Int. J. Nonlinear Anal. Appl.
Volume 12, Issue 1, Winter and Spring 2021, 419-432
ISSN: 2008-6822 (electronic)
http://dx.doi.org/10.22075/IJNAA.2021.4815

The effect of changes in sealing wall and horizontal drainage of Golfaraj dam on the values of lifting pressure parameters and maximum outlet gradient

Kambiz Mashkabadi[a], Yousef Zandi[b,*]

[a] *Department of Civil Engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran.*
[b] *Assistant Professor of Civil Engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran.*

Abstract

Dams are always considered as infrastructure structures and have vital value. An earthen dam is a body consisting of discontinuous soil particles of various sizes that need to be placed in front of a stream of water to store it. As water is stored behind the dam and its surface area increases, the potential energy of the water particles increases and due to its porous nature, it begins to move in it. Today, the main problem that has attracted the attention of engineers is the issue of seepage. So that the presence of seepage in earthen dams is inevitable. The aim of the present study was to investigate the different positions of the sealing wall and to select the best angle, length, number and distance, as well as to select the appropriate length for horizontal drainage Due to the geotechnical conditions, it is against the phenomenon of rug and lifting force. GeoStudio software is a collection of soil mechanics software based on finite element method through which various modellings and analyzes can be examined. This software includes various models such as SEEP / W which is used for flow analysis and seepage. In the present study, the SEEP / W model of this software package has been used. The SEEP / W model is based on the Darcy relation, which expresses the passage of water flow through the soil in both saturated and unsaturated states.

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 are suitable. Also, the optimal length of the sealing wall is 24 meters and its optimal number is 2. Increasing the distance between the two vertical sealing walls has increased the lifting pressure and reduced the maximum outlet gradient. Increasing the horizontal drainage length reduced the maximum output gradient, while having little effect on the uplift pressure.

Keywords: Leakage, sealing wall, horizontal drainage, Golfaraj Dam, SEEP / W

*Corresponding Author: Yousef Zandi
Email address: zandi@iaut.ac.ir (Kambiz Mashkabadi[a], Yousef Zandi[b,*])

Received: 30 June 2020 *Revised:* 5 October 2020

1. Introduction

Leakage is one of the main reasons for dam failure. Based on studies that usually take place before the construction of a dam, it is not always possible to accurately predict the hydraulic behavior of the dam body or the adjacent geological formations. Therefore, the possibility of seepage after the construction of the dam seems almost certain. Leakage intensity is acceptable in many cases as long as the safety of the dam is not compromised, otherwise sufficient consideration must be taken. From a safety point of view, it is important to examine the risks of seepage and intrusion due to the inherent complexity of their properties. Many dam reservoirs built in the world leak. This seepage may occur from the geological formations of the site or the foundation or from the body of the dam.

Water in the soil flows through interconnected ducts in the pores inside the soil mass. Therefore, the permeability coefficient of any soil indicates the ability of that soil to guide the fluid to pass through that soil, which is called the hydraulic conductivity. The value of soil hydraulic conductivity depends on several factors. These factors include fluid characteristics such as viscosity and soil characteristics such as pore size and size distribution, grain size curve, porosity ratio, grain surface roughness and degree of saturation and soil moisture content. Soil structure has a very important effect on the permeability coefficient [5].

Injection curtains, shield seals, overhead covers and sealing walls are the main and common methods of controlling seepage from dams. Sealing walls have high flexibility, low permeability and compressive strength in proportion to the applied pressure and are therefore used in areas that are weak, weak and with high permeability [25]. The stages of construction of sealing walls include the construction of a guide wall and work platform, trench drilling, adding drilling mud to stabilize the walls and finally filling it with suitable materials [8]. These filler materials can be aggregates mixed with bentonite mud, cement mixture and bentonite in the form of flowing mud or plastic concrete.

Plastic concrete with much lower strength than ordinary concrete, has high ductility and low permeability. In alluvial fields with weak soil, it is necessary for the sealing wall to be flexible and also to have sufficient resistance to withstand the stresses caused by the loading of the dam and also to control the seepage from under the dam. Horizontal drains are also widely used in medium height dams and are effective in controlling and directing seepage [20]. Therefore, in the present study, we try to increase the efficiency of sealing walls and horizontal drains by providing relative criteria, so that by using them in future designs, the appropriate angle, length, number and distance of sealing walls according to The geotechnical conditions of the desired area should be selected and also the ratio of horizontal drainage length to the width of the dam should be selected appropriately. The purpose of using a dam wall is to prevent seepage from the dams, which will be different depending on the location of the dam wall in different soils. Also, if there is intense tectonic activity under the construction site of the dam, so that the seam mass continues to a great depth and it is not possible to create a sealing wall at a depth, from a clay impermeable cover horizontally in Used upstream [12]. Various researchers have studied seepage and its problems and damages in earthen dams. Also, in this regard, various models and software have been used and the results have been presented. The results of research have led to the increasing progress of dam construction and provide appropriate methods in the design, construction and operation of earth dams. Using the results of research conducted by other researchers in relation to the research topic, to better understand the subject, its background, and study on the basics and identify different types of sealing methods, methods provided by other researchers and review them. One of the most important issues in the design of earth dams is determining the ratio of drainage in the body and foundation of the dam. The results showed that the seepage ratio calculated using the model is 7.8% different from the actual specified value, which is due to differences in the geometric dimensions of the dam section and non-isotropic soil

[10]. Hajiani Bushehrian et al. (2017) investigated the effect of horizontal drainage on the stability of homogeneous and inhomogeneous earth dams due to sudden drop in water level. In this study, equations that show the relationship between the numbers of horizontal drains, safety factor and pore water pressure are presented [21]. Ismail et al. (2017) conducted a parametric study to find the optimal length and position of horizontal drains. The results show that the minimum length required for drainage is 22.5 meters. The results of observations of piezometers at the site and the measured flow rates confirm that the presence of horizontal drains can effectively reduce the groundwater level under the dam [9]. Sai and Sircomidos (2017) used a numerical model to investigate the seepage of earth dams and in this regard used a two-dimensional numerical model HYDRUS STANDARD. The model has been validated with measured data from the dam site. From the results of this research, we can point to the high capability of the HYDRUS STANDARD numerical model in estimating the amount of seepage from the dam body [11]. Kumar and Mohan (2017) have studied the rate of seepage from earth dams using analytical methods. This research has been done in scale in the laboratory and three types of soil have been used in making this model. One of the results of this study is the low ability of analytical methods in unstable analysis [26]. Hekmatzadeh et al. (2018) investigated the effect of four sealing walls on the stability and reliability of diversion dams against piping. The results of sensitivity analysis showed that by increasing the shear strength parameter of the surface between the foundation and the dam, the probability of dam failure decreases. Also, with increasing the horizontal coefficient of earthquake, the probability of failure increases significantly [6]. According to studies conducted by other researchers, it can be concluded that the use of SEEP / W model is a good way to estimate the optimal values of various parameters of seepage in earth dams.

