analysis of seepage earth dams, applications and commercial software that are widely used by researchers and designers to model different aspects of seepage flow in earth dams, and concluded that modeling with Seep/w of acceptable accuracy and accuracy and has a high level and can be useful for efficient and economical large and complex problems. Rashidi et al. (2017) assessed the pore water pressure and settlement of the Gavshan earth dam and the comparison of instrumentation data, numerical modeling using FLAC (2D) software concluded that dam performance in terms of pore water pressure, and finally stability of the dam is positive. Haghighi et al. (2014) studied the construction of the cutoff wall in the earth dams and its effect on leakage. The results of this study indicate that with the construction of the cutoff wall along the banks with small reservoir volume and cutoff wall initially is unanticipated it is expected to increase the dam height and increase

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the rate of water harvesting from the dam reservoir. In another study, Moradi et al. (2017), studied the pore water pressure in the body of the earth dams in the construction stages. By modeling Damghan earth dam with Plaxis software and layer-to-layer analysis of dam construction steps and using Mohr Coulomb's behavioral model, they achieved positive results regarding the software's ability to simulate pore pressure stress. In addition, Mir Mohammad Hosseini et al. (2009) studied and evaluated the pore pressure at the core of the Karkheh Dam during construction and dewatering simultaneously using the instrumentation results. Luo et al. (2018) studied the behavioral variation of the Chengbihe reservoir dam in a period of 18 years. Using the results of the piezometric pressure and instrumentation settlement concluded that the maximum settlement of the dam in the central part is 178 mm, which is gradually from the center to the wings reduced. Maximum settlement at the wings was 65.8. In addition, most settlement observed at the upstream of the seals, which can be due to changes in water level and reservoir pressure. Javanmard et al. (2019), in an article on the pore water pressure of the Taham Dam using the results of instrumentation and Plexis software.

In the present study, changes in pressure and water head in the body and foundation of the Eyvashan earth dam during the operation period were evaluated using the software of Geostudio and Plaxis. Then, the measured values compared with predicted results to study the behavior parameters of the dam.

2. Materials and methods

2.1. Specification of the Eyvashan earth dam

Eyvashan Reservoir Dam is located 1.5 km from the upstream of the village of Eyvashan and about 57 km from Khorramabad in the coordinates of 48°49'2" and 33°28'31" degrees north, located on the Horod River. The area of the Horod river drainage basin up to the axis of the dam of Eyvashan is 120 square kilometers. The dam is a rock fill-earth dam type with a vertical clay of core that has a height of 62 meters (1804 meters above sea level), a crest height of 1868 meters and a normal elevation of 1864 meters above sea level. The volume of the reservoir in the normal value of the dam is 52 million cubic meters and the area of the lake at normal level is 2.3 square kilometers. Fig. 1, presents the Eyvashan earth dam.

Fig.1. Eyvashan earth dam.

The construction site of the Eyvashan reservoir from the geological point of view of the rock bed consists of conglomerate rocks that have outcrops in the boundaries of these rocks, but deposited on the conglomerate rock in the bottom of the valley of alluvial sedimentary deposits. In terms of lithology, the conglomerate of the axis and lake is composed of limestone, sandstone, slate, metamorphic rocks and igneous rocky parts with a silty-sandy and sometimes silt-clay matrix.

2.2. Instrumentation Installed in Eyvashan earth Dam

Installed instruments in the Eyvashan reservoir include Casagrande stand pipe Piezometers for measuring water pressure, observation wells for determining groundwater level and settlement meters to measure the body's settlement and v-notch seepage weir to measure the discharge of water leakage from The dam body used, which is a mechanical device and is one of the simplest types of tools installed in this dam. Electrical tools have a higher accuracy and the reading of them is possible by reader's devices and the possibility of remote reading. Electric piezometers for measuring pore water pressure, pressure gauge cells for measuring total stress, Inclinometer for measurement of change shapes, Extensometers for measuring elongation, Joint meters for Openings in rocky and earthy masses, Crack meters to measure crack widths, Earthquake accelerometers for measuring and recording the vibrational motion of the earth, and dozens of other tools are the most commonly used electrical tools in earth and Concrete dams, tunnels, caverns, railways and bridges used. The general status of the installed instrument of the Eyvashan Dam presented in Table 1.

Table 1. General condition of the equipment installed in the Eyvashan earth dam (Abdan Faraz Consulting Engineers Co).

