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STEADY/UNSTEADY FLOW THROUGH SMALL EARTHFILL DAMS

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Abstract

Small earthfill dams, without permanent water storage, are simple operation constructions without any outlet operation or control systems, and which provide water storage in flood wave periods. From the seepage point of view, these simple constructions have a specific complex behavior. Even if generally the body of the dam can be considered to be homogeneous, infiltration through partially saturated materials is unsteady. The water level rapidly increases from the minimum to the maximum level as the water storage volume is relatively low.

Keywords*: small dam, unsteady, unsaturated soil, seepage.*

1. Introduction

The present paper investigates small earthfill dams without permanent water storage, and built of homogenous soil on a permeable foundation of the same material.

The definition of small dams can be given according to the formulation of the French ICOLD [1], accepted in 2011 (**Figure 1**):

$$2.5 \text{ m} < H < 15 \text{ m} \quad (1)$$

and

$$H^2\sqrt{V} < 200 \quad (2)$$

According to this, the definition of small dam does not necessarily mean small height: the volume of the resulting water storage has to be considered as well. There exist small height dams which, due to the high volume of water stored can't be categorized as small dams. In the present paper the small dams are analyzed based on the following:

– in case of small dams, the flood waves last short periods of time;
– the level of water increases and decreases rapidly.

Infiltration is studied within these conditions, considering them unsteady (due to rapid variations of water levels) and the fill is considered in a partially saturated state. The rising time of water level is neglected, from empty lake, the water level is considered maxim from the beginning of the numerical simulation and stays constant while the water starts seeping.

The purpose of the study is to determine the time necessary for these infiltrations to become steady.

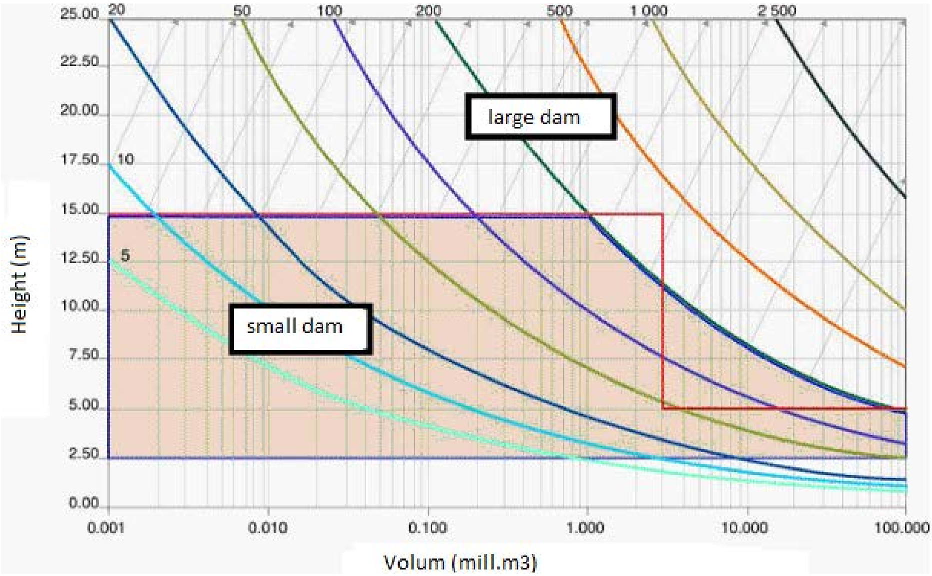

Figure 1. *ICOLD definition of a small dam* [1].

Accepted hypotheses: When the dam is completely empty, the ground is considered fully saturated, while the damn body is considered unsaturated and the initial saturation of the fill is determined based on the retention curves, characteristic to each type of soil studied [2].

The water level will increase quickly to 0.5 meter below the dam crown and remains constant.

