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Optimization of horizontal drain dimensions in heterogeneous earth dams using Artificial Neural Network (ANN): A case study on Marvak dam

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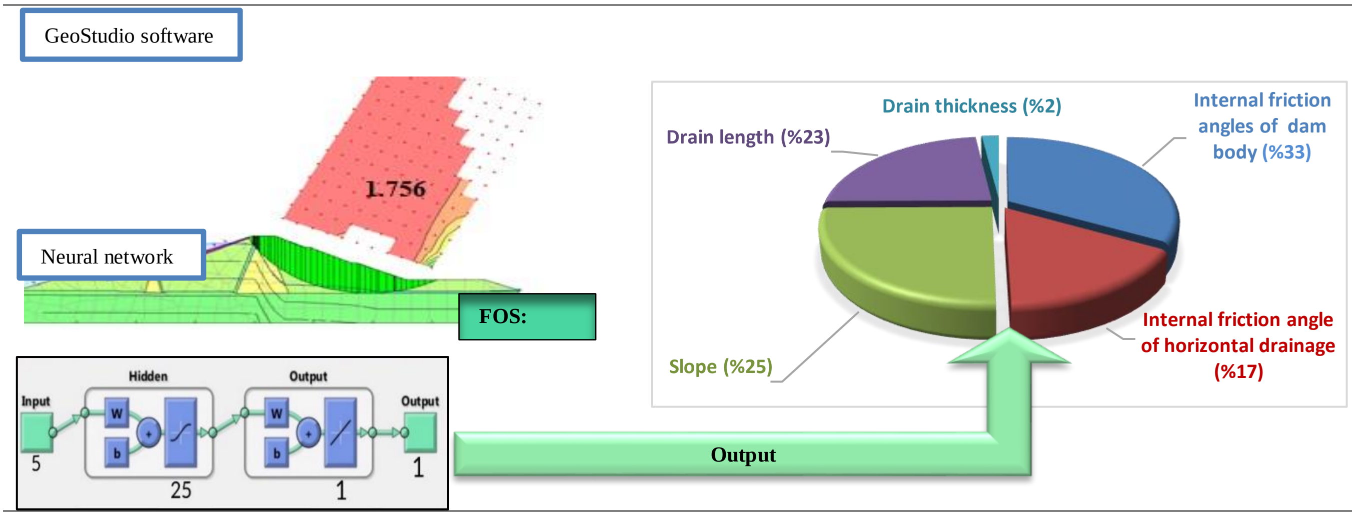
GRAPHICAL ABSTRACT



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ABSTRACT

It is important to design and optimize the dimensions of the dam drainage system to keep the dam's downstream shell dry and to prevent the increase of pore water pressure in the earth dam body. It will also be possible to find the minimum factor of safety (FOS) to reduce construction costs by optimizing the drainage dimensions. In this study, Marvak earth dam was modeled by GeoStudio software with real material parameters, and by changing the dimensions of drainage, the material of the material, and slope of the dam, the minimum factor of safety of the dam was obtained. To predict the minimum factor of safety, the software results were used in different cases in the two-layer neural network. By training the neural network from the data obtained from the modeling of the Marvak dam, the minimum factor of safety for horizontal drainage was obtained. To optimize, a command appropriate to the neural network function is taught, by which the optimal values of the dam parameters are calculated. The results of the study show that the two factors of the internal friction angle of the drainage material and the slope of the dam have the greatest impact on determining the minimum factor of safety of the dam.

1. Introduction

In order to achieve a suitable drainage plan, different design parameters such as drain length and width, number of drains and their location for these drains should be considered. If the optimal dimensions are found, the performance of these dams will be improved and, in terms of costs and expenses, the construction of the dam will be very short and cost-effective. Tesarik and Kealy (2005) modeled a number of earth dams, providing graphs for the estimation of the horizontal drainage function in lowering the protest line. On the basis of these graphs, they have analyzed two dams without drainage and horizontal drainage (drainage of a specified length) by a computer laboratory and model. Xu et al. (2002) conducted a study to optimize the earth dams, through a drop of the greatest line in the body of the dam to increase the percentage of body mass of the material in relation to saturated materials. Chahar Bhagu (2004) Using the Casagrande design, the practice line location was determined and then, the minimum and maximum horizontal drain lengths were obtained