Number Installed	Number Design	type Symbol	Type of tool	Row
24	24	EPF	Foundation piezometers	1
51	52	EPE	Body piezometers	2
29	29	TPC	Total cell pressure	3
8	8	SP	Stand pipe piezometers	4
2	2	INP	Iinclinometerr Insitu	5
7	4	IS	Inclinometer and Settlement	6

The instrumentation of the Eyvashan dam considered in four sections of 228-228, 229-229, 230-230 and 231-231, in the 0+249, 0+356, 0+ 477 and 0+ 546 km respectively. In the present study, the characterization of the tool installed in the section of 229 Eyvashan Reservoir Dam investigated. The maximum level of instrumentation related to the 229-229 cross section with seven levels and the minimum number of instrumentation levels related to the 231-231 section with five levels (Fig. 2).

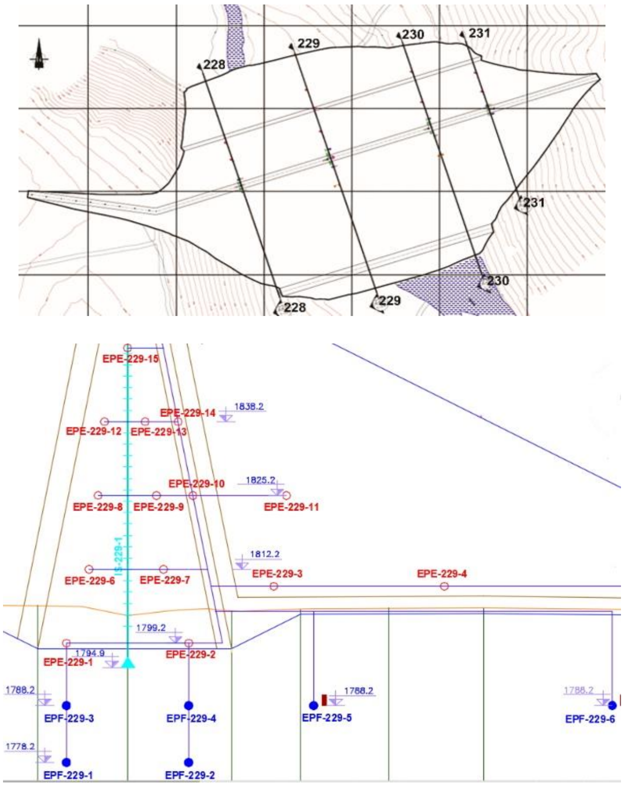

Fig. 2. The Position of the tooling sections on plan and cross section of the core of the dam Eyvashan 229.

2.3. Monitoring of electrical piezometer foundations (EPF)

In the level of 1778 meters above sea level, two piezometers mounted upstream, downstream, and equidistant from the axis. The trend of piezometric pressure variations on this level is such that during rising landings, it shows a rising trend and shows a slight decrease in the grazing course at the time of embankment stall. This process has become an incremental process during dewatering. In the upstream watershed, after the start of dewatering and at the last reading, the piezometric pressure is about 692 kPa and downstream 581 kPa, and the pressure difference is lower than the low 111 kPa. The piezometric

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alignment in this upstream and downstream level is 1849 and 1837 m above sea level, respectively (Abdan Faraz Consulting Engineers) (Fig. 3).

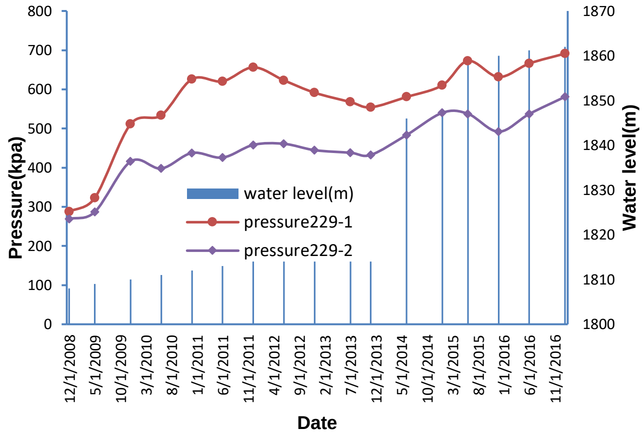

Fig. 3. Piezometric balance changes in foundation piezometers, level 1778, and section 229.

At 1788 meters above sea level, two piezometers in the upstream and downstream of the axis and two electric piezometers adjacent to the Casagrande piezometers in the downstream axis (Fig. 4). The piezometric alignment in upstream and downstream at the last readings is 1855 and 1819 meters above sea level, respectively. In addition, pressure upstream is about 351 kPa above the lower pressure. In addition, this difference accompanied by an increase in the level of the lake, which could be somewhat indicative of the proper functioning of the cut off. The downstream piezometers also show a nearly identical trend with their near-described piezometers, and the piezometric balance calculated in this tool (EPF-229-5, 6) reaches 1802 and 1803 m above sea level, respectively. In addition, shows a roughly identical trend at the downstream (Fig. 4).

