The Joint Influence of Cavities Presence and Rapid Drawdown Condition on Discharge Rate through Earth Dams

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Abstract

Seepage measurement and control is one of the most significant considerations in designing and safety of earth dams. This numerical study aims to simulate the influence of cavities presence on seepage through earth dams taking into account rapid drawdown conditions. A series of two-dimensional finite element models were analysed using PLAXIS 2D software to examine the influence of various factors related to cavities which included (cavity shape and cavity position in horizontal and vertical directions). Hardening Soil and Mohr-Coulomb were adopted for modelling the behaviour of embankment and sub-soil. A single cavity in various position and depths in the subsoil of upstream and downstream slopes was considered in these simulations. The results of the analyses showed that the existence of cavities beneath the upstream side considerably increases the discharge rate through earth dam compared to their existence beneath downstream. The results of the numerical simulation also indicated that variation of the location of the cavities in the horizontal direction is more effective than the changes in position in the vertical direction, as well the cavity shape has an insignificant effect on flow rates through the dam.

Key words: Earth Dams, Seepage Analysis, Cavities, Finite Element, PLAXIS 2D.

1. Introduction

In recent years, computer software adopting numerical methods have been widely used for modelling different leakage conditions in dams. PLAXIS 2D is a software based on the numerical solution method (Abhyankar and Bhole, 2011) is a powerful and easy to use finite element software designed to analyses two-dimensional problems of deformation and stability in soil and rock mechanics. The evaluation of the software began in 1987 at Delft University of Technology (Kahlström 2013). PLAXIS is utilized widely in different geotechnical engineering applications such as excavations, embankments and foundations, tunnelling, mining and reservoir geomechanics (Brinkgreve et al., 2018).

In the present investigation, the influence of the cavity presence on seepage through the earth dam model has been examined numerically beneath rapid drawdown condition using PLAXIS 2D considering the effect of horizontal cavity position, cavity depth and the cavity shape.

2. Finite element modelling

2.1 Modelling of the earth dam and the cavity

To evaluate the combined influence of cavities presence and rapid drawdown condition on seepage through an earth dam. The soil was modelled using a fine elemental mesh with fifteen-node triangular elements plane strain. The height of the considered earth dam model was 15m from the crest to the sub-soil, a crest width of 6m, subsoil depth of 20m and the inclinations of both the upstream and downstream were 1Vertical: 2.5 Horizontal. The height of the initial water level of the reservoir was 12m from the sub-soil thereafter it was speedily reduced to the level of 4m during 5 days for simulating rapid drawdown condition. Figure 1 depicts the geometry of the earth dam model and the schematic finite element mesh.

In this study, cavities were modelled using PLAXIS 2D code as idealized holes excavated away from the soil mass and assumed to have no lining. The seepage analyses were conducted using two types of cavities; circular and irregular cavity shape models. To study the influence of the cavity location the cavities were assumed in positions which varied vertically and horizontally in the sub-soil of the upstream side of the dam.

2.2 Material modelling

The Hardening Soil constitutive model and the Mohr-Coulomb (MC) model were utilized for modelling the soil of dam body and sub-soil respectively. Mohr-Coulomb is a perfect linear elastic-plastic model. Because it is easy to understand, simple and requires fewer soil parameters specified by simple tests, it is more commonly used compared to other models (Obrzud, 2010). The input parameters encompass, unit weight of soil (γ unsaturated $=17kN/m^3$ and γ saturated $=21kN/m^3$), Poisson's ratio ($v'=0.3$), cohesion ($C'=5\ kN/m^2$), angle of dilatancy ($\psi=5°$), internal angle of friction ($\phi'=35°$), coefficients of permeability in horizontal and vertical directions (k_x & k_y=0.01m/day), and the Young's modulus ($E'=5.0E4$) (Brinkgreve et al., 2018). Hardening Soil model has more flexibilities in modelling and encompasses more input parameters in soil modelling (Keyvanipour et al., 2012).