The general equation of seepage for unsaturated environment (Richards) is the following [3]:

$$\frac{\partial}{\partial x}\left(k_x(\psi)\frac{\partial \psi}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y(\psi)\frac{\partial \psi}{\partial y}\right)+$$

$$\frac{\partial}{\partial z}\left(k_z(\psi)\left(\frac{\partial \psi}{\partial z}+1\right)\right)=C(\psi)\frac{\partial \psi}{\partial t} \quad (3)$$

where $$C(\psi)=\frac{\partial \theta}{\partial \psi} \quad (4)$$

The hydraulic conductivity is the product of the relative and saturated permeability hydraulic conductivity. The relative permeability is determined based on the level of saturation, which depends on the pore water pressure. For initial conditions these can be derived based on the position of each node.

2. Calculation method

In order to solve the problem of seepage through unsaturated media it was necessary to choose a model for the permeability and retention characteristics: for water retention characteristics the model proposed by van Genuchten, and for the permeability functions the model proposed by Mualem [4].

Using "RETC" software [5] the following shape and flow parameters were obtained for the main soils used in our models:

CH
Fat clay
20% Clay; 40% Silt; 40% Sand
θ_R=0.0627; θ_S=0.4063
α=0.97; n=1.4966; m=0.3318
K_S=1.15x10^{-6} m/s

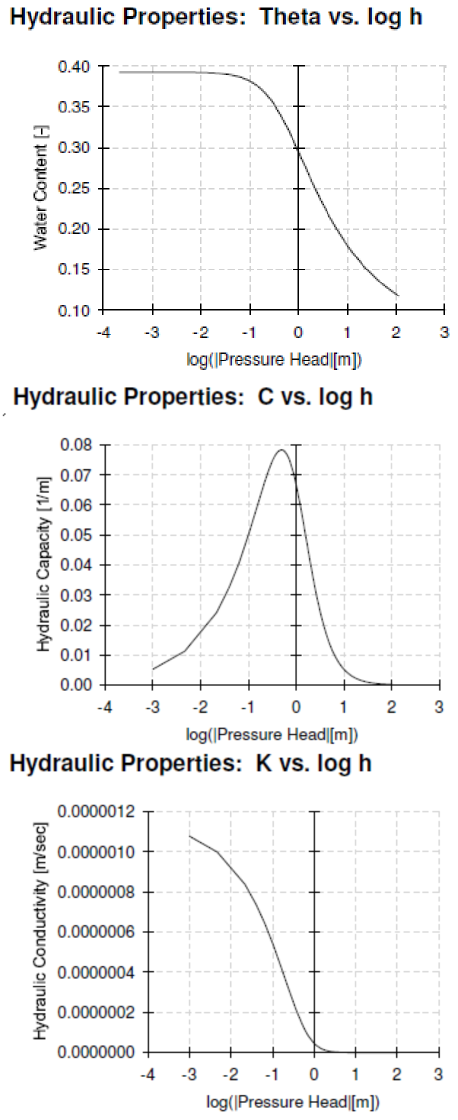

Figure 2. *Characteristic curves for fat clays.*

Characteristic curves and parameters for silty clays are as follows:

MH
Clay silt
35% Clay; 60% Silt; 5% Sand
θ_R=0.0937; θ_S=0.4862
α=0.92; n=1.485; m=0.3266
K_S=1.297x10^{-6} m/s