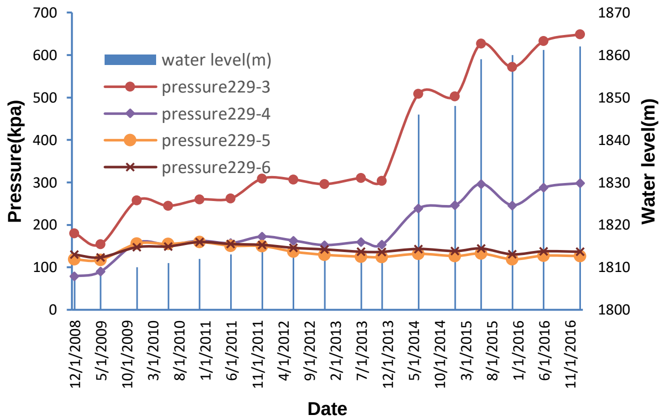

Fig. 4. Piezometric balance changes in foundation piezometers, 1788sections 229.

With rising reservoir water levels up to 1862 meters, upstream piezometers affected by piezometric changes in their surroundings, which is followed by a decrease in the piezometric balance at the same time.

2.4. Monitoring of electrical piezometer embankment (EPE)

At 1799 meters above sea level, two piezoelectric dams installed at the top and bottom of the clay core. The variation in the pore pressure created in the clay core was due to the increase in the embankment and in late 1992, with increasing reservoir water level; the pore volume increased ascending, at the last readings provided in the upstream 649 kPa and downstream 298 kPa (Fig. 5).

At altitude of 1812 meters above sea level, two piezometers of electricity in the clay core and 1809 meters above sea level, three electric piezometers in the bottom shell installed. Piezometers that have been installed inside the clay core have experienced a uniformity since the installation so far after the completion of the embankment operation and the beginning of the dewatering period, the pore pressure created is depleted, and in both the piezometers upstream and downstream of this pressure is negligible (Fig. 6).

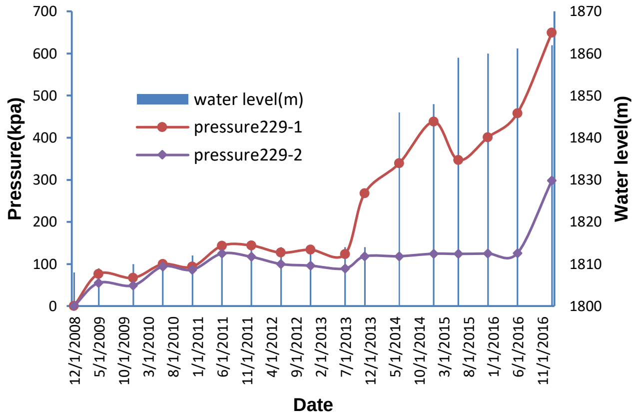

Fig. 5. Vent pore water pressure variations in the piezometers of the ditch installed at the 1799 level in section 229.

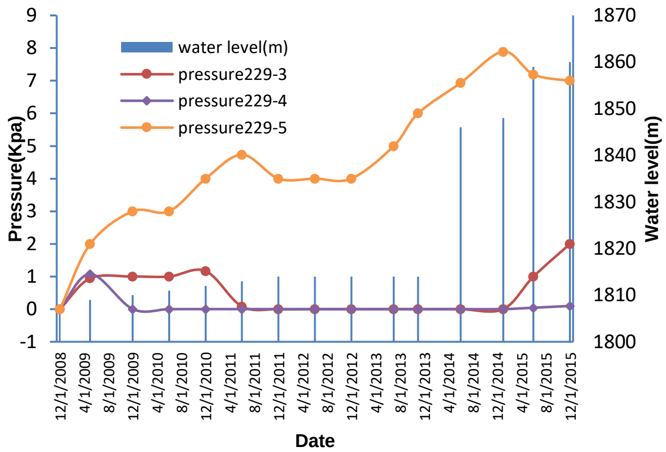

Fig. 6. Vent pressure variations in the piezometers of the ditch installed at the 1809 level, section 229.

In the downstream shell, the amount of pore pressure generated is uniform and constant, and the pore pressure created is negligible (Fig. 7).