2. Materials and methods

Materials and methods modelling water flow in soil using numerical methods can be very complex. Natural soil is generally heterogeneous and heterogeneous. Often, boundary conditions change over time and cannot always be defined with certainty at the beginning of an analysis. In principle, setting the right boundary conditions can sometimes be part of the solution. Also, when a soil is in unsaturated conditions, the permeability coefficient or hydraulic conductivity coefficient becomes a function of the water pressure of the negative cavities in the soil. Water pressure is the first unknown that needs to be determined, and numerical techniques need to be used to calculate the pore water pressure and material properties, which strongly make the solution method nonlinear. These complexities necessitate the use of numerical methods to analyze seepage problems in all but simple problems. A common approach is to use finite element relations. Numerical modeling of saturated and unsaturated seepage is a strongly nonlinear problem that requires repetitive techniques to solve. Consequently, numerical convergence is also a key issue. Also, time integration for transient state analysis depends on the size of the time steps relative to the size of the elements as well as the properties of the materials.

$$n_t = \beta_{11} + \beta_{12} m_t + \beta_{13} p_t + \varepsilon_{2t} \quad (1)$$

$$n_t = \left\{ \frac{(\beta_1\beta_{13} - \beta_{11}\beta_3) + \beta_{13}\beta_2 g_t - \beta_3\beta_{12} m_t - \beta_3\beta_{14} n_{t-1} + (\beta_{13}\varepsilon_{1t} - \beta_3\varepsilon_{2t})}{\beta_{13} - \beta_3} \right\} \quad (2)$$

$$p_t = \left\{ \frac{(\beta_1 - \beta_{11}) + \beta_2 g_t - \beta_{12} m_t - \beta_{14} n_{t-1} + (\varepsilon_{1t} - \varepsilon_{2t})}{\beta_{13} - \beta_3} \right\} \quad (3)$$

By solving the above two equations simultaneously, the unknown parameters can be determined.

The following formulas are used to determine the optimal sample size in order to do structural equations:

$$erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt \quad (4)$$

$$F(x; \mu, \sigma^2) = \frac{1}{2} \left[1 + erf\left(\frac{x - \mu}{\sigma\sqrt{2}} \right) \right] \quad (5)$$

Where μ, σ and erf are mean, standard deviation and error function, respectively. Now the same steps can be done using software.

The GeoStudio software package is one of the finite element-based geotechnical applications that can be used to investigate stress-strain, flow, seepage, slope stability, and dynamic analysis. This package includes SIGMA / W for stress-strain analysis, SEEP / W for flow and seepage analysis, SLOPE / W for slope stability analysis, QUAKE / W for dynamic analysis, TEMP / W for soil temperature distribution analysis, CTRAN / W is for analyzing the distribution of pollutants in the soil, VADOSE / W is for analyzing the effect of environmental conditions (such as sun, plants, precipitation, etc.) on the soil, and AIR / W is for modeling airflow. It should be noted that all parts of this software except SLOPE / W use the finite element method and only in this part of the software, the limit equilibrium method is used. All these parts can be connected and the output of one is the input of another. In this research, the SEEP / W model has been used for the relevant analyzes. The SEEP / W model is based on the finite element method and has been developed to investigate the seepage conditions and water flow in the soil and in general the distribution of pore pressures in porous media such as soil and rock. This section has the ability to draw the level of water flowing through the soil, calculating the flow rate for a specific section and drawing flow lines and potential. SEEP / W also has the ability to model the conditions of rapid discharge of the tank and create a function of rapid discharge of the tank over time, in addition to analysis in stable conditions. The possibility of modeling the conditions of rapid filling of the reservoir, semi-saturated conditions, permeability functions and volumetric moisture functions of the soil and continuously considering them together in the calculations are other important capabilities of this model. Other features of this model include drawing the level of water passing through the soil and velocity vectors and drawing flow lines, as well as the potential and calculating the flow rate for a certain section of soil. This model also has the ability to analyze under steady-state conditions and to study water and soil conditions in phased conditions. In the following, modeling was performed using SEEP / W and different modes of sealing wall and horizontal drainage in different models were investigated.

2.1. Study area

In this study, to investigate the effect of sealing wall and horizontal drainage on the uplift pressure below the dam and the outlet gradient, studies and modellings have been performed on the data related to Golfaraj dam. Golfaraj Dam is a project to transfer water flow in the amount of 6 cubic meters per second from Aras River water to Jolfa area to meet the drinking water and industrial needs of Aras Industrial Free Trade Zone. Golfaraj Dam is one of the storage dams of Golfaraj pumping project. Golfaraj Dam is an earthen dam that forms the main part of the body of the dam shell, which is filled with coarse-grained alluvial materials. In the middle of the dam body, a clay core has been installed as sealing components and on both sides of the filter core, to prevent the clay core from leaching into the coarse-grained materials of the dam shell. Figure 1 shows the position and components of the Golfaraj Dam. Table 1 provides the specifications related to the permeability of the dam components.