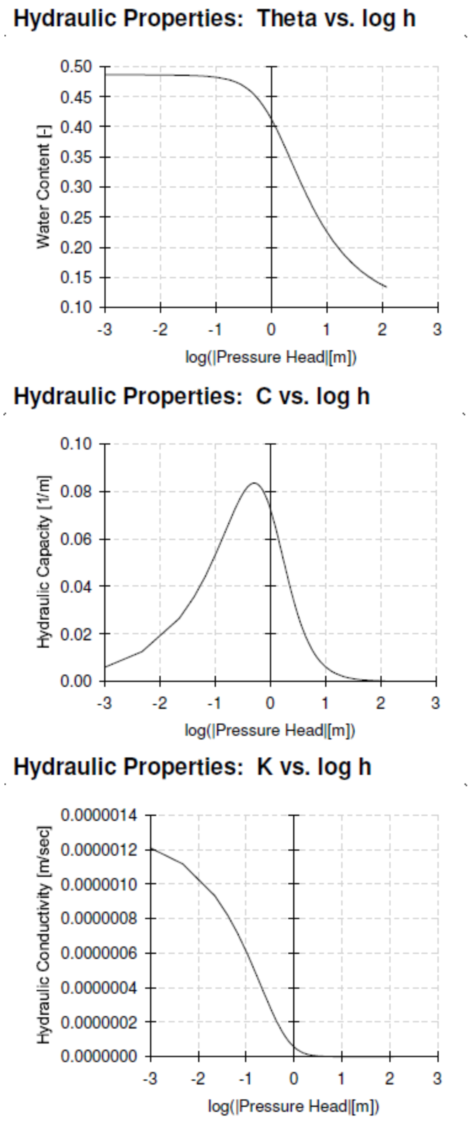

Figure 3. *Characteristic curves of clay silts.*

Characteristic curves and parameters for unsaturated sandy clay are as follows:

CL
Sandy clay
25% Clay; 20% Silt; 55% Sand
θ_R=0.0672; θ_S=0.3963
α=2.4; n=1.3348; m=0.2508;
K_S=1.416x10^{-6} m/s

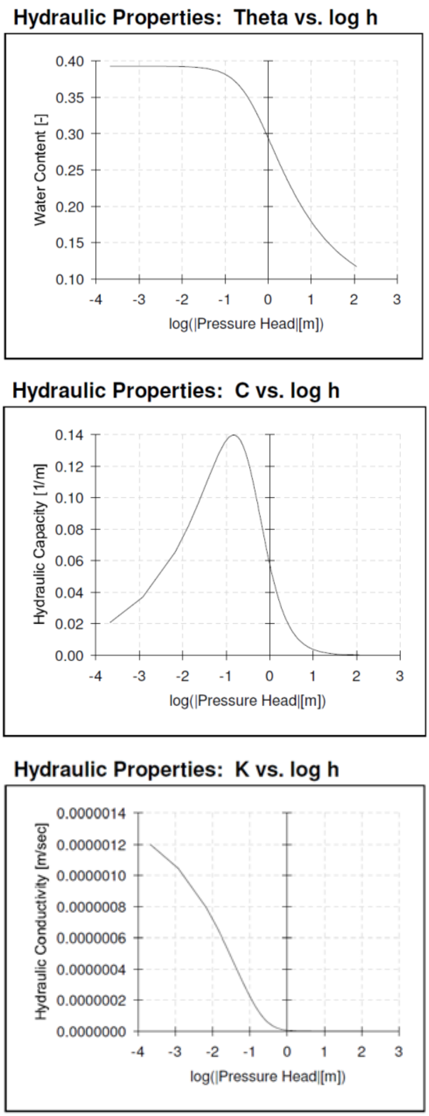

Figure 4. *Characteristic curves of sandy clays.*

Characteristic curves were obtained from databases based on the Van Genuchten-Mualem [4] equation:

$$k_r = S_e^l \left[1 - \left(1 - S_e^{1/m}\right)^m\right]^2 \qquad (5)$$

After the determination of calculation frame and parameters of soils, the characteristic cross-sections were identified. Three different types of dams were investigated for each soil type, with heights of 2, 5 and 10 meters. The crown width is dependent on the dam height, while the inclination is dependent on the soil type.

Table 1. *Slopes used in modeling.*

Type	Slope	
CH, MH	3.5:1	2.5:1
CL	3:1	2.5:1
SC, SM	2.5:1	2:1

The studied damns did not have drainage systems and the material of the dam's body was identical to the foundation soil. The calculation algorithm verified the time dependent variation of the infiltration curve at different points. A different, more time consuming approach for verifying the type of seepage would be to compare intermediate solution in each node with solution obtained in the case of steady seepage.

