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Investigating the Economic Effect of Using Geotextiles in Filters and Drainage in Earth Dams

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ABSTRACT

When leakage current goes in a coarser material from a relatively fine-grained soil, the fine-grained materials may move from their place, causing instability throughout the structure. In this case, the fine grains may fill the empty spaces of the drainage system, and prevent the movement of water in this part. Therefore, it will be necessary to create a filter in the structure. In earth dams with normal conditions, the use of granular filters is considered as the first option. If due to problems such as the preparation of aggregates or its high cost, the use of a variety of geosynthetics, especially geotextiles, which eliminates almost all the disadvantages of the traditional method, is recommended. In this research, through modeling a sample of an earth dam (Ahouyieh Baft dam), the effect of geotextile on drainage and its filtration according to different discharge values has been investigated. By conducting this type of research, the optimal mode of filtration, which is a combination of granular filters and geotextile layers, can be obtained and used in the design of dams. After constructing 61 models (1 real dam model and 60 software models using geotextile), the results of real dam model including filter and grain drainage with a thickness of 50 cm were compared with models with geotextile filter and drainage. The model with a granular filter with a thickness of 10 cm and 5 layers of type 2 geotextile with a cost reduction of 40.53% was selected in the filter section as an alternative to the granular filter with a thickness of 50 cm.

Keywords: *Geotextile, Drainage, Filtration, Earth dam, Economic performance*

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1. INTRODUCTION

In general, failure to control permeate in earth dams can lead to many financial and life losses. An overview of the dam's continuous occurrences up to 1986 has indicated that 48% of the failure of earth and gravel dams was due to internal erosion and the piping phenomenon. Studies display that the life of earth dams depends on factors such as water leakage, scour erosion of materials and the piping phenomenon. The filter is one of the most significant areas in the design of the body of zoned earth dams. In these dams, due to the use of different materials and considering the zone of consumed materials, the use of a transfer layer or filter is inevitable (Liu et al., 2008). The filter area may include the distance between the core zones, shell, drainage, protective rock cover, and so on. This area is used as a reliable and examined defense line to prevent the possible transport of core material caused by concentrated leakage (caused by any discontinuity). In case of not using the filter, by moving fine particles from the base layer to the coarse-grained layer, first, the space between the soil particles is emptied and the possibility of its destruction and instability increases; second, by blocking the empty spaces of the second layer, the passage of water is prevented, and the hydrostatic pressure increases sharply, which will play a role as a destructive factor in the above-mentioned boundary (Wei et al., 1985).

Filters and drains account for about 5 to 10 percent of the total volume of earthworks. In contrast, the extraction, processing and execution of these materials are high costly and the most troublesome materials among other materials in earth dams. Therefore, the filter is an important component, not only in terms of dam safety, but also from an economic point of view. In fact, the optimal design and implementation of the filter leads to greater reliability and economic savings. Filters in different parts of earth dams may be used in two ways of granular filters and filters consisting of geotextiles, which can be considered in combination with granular filters or as an alternative to them (Bergado and Sorlump, 2003).

In areas where due to construction conditions, there is a problem of supplying high quality sand in large volumes, and the project requires the supply of materials from long distances (several tens of kilometers), in such conditions the use of geotextiles can be an option that is technically and economically competitable with other options (Rajabalinejad et al., 2006).

Geotextile is made use of as one of the textiles and types of geosynthetic materials, including materials that are widely used today in filtration and drainage applications. In earth dams, these materials can be used as drainage, galleries and drainage cover to transfer water without creating pore pressure to the slope or downstream closet, and as a filter in the upstream of the dam and between the core and shell materials to prevent soil erosion in the body of the dam. The use of geotextiles in dams and earth dams was not out of the expectation, because unlike granular materials, in addition to