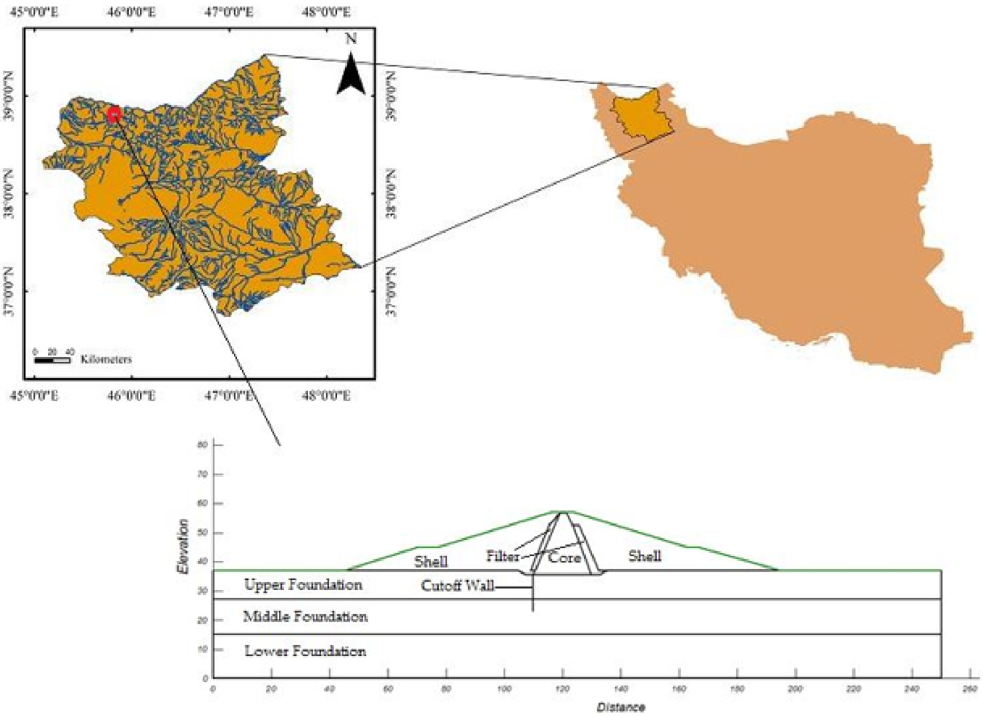

Figure 1: Location and components of Golfaraj Dam

Table 1: Permeability values of Golfaraj dam components

Type of the Material	**Kx(m/sec)**	**Kx/Ky**
Core	8×10^{-9}	0.1
Cutoff	3×10^{-8}	1.0
Shell	1×10^{-5}	0.5
Filter	1×10^{-6}	1.0
Upper foundation	5.6×10^{-6}	1.0
Middle	1×10^{-4}	1.0
Lower foundation	1.3×10^{-7}	1.0

3. Results and Discussion

In this section, in order to achieve the objectives of the research, changes in the upward pressure and maximum gradient of the dam outlet as well as changes in the seepage of the dam in different cases of change in length, angle, number and distance of the seal are evaluated. The analysis of the mentioned cases is discussed. In addition, horizontal drainage length changes are investigated and their impact results are presented. In preparing the models, the parameters affecting the lifting pressure and the boiling phenomenon under the earth dam have been changed and the effect of these changes has been investigated. In each series of models, by keeping all the parameters constant, only one parameter is changed and at the end, by comparing the results, the best scenarios are presented. First, seepage analysis, water movement analysis, velocity vectors and flow lines and all potentials and flow rate in the dam are investigated. The ferritic line is the surface below which the water pressure is positive, and above this surface is the capillary region with the negative pore pressure. This line is the highest flow path in the body of the earth dam. Figures 2 and 3 also show the flow lines passing under the fuselage and the water pressure holes of the hole and the flow rate for the Golfaraj dam.

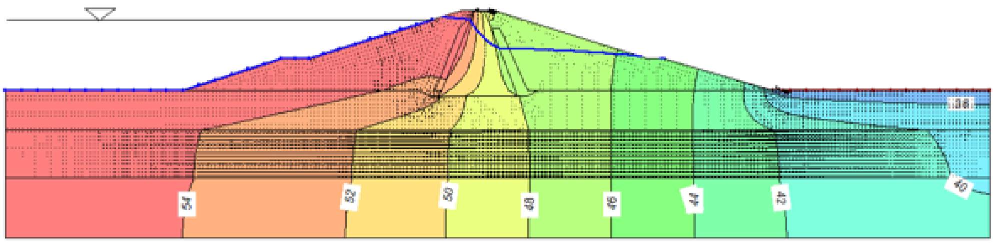

Figure 2: Ferriatic line, current vectors and potential lines

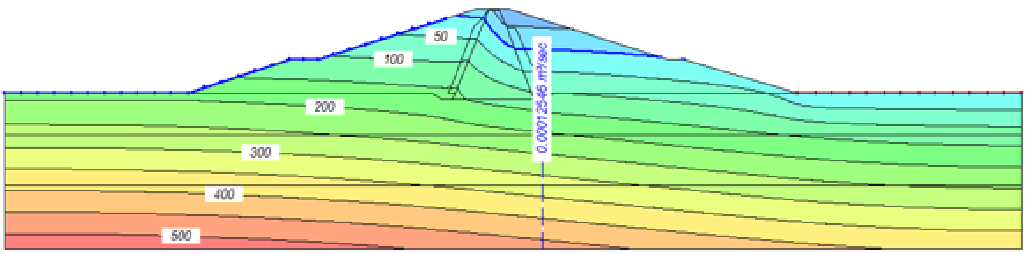

Figure 3: Cavity water pressure lines

3-1- The effect of the angle of the sealing wall Figure 4 shows the contour lines of both potential and water flow for a 12 m long vertical sealing wall located above the dam core.

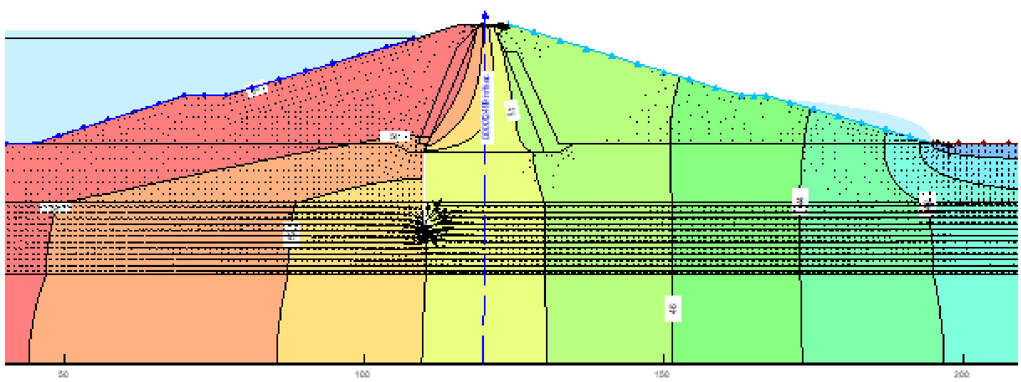

Figure 4: Water flow lines and vertical sealing wall upstream of the dam core

Figure 5 shows the effect of the slope angle of a sealing wall upstream and downstream of the dam core on the upward pressure.

