University of Tabriz

Journal of Civil and Environmental Engineering
Volume 54 (2024), Issue 1 (Spring), 201-210

EXTENDED ABSTRACT

Effect of Dimensions and Shape of Clay Core Section of Earth Dams on Reliability Coefficient of Hydraulic Failure

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Received: 04 February 2023; **Review:** 16 May 2023**; Accepted:** 07 June 2023

Keywords:
Earth dams, Hydraulic fracturing, Finite element, Impermeable core, Seepage.

1. Introduction

Hydraulic fracturing can occur in the fine-grained core of earthen dams. This phenomenon often occurs during the first water intake of the dam when the water pressure suddenly increases. Hydraulic fracturing in Erath dam has investigated laboratory by many researchers (Jaworski, 1981; Jian, 2022; Patel, 2017). In this research, the aim is to investigate numerically the phenomenon of hydraulic fracture and the effect of the dimensions and shape of the clay core section of the Hajiler Chai Dam (an earthen dam with impermeable clay core) located in East Azarbayjan province on the reliability coefficient of hydraulic fracture. For this purpose, first, using Geo-Studio, the phenomenon of hydraulic fracturing has been investigated in two sections in the middle of the core (A-A) and the upstream side of the core (B-B) of the dam for two types of materials CL and CH. Analyzes have been done in the stages of the end of construction, initial dewatering and steady state seepage, and the stages of dam construction have also been considered in the modeling. Also, the possibility of hydraulic fracture in thicker cores and the bottom of the core was also investigated. Finally, the reliability coefficient of hydraulic failure occurrence has been quantitatively calculated for each of the soils in stages and sections and with different criteria, and the suitable soil has been suggested for use in the dam core.

2. Methodology

2.1. Modeling

The modeling of this dam has been done in Geo-Studio software in two-dimensional form and in plane strain conditions. The analysis performed for this dam is Couple analysis of deformation and pore water pressure. The foundation of this dam is considered to be non-deformable. The dam shell is modeled elastically and the clay core of the dam is modeled fully elastic-plastic using the Mohr-Coulomb behavior model. Due to the high permeability of the shell material, it is assumed that pore water pressure will not be created in the shell during construction. In the following, 21 layers have been considered to simulate the staged construction of the dam.

2.2. End of the construction phase

At this stage of the analysis, because the reservoir has not yet been dewatering, unsaturated parameters and wet specific gravity are used for all materials. At this stage, because there is no water pressure for hydraulic

Publisher: Vice Chancellery for Research & Technology, University of Tabriz
DOI: 10.22034/CEEJ.2023.55246.2221
Online ISSN: 2717-4077
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cracking, there is no possibility of hydraulic failure. Therefore, this stage of analysis is done only to check the state of stresses and changes in the dam locations and in the state of total stress.

2.3. Initial dewatering stage and steady state

Considering that reservoir dewatering often takes place during a rainy season and on the other hand, the rate of dewatering creates undrained conditions in the core, with these interpretations it is useful to simulate the behavior of earthen dams in the initial dewatering analysis of core soil parameters. It is considered between UU and CD.

2.4. Hydraulic fracture criteria

Based on the simple tensile criterion, if the total stress in an element is at least (3 $\boldsymbol{\sigma}$) less than the pore water pressure (U) created in that element (U>3 $\boldsymbol{\sigma}$), it is assumed that hydraulic failure occurs in that element. The following experimental relationship shows the shear criterion of Ghanbari (2001) for predicting hydraulic fracture:

$$P_f = m\sigma_h + n \quad (1)$$

3. Results and discussion

The occurrence of hydraulic cracks in each element of the core of homogeneous earthen dams depends on the stress state of the mentioned element. Therefore, the presence of geometric heterogeneity, loading and materials are effective in this matter. According to the analyzes and graphs, it was observed that the probability of hydraulic failure is higher for CL soil than for CH soil. Therefore, CL soil should be selected as critical soil and CH soil as selected soil for the construction and implementation of the core. To ensure the correctness of the selected options as critical and selected borrows, the results obtained for these two borrows have been compared with the results of research by other researchers, including Fukushima (1986) and Satoh (2009).

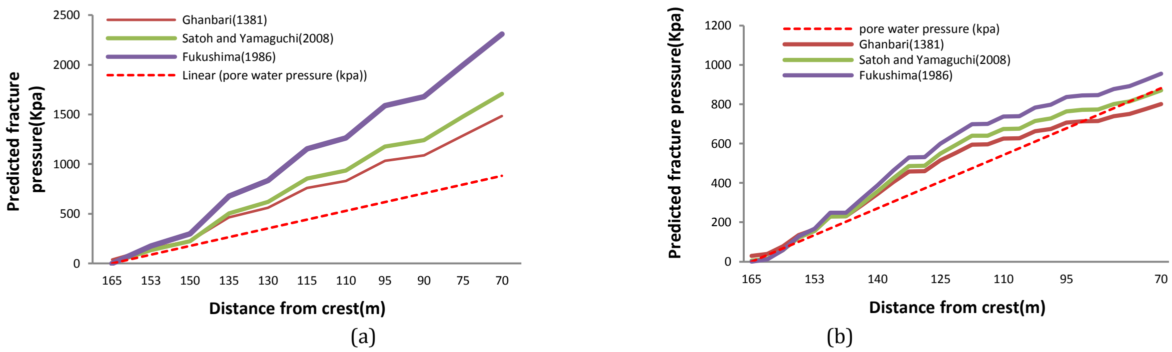


Fig. 1. (a) Comparison of hydraulic fracture pressure for CH soil in the stage of steady state in section A-A, (b) Comparison of hydraulic fracture pressure for CL soil in the stage of steady state in section A-A

As can be seen in the above graphs, for CL soil, some points downstream of the core are prone to hydraulic failure. While according to the criteria of other researchers, CH soil does not have much possibility of hydraulic failure. Therefore, taking into account the criteria of other researchers, CL soil is known as critical soil and prone to hydraulic failure, and its use in the dam core is not recommended.