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homogeneous earth dams. Mishra and Singh (2005) studied the flow of water within the embankment, the practice line position, the minimum distance between the frets line and the downstream slope, and considered the position and the effective length of the horizontal drain, taking into account the water capillary effect in the soil. Alonso and Pinyol (2008) presented the problem of water level reduction as a flow deformation problem for saturated/unsaturated conditions. In their study, the role of different soil properties in explaining the phenomena that occur at the time of discharge is discussed. Malikpour et al. (2012) studied the effect of horizontal drain length and thickness on a steep gradient stability under Drawdown conditions in a homogeneous earth dam. Lowe and Karafiath in (1980), Baker et al. (1993) and the American Army Corps of Engineers at (2003) is among the researchers who have studied the stability of slopes in non-drained conditions. Also, Svano and Nordal (1987), Wright and Duncan (1987), Lane and Griffiths (2000) and Berilgen (2007) to investigate the stability of soil gradients after surface changes Reservoir water examined the effective shear strength parameters of the soil under drainage conditions. The research emphasizes the importance of the role of drainage as one of the sustainability factors of the slopes of the earth. Some researchers, including, Duncan and Wright (2005) emphasize the role of the T parameter, which is called the time without the dimension of consolidation, in determining the drainage state (drainage behavior) and slope stability Earthy. According to their research, more than 99 percent of the permeate overpressure from the reservoir's reservoir drop is depreciated over 3 ≥T, and for more time, drainage behavior should be considered in the analysis of the stability of the gradient. Zomorodiyan & Abdollahzadeh (2012) measured and fixed the drainage in the upstream slopes of the dams, measured the decrease of pore water pressure and calculated the reliability and stability coefficient. Barber et al. (2017) conducted experiments on drainage systems in earth dams to select the most appropriate type of drainage system to prevent leakage and internal erosion of the dam body. For this purpose, a laboratory model of a homogeneous earth dam was tested in several types of drainage in a laboratory flame with sealing in different conditions and the leakage conditions were analyzed. Results showed that the system of drainage of the paw in average length and thickness with a leakage rate of 18.55 m/day in the laboratory flop and the amount of 17.55 m/day in Plaxis software has the lowest leakage rate. In addition, the results showed that the haulage system with a confidence coefficient of 1.656 had the best stability against slip. Kalantari and Nazeri (2016) investigated the stability of the dam with the specification of materials used in the dam. They showed the effect of different material quality on the stability of earth dams using modeling using Geostudio software. Yazdaniyan et al. (2016) studied the effect of elevation on the status of heterogeneous earth dams. Their models are considered for a heterogeneous earth dam with the same characteristics of materials with different heights, as well as rapid leakage and different permeability. For their research, they designed two models with different heights of 62 and 133 and a crown width of 6 in Geostudio software. After comparing the results obtained from the analysis of both models, it was found that the coefficient of reliability for dams is shorter than the longest dams. Fattah et al. (2017) also studied the phenomenon of saturation in earth dams using the Geostudio software. Their results showed that at the time of rapid discharge of the reservoir, the pore water pressure in the dam body was linearly reduced, indicating a steady flow state. Darabi and Maleki (2017) studied the effect of drainage geometry on the dynamic response of the homogeneous earth dam. Their results showed that the quaternary drainage in the earthquake caused less permeate water pressure than the drainage. In this study, the Marvak earth dam is modeled with real parameters in Geostudio software, and with the changes in parameters affecting the factor of safety (dimensions of drainage, material specifications and the slope of the body), a minimum coefficient of reliability for the dam is obtained. Then, for different scenarios of software results using the horizontal neural network, horizontal drain dimensions will be optimized. Also, the percentage effect of different parameters of the dam in the factor of safety will be minimized.

2. Materials and methods

2.1. Introduction of Marvak earth dam

Marvak reservoir dam about 38 km from Dorud city in 2003 with the aim of storing 120 million m^3/year of water from the river Tireh Rood, supplying 50 million m^3 of water needs of Silakhor plain with the area of 5500 hec, providing the existing land rights and also Flood control is constructed. Marvak Dam is a pebble type with a clay core with a crest length of 451 meters and a crown width of 15 meters and a height of 68 meters from the riverbed (Fig. 1).

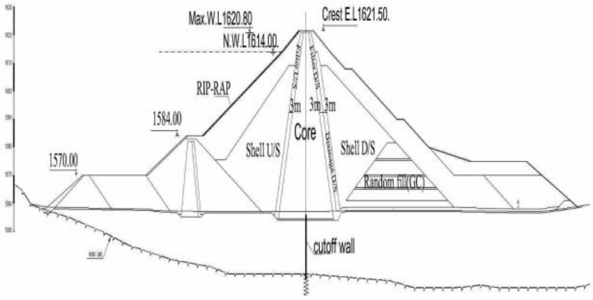

Fig. 1. Marvak earth dam.

2.2. Modeling the Marvak earth dam with Geostudio software

To simulate the dam, first, we introduce the characteristics of the material used in the dam body to introduce the software and the geometry of the model and then define the slip and water pressure analysis using the Mohr-Coulomb Behavioral Model. The parameters affecting the reliability of the Marvak earth dam are shown in Fig. 2 and the permitted range of variations of each of the parameters (Table 1). (1) Downstream slope: According to the dam construction regulations, consider the three slopes (1:1), the mean slope (1:2) and the low slope (1:3 the actual slope of the dam) for the downstream of the dam Taken. (2) Internal friction angle of body material: This parameter has a value between 27 and 35 degrees. (3) Drain length and thickness: The drainage lengths are minimum and maximum, respectively 81 and 197 meters. Determining the minimum and maximum effective length of the drain depends on other parameters of the dam. The minimum thickness of the drain is determined according to the Geostudio output. (3) The internal friction angle of the drain material: This parameter has a value between 33 and 40 degrees. (4) Phreatic line: The range of variations of the phreatic water line will be achieved using Geostudio results. After modeling the actual parameters of the dam in the Geostudio software, the factor of safety of 1.756 was obtained for this dam. Thus, for all predicted models, the coefficient of confidence will be obtained (Fig. 3).