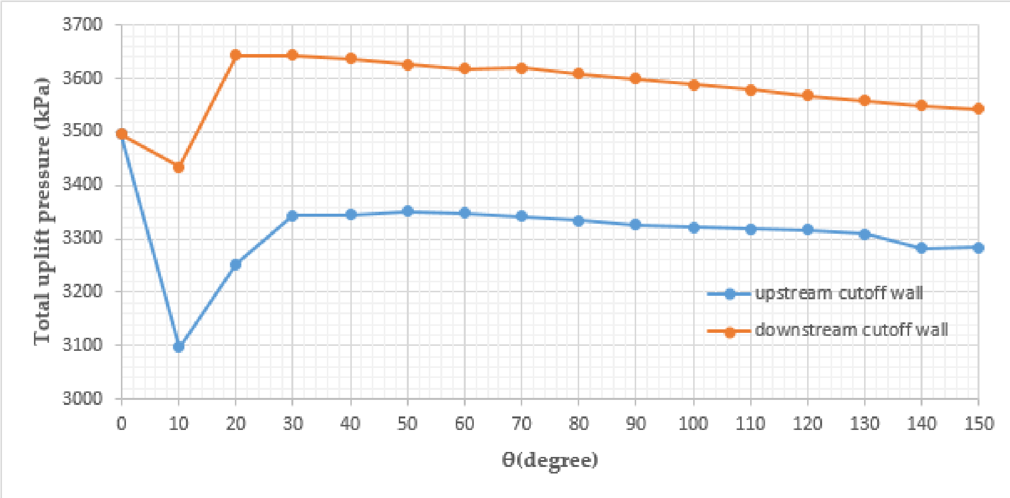

Figure 5: Total lift pressure changes below the Golfaraj Dam with a sealing wall upstream and downstream for different angle values

As shown in Figure 5, when the slope angle of the sealing wall increases from 10 to 30 degrees, the upward pressure increases. The total rise pressure is then reduced by increasing the slope angle of the sealing wall from 30 to 150 degrees. Also, as shown in Figure 6, when the sealing wall is located downstream of the slope, the same results are obtained upstream. In general, the diagram shows that increasing the slope of the sealing wall angle from one slope onwards has little effect on the upward pressure. Depending on the shape, the lifting pressure will be lower if the sealing wall is located above the core. Figure 6 shows the effect of the slope angle of a sealing wall upstream and downstream of the core on the maximum output gradient at ground level near the downstream of the Golfaraj Dam.

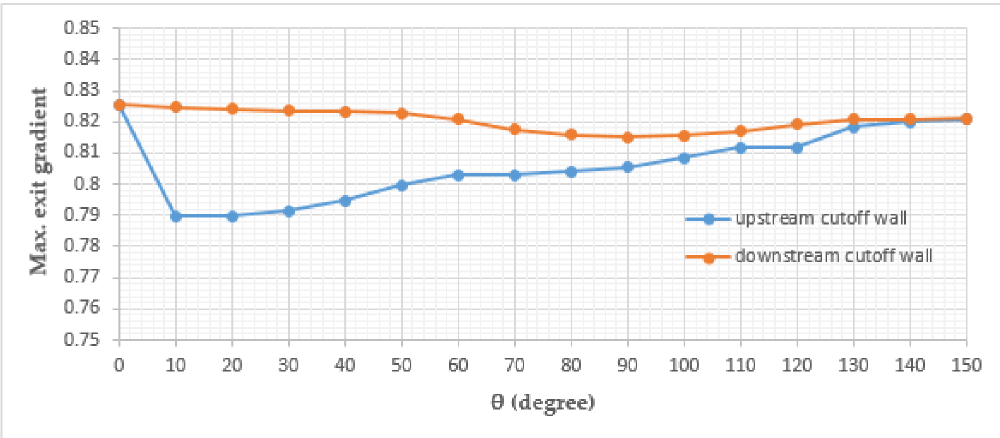

Figure 6: Changes in the maximum output gradient of Golfaraj Dam with a sealing wall upstream and downstream for different angle values

As can be seen in Figure 6, by increasing the slope angle of the upstream sealing wall from 20 to 150, the maximum output gradient has increased. Therefore, the use of a sealing wall above the dam core with a slope angle of 20 degrees is useful in increasing the safety of the dam against the boiling phenomenon. Also, according to Figure 6, when the sealing wall is located downstream of the dam core, the maximum output gradient decreases by increasing the slope angle of the sealing wall from 10 to 100 degrees. As the slope angle increases from 100 ° to 150 °, the output gradient also increases. According to the diagram, it is clear that the greater the angle of inclination of the dam wall downstream of the dam to the horizon, the greater the safety of the dam against the boiling phenomenon. Therefore, the best angle of execution of the sealing wall downstream of the core to deal with the phenomenon of boiling is an angle of 100 degrees. 3-2- Impact of vertical seal wall length To investigate the effect of different parameters by changing the length of the sealing wall located above the core of Golfaraj Dam, lengths of 6, 12, 18 and 24 meters have been selected. Figure 7 shows the cross-sectional potential of the dam for the sealing wall with a length of 24 meters. For a length of 24 meters, due to the fact that the sealing wall has reached the bed with very low permeability, some water has flowed downstream through the dam body.

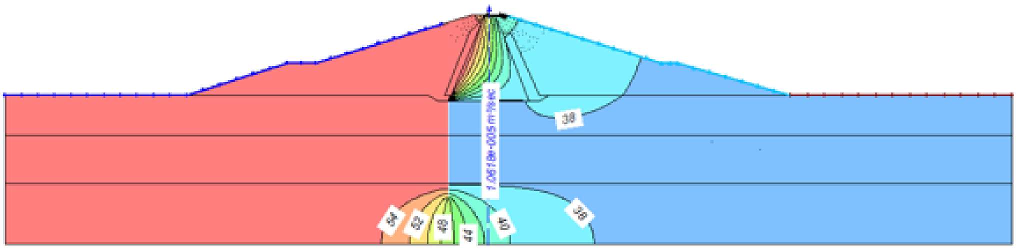

Figure 7: Contour lines of the potential of Golfaraj Dam with a sealing wall 24 meters long

Figures 8 and 9 show the changes in total rising pressure and maximum outlet gradient relative to changes in sealing wall length, respectively.