The seepage curve was determined for 24 hours, 4 days and 14 days from the beginning of investigations and can be seen in **Figure 5**.

By analysing the curve the time at which the flow becomes steady can be identified (**Figure 6.**).

It can be noticed that in the case of the 2 meter high dam, the seepage becomes steady only after 175 days. Here it must be emphasized that the variation of infiltration curve becomes very slow after 50 days.

In case of the 5 meter dam, the variation of curve lasts 600 days (**Figure 7**.).

In case of the 10 meter high dam the flow remains unsteady even after 1000 days. The levels determined by the piezometers situated at 25, 30 and 35 meter from the upper dam toe are represented on **Figure 8.**

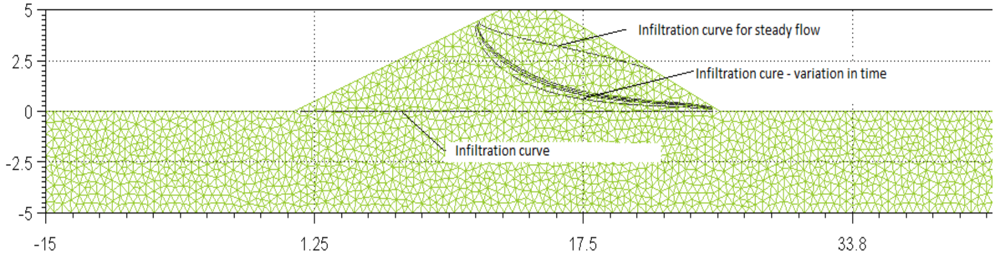

Figure 5. *Graphical representation of infiltration curves.*

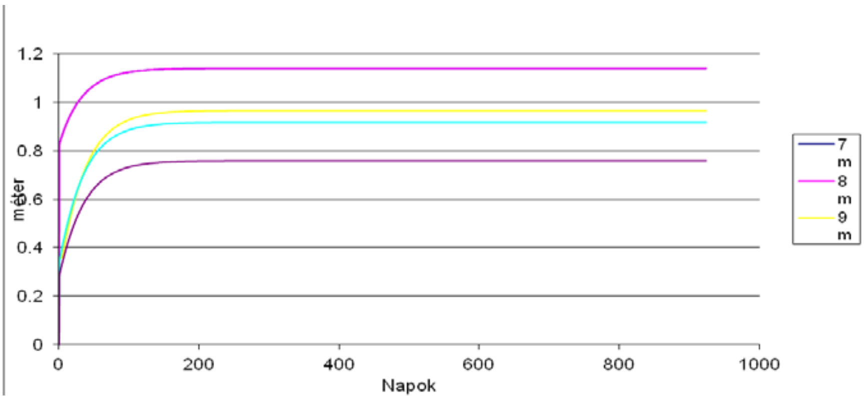

Figure 6. *Time dependent variation of the piezometric water level of the two meter tall clay silt dam at different distances from the upper damn toe.*

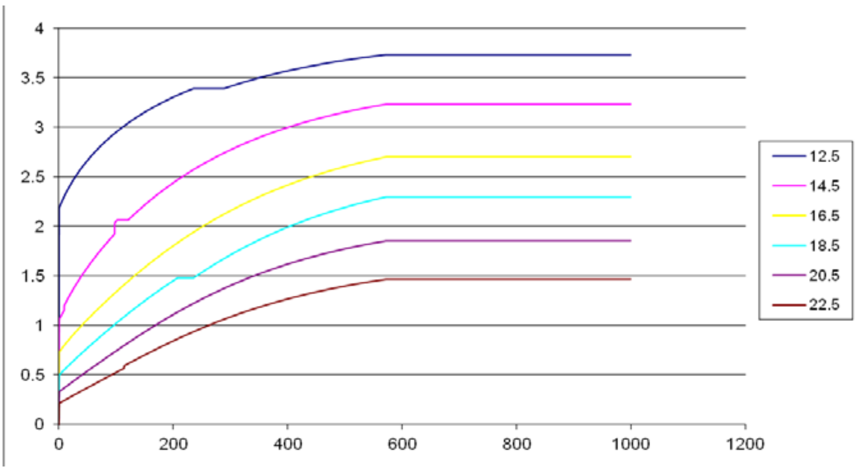

Figure 7. *Time dependent variation of the piezometric water level of the five meter tall fine silty sand dam at different distances from the upper damn toe.*