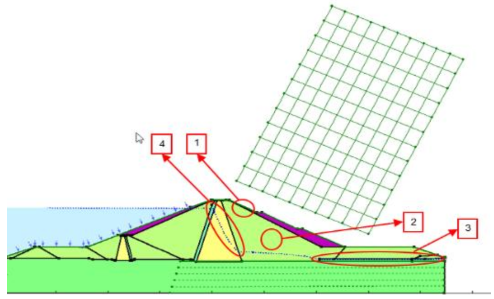

Fig. 2. Marvak earth dam model in Geostudio software.

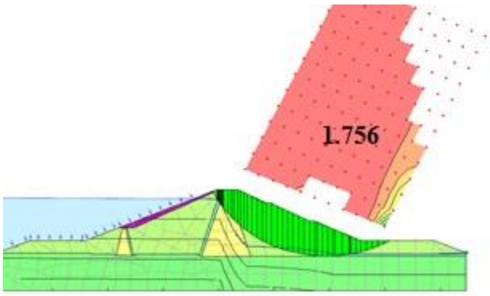

Fig. 3. Marvak earth dam factor of safety.

2.3. Calculation of heterogeneous dam factor of safety using neural network

Using the neural network and existing training data, one can calculate the dam factor for various parameters without the need for modeling in the Geostudio software. The desired neural network has

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two layers with five inputs and one output. Since the dam, height is constant, so the dam height parameter is eliminated from the neural network training process. Neural network inputs, including the internal friction angle of the body material, the internal friction angle of the drainage material, the slope of the dam, the drain thickness and the length of the drain and the output of the neural network, is the dam confinement factor. A total of 702 data categories are used for training the neural network. In the training of the neural network, only 70 % of the data (492 data) is used and 30 % of the remaining data (210 data) is used for testing the network. To train the neural network from 25 neurons in the first layer and one neuron in the second layer (Fig. 4). Also, if the number of neurons is less than 25, then the prediction accuracy of the quasi-nervous confidence will decrease. Therefore, 25 neurons have been used to provide a neural network structure with the same low number of neurons that has high accuracy in predicting the dam factor of safety. The training algorithm used for the Bayesian Regularization Neural Network, which has a longer running time and more accuracy in neural network training, than other training algorithms. Neural network training is stopped after 1000 repetitions. The R and MSE parameters of the training indicate that the value of R is very close to one and the MSE value is very close to zero, which indicates the proper training of the neural network. The Toolbox charts of the MATLAB neural network are shown in Figs. 5 and 6 for dam data. As it is seen, with the stepwise change of factors affecting the dam factor of safety, the dam factor of safety will be small in step changes, so the neural network should have a very high accuracy in predicting the dam factor of safety. Figs. 5 and 6 show the proper training of the dam's neural network.

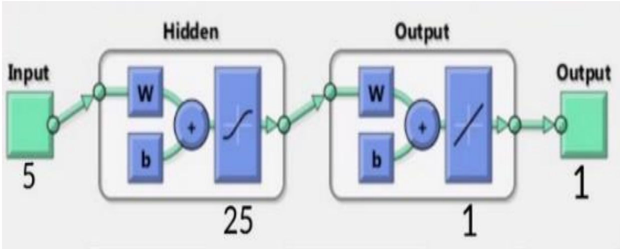

Fig. 4. The 2-layer Neural Network.

Table 1. The allowable range of variation of heterogeneous dam parameters.

Drain thickness (m)	Drain length (m)	Dam gradient	Friction angle of drainage material (degree)	Internal friction angle of body material (degree)	Parameter
2.25-3.25	81-197	1-3	33-40	27-35	Allowed range

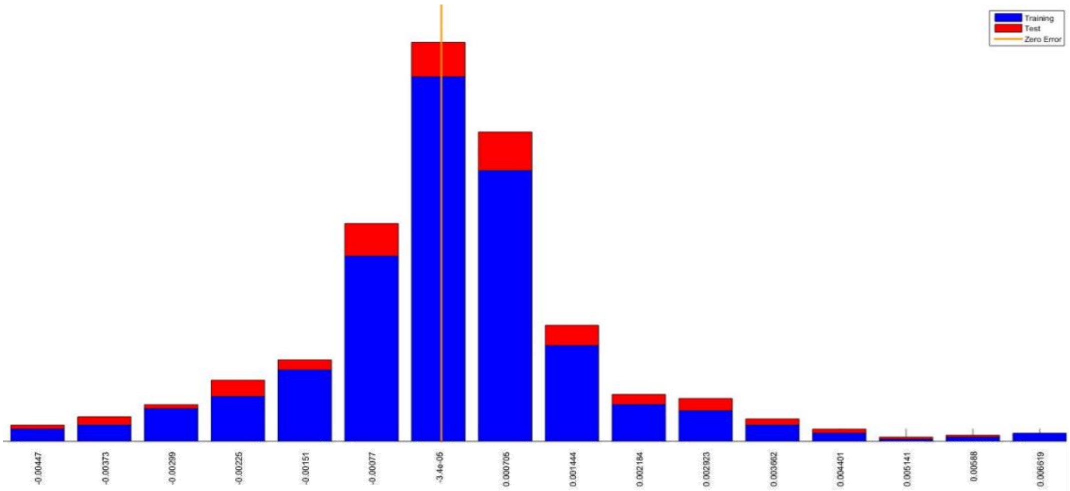

Fig. 5. The error histogram of dam data.