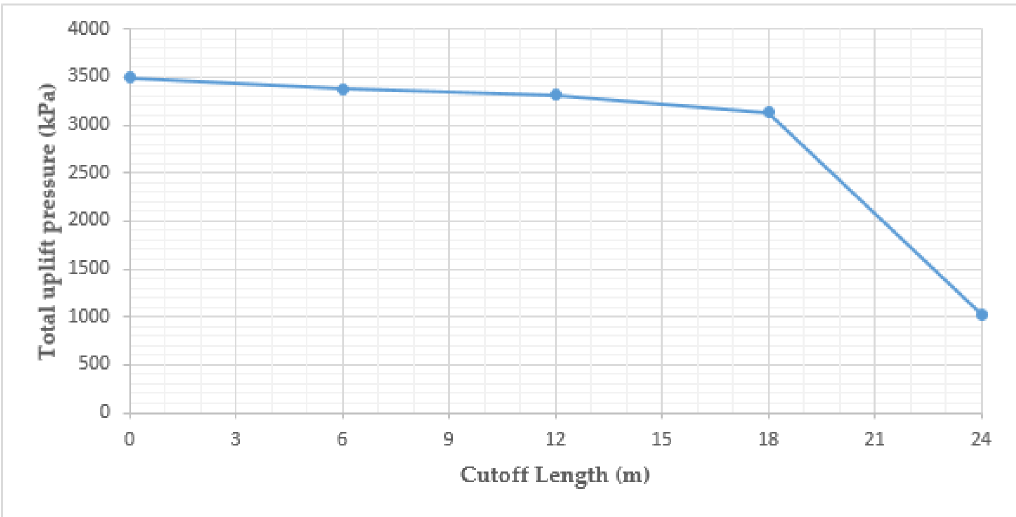

Figure 8: Changes in the rising pressure of the Golfaraj Dam with changes in the length of the sealing wall

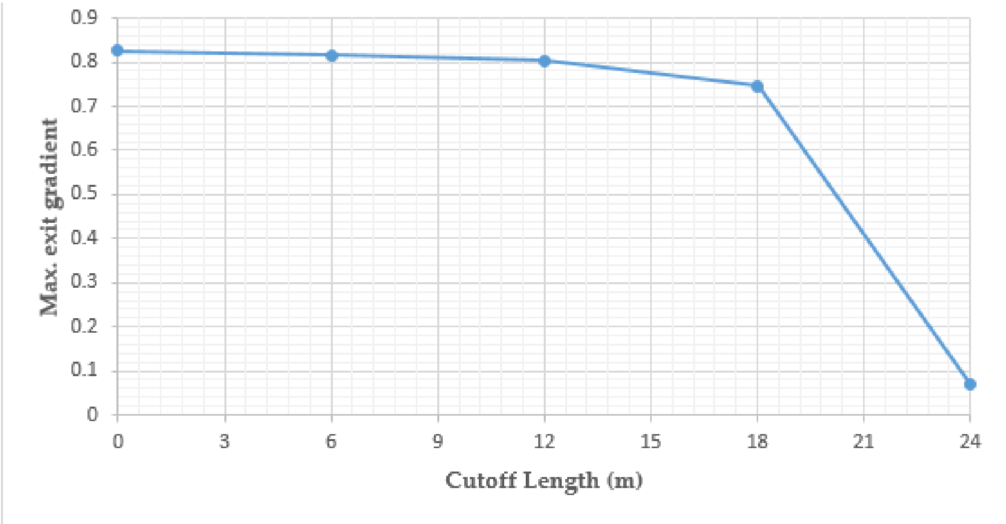

Figure 9: Changes in the maximum output gradient of Golfaraj Dam with changes in the length of the sealing wall

According to Figures 8 and 9, increasing the length of the sealing wall to 6, 12 and 18 meters has a slight change on the total rise pressure and the maximum outlet gradient. With increasing the length from 18 to 24 meters, due to the change of the foundation layer under the dam body, the amount of upward pressure compared to the sealing wall with a length of 18 meters has decreased by 65%. For the maximum output gradient, increasing the length of the sealing wall from 18 to 24 meters has reduced it by up to 90%. Therefore, due to the permeability and thickness of the bed layers under the Golfaraj Dam, the length of 24 meters of the sealing wall is a suitable length to prevent the uplift under the dam and the boiling phenomenon. 3-3- The effect of the number of sealing walls The effect of the number of sealing walls under the core of Golfaraj Dam with equal length and distance (L = 12m and S = 3m) on the total lifting pressure and maximum outlet gradient is shown in Figures 10 and 11.

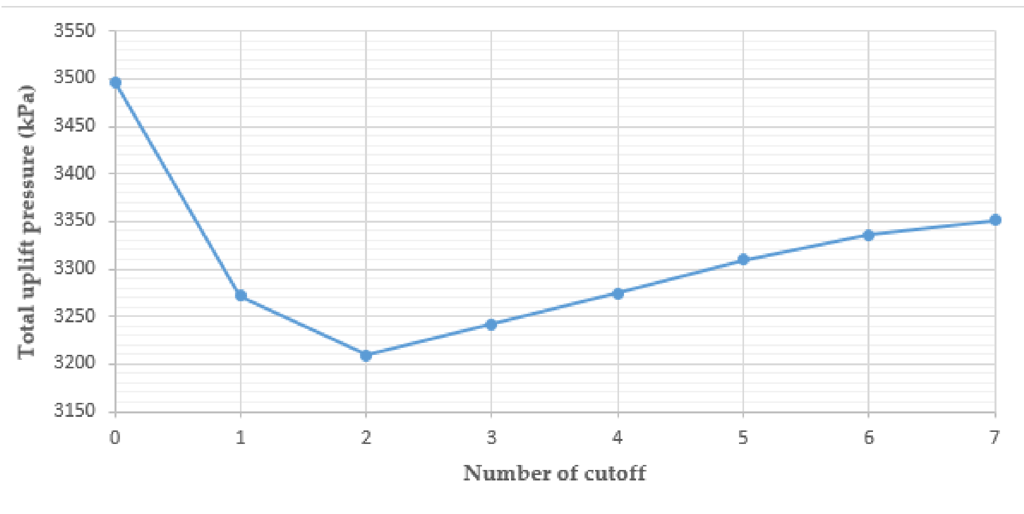

Figure 10: Variation of total uplift pressure under the dam core for different number of sealing walls under Golfaraj dam