having filter and drainage properties, they also have good tensile strength and segregation capability (Faure et al., 2006).
In the past several years, the application of geotextiles in hydraulic and geotechnical engineering based on their technical and economic benefits has increased in comparison with typical materials. The results of the effect of using these materials for filtration and drainage as a substitute for natural materials or in combination with them are basically applicable to control water seepage in earth structures and reduce construction costs and accelerate the implementation compared to other materials in designing filtering systems and drainage of earthworks, especially in areas where materials of the desired quality are not available or their supply is costly. In order to use geotextiles as filters and drainage in the construction and reconstruction of earth dams, it is necessary to determine the physical properties as well as the effect of its use in controlling leakage and preventing the phenomenon of piping. Physical characteristics such as specific gravity, unit weight of surface and thickness are determined by the manufacturing factory.
Liu et al. (2006) suggested a model for the performance of nonwoven geotextiles for mudflow filtration. They studied the filtration performance using random probability theory based on the pore size distribution of nonwoven geotextiles theory based on the polyhyedron- Poisson theory proposed by Lombard, Rollin and Wolff, and proposed a mathematical model for the mass of soil passing through the geotextile, and validated it by testing the mudflow with their own constructed device. When the experimental results obtained from four different samples were compared with the theoretical solution, they indicated that the present model for non-woven geotextiles with hot glue had an accuracy of about 93% (Liu and Chu, 2006).
Professor Bergado and his colleague examined the use of geosynthetics to control erosion and preserve the environment in a study (Namkading Riverbank) (Bergado and Soralump, 2003). Near the banks of the Namkading River in Thailand, slope degradation and soil erosion occurred that a combination of gabions, blankets and geotextiles was used to solve this problem. The needle geotextile used in this project was used for drainage, filtration, separation and reinforcement (Bergado and Soralump, 2003). The results of slope stability analysis presented that the slope remained quite stable even in critical conditions such as water height decrease, which indicates the very good performance of the treatment method. The desired geotextile was selected based on the criteria of permeability, storage and allowable strength (Bergado and Soralump, 2003).
Since in designing most zoned earth dams in the world, the filter is of the granular type, and in limited cases, geotextile materials have been used as a substitute for granular materials or a combination of the two in designing dam filters, more research studies are needed for replacing these materials or combining them with granular materials. Therefore, in this study, in order to better understand and compare the two types of granular filters and geotextile-granular composite filters, a case study on this issue in Ahouyieh Baft dam has been conducted.

2. MATERIALS AND METHODS:

Choosing the type of Ahouyieh dam

Dams are divided into three general categories of concrete (double curvature arch or gravity), rockfill and earthfill according to the type of materials used. The primary effective factors in determining the type of dam in a particular local position are the shape of the valley, the geological features of the walls and the way of the geological formation of the bed. In a narrow V-shaped valley with a steep slope on both sides of the valley and the possibility of arc thrust forces, the choice of a two-arc dam is appropriate. But in a wide valley with a shallow depth and a relatively strong foundation bed, building a weight barrier is more economical. If the stiffness of the foundation layers is reduced in the recent conditions, the option of choosing earth dam will be more appropriate. One of the most important economic principles in choosing the type of dam in the form of soil is the existence of local materials within the dam. In some cases, this situation is limited, and only one type of soil can be found on site. In such a case, the economic conditions of the design require the maximum use of this type of soil. If the soil is impermeable, the design will be homogeneous earth dam, and only a small amount of fine-grained material will be needed to control water leakage. If the soil is granular and permeable, a dam can be designed heterogeneously by considering a core to control water leakage. In the case of Ahouyieh Dam, due to the special characteristics of concrete dams, the use of this option will be excluded. According to the results of the primary studies, fine-grained and coarse-grained soils exist within the project area, and it is possible to build a heterogeneous soil dam in this area. Therefore, Ahouyieh dam is considered as "heterogeneous with clay core".

Figure 1: Site reservoir considered for Ahouyieh dam

Meteorological studies of the project

The aim of meteorological studies in dam studies is to determine the basic factors required in the design, including determining the water requirement and reservoir capacity of the dam and water intake facilities, and finally planning water resources, determining the maximum instantaneous discharge for overflow and determining water intake facilities. For this purpose, in meteorological studies, all climatic parameters affecting the climate of the region, including temperature, wind, humidity, evaporation and rainfall are examined. Also, the morphology (physiography) of the basin, river flow, project flood, sediment and water quality of the project area are investigated in hydrological studies. The climate of the region has been determined as a cold semi-arid climate based on the analysis of statistical data of different stations and according to the existing methods.