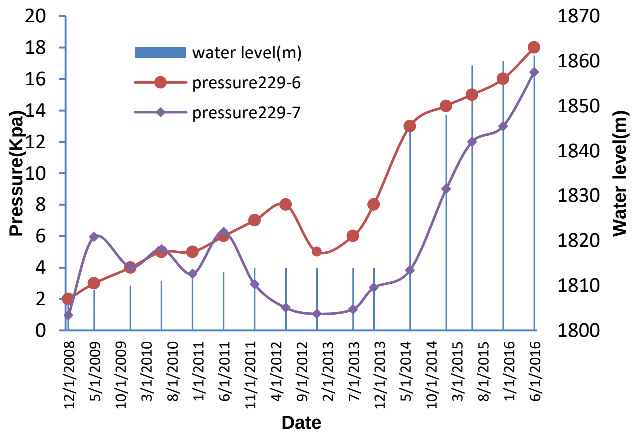

Fig. 7. Vent pressure variations in the piezometers of the ditch installed at the level 1812, section 229.

At altitude of 1825 m above sea level, two piezometers are located on the upstream and downstream of the clay core and two piezometers in the bottom crest, the piezometer mounted above the hand after the

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start of intake and at the last reading, the pressure of 276 kPa. Also, the piezometer mounted at the bottom of the last revision shows a pore pressure near 138 kPa, but a piezometer mounted in the bottom-down filter since the beginning of the year 2011, with the start of a gentle ascension garlic embankment and at the last reading it shows a pressure of about 31kPa. The piezometer fitted in the bottom shell at the last reading recorded a piezometric pressure of 75 kilopascals (Fig. 8).

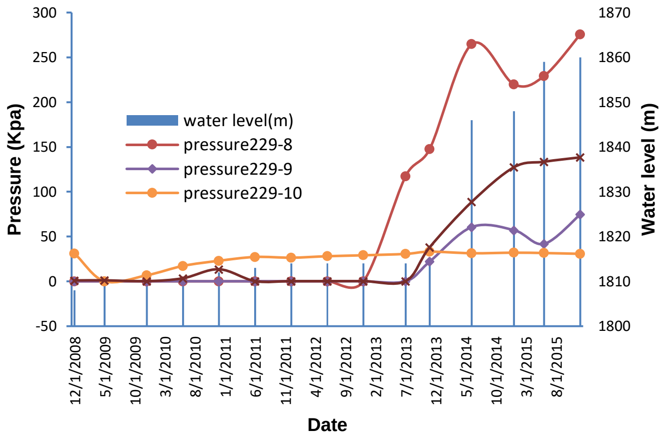

Fig. 8. Vent pressure variations in the piezometers of the ditch installed at the 1825 level, section 229.

At an altitude of 1838 m above sea level, there are three piezometers of electricity in the clay core and in a lane filter. The upper piezometer of the cluster of the jet pressure of 276 kPa and the lower piezometer of the pressure limit is 268 kPa. The piezometer inside the filter material shows a very small pore pressure, which appears to be natural due to the surrounding environment. The electrical piezometer installed at the level of 1851 has shown that the pore pressure is negligible at zero, which can be due to a dry area around the tool (Fig. 9).

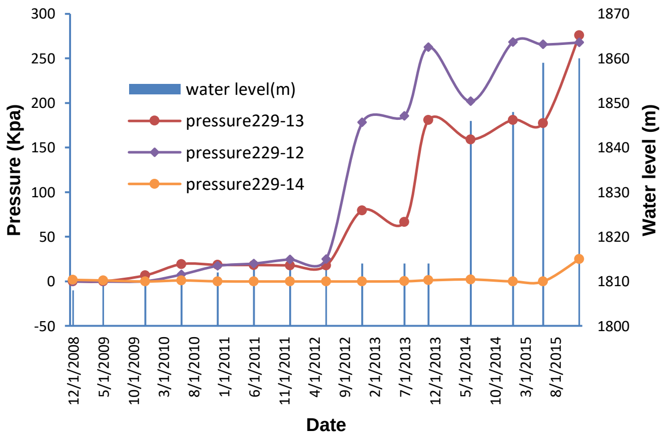

Fig. 9. Vent pressure variations in the piezometers of the ditch installed at the 1838 level, section 229.

3. Results and discussion

3.1. Investigation of the results of the water pressure of the dam of Eyvashan

Increasing the pore pressure of the water leads to failure in the excavation. Among the destructive effects of increasing pore pressure, we can mention the following:

A. The most common effect of increasing the pore pressure on soil dams is the unsteadiness of the gravel slope.

B. Increasing the pressure of the pore water leads to an increase in compressive forces upstream of the hydraulic structures and instability of the structures.