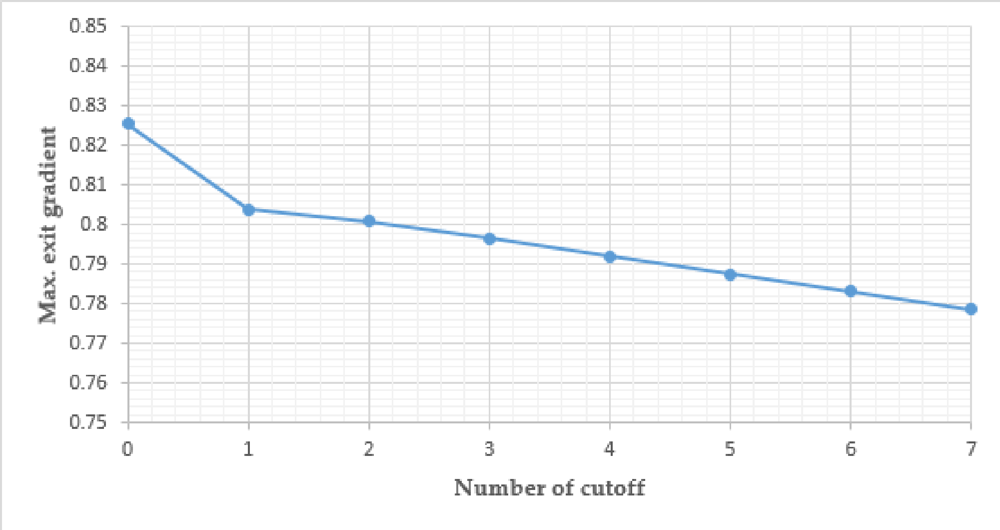

Figure 11: Changes in the maximum output gradient for a different number of sealing walls below the Golfaraj Dam

According to Figure 10, it can be seen that for the cases with 2, 3, 4, 5, 6 and 7 sealing walls under the dam core, and the total lifting pressure value in its maximum state is about 6% compared to the position of a wall. The seal has been reduced. Therefore, the best number of sealing walls is to reduce the total buoyancy pressure or increase the safety against the buoyancy pressure of the two sealing walls. Figure 11 also shows that for cases with 1, 2, 3, 4, 5, 6 and 7 sealing walls, increasing the number of sealing walls slightly increases the safety against the boiling phenomenon. 3-4- The effect of horizontal distance between two vertical sealing walls In order to investigate the effect of the distance between the two vertical sealing walls on the elevation of the body and the boiling phenomenon of Golfaraj Dam, the distance between the two sealing walls is 2, 4, 6, ..., 18 and 20 meters from the first sealing wall, respectively. Was taken. For this purpose and the creation of models, the length of the walls is assumed to be 12 meters.

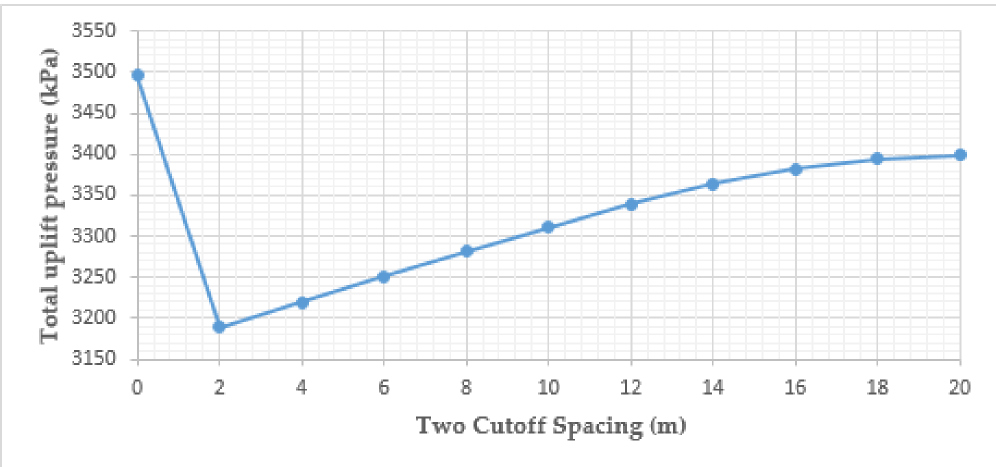

Figure 12: Changes in the total uplift pressure below the dam core for different values of the distance between the two sealing walls

Figure 13: Changes in the maximum output gradient for different values of the distance between two sealing walls

The effect of spacing between the two vertical sealing walls on the upward pressure below the Golfaraj Dam is shown in Figure 12. As can be seen in the figure, the use of longer distances between the two sealing walls below the dam core has resulted in an increase in total overburden pressure or a decrease in upfront pressure safety. Figure 13 also shows the effect of the distance between two vertical sealing walls on the maximum output gradient, in which the maximum output gradient downstream of the dam decreases with increasing distance between the two sealing walls. The maximum amount of output gradient reduction occurs at a distance of 60 m. In other words, the most appropriate distance between two vertical sealing walls in front of the boiling phenomenon is when the second sealing wall is in the core. 3-5- Impact of horizontal drainage length In order to investigate the effect of downstream horizontal drainage length on the total lifting pressure and maximum outlet gradient, lengths of 5, 10, 15, ..., 55 and 60 m were selected for the models. Figure 14 shows the potential of the Golfaraj Dam for the 22 m long sealing wall in the middle and below the dam core, as well as the horizontal drainage downstream of the 35 m long dam.