Streamflow

Estimation of monthly and annual streamflow is one of the most important factors in determining the area under cultivation and planning water resources in the project area. For this purpose, among the statistics of 12 hydrometric stations near the project area that had a suitable area appropriate to the area of the project basin, was selected and the length of the statistical period was considered 40 years (1960-1961 to 2000-2001). Also, Jiroft hydrometric station was used as the base station due to its statistical adequacy and accuracy and Pol Baft station was used as the index station due to climatic and hydrological similarity to the design area.

Carrying Transport

In order to accurately design the construction of reservoir dams and determine the useful life of a dam, it is necessary to evaluate and estimate the total volume of annual sediment production in a basin area. Based on the calculations, the amount of annual sediment yield in the project area is 1871 cubic meters. Also, 25-year and 50-year sediment volumes have been calculated as 466774.6 and 93549.2 cubic meters, respectively.

General geological characteristics

The basin area of Ahouyieh earthen dam design is located in the territory of a mountainous to semi-mountainous morphological unit that has an altitude range between 2500 to 3500 meters above sea level. On the western side of the basin, the main waterway with a general north-south direction has a water flow in the bed, the direction of flow in which is from north to south with a lot of maze. There are also four major waterways in the study plan area. These waterways have two trends in the direction of water flow from the northeast and northwest to the southwest and southeast. In a general view, the vegetation status of the study area can be stated as follows: in the outcrop of Miocene deposits, which has a high potential for erosion and can have a higher level of debris than other geological formations, the highest level of vegetation can be seen. After that, in the territory of the present-day deposits and low slopes with Eocene outcrop, the rest of the arable lands have been formed. In total, about 10% of the basin area has been covered with vegetation.

Engineering Geology

The reservoir area and the axis of Ahouyieh earth dam are located in the territory of a shallow valley with walls with medium slope, and the shape of the valley is V-shaped at the location of the dam axis, and a small seasonal river flows in its basement line, its bed generally includes a high rock foundation. The not-so-wide alluvial sediments of this small zone with an approximate slope of about 5% in the general direction of NW-SE have been deposited on the banks of this seasonal river. No traces of aqueducts, springs or wells have been observed in the field geological examination and survey conducted in the area of the axis and the reservoir of the dam. The reservoir area and axis of Ahouyieh earthen dam in terms of geostructure only include discontinuity levels in the slight rock outcrop in the left bank of the reservoir and the axis of the dam. At the site of the Ahouyieh earthen dam project, earthen slopes are generally associated with debris deposits (in situ debris or water wash deposits) at the site of the axis supports and the reservoir of the dam, especially its right bank. In case of this dam, the quality of the rock mass is relatively good. Also, the internal friction angle of the rock mass is in the range of 23-32 degrees and its cohesion is estimated to be 275-275 kPa. In general, according to the geometric properties of discontinuity surfaces, the result of permeability potential can be estimated as appropriate.

Filter and drainage

In the downstream part of the dam body if the dam is homogeneous or in the downstream and upstream part of the clay core and adjacent to it, if a heterogeneous dam is considered, it is used to prevent the migration of fine particles toward downstream and to drain the water in the body of the dam. These materials can be obtained by sieving alluvial materials in the bed of Ahouyieh river.

Water

Since the construction of different components of the earth dam body requires spraying the embankment layers of fine-grained clay material and mixed or coarse-grained dam shell at the time of bashing, and also to prepare the required concrete in the construction of the overflow structure of the dam and ... , there is an urgent need to water. Therefore, the required water supply site should be as close as possible to the dam site. With the conducted field studies, water can be provided by constructing a pool in the area of the reservoir and next to the main waterway, which is about 200-150 meters away from the project site. Chemically, the used water must have the necessary standards, which according to the field visit and the geological characteristics of the area, apparently the water is of good quality.

GeoStudio software

GeoStudio software is one of the geotechnical programs based on finite elements, and analyses such as stress-strain, seepage, slope stability and dynamic analysis can be examined through using it. This software includes SIGMA / W programs for stress-strain analysis, SEEP / W for flow and seepage analysis, SLOPE / W for slope stability analysis, QUAKE / W for dynamic analysis and other applied parts (Johari and Pakniat, 2009).