The Hardening Soil model is nonlinear elasto-plastic and its required input parameters include (γ_{us}=16kN/m^3 and γ_s=20kN/m^3), ν′=0.3, C′=25 kN/m^2, ψ= 1°, ϕ′=22.5°, (kx & ky=10.0E-4m/day), soil stiffness parameters include reference modulus of primary loading in standard drained triaxial test (E_{50}^{ref} =25.0E3 kN/m^2), reference modulus of primary loading in drained oedometer test (E_{ode}^{ref}=25.0E3 kN/m^2), reference modulus of unloading /reloading in drained triaxial test (E_{ur}^{ref}=75.0E3 kN/m^2) (Brinkgreve et al., 2018).

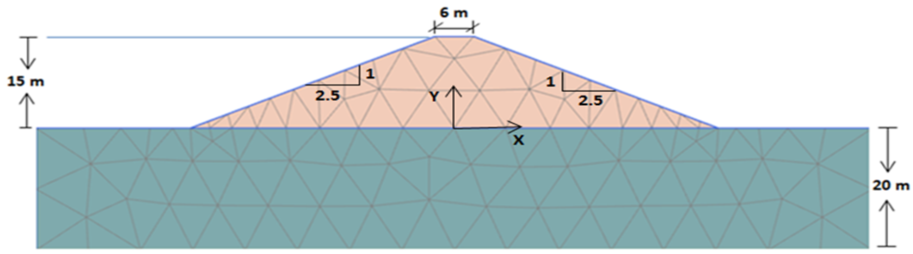


Figure 1: Earth dam model geometry and finite element mesh

3. Seepage Results and Analysis

3.1 Influence of existence and horizontal position of cavity

In order to investigate the influence of the variation of the cavity position in the horizontal direction on flow rate, eight horizontal positions of cavities were selected. These positions start from the dam centerline toward the end of the dam base and are 0, -8, -17, -20, -24, -28, -35 and -40m away from the centreline. The cavity horizontal position (X) is the horizontal distance from cavity centerline to earth dam centerline. The seepage analysis was implemented considering the existence of a single cavity model of the diameter of 60cm positioned at the depth of 1m in all considered horizontal locations.

Figure 2 reveals a comparison between the effect of circular and irregular cavities on the flow rate through the earth dams. The results showed that the presence of circular cavity at location L2 (-8, -1) led to a great increase in the flow rate 459.2*10^{-3}m/day compared to 2.58*10^{-3}m/day for a cavity-free model. Generally, the increase in the flux rate ranged from 3.05*10^{-3}m/day to 26.4*10^{-3}m/day for locations L8 (-40, -1) and L1 (0, -1) respectively. It is worth mentioning that this impact decreases as the cavity position becomes closer to the end of the dam base toward the location L8 where the flow rate in this location amounted to 3.05*10^{-3}m/day compared to 2.58*10^{-3}m/day in the case of absence of cavities.

It is seen from the results that presence of irregular cavities considerably increases the flow rate, the flow rate increased from 3.127*10^{-3}m/day for the model without cavities to 579.4*10^{-3}m/day for the model with a cavity at location L2 (-8, -1). As it is clearly indicated by the results, the influence of cavities is associated with their horizontal position where the flow rate values range from 3.532*10^{-3}m/day to 579.4*10^{-3}m/day for models with a single cavity at locations between L8 and L2. The results also showed that the flow rate reduces as the distance between the dam centerline and the cavity centerline increase. The comparison indicated that the cavity shape has an insignificant effect on flow rates at all studied locations with the exception of location L2 (-8, -1) in which the flow rate increased by 26.17 % when using an irregular cavity model compared to a circular cavity model with equivalent cross-sectional area.

