Optimization of the Clay Core of Earth Dams with Regression Method

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ABSTRACT

In the optimal design for the core cross-section of an earth dam, the type of material, its dimensions, and its shape are very important. So with the least volume of materials, it has the greatest effect in reducing the amount of seepage from the dam body and maintaining its stability. The purpose of this research is to develop a model for optimizing the core geometry of Hajilerchai dam near Tabriz city based on the integration of the equations obtained from the simulation of seepage, hydraulic gradient, and stability reliability factor with the Simplex algorithm. In this study, two objective functions were considered, one is the volume of soil material per unit length of the dam and the other is the seepage rate from the dam body. Then, by defining 50 different sections of the core of the earth dam and using the results of numerical analysis of seepage regression relationships, stability coefficient and hydraulic gradient were obtained. To validate the regression relationships, the values of stability coefficient, hydraulic gradient, and seepage obtained from the optimal core model were compared with the results obtained from GeoStudio software models in three sections. This comparison showed a high correlation of about 99%. The results of the model developed to determine the optimal dimensions of the earth dam core were compared with the actual dimensions of Hajilerchai dam which indicated a reduction in the volume of materials required for the construction of the dam core by about 12%, which also provides the necessary stability.

KEYWORDS: Earth dams, Optimization, Hydraulic fracturing, Regression method, GeoStudio.

Introduction

One of the basic steps in the design of earth dams is stability and safety check under different conditions. Hydraulic failure is one of the important reasons for the deterioration of earth dams, which occurs for various reasons such as cracking, arching [1-2], and piping. The core of earth dams is important in seepage control from the dam body. Therefore, choosing the type of materials, dimensions, and shape of the dam core cross section is very important [3]. Since the core must be made of fine-grained materials due to the need for very low permeability, its shear resistance is inevitably lower than other parts of the dam body. Therefore, in terms of the stability of the dam, the thinner the core is, the better, on the other hand, the thicker the core of the dam, the greater its resistance to water leakage and internal erosion, and the risk of breach or cracks resulting from the differential settlement is reduced [4-5]. In addition, economic considerations are one of the most important factors in choosing the geometry of the dam core. Usually, the design of earth dams is done experimentally and based on the opinion of the designer. The use of different optimization methods in the problems of earth dams has attracted the attention of researchers in the last few decades [6-8].

Methodology

Regression equations

A regression model has been used to calculate seepage from the dam body in the optimization problem. This model was obtained based on seepage values calculated from 50 dam cross-sections with different geometries that have been analyzed by SEEP/W software by numerically solving the Laplace seepage equation. Equation (1) shows the flow rate per unit length of the dam:

$$\frac{q}{kl} = -21.933\frac{b}{H} + 2.234 \tag{1}$$

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where q is the flow rate per unit length of the dam (m^3/s.m), k is the permeability coefficient of the core (*m/s*), l is the height of the reservoir water (*m*), h is the height of the dam (*m*) and b is the crest width of the core (*m*). In the same way, equations (2) and (3) show the regression relation of the stability coefficient of the slope and hydraulic gradient:

$$SF = 1.975 - 0.169\frac{d}{x} + 0.003\frac{b}{y} \quad (2)$$

where d is the width of the core on the foundation (m), x is the width of the dam (*m*) and y is the crest width of the dam (*m*).

$$i = 2.42 + 0.97\frac{b}{l} - 2.08\frac{d}{l} \quad (3)$$

where i is the hydraulic gradient, d is the width of the core on the foundation (m) and l is the height of the reservoir water (*m*).

Objective functions and constraints

In this study, two objective functions are discussed. The volume of soil and the amount of seepage from the dam body. Also, two constraints have been considered as 1.5 for the safety factor against static stability[9] and the constraint of the hydraulic gradient, whose value must be less than the critical value.

Results and Discussion

Regression models were prepared using SPSS software to calculate design variables including seepage as Equation (1), stability factor as Equation (2), and hydraulic gradient as Equation (3). After determining the design variables as well as the objective functions and constraints, the optimization of the clay core dimensions of the earth dams was done in the Simplex space. To implement the program, the characteristics of the dam body materials and a series of known parameters such as the height and width of the dam core crest were used. The results obtained from the optimization program of the clay core dimensions of this dam compared to the actual dimensions of its clay core are shown in Table 1.

Table 1: Comparison of the optimal results obtained for the Hajilerchai dam with its actual dimensions

	Actual dimensions	Optimum dimensions
Crest width of the core (*m*)	4	3.5
Base Width of the core (*m*)	50	44
The slope of the core faces	1:4	1:4/6
Core material volume (m^3/m)	2565	2256

For example, the actual values of the crest width of the core have decreased from 4 meters to 3.5 meters and the width of the core on the foundation has decreased from 50 meters to 44 meters in the optimization model. This fact shows a decrease in the amount of soil required for the construction of the dam core by about 12%. Also, to validate the results of the research, the reliability coefficient values of stability, seepage, and hydraulic gradient were modeled and calculated once in the SPSS space and once again in the GeoStudio software. The comparison showed that the values calculated from the implementation of the program and the implementation of GeoStudio software models have a high correlation of about 99% and there is no significant difference between them as in Table 2.

Table 2: Pearson's correlation coefficient between the data calculated from the implementation of SPSS and GeoStudio model

Geostudio	SPSS	Model
0.991	1	SPSS
1	0.991	GeoStudio

Conclusion

The proposed method in this research is capable of optimal design of the dam core, and this method reduces the extra effort to achieve an optimal design and leads to a reduction in the time required for trial and error. In this method, while minimizing the size and volume of the clay core, the stability of the dam was also checked. Due to the mutual influence of different parts of a dam on each other, the reduction of core dimensions has affected different parts of the dam and has caused a reduction in their volume and implementation costs, which are important factors in choosing a plan and making it operational. The results show that the new regression model has a successful performance in estimating the amount of seepage, hydraulic gradient, and reliability factor of dam stability, under constant seepage conditions, and the existing optimization model can prepare the optimal clay core design for regional earth dams.

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