Modeling in SEEP / W program

This part of GeoStudio software is related to the study of seepage conditions and water flow in the soil. One of the capabilities of this part of the program is calculating the flow rate for a certain section of soil and calculating the flow rate (leakage rate) of a whole embankment. The SEEP / W program also has the capability to perform analysis in steady state conditions (Johari and Pakniat, 2009).

Upstream and downstream water heads are applied using the Draw Boundary Condition menu. Through this menu, the amount of head or flow rate can be assigned to the existing nodes. For example, upstream should have a head of 100 meters to the water level and downstream should have a head of 35 meters.

Determining the flow rate is done using the Draw Flux Section menu. Through this menu, the sections that are intended for calculating the flow rate are drawn, and after analysis, the amount of flow rate is presented through the Draw Flux Label command.

After modeling the problem and assigning the specifications of materials to it and other mentioned cases, the model is ready for analysis (Johari and Pakniat, 2009).

Modeling in SLOPE / W program

This program is from GeoStudio software suite to check the stability of ramps and determine the reliability of slope design. One of the most significant features of this program is the possibility of modeling reinforcements such as restraints, nails and geosynthetics in order to increase the safety of slopes. Various factors affect the stability of slopes. These parameters include soil cohesion, soil friction coefficient, water level, presence or absence of reinforcers, etc. We can not use a file from SIGMA / W or SEEP / W to model the project in SLOPE / W. The Material Properties option in the KeyIn menu is used to assign material properties. In this window, we have to define the basic parameters related to each of the materials used such as specific gravity, cohesion, internal friction angle and the desired resistance model. In this project, the Mohr-Coulomb resistance model has been used (Johari and Pakniat, 2009).

The most common method of expressing the shear strength of geotechnical materials is the Mohr-Columb equation, which is expressed as follows:

$$\tau = c + \sigma_n \tan \emptyset \quad (1)$$

Equation 1 is a straight line equation that displays the relationship between shear strength and normal stress. The intersection of the line with the shear strength axis indicates the cohesion (C) and the slope of the line shows the internal friction angle (ϕ).

Parameters c and ϕ can be total resistance parameters or effective resistance parameters. From the point of view of slope stability analysis, effective resistance parameters provide a more realistic solution, especially for the critical slip surface.

Modeling in SIGMA / W program

This part of GeoStudio software is related to Load / Deformation analysis, in situ stress and consolidation through which total and interparticle stresses and pore water pressure can be obtained, and through which the resulting deformations in the soil can be observed.

After performing the analysis operations, using the Contours option located in the Draw menu, a window according to Figure 5-22 will open, which can be used in the Contour Parameter section, the parameter required to extract the maximum and minimum values and display the color contour in the model cross section can be determined in the program.

3. FINDINGS

Modeling

Considering the thickness of 50 cm of granular filter in the downstream of Ahouyieh Baft dam, after constructing and studying a model with real performance specifications, 60 different models were built as follows and were used as a basis for comparison.

1. Granular filter with a thickness of 40 cm, with 5 layers of geotextile, with 10 layers of geotextile, with 15 layers of geotextile and with 20 layers of geotextile (from type 1, type 2 and type 3 geotextiles)
2. Granular filter with a thickness of 30 cm, with 5 layers of geotextiles, with 10 layers of geotextiles, with 15 layers of geotextiles and with 20 layers of geotextiles (from type 1, type 2 and type 3 geotextiles)
3. Granular filter with a thickness of 20 cm, with 5 layers of geotextile, with 10 layers of geotextile, with 15 layers of geotextile and with 20 layers of geotextile (from type 1, type 2 and type 3 geotextiles)
4. Granular filter with a thickness of 10 cm, with 5 layers of geotextile, with 10 layers of geotextile, with 15 layers of geotextile and with 20 layers of geotextile (from type 1, type 2 and type 3 geotextiles)
5. Without granular filter, with 5 layers of geotextile, with 10 layers of geotextile, with 15 layers of geotextile and with 20 layers of geotextile (from type 1, type 2 and type 3 geotextiles)

Typically in two-dimensional analyses of earth dams, the analysis is performed in the critical cross section and maximum dam and according to the prevailing conditions in the form of plane strain. To this aim, the middle section of Ahouyieh Baft dam was selected, in which the height of the dam from the core floor is equal to 23 meters. The maximum width of this section was 141 meters. The water level behind the dam is considered to be at the maximum water level (20 meters). In this section, the results of stable seepage analysis have been presented.