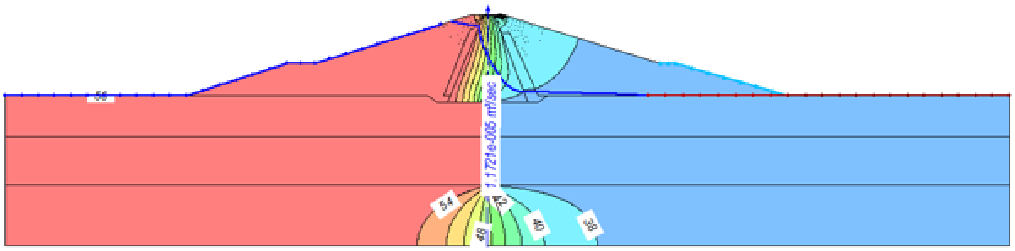

Figure 14: Co-potential lines of Golfaraj dam by creating horizontal drainage with a length of 35 meters

Figures 15 and 16 show the effect of downstream horizontal drainage length on the total subsurface pressure and output gradient, respectively.

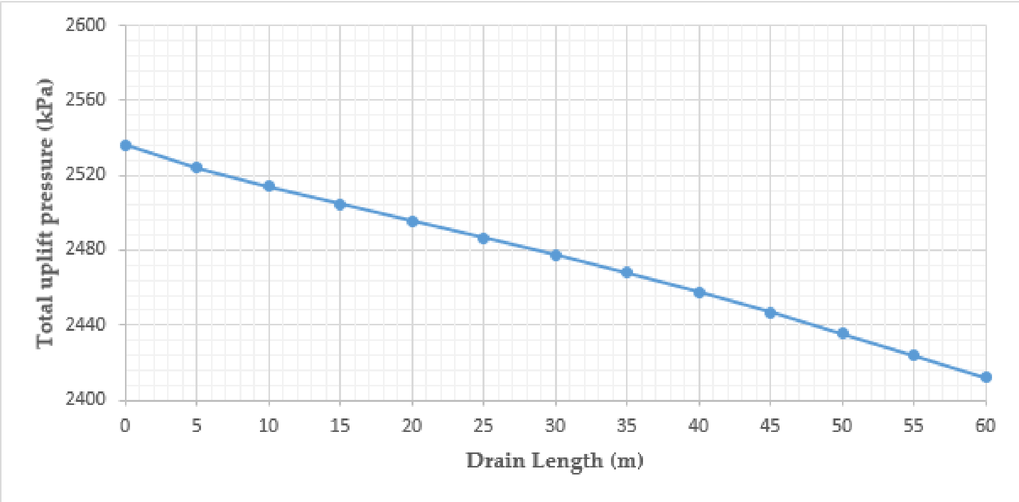

Figure 15: Changes in the total upward pressure below the core of the Golfaraj Dam relative to the increase in horizontal drainage length

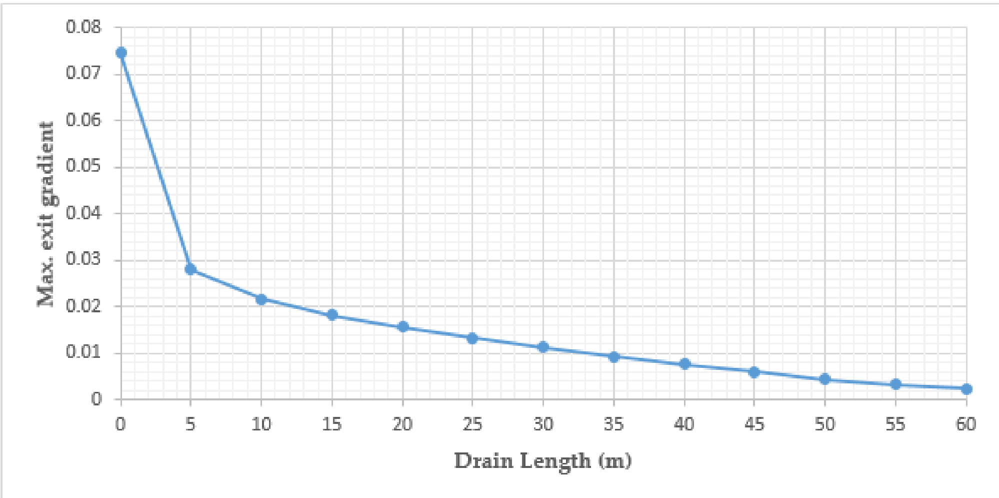

Figure 16: Changes in the maximum output gradient with increasing horizontal drainage length

According to Figure 15, increasing the horizontal drainage length reduces the lifting pressure. Creating horizontal drainage to a minimum length of 5 meters and a maximum length of 60 meters, which is equal to the downstream length of the shell, reduces the lifting pressure by 1% and 5%, respectively. This diagram shows that for the cross section and specifications considered for Golfaraj dam, creating and increasing the length of horizontal drainage has little effect on the lifting pressure. Figure 16 also shows that creating a 5 m long horizontal drain reduces the maximum output gradient by 65%. Increasing the length of horizontal drainage from 5 meters to 60 meters also reduces the maximum output gradient by 92%. Therefore, increasing the length of horizontal drainage has a direct and large effect on the output gradient, and the longer the length of horizontal drainage, the greater the safety of the dam against the boiling phenomenon.

4. CONCLUSION

In this case study with a case study on Golfaraj dam to investigate the effect of various parameters of the sealing wall including angle, length, number of sealing walls, distance between the two sealing walls and also the effect of horizontal drainage on the lifting pressure below the core and maximum The output gradient is determined by determining the optimal values of these parameters. The following is a summary of the results obtained from the various modeling modes. 1- For angles of 30 to 150 degrees, the total lifting pressure is reduced. To counteract the boiling phenomenon, a 20-degree angle is suitable for the upstream sealing wall and a 100-degree angle for the downstream sealing wall. 2- The optimal length of the sealing wall to reduce the lifting force and the boiling phenomenon is equal to 24 meters. 3- The best number of sealing walls to reduce the lifting pressure and maximum outlet gradient is equal to 2. 4- Using more distances between the two sealing walls under the dam core has led to an increase in the total upward pressure. While the most suitable distance between the two walls of the vertical seal in front of the boiling phenomenon is when the second sealing wall is located in the core of the core. 5- Creating and increasing the length of horizontal drainage has little effect on the lifting pressure. While it has a direct and large effect on the maximum output gradient, and the longer the horizontal drainage, the greater the safety of the dam against the boiling phenomenon. Regarding future research, the following topics are suggested: A) Investigation of the desired parameters in Golfaraj dam in the unstable state of flow B) Investigating similar cases on several different dams and providing the best and most economical solutions for different types of earthen dams; C) Investigating the effect of other seepage control methods such as injection curtains, clay blankets and sloping drains in dams; D) Evaluation of the dynamic behavior of the sealing wall of earthen dams with different lengths and thicknesses in the clay core of the dam; E) Evaluating the performance of the parameters studied in the present study on the stability of upstream and downstream slopes of the dam.