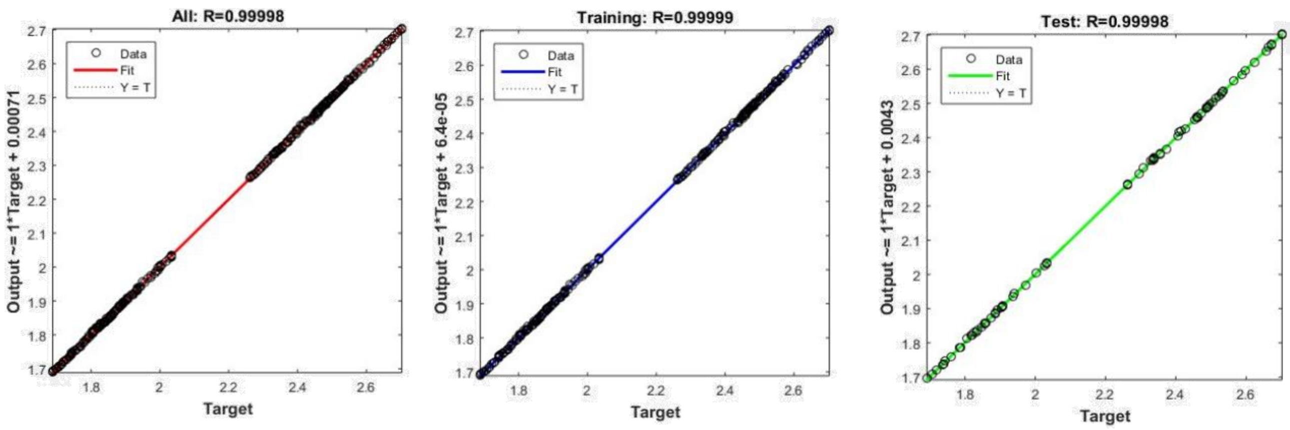

Fig. 6. Dam data regression diagram.

In Fig. 5, which relates to the frequency of learning errors for different error values, for most data, the training error is close to zero. In addition, in Fig. 5, the data have a very high linear correlation. The results of the factor of safety calculated by the neural network are only -0/0025 (equivalent to -0,322, that is, less than 1%) of the fault in calculating the dam factor of safety. After training the dam's neural network, the extracted function is used to optimize the dimensions of the drain. It should be noted that the role of the neural network in the problem of optimizing the production of fault-proof faults.

3. Results and discussion

Considering that it is difficult to find a function for dam costs, therefore, in optimizing costs, the slope of the dam is optimized as the

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main factor in reducing costs. The optimal values of the parameters affecting the dam guarantee factor should be able to have at least the optimum damping factor (the maximum gradient, in which case the cost of building the dam is significantly reduced), the optimum drainage dimension (the product of the length in the thickness of the drain has the minimum possible value) Provide. In order to implement the optimization problem by following the priorities, an M-file program written in MATLAB is written in the program to construct damping factor of safety to the neural network, and this program calculates the optimal parameters of the dam parameters in the MATLAB.

3.1. Investigating the effective parameters in the factor of safety

To study the effective factors on the coefficient of reliability of the heterogeneous dam, Marvak dam has been used. Since the height of this dam is constant, the height parameter is not considered (Table 2).

Table 2. Primary conditions for heterogeneous dam.

Model	Internal friction angles of dam body (°)	Internal friction angle of horizontal drainage (°)	Slope	Drain length (m)	Drain thickness (m)
A	27	33	1:3	2.25	130
B	35	40	1:3	2.25	130

In this study, two modes (A) are minimal and (B) the maximum is considered for initial conditions. Considered the slope, the main slope of Marvak Dam and also the length of the drain are considered with respect to the minimum factor of safety. In addition, the drain thickness is obtained from the results of the Geostudio software. Regarding the friction angle of the body and drain, once the value of the parameters is analyzed with the least amount and again with the highest value, to determine the lowest and maximum effects of the parameters on the damping factor. The reason for considering the two modes A and B is to create the same conditions for finding the maximum effect of the friction angle of the body and the angle of friction on the drain factor. The permitted range of variation of the heterogeneous dam parameters is shown in Table 3.

3.1.1. Model A (initial condition of the heterogeneous dam)

3.1.1.1. Effect of the friction angle on the factor of safety

In this case, the friction angle of the body is changed in steps of 27 to 30, and other parameters of the dam will have values according to Table 3. The results of the effect of the friction angle on the dam factor of safety in A are shown in Table 4 and Fig. 7.