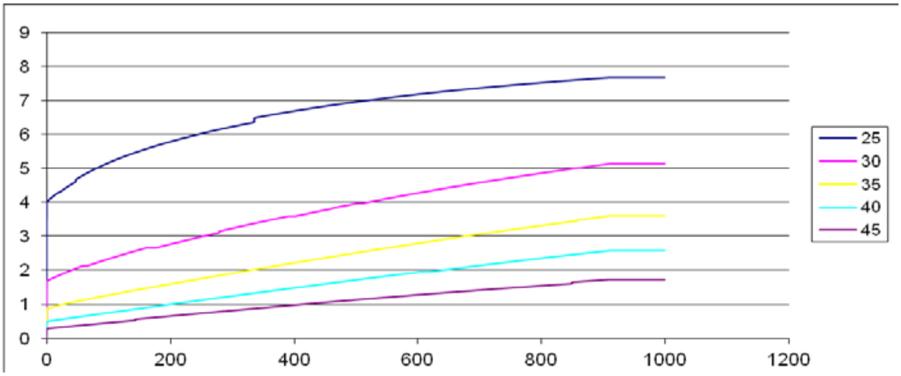

Figure 8. *Time dependent variation of the piezometric water level of the ten meter tall fine silty sand dam at different distances from the upper damn toe.*

3. Conclusions

Despite the fact that the position of the saturated zone is one of the main parameters in studies of slope stability for earthfill dams, it can be noticed that this is not applicable to dams without permanent storage independent of dam height or fill material.

In the case of flood waves, the infiltrations do not become steady in the critical period. The seepage curve should not be considered when calculating the sliding risk of slopes in case of dams without permanent storage. The infiltration curve does not depend on the maximum water level and only depends on the normal water level for small homogenous dams with permanent storage. Due to the low saturation level of the materials, the dam's body serves as a sealing element, which prohibits the raising of the saturated zone during short events such as floods.

In real operational conditions, the small dams with poor maintenance show a faster change of seepage curve due to cracks and rodent galleries. With proper maintenance of vegetative protection such behavior can be assured, which agrees with the experimental calculations performed in this study. The preservation of vegetation cover obstructs the fast drying of the fill materials and the spreading of rodents can be obstructed with the correct maintenance of the grass covers used for the slope's protection against rainwater erosion.

Bibliography

[1] French Committee on Dams and Reservoirs *Guidelines for Design, Construction, and Monitoring*. Coordinator Gerard Degoutte. ISBN 2-85362-448, 1997.

[2] Botoș M. L.: *Contribuţii la studiul comportării în exploatare a barajelor cu acumulări nepermanente în varianta transformării în acumulări permanente,* PhD thesis, "Politehnica" University of Timișoara, Timișoara, Romania, 2015.

[3] Leij F. J., Van Genuchten M. T.: *Characterization and measurement of the hydraulic properties of unsaturated porous media*. In: Proceedings of International Workshop, Characterization and Measurements of the Hydraulic Properties of Unsaturated Porous Media. (eds.: van Genuchten M.Th., Leij F.J., Wu L.) University of California, Riverside, CA, 1999, 31–42.

[4] Mualem, Y.: *A new model for predicting the hydraulic conductivity of unsaturated porous media*. Water Resources Research 12/3. (1976) 513–522.

[5] Van Genuchten M. T., Leij F. J.; Yates S. R.: *The RETC code for quantifying the hydraulic functions of unsaturated soils*. Res. Rep. 600 2.91 065. United States Environmental Protection Agency, Ada, 1991.