C. The pressure of the pore water may result in the upward force rising in the soil of the enclosed soil located downstream of the dam. The destruction begins when the force reaches upward from the force due to the weight of the layer resulting in destruction as a scouring or flood phenomenon. The confidence level used for upward forces is the expression it is from the ratio of overhead forces to the upward force of water, which is expressed as 1.

$$Sf=\frac{Gs\times t}{(1+e)\times h} \quad (1)$$

In relation (1), Gs is the relative density of solids, t is thickness, e is the porosity of the enclosing soil layer, h is the piezometric height in the substrate, and the minimum confidence coefficient 2 is required. In order to check the pore pressure of the block in the dam of Eyvashan, the tools installed in section 229 selected. Section 229 is a cross section with maximum height of the dam of Eyvashan. The results include readings made on June 21, 2016 at the level of the reservoir equal to 1861.20 meters above sea level. In this research, for verifying the data obtained from instrumentation readings, the pore water pressure of the Eyvashan earth dam using Plaxis and Geostudio software presented in two-dimensional and under the conditions of the flattened geometric model, which simplifies the calculations. Then, the results of a numerical analysis compared with the results of the observation. Plaxis software is intended for detailed analysis of mesh by 15-node elements. The permeability of the materials used in the leak analysis is presented in Table 2. The displacement of the body piezometric and the pore, the pore pressure contours and the total head contours in the Geostudio model shown in section 229 of the Eyvashan earth dam (Figs. 10, 11, 12, 13 and 14). The pore water pressure at the tank floor level is 53.5 m, which is equivalent to the reservoir water level (1861.20 m above sea level). The phreatic line does not show a drop in the upper shell due to the high permeability of the upstream crust, and a significant hydraulic gradient is observed in the core, which is evidence of the proper functioning of the core, that is, counteracting the permeability of the flow of water. As can be seen, the equilibrium of the pressure lines in the earth's dam is indicative of the continuity of the permafrost in the body of the earth dam.

Table 2. Permeability of various materials of Eyvashan Dam.

Materials	Kx(m/sec)	Ky/Kx
Core	10-2×2.5	0.2
Shell	10-3×1	1
Filter	10-4×1	0.5
Drain	10-2×2	1
Alluvial	10-3×5	1
Foundation	10-9×1	1
Cutoff	10-7×1	1

In Table 3, the values of the water pressure of the pore water pressure read by the piezometers and the results of computer modeling presented as a pressure height. Generally, phreatic line in the dam is the boundary between the positive and negative pore pressures. As the points below the free surface flow line have positive pore water pressure values and the points located above this line have negative water pressure values due to the occurrence of the suction phenomenon in the upper regions. In this research, zero indicates negative values of pore water pressure. In Figs. 15, 14 and 16, presents respectively, the mesh, pore pressure and total head contours in Plaxis software model of the Eyvashan earth dam.

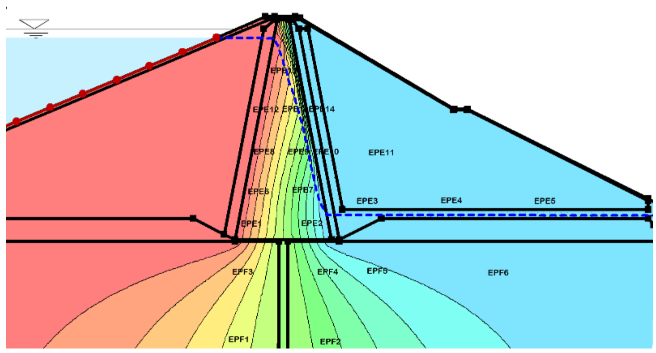

Fig. 10. The position of the body's and foundation Piezometers (Geostudio).

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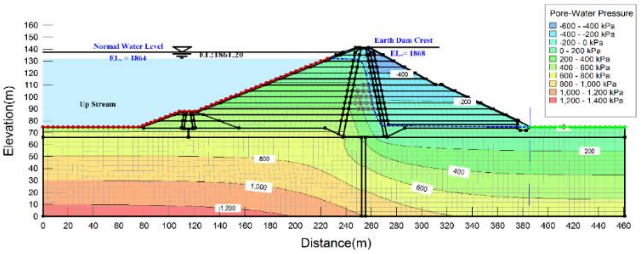


Fig. 11. Pore Water Pressure Contours of the Eyvashan earth Dam (Geostudio).

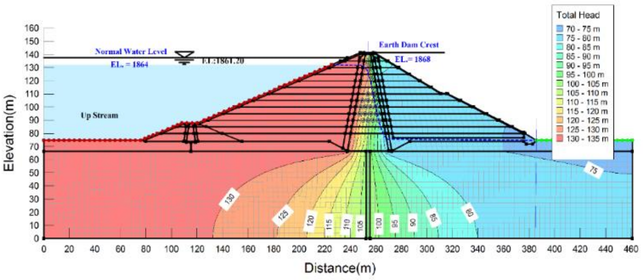


Fig. 12. The head concentrators of the Eyvashan earth dam (Geostudio).