In general, seepage control in dams is a part of the basic analysis in their design and study. It is necessary to control the seepage and the ways in which the seepage can be controlled in order to prevent uneconomical and excessive leakage that leads to instability in the face of the piping phenomenon. The purpose of using a filter and drainage system is to facilitate leakage flow and hydrostatic pressure depletion so that the exit of fine particles would not lead to instability. In this regard, first the effect of the granular filter layer with a thickness of 50 cm, and then the performance of the granular filter with different thicknesses using different layers and types of geotextiles in the downstream filter of the dam were investigated.

As it was stated, first the real dam model was made with a granular filter thickness of 50 cm, which was leaked at a rate of × 10-2 24 3.2412 with a unit of square centimeter per second, which by multiplying this number along the dam (284 meters) the flow rate 920.50 in cubic centimeters per second, as indicated in Figure 2, Which was the basis for comparison with models with granular filters of different thicknesses using different layers and types of geotextiles in the downstream filter of the dam.

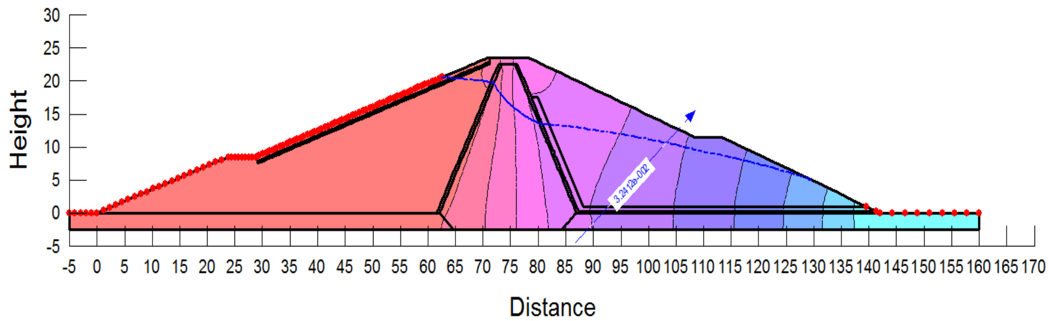
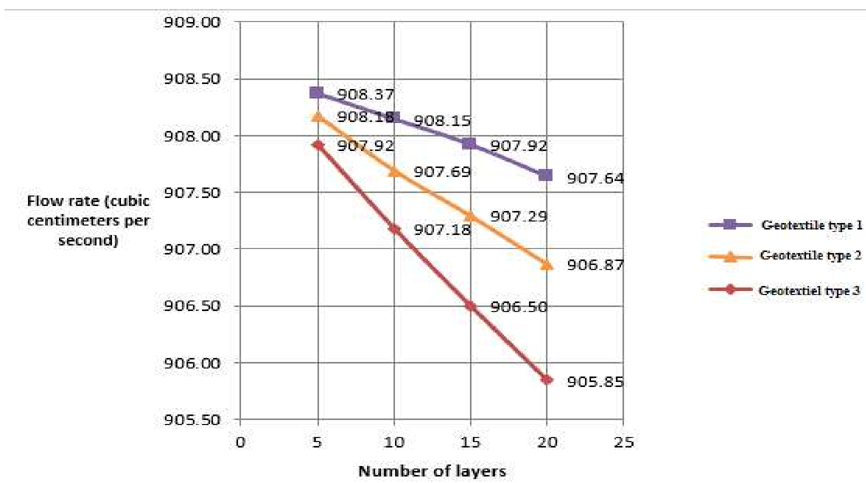


