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Investigating the Effect of Seepage on Earth Dam Using Geostudio (Case Study "Jereh" Dam Reservoir)

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Earth dam is one of the oldest constructional establishments that man has used in agricultural fields and provision of potable water for his primitive needs. The water impounded in reservoir may be leaked through a dam body, its foundation or its abutments which has significant importance in the stability of dams and in particular earth dams. When water leaks through such dams it causes many problems. The purpose of this study was to find out the ways to reduce and control the rate of seepage in Jereh earth dam reservoir by numerical methods in finite element analysis. This research was conducted at Jereh Ramhormoz earth dam located 35km northeast of Ramhormoz city in 2013. Different kinds of soft wares are prepared for predicting and calculating seepage flow rate which are cost-effective and need less time to analyze the seepage before dam construction as compared to that of laboratory models. To do so, the effect of seepage on earth dam was investigated by using Geostudio software through which SEEP/W was used to analyze seepage and flow net. At the end the obtained results were analyzed as well. The results showed that for reducing the seepage rate in the given dam, upstream blanket with the thickness of .05 m and low permeability materials including geomembrane can be used. Moreover, concrete upstream blanket that is more cost-effective can be applied.

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Introduction

In general, the water stored behind a dam is used for irrigation, potable water consumption for human and cattle, power generation, flood prevention, and to protect downstream villages, establishments, and watershed erosion from being damaged. Because of limited facilities and a lack of understanding of hydraulic and soil mechanic laws, the height of dams and earth dykes had not been exceeded from a specific limitation, although there were no such limitation regarding the length and width of the dam. In general, the earth dam should be constructed in a place where its preference to concrete dam is proved. Normally the condition of infrastructure justifies the preference of earth dam to the

concrete one. The specifications of core, rock and the soil of foundation dam and its abutments, the availability of material for dam construction, the design and the shape of dam and finally the implementation constraints can be effective factors to choose the proper procedures to seal the dam but they still cannot solve the seepage problem completely.

The theory of the research

The seepage flow simulation through body, foundation of earth dam in the rivers that have less flow rate and in places where water resources are limited is considered as one of the important factors to reduce the water losses and the stability of dams. The optimum use of water in a country like Iran which has arid to semi-arid climate is very important especially in developments of agricultural activities. The optimum utilization of water resources for the given purpose cannot be possible without entire consideration of economic and social criteria. Paying attention to the expenses allocated to water resources, social benefits of water is important to improve economic development of water industry. On the other hand, the methods used in exploitation of water resources in particular surface water like rivers are different. Each of these methods has specific features and shows different performance in different conditions of river. So, the evaluation of these methods has a major role in improving water utilization. Dams are structures which are constructed across the river for storing water resources.

The saturated and unsaturated zones are observed in all earth dams which are in contact with the atmosphere. In saturated zone, pore pressure is always positive and increases with increasing depth. The pore water pressure is negative in unsaturated zone above water table as compared to atmospheric pressure and with increasing distance from the water table it becomes more negative and near the surface of earth reaches the most negative value. Considering the effect of seepage and piping on increasing the probability of earth dam failure and decreasing its efficiency, seepage analysis is essential to assess the dam safety level. The clay in contact with water prevents the moisture absorbing and water transferring and acts as a sort of moisture insulation. When the whole dam is made of clay it is homogenous dam, but if the core of dam is clay and it is surrounded with coarse stone, the dam is non-homogenous. The characteristic of rock, the soil of dam foundation and its abutments, the availability of materials for dam construction, design and the shape of the dam and implementation constraints can be effective in selecting the proper procedures for sealing the dam. In this respect, some researches are carried out as follows:

Dunnicliff believed that the dam safety depends on not only the design and construction but also the entire behavior report and review of its performance during the construction and operation [1]. Soil behavior parameters such as total stress, pore pressure and strain is constantly changing due to some factors like foundation movement, strengthen the core, and changes in moisture content of material during the construction of a dam. In this way, dam safety monitoring is necessary. Researchers concluded that the expansion of pore water pressure in core that may occur as a result of the gradual increase of dam height should always be considered by engineers during the construction [2]. Instrumentation and monitoring dam during construction will help a lot in a way that a temporary full water filling may be recommended at some stages of construction. Myers and Stateler purposed that monitoring the record of earth dam behavior is a part of comprehensive program which controls the stability of earth dams [3]. In other words, the main goal is to detect any possible problems that threaten the stability of the dam. So, monitoring by accurate instruments solves this problem as well. Asghari and Olapoor examined a case study entitled as "To Compare the Static Analysis Results of Asphaltic Core Earth Dam with Clay Core Earth Dam" by Geostudio 2004 Software. The results showed that the magnification factor value of dam with clay core is more than that of vertical asphaltic core [4].

Earth dams

The construction of earth dams for controlling and storing of water has been common since many years ago. Nowadays, man has been able to construct earth dams with considerable height by the development of technological capabilities, valuable contributions to science of soil mechanics, and more accurate studies so, at present time the earth and rock dams are the highest dams in the world.

In addition, the places that earlier were distinguished as not proper for this purpose, now they can be prepared for the foundation of earth dam construction. In order to provide an accurate and logical design in earth dams it is essential to study the status of dam foundation and its material composition entirely. Moreover, the dam implementation should be carried out according to controlled methods and the proposed plan of design.

As a principle, two certain points are:

1- As a reservoir, the dams must be impermeable.
2- In all possible conditions (Just after the construction, during the construction, full reservoir, overflowing, raining or even rare flooding of thousands years) the dam must be resistant.

Nowadays, the method of earth dam construction is primarily by mechanical compaction however; there are other methods such as hydraulic and semi hydraulic fill methods which are used less. The main part of the earth dam which is compacted soil, is called the body of dam (actually the structure of the dam) and the place where the dam is located on is called foundation, to the extent that is affected by the pressure of the dam and permeability of dam water. Besides these two

main parts, there are other parts such as sluices, drains, upstream and downstream blankets and etc. which have major role regarding, dam safety and its performance.

Materials and methods

Jereh dam of Ramhormoz with a height of 113 meters from foundation and the crest length of 740 m is constructed on Zard River. It is located 35km northeast of the Ramhormoz city and is ready to be operated. Jereh dam of Ramhormoz is an earth dam with clay core and a reservoir size of 260 million m3 that is able to supply required water of 22 thousand and 300 acres of land of Ramhormoz plain for mechanized agriculture under irrigation and drainage network (Fig.1). The first phase of Jereh dam reservoir of Ramhormoz project was started in 1996 and also the opening date was in 2013. The operation of this project and full water filling improves the livelihoods and economic status of farmers, increases agricultural production and employment opportunities. All the properties of the earth dam under construction such as height of foundation, embankment height, crest width and the material properties used in the construction of the dam, such as elastic modulus, Poisson's ratio, saturated unit weight, wet weight, volume weight water, internal friction angle coefficient of cohesion, and other required properties were taken from the consulting engineers company who were responsible for designing and constructing the project. Moreover, the aforementioned properties were entered in Geostudio software and then the obtained model was analyzed using a finite element analysis.

At the time of dam operation when the reservoir is full of water, a flow of water transmits a force to the soil particles, like that of flowing water friction force in pipes, which is called seepage force. Since Jereh dam body is a type of non-homogenous, in fact the core material has a role of sealing element in dam body that has low permeability, but the permeability of the core is not completely zero (Fig.2). Therefore, the seepage flow is not completely stopped but it will have a slow seepage flow rate.