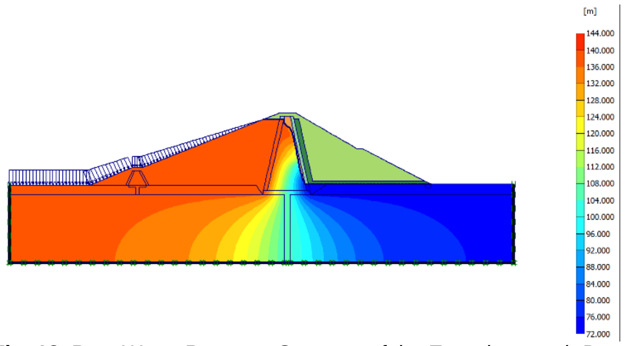


Fig. 13. Pore Water Pressure Contours of the Eyvashan earth Dam (Plaxis).

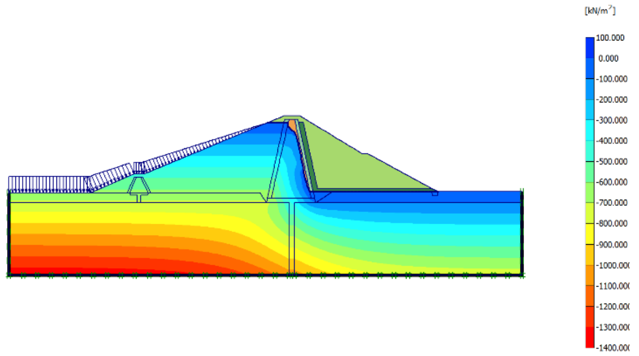


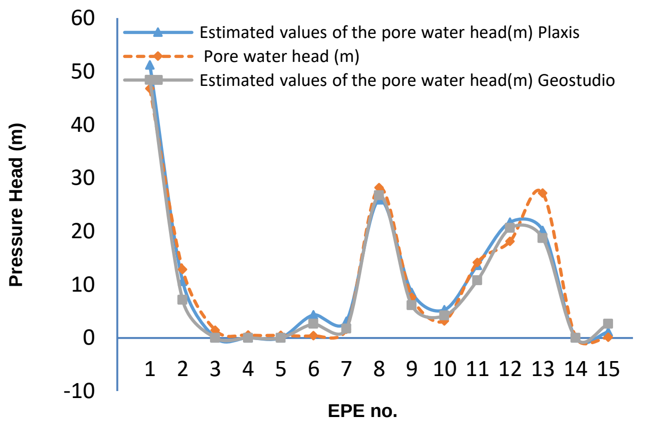
Fig. 14. The head concentrators of the Eyvashan earth dam (Plaxis).

Fig. 15 compares readings from instrumentation and numerical modeling results for foundation and embankment piezometers. These values relate to the pore water pressure of the body and foundation the Eyvashan earth dam. In this study, the pore water pressure at zero above the free flow level is considered.

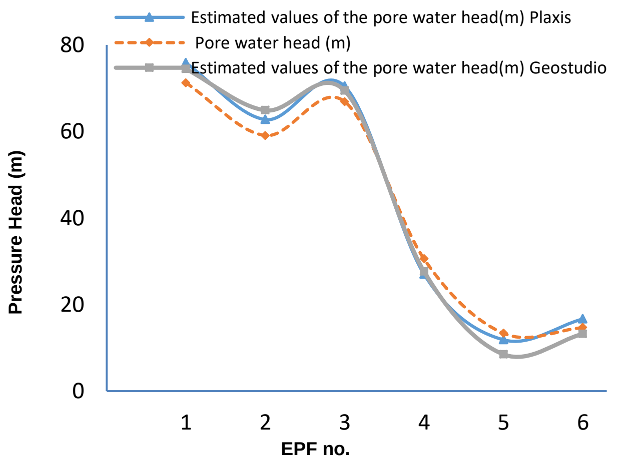
In general, the values obtained from instrumental readings and numerical analysis are in good agreement with each other. As you can see, the results of reading the electric piezometers in the clay core at the 1806 and 1825 m altitudes above sea level indicate lowering the pressure from the upstream downstream of the core, which indicates the correct functioning of these piezometers (Fig. 16). As shown in Fig. 17, the values obtained from numerical analysis, both quantitatively and formally, are very consistent with the results of instrumentation readings. EPF-1 and EPF-3 piezoelectric devices are located on the upstream side of the cutoff and the EPF-2 and EPF-4 pyrometers are on the lower side and close to it. In addition, in Fig. 17, the pressure level at the lower side of the cutoff has a sudden drop in numerical modeling results and in the observed results, which indicates the correct functioning of the injection cutoff.