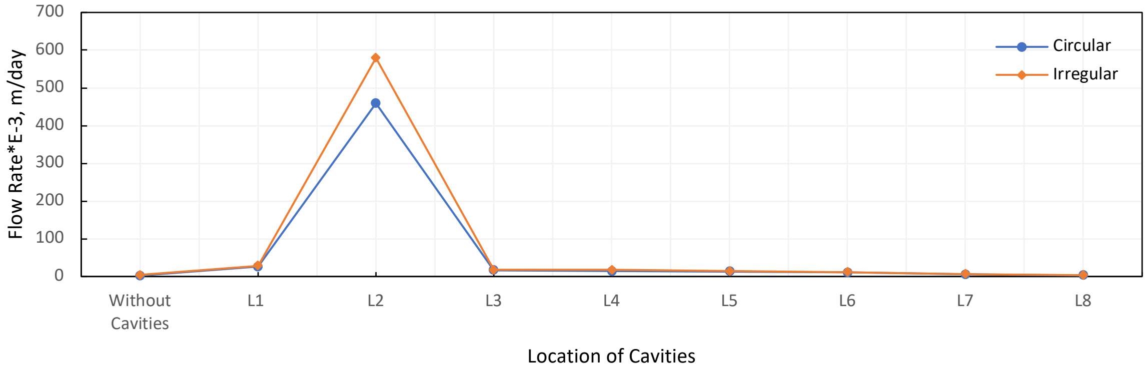


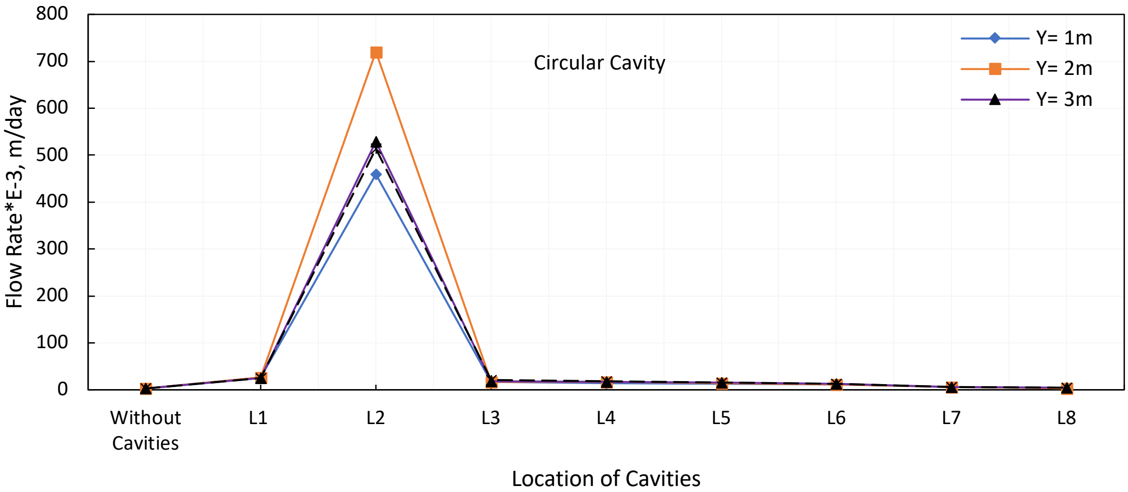
Figure 2: Comparison between the effect of presence of circular and irregularly shaped cavities in various horizontal positions and at the depth of 1m

3.2 Influence of cavity depth

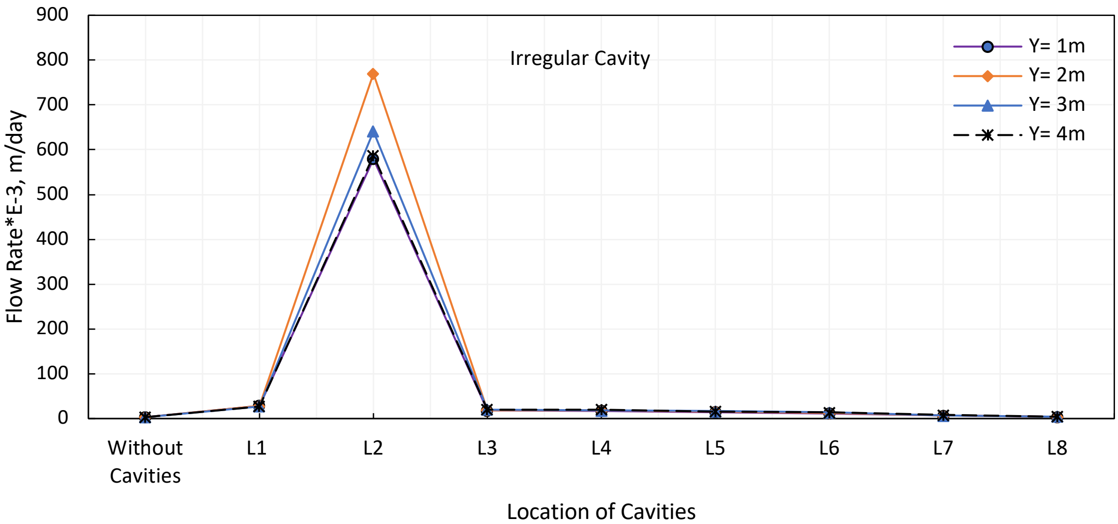
To assess the influence of cavity depth on seepage through earth dams four depths for cavities were selected in the sub-soil of upstream Y= 1m, 2m, 3m and 4mkeeping the same horizontal cavity positions as presented above. Cavity depth (Y) is the vertical distance from the dam base to cavity centreline.