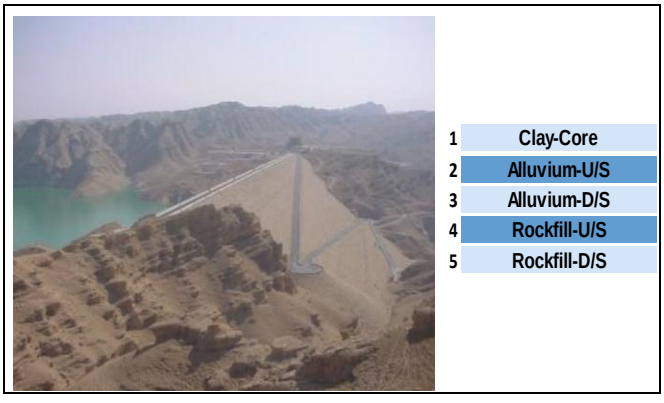

Fig. 1: A view from Jereh dam

Among the soft wares, Geostudio is a geotechnical applications based on finite elements through which, analyses such as stress-strain, flow, seepage, slope stability, dynamic analysis, and also rapidly declining condition can be investigated. This software includes parts of 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 analyzing the temperature distribution in soil, CTRAN/W to analyze the distribution of contaminants in soil and VADOSE/W to analyze the effect of environmental conditions on soil.

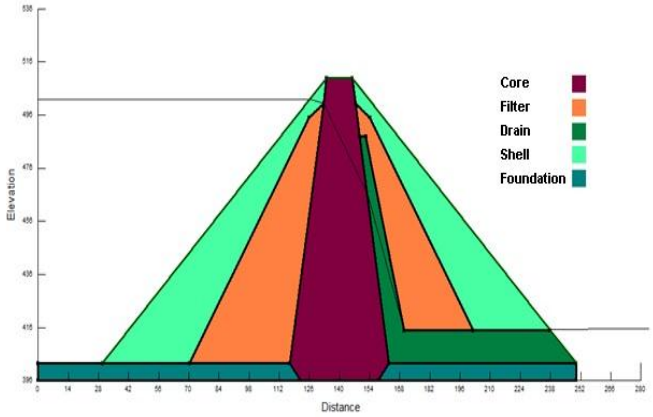

Fig. 2: Different parts of the dam with material definition

Results and discussion

Analysis of seepage flow rate through dam body

The flow rate and velocity vector in a cross section of the dam is illustrated in Fig. 3. The flow rate through the cross section of the dam, equal to 0.00295 cubic meters per second, was measured. Regarding to the considerable value, it is essential to take drastic measures to reduce the seepage rate.

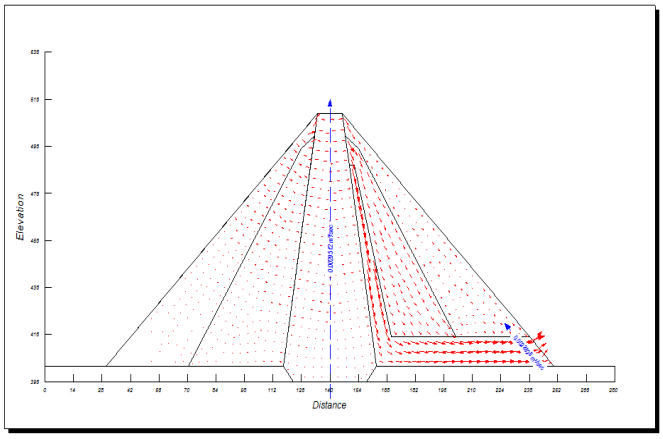

Fig. 3: The flow rate and velocity vectors through dam body

As it can be seen, Fig.4 displays 0.00288 cubic meters per second of seepage flow is transferred by downstream filter which approximately 97% of seepage flow transfers to downstream by this way and only about 0.00007 cubic meters per second of the seepage directly passes through the dam. This value is insignificant in such a dam.

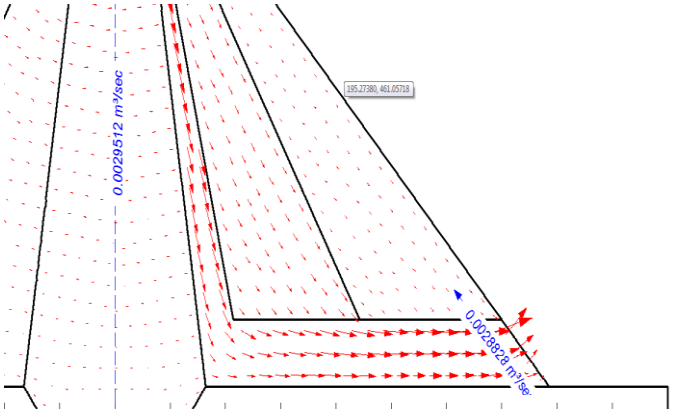

Fig. 4: The flow rate and exit velocity vectors

Strategies for reducing seepage

In order to reduce the seepage of this dam, upstream blanket with a low permeability coefficient such as geomembrane materials can be used. Geomembrane materials are mostly composed of materials such as bentonite, clay soils, and high density polyethylene. Due to high concentration, geomembranes have a very low hydraulic conductivity.