Figure 2 - Analysis of the output discharge of the actual dam

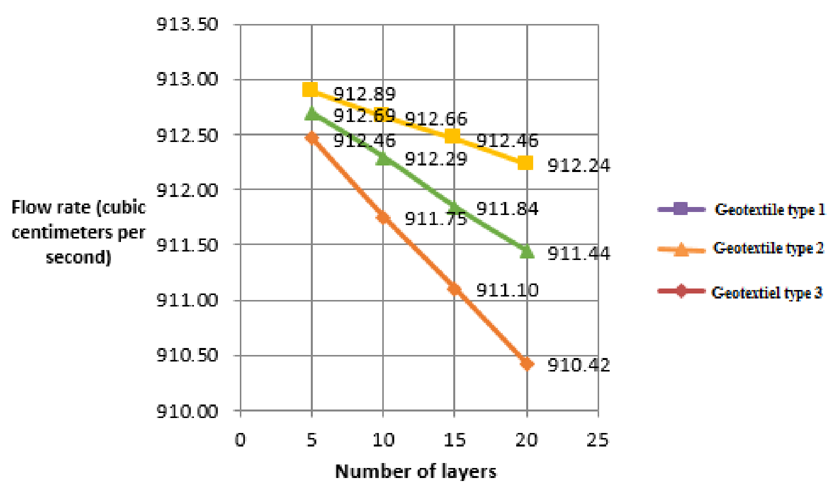
Investigation granular filter performance with number of layers and different types of geotextiles

In this section, the effect of increasing the number of layers and different types of downstream granular filter geotextiles on the filtration performance of the geotextile-soil system by considering the thickness of the grain filter at each stage as constant was examined. To this aim, to investigate the effect of the number of layers and different types of geotextiles on the filter performance downstream of the dam, models were made using GeoStudio software, and the results of the models were compared with each other.

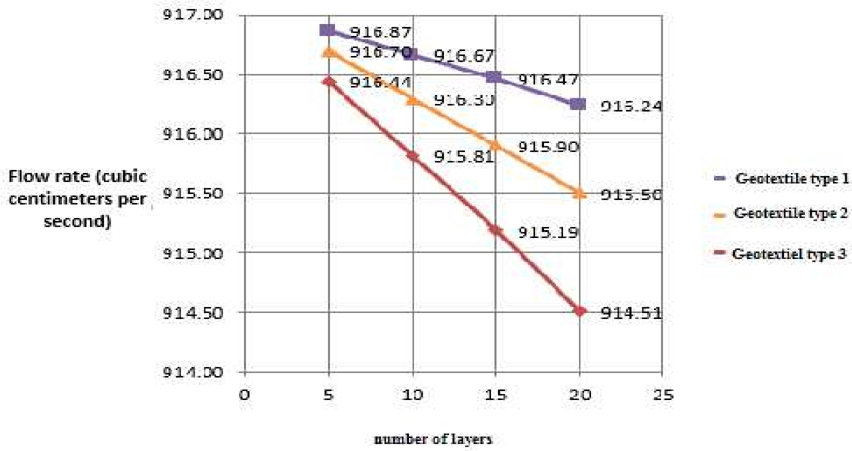
The results of the analysis have been indicated in the diagrams in Figure 3:



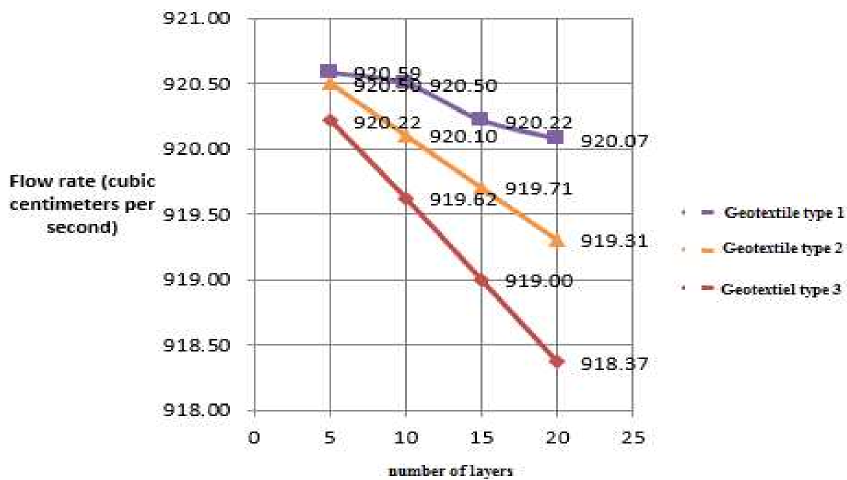
(a)