The results presented in Figure 3a exhibit the influence of depth of the circular cavity on the flow rate. As shown, the flow rate values increase slightly with increasing cavity depth from 1m to 4 m. E.g. at locations L3 and L8 the flow rates increase from 15.47*10^{-3}m/day to 19.13*10^{-3}m/day and from 2.81*10^{-3}m/day to 4.16*10^{-3}m/day when the cavity depth changes from 1m to 4m respectively. This increase is more significant when the model contains a cavity situated at location L2, where the flow rate value increases from 459.8*10^{-3}m/day at the depth of 1m to 721.2*10^{-3}m/day at the depth of 2m and then reduces to 527.5*10^{-3}m/day at the depth of 4m.

Results in Figure 3b indicate the influence of depth of irregularly-shaped cavities on the flow rate. It is clear that the flow rate values increase somewhat with increasing cavity depth from 1m to 4m for all horizontal positions except positions X1(0) and X2 (-8). In X1location there is a slight decrease in flow rates from 28.92*10^{-3}m/day to 27.3*10^{-3}m/day with increasing the depth, whilst the flow rate increases from 579.4*10^{-3}m/day to 769.9*10^{-3}m/day then reduces to 587*10^{-3}m/day as the depth increases to 2m and then to 4m. It is clear that the horizontal cavity position is more influential on seepage rate through the earth dams compared to cavity depth.



(a)



(b)

Figure 3: Flow rate vs. location of cavities for a: circular cavity model, b: irregularly-shaped cavity model at various depths

4. Conclusions

Influence of cavities in terms of shape, horizontal position and depth on seepage through earth dams has been studied in the current investigation. Based on the results presented, the following key conclusions can be drawn:

- Presence of cavities in the sub-soil of an earth dam during rapid drawdown condition considerably increases the flow rates through the dam.
- Variation of cavity position horizontally significantly affects flow rates whilst relocation in the vertical direction does not seem to be as influential.
- Effect of the presence of cavities becomes less considerable on flow rate as the horizontal distance between the cavity centerline and the dam centerline increases.
- An increasing vertical distance between the centerline of the cavity and the base surface of the earth dam seems to have a smaller influence on the flow rate, even though with increasing the cavity depth, flow rate through the earth dam still increases.
- The cavity shape has an insignificant effect on flow rates through the dam.
- The horizontal cavity position (in X-direction) is the most effective factor on the seepage among all the studied factors in this research.

References

- Abhyankar, S.P. and Bhole, S.D., 2011. Application of FEM in Civil Engineering applications. International Journal of Earth Sciences and Engineering, 4 (6) SPL, 2011, pp.748-751.
- Brinkgreve, R.B.J., Kumarswamy, S.M, Swolfs, W.M. & Foria, F. (2018). PlAXIS finite element code for soil and rock analysis. Delft University of Technology & Plaxis bv, The Netherland.
- Obrzud, R. F. (2010). On the use of the Hardening Soil Small Strain model in geotechnical practice. Numerics in Geotechnics and Structures, 15-32.
- Kahlström M (2013). Plaxis 2D comparison of Mohr-Coulomb and soft soil material models.
- Keyvanipour, M., Moharrampour, M., & Faghih, S. (2012). An Evaluation and Comparison of Bar Embankment Behavior with Instrumentation Data and Software PLAXIS. In International Conference on Environment Science and Engineering, Singapore (pp. 197-200).