These materials can have a long lifespan and show considerable flexibility against physical changes of the environment such as heat, extreme cold, and deformation of dam caused by subsidence as well as other environmental factors. Nowadays, the implementation of the blanket has an important role in sealing dams and the channels conveying water. Geomembrane materials with a thickness of 0.5 mm and the determined permeability coefficient can be used. It seems that by using the upstream blanket, the seepage rate through dam body is significantly reduced and the phreatic line extremely lowered.

Another suggestion of this study to reduce the rate of dam leakage is a concrete blanket on upstream slope of the dam which would be more economically cost-effective. The coefficient permeability of concrete is very low and it has unchanged and high strength structure. It seems that when phreatic line intersects the concrete layer, it is extremely lowered as compared to other situations.

Analysis of pore water pressure thorough dam body

The rate of pore water pressure of dam body in isobaric lines is shown below (Fig. 5). The rate of pore pressure is negative and water movement in this area is affected by soil suction force and capillary rise of water.

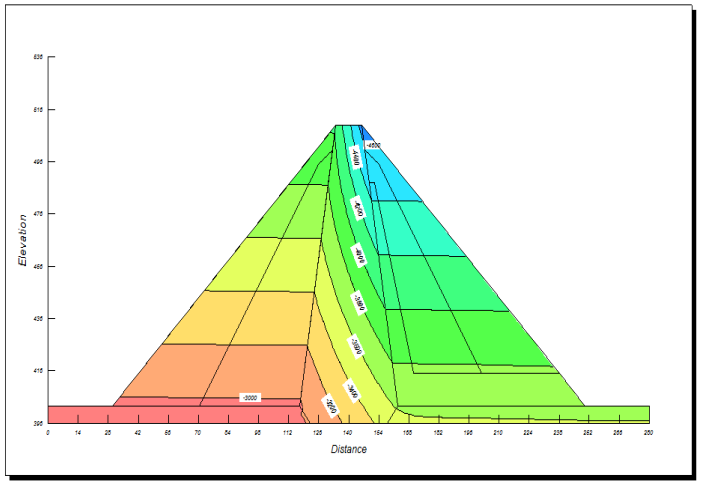

Fig. 5: Lines of pore water pressure in dam body

The following Figure (Fig. 6) illustrates the relationship between the pore water pressure and the height of dam. This figure is obtained from the core center of the dam. As moving from dam foundation to the crest of dam the pore water pressure reduces like a square function.

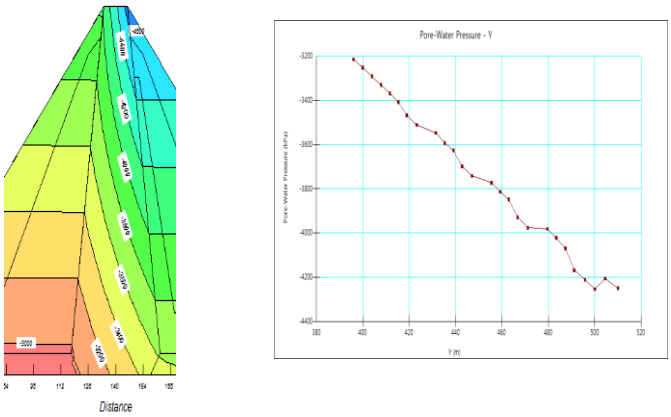

Fig. 6: The pore water pressure in dam core

Investigating flow lines in dam

The following Figure (Fig.7) illustrates flow nets which obtained from equipotential lines and flow lines. Because of the unique shape of the layers in dam body and difference between permeability of equipotential lines and flow lines, the flow net can be seen as squares in core and as rectangles in upstream and downstream shells.