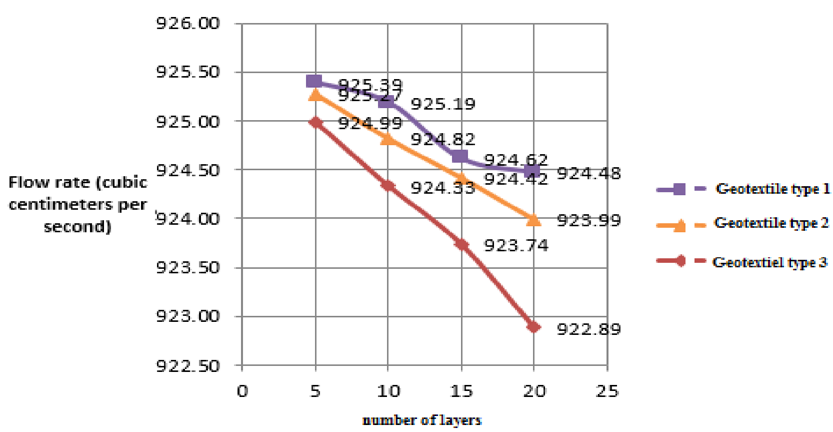
(b)



(c)



(d)



(e)

Figure 3-a) Changes in flow rate in the form of 40 cm granular filter and the number of layers and types of geotextiles, B) Changes in the flow rate in the state of 30 cm granular filter and the number of layers and types of geotextiles, c) Changes in the flow rate in the state of granular filter of 20 cm and the number of layers and types of geotextiles, D) Changes in the flow rate in the state of 10 cm granular filter and the number of layers and types of geotextiles, c) Changes in the flow rate in the state of no granular filters and the number of layers and types of geotextiles.

Examining Figure 3, it can be observed that in a grnular filter with a thickness of 40 cm and 12 types of combinations with the number of layers and different types of geotextiles, by increasing the number of layers by 5 in different types, the flow rate decreases by an average of 3.66% (Figure 3 a).
In a granular filter with a thickness of 30 cm and 12 types of combinations with the number of layers and different types of geotextiles, with a linear increase in the number of layers, the flow rate decreases linearly, and with increasing weight of geotextile slope which increases the slope of the flow rate reduction increases (Figure 3 b).
The rate of flow reduction from 5 layers to 20 layers in type 1, type 2 and type 3 geotextiles is 7%, 13% and 21%, respectively, which indicates that by increasing the surface unit weight of various types of geotextiles used in downstream filter, leakage flow changes, has had a decreasing trend (Figure 3c).
As the thickness of the granular filter decreases, the flow rate increases, so the flow velocity will increase, and the obtained results are in line with the expectation theory (Figure 3d).
By removing the granular filter due to the linear increase in the number of geotextile layers, considering that all flow regulation is done by the geotextile, the process of reducing the irregular and non-linear flow rate indicates the effective presence of the granular filter even with minimal thickness in discharge flow regulation (Figure 3 e).
Based on the results of the analysis of graphs obtained from 60 models:

1) With increasing the number of geotextile layers, the leakage rate has decreased.
2) The decreasing trend of leakage flow changes against increasing the number of different layers of geotextile indicating that in the constant thickness of the granular filter layer, increasing the number of geotextile layers has led to a decrease in the fluid flow capacity of the filter layer.
3) With the use of geotextiles, in fact, the permeability of the whole system of the geotextile-soil downstream filter area is reduced, as a result of which the flow velocity is reduced. In contrast, by reducing the thickness or removing the granular filter, the leakage flow rate changes have been increasing.
4) With the increase in surface unit weight of the types of geotextiles used in the downstream filter, changes in leakage flow have had a decreasing trend;

