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EXTENDED ABSTRACT

Investigation of a Modeling-Based Framework for Optimizing the Cross-Section of Cored Earth Dams

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1. Introduction

Cored earth dam is one of the most widely used dams, the construction of which is highly accepted among dam designers. The construction of these structures is very expensive, so optimizing the cost of design and construction of earth dams can be so helpful.

Today, many optimization problems cannot be solved in practice with traditional optimization methods due to their large size and complexity. For this purpose, metaheuristic algorithms can be used, of which PSO is one. In the present study, the cross-sectional optimization of earth dams as the main part of the dam cost has been investigated by controlling the stability of slope in steady-state seepage condition.

2. Methodology

2.1. The process of finding the optimum cross-section of an earth dam

In this research, for optimizing the cross-section of an earth dam a finite element software was used to control the slope stability (Brinkgreve, 2006), a statistical software was used to formulate the stability reliability and finally a metaheuristic algorithm was used to optimize the cross-section of the earth dam. The flowchart of optimization of the present study for determining the optimum cross-section is shown in Fig. 1.

2.2. Specifications of Farrokhi-Qaen dam

Farrokhi-Qaen dam is an earth dam with a vertical clay core with a height of 19 meters from the riverbed, normal height of 14 meters, reservoir volume of 9 million cubic meters, crest length of 927 meters and crest width of 8 meters. This dam is in the north of South Khorasan province. The geometric characteristics of the dam are shown in Fig. 2 and the properties of the used materials are presented in Table 1 (Kavosh-peye-Mashhad Consulting Engineering, 2009).

3. Results and discussion

3.1. Selecting constant and variable design parameters

To optimally design the cross-section of earth dams, as shown in Fig. 1, it is necessary to first divide the required data into two categories: fixed and variable. Fig. 3 shows the variables required in the dam geometry to obtain the cross-sectional area of the dam. Some variables related to soil properties also include core internal friction coefficient (ϕ_{core}), core cohesion coefficient (C_{core}), dry specific weight of the core ($\gamma_{dry\text{-}core}$), wet specific weight of the core ($\gamma_{wet\text{-}core}$), dry specific weight of the shell ($\gamma_{dry\text{-}shell}$), wet specific weight of the shell ($\gamma_{wet\text{-}shell}$) and shell internal friction coefficient (ϕ_{shell}).

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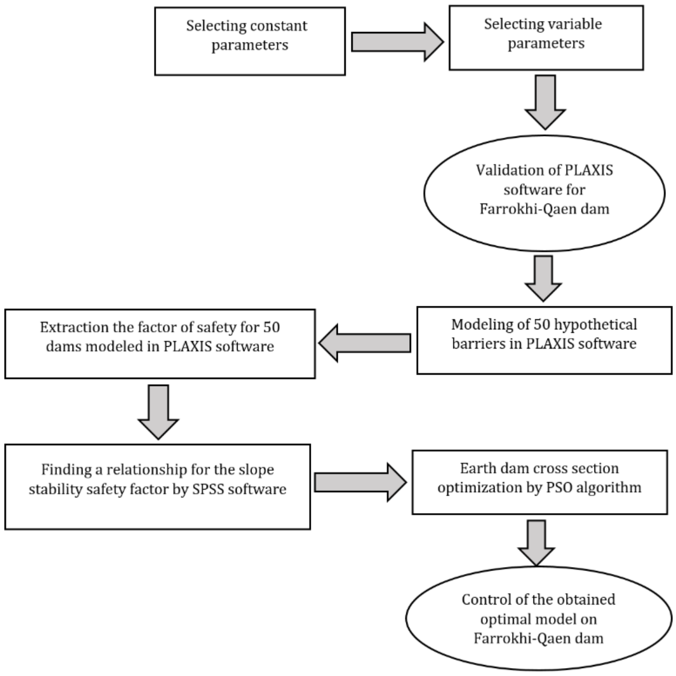

Fig. 1. The flowchart of optimization of the earth dam in the present study

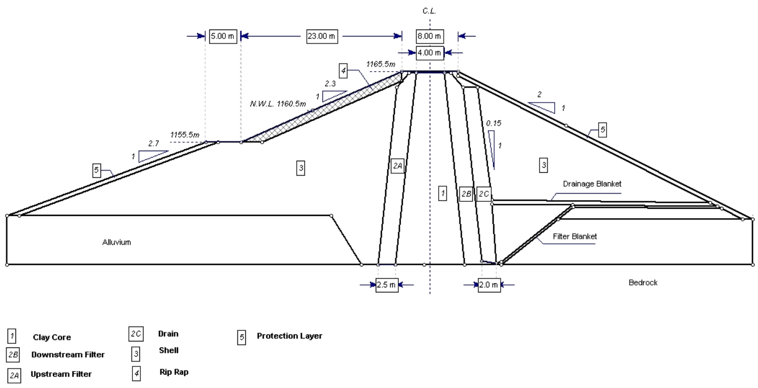

Fig. 2. Geometric characteristics of Farrokhi-Qaen earth dam (Kavosh-peye-Mashhad Consulting Engineering, 2009)

Table 1. Geotechnical characteristics of materials used in Farrokhi-Qaen earth dam (Kavosh-peye-Mashhad Consulting Engineering, 2009)