Table 3. Measured and predicted values of pore pressure of core and Eyvashan dam for the instruments installed in the section of 229 reservoir levels.

Piezometer	Above sea level (m)	Measured value of the pore water head (m)	Estimated values of the pore water head Plaxis (m)	Estimated values of the pore water head Geostudio (m)
EPE-1	1806.32	46.75	51.2	48.4
EPE-2	1806.30	12.82	10.6	7.1
EPE-3	1809.20	1.4	0	0
EPE-4	1809.25	0.5	0	0
EPE-5	1809.26	0.43	0	0
EPE-6	1812.20	0.37	4.3	2.6
EPE-7	1812.12	1.58	3.1	1.7
EPE-8	1825.36	28.15	25.9	26.7
EPE-9	1825.27	7.61	8.5	6.1
EPE-10	1825.29	3.15	5.26	4.19
EPE-11	1825.22	14.12	13.6	10.78
EPE-12	1838.29	18.11	21.7	20.6
EPE-13	1838.41	27.12	20.14	18.7
EPE-14	1838.51	0.1	0	0
EPE-15	1851.35	0.1	1.1	2.6
EPF-1	1778.2	71.26	75.9	74.51
EPF-2	1778.2	59.09	62.8	64.94
EPF-3	1778.2	66.92	70.5	69.46
EPF-4	1788.2	30.6	27.1	27.64
EPF-5	1788.2	13.42	11.9	8.54
EPF-6	1788.2	14.7	16.7	13.28



(a)



(b)

Fig. 15. Comparison of the observed values and predicted values of the pore water head of the section 229 (a) Electric piezometers of the embankment, b) Electric piezometers of the foundation.

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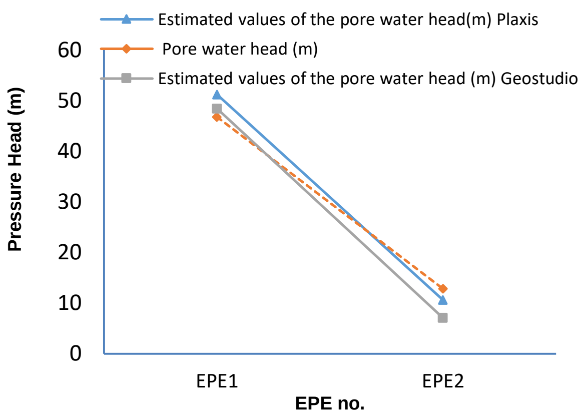
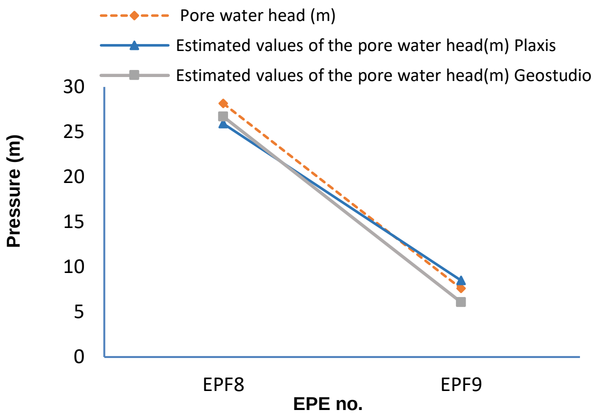


(a)

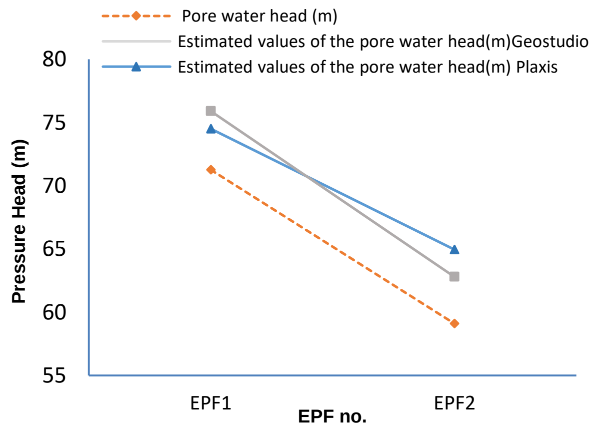


(b)