By comparing the output discharges of the models presented in the diagrams and assuming a constant discharge of the actual dam model, the following options with a discharge equal to the discharge of the actual dam model with a 50 cm granular filter were selected as competitive options:

1. Sample with a granular filter with a thickness of 10 cm and 5 layers of type 2 geotextile
2. Sample with a granular filter with a thickness of 10 cm and 10 layers of type 1 geotextile

In the next pages, considering the technical and economic issues and the performed analyses and studies, one of the two proposed options, will be selected as a replacement sample for a 50 cm granular filter.

Economic comparison

One of the advantages of using geotextiles as filters in earth dams is a significant reduction in material, labor and time costs. In this section, for economical comparison of granular filters and geotextile-grain composite filters, effective parameters and related costs must be considered. In Table 1, the costs of implementing the filter of the two options selected in the previous section with the actual dam have been compared and presented. In the calculations, the length of the dam has been considered 284 meters, and the length of the oblique and horizontal sections of the downstream filter has been considered 78 meters.

Table 1- Comparison of the cost of filter implementation of the two selected options with geotextiles and the sample of the actual dam granular filter

Percentage reduction in the price of selected samples compared to the granular filter with a thickness of 50 cm	Price (million rials)	option
0%	597	Granular filter with a thickness of 50 cm
40.53%	355	A sample having a granular filter with a thickness of 10 cm and 5 layers of type 2 geotextile
27.47%	433	A sample having a granular filter with a thickness of 10 cm and 10 layers of type 1 geotextile

4. CONCLUSION:

Earth dams are exposed to different types of stresses during construction and during operation, including stresses resulting from dam subsidence and stresses from the dam body, static water pressure, dynamic forces of waves, earthquakes, etc. In order to ensure the resistance of earth dams to the above stresses, all necessary considerations must be taken, and the design must be implemented safely. With the advancement of computer science and the development of numerical methods such as finite element methods, it has become possible to determine the displacements, stresses and pressures of porous water. Using these methods, changes in other quantities in the soil environment, such as calculating the amount of water loss in the dam, drawing the flow path from the body and the dam foundation, and so on can be examined and analyzed.
The purpose of this study is to investigate the performance of geotextile filter as an alternative or combination of granular filter. To this aim, different models were developed and the results were reviewed.
The results of the built models for investigating the effect of the geotextile layer on the performance of the downstream filter area are as follows:
In the built model with a downstream filter area with a thickness of 50 cm:

- The minimum reliability coefficient was 2.11, which was within an acceptable range.

- The results of the calculated height subsidence in the studied section show that the maximum subsidence, which was equal to 0.006 of the dam height, has occurred. Sedimentation percentage is 0.6% of the dam height, which is an acceptable value.
- The porous water pressure is always less than the vertical and horizontal stresses, and therefore, there is no problem with hydraulic failure.

In the built model with the combined geotextile filter area - downstream granular materials:

- If geotextiles are used in the oblique and horizontal parts of the downstream filter area, it is observed that with increasing the number of layers, the safety coefficient increases.
- Based on the results of numerical models, with increasing the number of geotextile layers, the flow rate per unit width has decreased.
- The decreasing trend of flow changes per unit width versus increasing the number of different geotextile layers shows that in the constant thickness of the filter layer, increasing the number of geotextile layers horizontally and obliquely has decreased the fluid flow capacity of the filter layer.
- Increasing the number of geotextile layers in the downstream filter layers with less thickness, has a greater effect, and with increasing the thickness of the filter layer, its effect has decreased.
- As the thickness of the granular filter increases, the flow decreases, so the flow velocity will decrease, that the obtained results are in line with the theoretical expectation.
- Considering economic issues, the following option can be replaced with a 50 cm granular filter:
  - ✓ Sample with a granular filter with a thickness of 10 cm and 5 layers of type 2 geotextile

In general, considering that the analysis of rapid discharge mode in earth dams is necessary and is done in the designs, therefore, for future studies on numerical modeling, the use of geotextiles in rapid discharge mode should be considered.

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