In this part, for further comparison, the reliability coefficient of hydraulic failure occurrence is calculated based on the Ghanbari shear criterion for each of the soils in the stage of initial dewatering and steady state, and its average values are presented in Table 1. This reliability factor is actually the ratio of fracture pressure to pore water pressure and it is different for different soils in different stages and in different criteria.

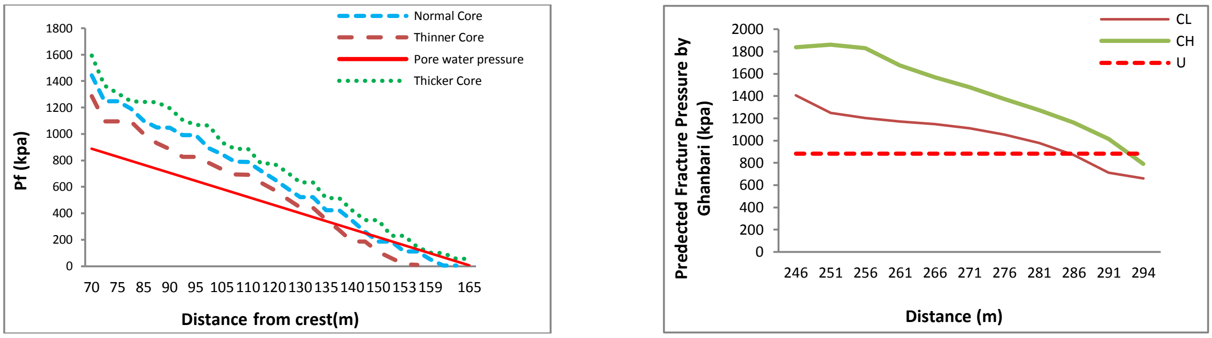
Table 1. Average values of reliability coefficient of hydraulic failure occurrence based on Ghanbari criteria (2001) for Hajiler Dam in Tabriz

Steady state		Initial dewatering		Soil type
Section				
B-B	A-A	B-B	A-A	
2.58	1.94	2.45	1.36	CL
2.7	2.04	2.62	1.73	CH

According to Table 1, it can be seen that the values of reliability coefficients in the initial dewatering stage are lower compared to the steady state and the probability of hydraulic fracturing is higher. Therefore, dewatering of the dam reservoir is the most likely time of hydraulic fracturing.

3.2. Investigating the effect of core geometry on hydraulic fracture pressure

In this section, by changing the geometry of the core, analyzes have been performed for thicker and thinner core than the main core for CH soil. According to Fig. (2-a), it can be concluded that with the thinnering of the core, the hydraulic fracture pressure will decrease and therefore the probability of hydraulic fracture will also increase. Also, in Fig. (2-b), the possibility of hydraulic failure for both CH and CL soils at the bottom of the core is presented based on the simple tensile criterion. As can be seen, a relatively significant part of the core floor for CL soil is prone to hydraulic failure. However, for CH soil, there is a possibility of failure at only one point in the downstream.



(a) (b)

Fig. 2. (a) Comparison of fracturing pressure (kpa) in the dam considering thinner and thicker core based on simple tensile criterion (CH), (b) Investigating the possibility of hydraulic failure at the bottom of the core based on the Ghanbari shear criterion (2009)

4. Conclusions

The comparison showed that in CL soil there was the highest possibility of failure and also the initial dewatering stage is more critical than steady state. The probability of hydraulic fracture rupture in the A-A section (middle of the core) is higher than in the B-B section (oblique line next to the core) for both CL and CH soils in the stage of initial dewatering and steady state. To ensure the correctness of the modeling work, the results obtained for critical soil (CL) and selected soil (CH) were compared using other criteria such as Fukushima (1986) and Yamaguchi (2009) and the results of this comparison also showed that the probability Hydraulic fracture in critical soil is more than selected soil. The comparison of the criteria used in predicting the hydraulic fracture pressure showed that in most cases the Fukushima criterion has the most optimistic results and the Ghanbari criterion has the most conservative results. It is noteworthy that the criterion of Sato and Yamaguchi (2009) does not give correct results for low stresses because the coefficient n is negative for fine-grained soils and in low stresses, the hydraulic fracture pressure is negative, which it's not correct. Also, the results showed that with the narrowing of the core, the hydraulic fracture pressure is reduced and therefore the probability of hydraulic fracture will also increase.

5. References

Jaworski GW, Duncan JM, Seed HB, "Laboratory study of hydraulic fracturing", Journal of the Geotechnical Engineering Division, 1981, ASCE, 107 (6), 713-732. https://doi.org/10.1061/AJGEB6.0001147

Jian CH, Kuaga Sheng ZH, Han L, "Laboratory investigation on hydraulic fracture propagation in sandstone-mudstone-shale layers", Petroleum Science, 2022, 19 (4), 1664-1673. https://doi.org/10.1016/j.petsci.2022.03.018

Patel SM, Sandergeld CS, Rai, "Laboratory Study of Hydraulic Fracturing by Ciclic Injection", International Journal of Rock Mechanics and Mining Science, 2017, 95, 8-15. https://doi.org/10.1016/j.ijrmms.2017.03.008

Satoh H, Yamaguchi Y, "Laboratory hydraulic fracturing tests for core materials using large size hollow cylindrical specimens", The International Symposium on Rockfill Dams, 2009.

Fukushima S, "Hydraulic fracturing criterion in the core of fill dam", Report of Fujita Kogyo Technical Institute, 1986, 22, 131-136.