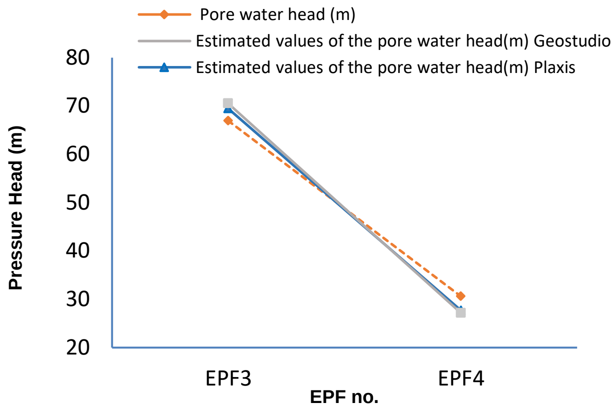
Fig.16. Pressure drop from upstream downstream of the core at two different levels (observational and numerical analysis), (a) 1806 meters and (b) 1825 meters.

In order to evaluate and compare the performance of the instrumentation and the Geostudio model, multivariate regression used from the criterion of the coefficient of explanation (Eq. 2).

$$R^2=1-\frac{\sum_{i=1}^{n}(Pi-Oi)^2}{\sum_{i=1}^{n}(Pi-Oave)^2} \quad (2)$$



(a)



(b)

Fig. 17. Decrease of pressure height by flow through the drain valve at two different levels from the dam, (a) 1778 meters and (b) 1888 meters.

In (2) n is the number of samples, Oi and Pi are respectively the observed values and the predicted values, and Oave is the mean of observational values. The explanatory factor shows that the regression line between the predicted and measured values is close to how close it is to the regression line with a slope of 1. In calculations, the closer R^2 to the number one, the more efficient the model is. Indeed, if the value of R^2 is equivalent to one, it shows a perfect fit, indicating a complete fit between the observational and predicted data. By applying equation (2) on observed and predicted data, the coefficient of explanation for Geostudio software was 0.9834 and for Plaxis 0.9863 software, which showed the correspondence of the results of pore water pressure for values Instrumentation and predicted values (Figs. 18 and 19).

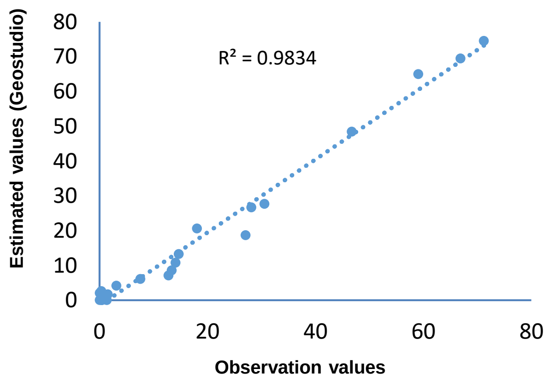


Fig. 18. Distribution diagram for observed and predicted values (Geostudio).

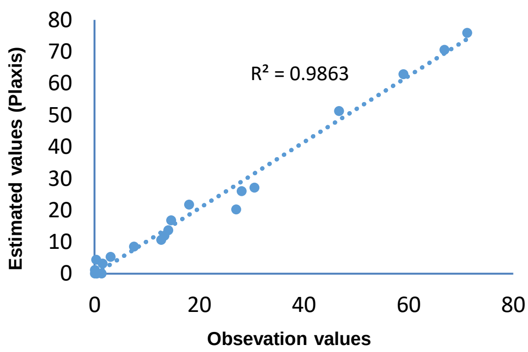


Fig. 19. Distribution diagram for observed and predicted values (Plaxis).

Please cite this article as: B. Beiranvand, M. Komasi, Monitoring and numerical analysis of pore water pressure changes Eyvashan dam during the first dewatering period, Journal of Applied Research in Water and Wastewater, 6 (1), 2019, 1-7.

4. Conclusions

The values obtained from numerical analysis, both quantitatively and formally, are very consistent with the results of instrumentation readings. In addition, the free surface flow line (phreatic line) derived from numerical modeling in the dam is quantitatively and qualitatively similar to the actual line of free surface of the extraction stream from the installed piezometers. Installed piezometers upstream of the core show a higher pressure than the downstream, due to the high saturation state of the phreatic line. In addition, the core performance in dealing with leakage up to this time is well suited to the initial design of the dam and indicates the sustainable behavior of the dam in terms of trawl. A slight change slightly observed in the farther line from the numerical model to the actual flow conditions of the body and the dam of the dam may be due to the application of the mechanical parameters of the soil considered in the design of the dam. It is likely that the actual soil material used in the body of the Eyvashan dam and, consequently, have parameters such as the difference in design values. In addition, the numerical analysis of the leakage carried out in a two-dimensional fashion while the actual flow in the earth's dams is three-dimensional, this difference can be justified in the phreatic line.

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