Table 3. Permitted range of variation of heterogeneous dam parameters

Body angle of friction (degrees)	Friction angle of drainage material (degree)	Dam slope	Drain thickness (m)	Drain length (m)
2.25	130	1:3	33	27,33
2.25	130	1:3	33,40	27
2.25	130	1:3	33	27
2.25	81,197	1:3	33	27
2.25, 3.25	130	1:3	33	27
2.25	130	1:3	40	27,35
2.25	130	1:3	37,40	35
2.25	130	1:3 , 1:1	40	35
2.25	81,197	1:3	40	35
2.25, 3.25	130	1:3	40	35

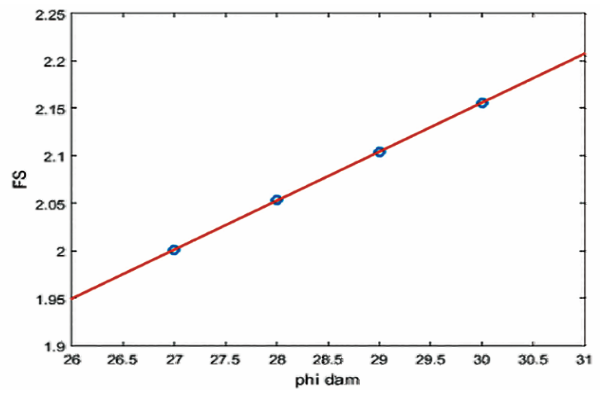

Fig. 7. Linear approximation of the effect of the friction angle on the factor of safety (model A).

In Model A, the maximum confidence level for the maximum friction angle change is 0.15. With respect to Fig. 7, it seems that a line can approximate the points. The plotted line runs exactly from all points, but to insert visual errors, enter the factor of safety in the approximated linear function and obtain the approximate angle of the friction of the body. Then it is compared with the exact amount of friction angle of the body and their difference is considered as the error of the friction angle of the body. Given that the magnitudes of this error are negligible, the linear approximation of the Model A is very suitable and it can be said that the relation between the friction angle of the body and the linear factor of safety.

3.1.1.2. Effect of drainage friction angle on the factor of safety

In this case, the friction angle of the drain has been changed in steps of 33 to 40 units, and other parameters of the dam will have values according to Table 3. The results of the impact of the drainage friction angle on the damping coefficient in the A state are shown in Table 5 and Fig. 8. Instate A, the maximum change in the factor of safety for a maximum change in the friction angle of the drain is equal to 0.20. We repeat the steps of the friction angle of the body for the drag angle of the drain and approximate the points in Table 5 with a line. As shown in Fig. 8, the drainage friction angle is linear with the dam factor of safety in A.

Table 4. Effect of friction angle on the factor of safety (model A).

30	29	28	27	Body angle of friction (degree)
2.156	2.104	2.053	2.001	Factor of safety (FOS)

3.1.1.3. Effect of the slope on the factor of safety

It should be noted that in this study, the gradient 1: 3 is the main slope of the Marvak dam, and the gradient 1: 2 is steeper than the 1: 3 slope and 1: 1 slope than the slope of 1: 2. The results of the gradient effect on the damping coefficient in the A state are shown in Table 6. Instate A, the maximum change in the factor of safety for a maximum slope change of the dam is 0.195.

Table 5. Effect of drainage friction angle on the factor of safety (model A).

Friction angle of drainage	Factor of safety (FOS)
33	2.001
34	2.029
35	2.055
36	2.083
37	2.111
38	2.140
39	2.170
40	2.201

3.1.1.4. Effect of drain length on the factor of safety

Due to a large number of data, we change the length of the drain on larger stairs (4 meters stairs instead of 2 meters) (Table 7). Instate A, the maximum change in the factor of safety for maximum drain length variation is 0.195 as shown in Fig. 9, the length of the drain is linear with the dam factor of safety.

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Table 6. Effect of the slope of the dam on the factor of safety (model A).

1:3	1:2	1:1	Slope
2.001	1.881	1.806	Factor of safety (FOS)

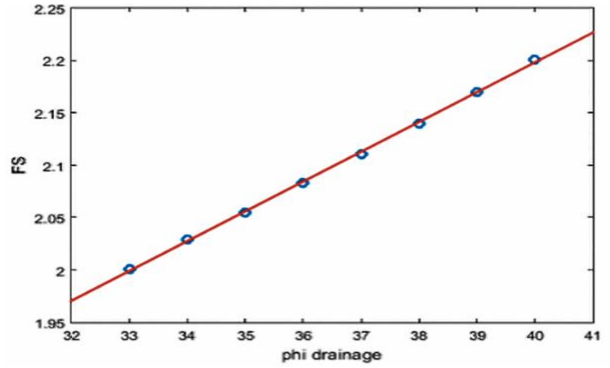

Fig. 8. Linear approximation of the effect of drainage friction angle on the factor of safety (model A).