Layer	Internal friction angle ($\phi°$)	Cohesion(c) (KN/ m^2)	Modulus of elasticity (E) (KN/ m^2)	Saturated specific weight (γ) (KN/ m^3)	Wet specific weight (γ) (KN/ m^3)	Poisson's ratio υ
Clay Core	$\phi_{UU} = 0$ $\phi_{CU} = 21$ $\phi_{CD} = 22$	$C_{UU} = 42$ $C_{CU} = 45$ $C_{CD} = 45$	3000	21.2	20.5	0.4
Shell	41.5	0	30000	22.4	22	0.37
Filter	30	0	10000	21	20.5	0.35
Drain	32	0	10000	23	22	0.35
Alluvium	30	0	8000	21	20	0.35

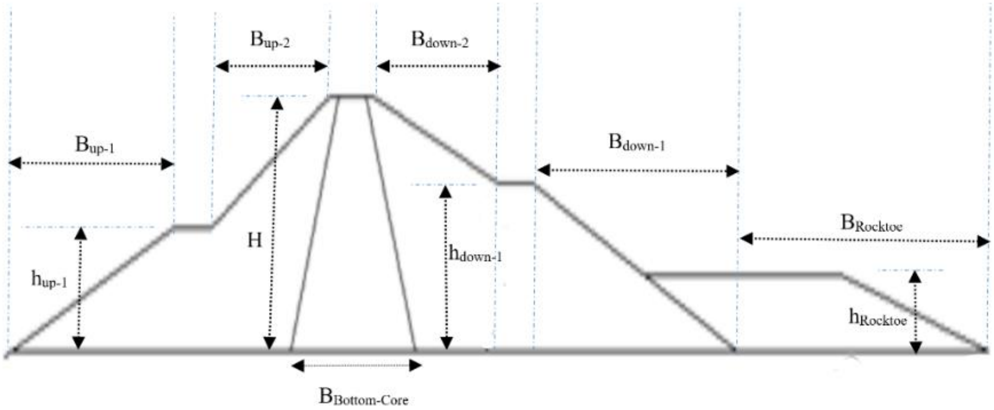

Fig. 3. Geometric variable parameters considered in the modeling process of the present study

3.2. Optimizing the cross-section of an earth dam

Initially, after validation of PLAXIS software for Farrokhi-Qaen earth dam and ensuring its proper performance, the factor of safety (F) under steady-state seepage condition were extracted for 50 hypothetical dam models, all of which had toe weight and berms. Next, in SPSS software, a mathematical model for calculating F as a linear function of the considered variables was obtained (Eq. 1).

$$F = -3.118 + (0.006.B_{up-1}) - (0.007.B_{up-2}) + (0.006.B_{down-2}) + (0.013.B_{down-1}) - (0.037.h_{up-1}) - (0.020.h_{down-1}) - (0.004.B_{bottom-core}) + (0.01.H) + (0.001.B_{Rocktoe}) - (0.001.h_{Rocktoe}) + (0.003.\phi_{core}) + (0.015.C_{core}) - (0.009.\gamma_{dry-core}) + (0.098.\gamma_{wet-core}) + (0.088.\phi_{shell}) - (0.083.\gamma_{dry-shell}) + (0.031.\gamma_{wet-shell}) \quad (1)$$

Then, using MATLAB software and implementation the PSO algorithm, the cross-section optimization of the earth dam was performed with the condition of controlling the slope stability of the dam. The objective function was to minimize the cross section of the dam (Eq. 2) and the variables included 17 main characteristics related to dam geometry and soil features.

Function Y=AREA (u)

$$Y = \left(\frac{B_{\text{up}-1} \times h_{\text{up}-1}}{2}\right) + (4 \times h_{\text{up}-1}) + \left(\frac{(h_{\text{up}-1}+H) \times B_{\text{up}-2}}{2}\right) + (B_{crest} \times \text{H}) + \left(\frac{(\text{H}+h_{down-1}) \times B_{\text{down}-2}}{2}\right) + (4 \times h_{down-1}) + \left(\frac{B_{\text{down}-1} \times h_{down-1}}{2}\right) + (B_{\text{Rocktoe}} \times h_{\text{Rocktoe}})\ ; \quad (2)$$

end

In order to ensure the stability of the dam slope, the constraint was entered into the optimization algorithm as a safety factor greater than 1.5. Also geometric constraints and constraints related to soil characteristics were applied based on the recommendations of reputable references so that the results obtained for the optimal dam have the characteristics of a real dam.

Finally, the optimal model was tested on Farrokhi-Qaen Dam. The results showed a 13% reduction in cross-sectional area and 138,000 cubic meters of optimal dam volume compared to the constructed dam.

4. Conclusions

In general, the research results can be summarized as follows:

- Using the information of the dams modeled in PLAXIS software as inputs of SPSS software, a linear mathematical relation can be created to calculate the stability safety factor of cored earth dams. The values of the error indicators obtained from the validation step showed the validity of the obtained equation and its generalizability.
- The PSO algorithm had an acceptable performance in optimizing the cross section of the earth dam.
- The generated model is used to optimize the earth dam at any height. It has the ability to extract the optimal cross-section variables of the earth dam.
- Using the obtained modeling framework to optimize the cross section of the earth dam for Farrokhi-Qaen dam was able to reduce the cross section of this dam by 13%, which indicates the efficiency and generalizability of the optimal model on any earth dam with a vertical core.

5. References

Kavosh-peye-Mashhad Consulting Engineering, “Study report on the construction of the dam and the irrigation and drainage network of Farrokhi-Qaen Dam”, Ministry of Energy-South Khorasan Regional Water Authority, 2009.

Brinkgreve R, “Plaxis: Finite Element Code for Soil and Rock Analysis (Users Guide)”, Balkema, 2006.