References

[1] A. Abdulhadi, A. Delewy,K. Abdul-Hassan, and H. Al-Musawi, Optimum design of control devices for safe seepage under hydraulic structures. Journal of Engineering and Development, 10, 1, (2006), 66-87.

[2] I. Arshad, , M. M. Babar and C. A. E. Vallejera, Computation of seepage and exit gradient through a non-homogeneous earth dam without cutoff walls by using Geo-Slope (SEEP/W) Software. PSM Biological Research, 4, 1,(2019), 40-50.

[3] A. Asadi Sakhmarsi ,H. Akhbari,P. Naeimi and A. Kiapey, The effect of the cutoff wall conditions on the seepage characteristics of homogeneous earth-fill dams using SEEP/W. WALIA Journal, 30, S2, (2014), 176-182.

[4] B. R. Chahar, Determination of length of horizontal drain in homogenous earth dams. Journal of Irrigation and Drainage Engineering, 130, 6, (2004), 530-536.

[5] B. M.Das, Principal of geotechnical engineering fifth edition. Thomas Learning. (2001).

[6] K. E. Fadaei,S. Shojaee and R. Memarzadeh, Numerical simulation of seepage flow through dam foundation using smooth particle hydrodynamics method (RESEARCH NOTE). International Journal of Engineering, 32, 4, (2019), 484-488.

[7] B. Goharnejad, M. Noury,A. Noorzad, A. Shamsaie and A. Goharnejad, The effect of clay blanket thickness to prevent seepage in dam reservor. Research Journal of Environmental Sciences, 4, 6,(2010), 558-565.

[8] Y. M. A. Hashash, J. J. Hook, B.Schmidt, and J. Yao, Seismic design and analysis of underground structures. Tunnelling and Underground Space Technology, 16, 4, (2001), 247-293.

[9] A. A. Hekmatzadeh,F. Zarei, A. Johari and A. Torabi Haghighi, Reliability analysis of stability against piping and sliding in diversion dams, considering four cutoff wall configurations. Computers and Geotechnics, 98, (2018), 217-231.

[10] M. A. M. Ismail, and I. Abustan, Parametric study of horizontal drains for slope stability measure: A case study in Putrajaya, Malaysia. KSCE Journal of Civil Engineering, 21, 6, (2017), 2162-2167.

[11] M. Javanmard, R. Mottaghi and S. M. M. Hosseini, Investigating the influence of penetration length of cutoff wall on its dynamic interaction with core and foundation of earth dam. Civil Engineering Journal. 4, 12, (2018), 3019-3026.

[12] V. J. Johnson, Mechanics of cavitation. Journal of the Hydraulics Division, 89, 3, (1963), 251-275.

[13] A. Kamanbedast and A. Delvari,Analysis of earth dam: Seepage and stability using Ansys and Geo-Studio softwares. World Applied Sciences Journal, 17, 9, (2013), 1087-1094.

[14] H. Khalili Shayan and E. Amiri, Effects of blankets, drains and cutoff wall on reducing uplift pressure, seepge and exit gradient under hydraulic structures. International Journal of Civil Engineering, 13, 4,(2015), 486-500.

[15] A. Malekpour, D. Farsadizadeh, A. Hosseinzadeh Dalir, and J. Sadrekarimi, Effect of horizontal drain size on the stability of an embankment dam in steady and transient seepage conditions. Turkish Journal of Engineering and Environmental Sciences, 36, 2,(2012),139-152.

[16] B. Mansuri and F. Salmasi, Effect of horizontal drain length and cutoff wall on seepage and uplift pressure in heterogeneous earth dam with numerical simulation. Journal of Civil Engineering and Urbanism, 3, 3,(2013), 114-121.

[17] G. C. Mishra,and A. K. Singh, Seepage through a levee. International Journal of Geomechanics, 5, 1, (2005), 74-79.

[18] A. Moharrami , G. Moradi,M. H. Bonab, J. Katebi and G. Moharrami, Performance of cutoff walls under hydraulic structures against uplift pressure and piping phenomenon. Geotechnical and Geological Engineering, 33, 1, (2014), 95-103.

[19] M. Mortazavi and S. Soleimani, Leakage analysis of embankment dams using SEEP/W, SEEP/3D software. Journal of Applied Environmental and Biological Sciences, 5, 10,(2015), 122-128.

[20] Y. Ninomiya,R. Hagiwara, and T. Azuma, Rise of excess pore water pressure and uplift of underground structures due to liquefaction. Earthquake Geotechnical Engineering-International Conference, Rotterdam, the Netherlands: Balkema, 2, (1995), 1023-1030.

[21] J. Niec, P. Zawadzhi, Z. Walczak and M. Spychala, Calculating earth dam seepage using HYDRUS software applications. Acta Scientiarum Polonorum, 16, 3, (2017), 43-56.

[22] V. Nourani, E. Sharghi,and M. H. Aminfar, Integrated ANN model for earthfill dams seepage analysis: Sattarkhan Dam in Iran. Artificial Intelligence Research, 1, 2, (2012), 22-37.

[23] B. M. A. Noori, and S. I. Khaleel, Evaluation of seepage and stability of Duhok Dam. Al-Rafidain Engineering, 19, 1, (2010), 42-58.

[24] M. S. Pakbaz, A. Dardaei and J. Salahshoor , Evaluation of performance of plastic concert cutoff wall in Karkheh Dam using 3-D seepage analysis and measurement. Journal of Applied Sciences, 9, 4, (2009), 724-730.

[25] B. Schmidt, and Y. M. A. Hashash, Preventing tunnel floatation due to liquefaction. In: Proceedings of the 2nd international conference on earthquake geotechnical engineering, Lisbon, Portugal, 3, (1999), 509-512.

[26] A. Ullah, A. Kassim, I. Alam, M. Junaid, and I. S. Ahmad, Efficiency analysis of seepage of Baz Ali small dam, Kurram Agency using clay blanket and cutoff wall with sand filter. Bulletin of the Geological Society of Malaysia, 67, (2019), 113-118.