Table 7. Impact of drainage length on the factor of safety (model A).

Drain length	The factor of safety (FOS)
81-91	1.807
95	1.820
99	1.839
103	1.859
107	1.878
111	1.895
115	1.922
119	1.941
123	1.973
127	1.995
131-197	2.002

3.1.1.5. Effect of drainage thickness on the factor of safety

The drainage thickness in this dam has only two permitted values of 2.25 and 3.25 meters, respectively, with the corresponding factor of safety s of 2.001 and 2.019 respectively. In this case, the maximum change in the factor of safety for maximum change in drain thickness is 0.018, which is the effect of drainage thickness on the dam factor of safety because its permitted range of variations is very limited.

3.2.1. Investigation of model B (heterogeneous dam conditions)

3.2.1.1. Effect of the friction angle on the factor of safety

In this case, the friction angle of the body has been changed to a single step of 27 to 35, and other parameters of the dam will have values according to Table 3. The results of the effect of the friction angle on the factor of safety in Mode B are shown in Table 8 and Fig. 10. In this case, the maximum value of the factor of safety change in the maximum change in the friction angle of the body is 0.49. In this case, the friction angle of the body is linear with the factor of safety (Fig. 10).

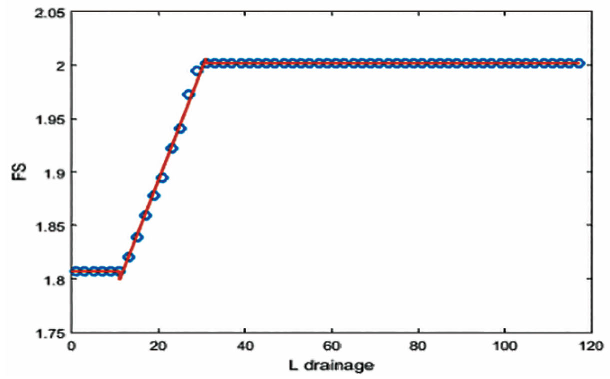

Fig. 9. Linear approximation the effect of drainage length on the factor of safety (model A).

Table 8. Effect of friction angle on the factor of safety (model B).

Body angle of friction (degree)	Factor of safety (FOS)
27	2.201
28	2.251
29	2.303
30	2.356
31	2.410
32	2.466
33	2.522
34	2.580
35	2.640

3.2.1.2. Effect of Internal friction angle of horizontal drainage on the factor of safety

In this case, the friction angle of the drain is changed in the form of single steps from 37 to 40, and other parameters of the dam will have values according to Table 3. The results of the effect of the Internal friction angle of horizontal drainage on the factor of safety in state B are shown in Table 9 and Fig. 11.

Table 9. Effect of Internal friction angle of horizontal drainage on the factor of safety (model B)

Internal friction angle of horizontal drainage (°)	Factor of safety (FOS)
37	2.548
38	2.580
39	2.610
40	2.640

In this case, the maximum change in the factor of safety for the maximum change in the friction angle of the drain is 0.092. In this case, the friction angle of the drain is linear with the dam factor of safety (Fig. 11).

3.2.1.3. Effect of the slope on the factor of safety

Considering that this slope is 1:3, the main slope of Marvak dam is 1:2 slope 1:1 slope and 1: 1 slope is steeper than 1:1 slope. The results of the effect of the slope on the dam factor of safety in B state are shown in Table 10.

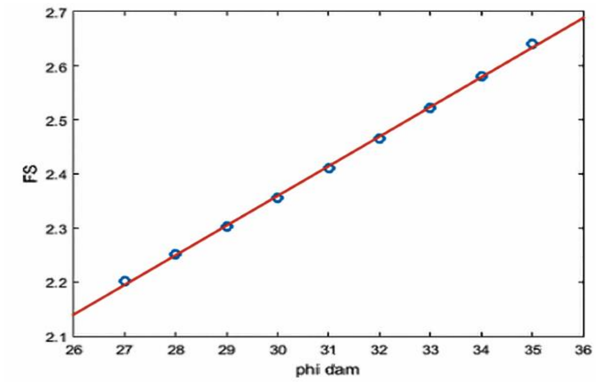

Fig. 10. Linear approximation of the effect of the friction angle on the factor of safety (model B).

Table 10. Effect of the slope of the dam on the factor of safety (model B).

1:3	1:2	1:1	Slope
2.640	2.480	2.383	Factor of safety (FOS)

In this case, the maximum change in the factor of safety for the maximum slope of the dam is equal to 0.257.

3.2.1.4. Effect of drain length on the factor of safety

Due to a large number of data, we change the length of the drain on larger stores (4 meters stairs instead of 2 meters) (Table 11). Instate A, the maximum change in the factor of safety for maximum drain length variation is 0.218 as shown in Fig. 12, the length of the drain is linear with the dam factor of safety.