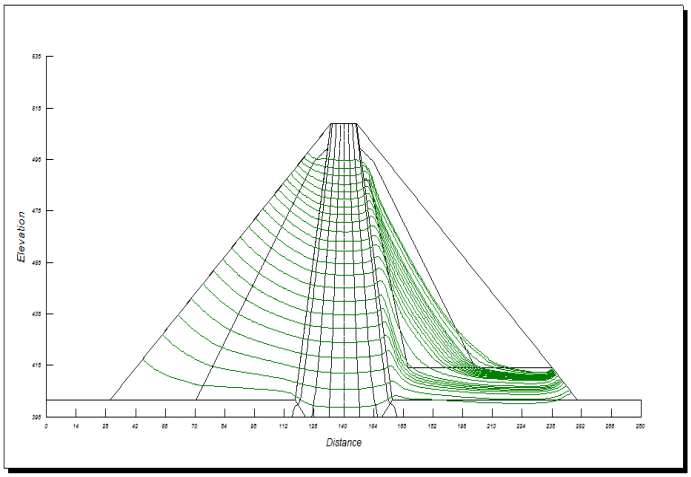

Fig. 7: Illustration of flow net in dam body

Investigating the pressure gradient in dam body

The pressure gradient in dam is illustrated in Figure below (Fig.8). Regarding their values, the pressure difference between upstream and downstream of the dam shows the effect of core on reduction of pressure flow. The pressure of downstream and upstream is 35 and 95 meters respectively which is reduced about 60 meters.

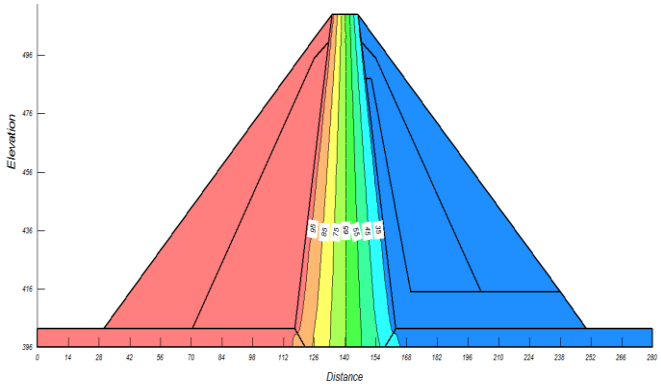

Fig. 8: The pressure drop gradient between upstream and Downstream

Investigating flow velocity through the dam body

As can be seen in following Figure (Fig. 9), the flow velocity through body and downstream filter of the dam are shown. The velocity near the core is 0.000002 meters per second. As approaching to the last layer, the flow velocity will be gradually reduced, in addition; the seepage flow velocity reaches at 0.00022 meters per second in last layer.

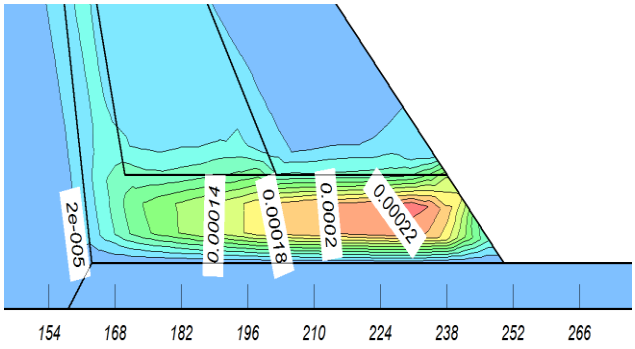

Fig.9: The seepage flow velocity exiting from the dam body

Conclusions

As seepage is a problematic issue in earth dams, this study attempted to investigate seepage effect on Jereh earth dam by Geostudio software through which using SEEP/W to do seepage analysis. Some strategies were proposed to reduce and control seepage flow rate. The following recommendations are suggested for further studies. It is recommended that other studies be carried out to investigate other earth dams by the given software. It is suggested that other researches apply different kinds of software as well as other numerical models to compare them with the aforementioned software. Moreover, it is hoped that further research be done to investigate slope stability, the effect of earthquake on Jereh dam and study the homogenous earth dams too.

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