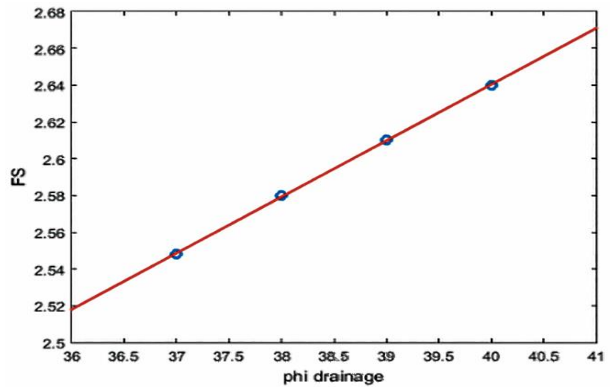

Fig. 11. Linear approximation of the effect of the friction angle of the drain on the factor of safety (model B).

3.2.1.5. Effect of drainage thickness on the factor of safety

The drainage thickness in this dam has only two permitted values of 2.25 and 3.25 meters, respectively, with the corresponding factor of safety s of 2.640 and 2.657 respectively. In this case, the maximum change in the factor of safety for maximum change in drain thickness is 0.018, which is the effect of drainage thickness on the dam factor of safety because its permitted range of variations is very limited.

Table 11. Impact of drainage length on the factor of safety (model B).

Drain length	Factor of safety (FOS)
81-91	2.455
95	2.464
99	2.480
103	2.497
107	2.515
111	2.533
115	2.552
119	2.571
123	2.609
127	2.632
131-197	2.673

3.3. Percentage of the effect of different parameters on the factor of safety

Maximum effect of parameters effective on Marvak dam confidence in equal conditions based on the results of the two models A and B is shown in Fig. 13.

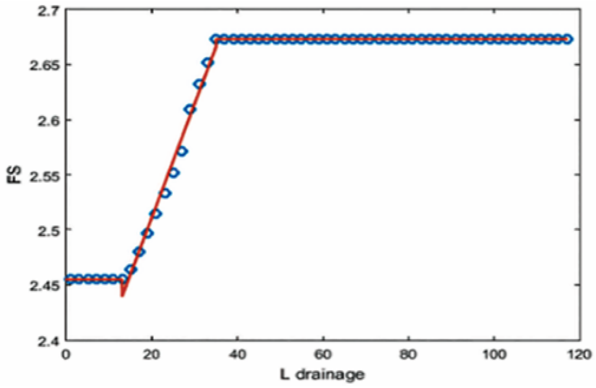

Fig. 12. Linear approximation the effect of drainage length on the factor of safety (model B).

The greatest influence of the parameters on the factor of safety of the dam is devoted to the friction angle of the body, the bottom slope of the dam, the length of the drain, the drainage friction angle, the thickness of the drain. From the point of view of cost reduction and a minimum factor of safety, it is preferred that the dam has the highest possible gradient. In addition, materials with suitable friction angle in the dam or the drainage body should be used and the length of the drain has a good value. Of course, using materials with high friction angle in the body and drainage with the maximum possible length of the drain (the maximum length effect is effective because the length of the drain does not have a significant effect of the factor of safety), the minimum factor of safety the dam required is not provided. In this case, the damping gradient should reduce the optimum value of the minimum factor of safety. In comparison with the actual conditions of the Marvak dam, we compare the factor of safety in the following three cases (Table 12).

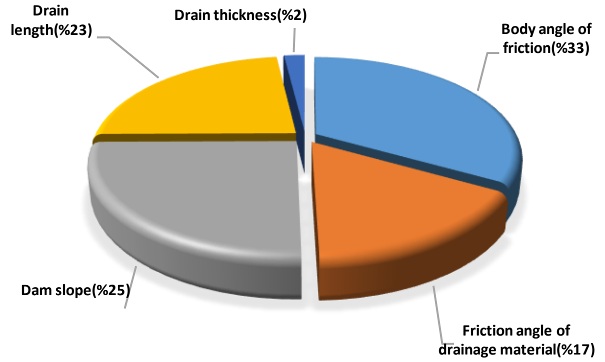

Fig.13. Effect of different parameters on Marvak Dam factor of safety.

The first mode (current conditions of Marvak dam): Marvak dam with real parameters (internal friction angle of body material 35, an internal angle of friction of drain material of 37 and the full length of drainage) are modeled in Geostudio software. In this case, the coefficient of confidence was obtained at 2.597.

Second mode: In order to reduce the volume of Marvak Dam operations and thus reduce the cost of construction, the dam is increased as much as possible (slope1: 1) and the damaged reduced factor of safety is attempted by changing the dimensions of the drainage. In addition, with the increase of the slope of the dam, the dam's factor of safety should not be changed or not significantly reduced. Therefore, the internal friction angle of 35° for the body materials, the friction angle of the drainage material, 40° bar and the maximum drain length is proposed. The slope of the dam is also 1:1. In this case, the factor of safety of the dam is 2.460, which decreases by 5.28 % compared to the original factor of safety of 2.597, but instead, the volume of the earthy operations of the dam decreased by 9.8 % (according to numerical calculations).

Third mode: In this case, the angle of internal friction of the body of the dam is 35 degrees, the internal friction angle of the drainage material is 33 degrees, and the slope of the dam is 1: 3. The internal friction angle of the body material is 35. If the internal friction angle of the drainage material is 33 (lower), the factor of safety increases with decreasing drain length. Because the body materials have a more internal friction angle than drainage materials, they fill the drainage material and increase the factor of safety that the drainage process is in trouble. Therefore, this is not logically correct.

3.4. Optimization of heterogeneous dam parameters

Due to the high cost of building dams, a minimum factor of safety should be considered. Since several parameters affect the dam factor, it is preferable that the minimum factor of safety of the dam is to be met by parameters that provide less costly for dam construction. Dam gradient is one of the important parameters in the dam factor of safety, but providing the minimum dam factor of safety with this parameter dramatically increases dam construction costs. Dimensions of dam drainage are one of the factors affecting the dam factor of safety, but less effective than slope dam. If it is possible to change the dimensions of the drain, a minimum factor of safety of the dam is provided, and then the cost of building the dam dramatically decreases. In this research, the minimum factor of safety of the heterogeneous dam is considered, and the drain for the dam has attempted the minimum factor of safety. Therefore, a Mfile program written in MATLAB software that fully complies with the neural network function of heterogeneous dams and is able to provide a minimum factor of safety of the dam so that in addition to reducing the cost of building the dam, the dam drain dimensions are also optimized. The reason for not using MATLAB optimization towers is the existence of some limitations in the data

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available for training the neural network. The program is composed of 5 sections as follows.

Section 1: In this section, the allowed range of neural network inputs for heterogeneous dams is firstly determined, and then the neural network produces dam construction factor of safety.

Section 2: Among the confidence factor of safety, the factor of safety is chosen to be within the range of Fw + 0.2Fw, where Fw is the minimum required factor of safety for the dam. The reason for considering 20 % Tolerance for Fw is that the input and output data of the neural network are discrete, and the exact amount of Fw may not be achievable.

Section 3: Among the data in the second section, data are selected which provide the maximum possible slope of the dam, as the slope of the damper slows down dramatically. If such data were not available, the slope of the dam should be reduced to the point where the coefficient of confidence would be 2.

Section 4: Data from the third section is selected for data that is the product of the drain length in the drainage thickness minimum. In this case, from the top four stages, a data set is provided that, while reducing the volume of ground operations (by maximizing the slope of the dam), the drainage dimensions of the dam are also optimized, while the minimum factor of safety required for the dam is also provided. In some cases, the program writes a zero length for a dam drain, which means that there is no need for drainage to provide a minimum factor of safety of the dam. The drainage should be used to drain water from the dam, so in this case, according to the fifth section, we act.

Section 5: In this section, the minimum effective drain length is selected as the optimal drain length. For the minimum required factor of safety, the maximum slope of the dam and the dimensions of the drain must be minimized, which means reducing the cost of building the dam. In the second case, from Table 12 to increase the factor of safety, the drain length is considered the maximum possible value, while according to Table 13; the optimal drain length is 88 meters. The factor of safety corresponds to the optimal drainage dimensions of 2.2655, which is lower than the main dam (factor of safety 2.597), reliability of 12.66 %. In addition, the volume of earthquake operations has decreased by 9.8 % (according to numerical calculations) and because the dam drainage dimension is also optimal then the dam construction cost is decreasing more and more.

Table. 12. Comparison of different scenarios for optimizing Marvak dam parameters.

Parameter / State	First state (current conditions of Marvak dam)	Second mode	Third mode
Friction angle of body materials (degrees)	35	35	35
Friction angle of drainage material (degree)	37	40	33
Slope dam	1:3	1:1	1:3
Drain length (m)	197	197	-
Drain thickness (m)	2.25	2.25	-

Table 13. Optimization of heterogeneous dam parameters using MATLAB neural network and coding.

Factor of safety (FOS)	Drain thickness (m)	Drain length (m)	Slope	Internal friction angle of drainage material (degree)	Friction angle of body materials (degrees)
2.0002	2.25	130	3	33	27
Always less than 2	-	-	2	33	27
Always less than 2	-	-	1	33	27
2.4581	2.25	0→93	3	40	35
2.3376	2.25	0→92	2	40	35
2.2655	2.25	0→88	1	40	35

4. Conclusions

In this research, the main factors affecting the factor of safety of earth dams were investigated and the maximum effect of each of the parameters on the factor of safety of the dam was determined in the case and in equal conditions. The parameters are classified in terms of costs and impact on the dam factor of safety, and each of them was used to optimize the dam construction costs or to provide the required factor of safety of the dam. Dam gradients account for a large part of the dam construction costs and have a significant impact on the dam reliability. On the other hand, the effect of the internal friction angle on the material of the dam or drainage and the length of the drain is also high on the dam reliability, with the difference that their costs are far lower. Therefore, from the point of view of cost and a minimum factor of safety, it is better to optimize the slope of the dam in order to reduce the construction costs and to use the internal friction angle of the material of the dam or drainage material and the length of the drain. Finally, it was determined that the two factors of the internal friction angle of the body material and the slope of the dam have the greatest effect on the dam factor of safety.

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