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THE STUDY OF INFILTRATION THROUGH A EARTH DAM BY DIFFERENT METHODS

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Abstract: Infiltration through porous media is a phenomenon which has many applications in civil engineering like: earth dykes for river regulation works, earth dams for different purposes, irrigation and drainage arrangements, dewatering in constructions etcetera. By unknowing the phenomena and governing laws huge damages can occur. This phenomenon is studied by groundwater hydraulic and it is applied for designing and maintenance of the water engineering works mentioned above. The infiltrations through porous media are well described in technical literature, being completed by field studies and in the last years, because of the huge progresses developed in the IT field, the numerical modeling is used. The present paper presents a specific case study of the infiltration through a homogenous earth dam. Theoretical issues, the governing equations and solving methods are presented. Usually, the specific equations are partially differential equations which by specific techniques to ordinary equations are reduced, suitable solving being represented by analytical or numerical methods. Also, the infiltration was studied in the department lab by a physical model. Both theoretical and lab results were compared and final conclusions accomplished.

Keywords: earth dam, infiltration, analytical, numerical and experimental methods

1. INTRODUCTION

The earth dikes (homogeneous or inhomogeneous) have multiple employments in the civil engineering field: irrigation and drainages, river regulation works, flooding protection, water supply, waste disposal sites, etc. The dikes constructed by local materials have the advantage of low cost of the transportation of the material but, the analysis of cost-benefits it must be taken into consideration the physical characteristics of the material, the foundation conditions and the economic importance of the arrangement.

Seepage and infiltration can occur through earth dams and the shape of free water surface is the so called infiltration curve. The influence of the infiltration through the earth dam is represented by the lost water (flow rate) and depending on the location of the infiltration curve on the downstream slope, means a risk on the stability of the dam. In the most of the practical cases in water engineering, the goal is to produce a small elevation of the infiltration curve on downstream slope. When this is even difficult to obtain, additional technical measures can be taken such as clay core, impervious screens, drainage systems, etc, in order to lowering the infiltration point on the downstream slope of the dam.

The study of the seepage and infiltration through a homogeneous earth dam can be carried out by analytical, numerical methods or even by lab experiences. In the present paper the analytical method represented by solution, the numerical method consisting in GEO-SLOPE model and, finally by lab experiences in the hydraulic lab department was performed. It can be mentioned than the order of the used methods for seepage and infiltration study was in reverse order regarding the method enumeration mentioned above. Based on the producer specifications of the experimental stand, ARMFIELD LIMITED, U.K., consisting in the characteristics of used material (sand) for the dam, in geometrical dimensions, limited values for upstream and downstream slopes, the same model was used for analytical and numerical studies as for the lab experiment.

For all used methods in the study, the most important parameter of the material is the permeability which can be measured in the lab, or, for extreme situations, its value can be considered based on the literature.

2. ANALYTICAL SOLUTION

In the groundwater hydraulics is impossible to use the general equations developed for current tubes like pipes or open channels. In this case it was necessary to introduce the concept of continuous media for porous media, in which the flow occurs through the whole volume of the material. Starting from this approach now is possible to apply the mechanical principles of continuous media, to continue with necessary mathematical considerations (material derivative, the derivative of a triple integral)

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[9] and, finally to obtain the general equations for the groundwater flow.
The first equation is the movement equation, so called Darcy's equation:

$$\vec{v} = k\nabla h \quad (1)$$

where:
-v- the velocity, $[LT^{-1}]$
-k- the material permeability, $[LT^{-1}]$
- ∇ -Hamilton's operator

$$\frac{\partial}{\partial x}\vec{i} + \frac{\partial}{\partial y}\vec{j} + \frac{\partial}{\partial z}\vec{k} = 0 \quad (2)$$

- h –water level reported to a specific datum, [L]

The equation (1) is a subject of mathematical demonstration, but was obtained based on lab measurements by Henry P. Darcy since 1856.

The second equation is the continuity equation:

$$\nabla \cdot \vec{v} = 0 \quad (3)$$

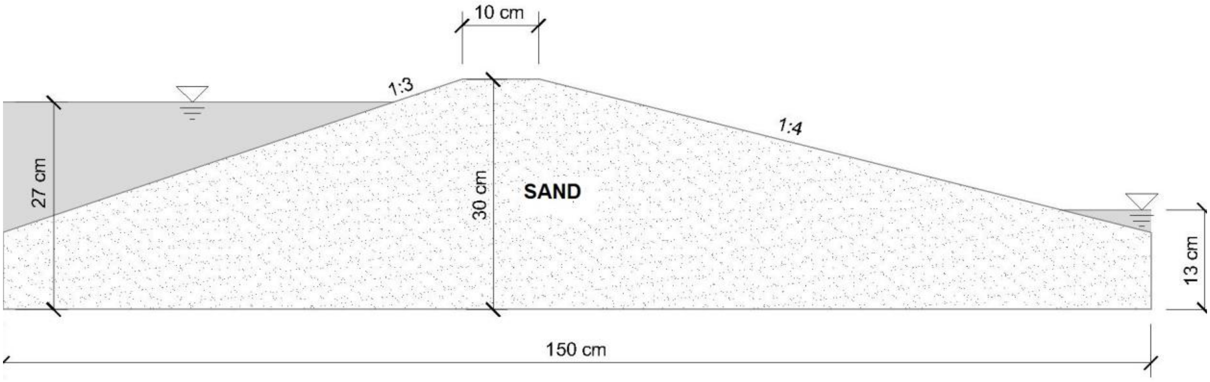

Figure 1. Cross section of the sand dam

By combining the equations (1) and (3), the general form equation for groundwater flow is obtained, useful in many engineering issues:

$$\nabla\left(k\nabla h\right) = 0 \quad (4)$$

In the case of 3D development, the equation (3) takes the extended form as follows:

$$\frac{\partial}{\partial x}\left(k\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial h}{\partial z}\right) = 0 \quad [5]$$

It must be mentioned than according to Duppuits's assumption [3] (plan horizontally groundwater flow), the last term of equation describing the vertical flow is neglected.

A specific dam constructed by sand is represented in the Figure 1, for which the following geometrical and material parameters can be taken into discussion as follows:
-the dam was constructed in the lab, so than the geometry is reduced at the small scale (dam elevation of 27 cm and 150 cm length at the bottom);
-both upstream and downstream slopes were established from stability restrictions in the case of saturated porous media, in fact the sand;
-for the homogeneous dam sand, a constant permeability was considered in value of 0.0001m/s based on literature [2, 9];
-the groundwater flow is considered as steady state, plane movement and laminar flow (so that Darcy's law is applicable), with constant water levels on upstream and downstream slopes, as boundary conditions;

The classical analytical solution for this case was developed by Pavlovsky [2,3] based on the analytical functions in terms of complex variables.

According to the Figure 2, the whole dam flow area was split in three different zones for which, the specific three equations are presented below:

Zone I:

$$\frac{q}{k} = \frac{H_b - d_0 - h}{n} \cdot \ln\frac{H_b}{H_b - h} \quad (6)$$

Zone II:

$$\frac{q}{k} = \frac{1}{2s}\left[h^2 - \left(h_0 + a_0\right)^2\right] \quad (7)$$

Zone III:

$$\frac{q}{k} = \frac{a_0}{m}\left(1 + \ln\frac{a_0 + h_0}{a_0}\right) \quad (8)$$

The fourth equation is given by geometrical conditions.

$$L = b + m\left[H_b – \left(a_o + h_o\right)\right] \quad (9)$$

In above equations the unknown parameters are:
H_b, s, a_0, and q.
One practical way to solve the set of four equations is so called graphical- analytical method [const].

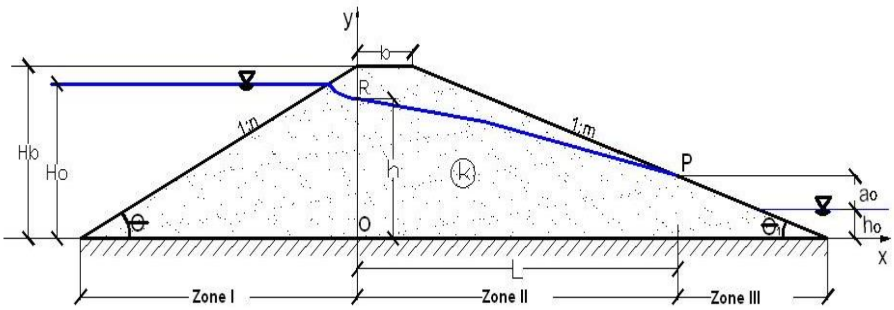

Figure 2. Hydraulic scheme in Pavlovski solution

The next notations/parameters can be introduced as follows:

$$s = b + m[H_b - (a_o + h_o)] \qquad (10)$$

$$A = 1 + \ln\frac{a_0 + h}{a_0} \qquad (11)$$

$$h = \sqrt{\frac{2sa_0A + h}{m} + (h_0 + a_0)^2} \qquad (12)$$

and two different functions $F_1(a_0)$ and $F_2(a_0)$ in term of the unknown parameter a_0:

$$F_1(a_0) = \frac{H_b - d_0 - h}{n} \ln\frac{H_b}{H_b - h} \qquad (13)$$

$$F_2(a_0) = \frac{a_0}{m} \quad A \qquad (14)$$

By intersecting the functions $F_1(a_0)$ and $F_2(a_0)$ in the graphic representation (Figure 3), the solution for a_0 parameter can be easely found, the rest of parameters being calculated by (10-12) relationships.

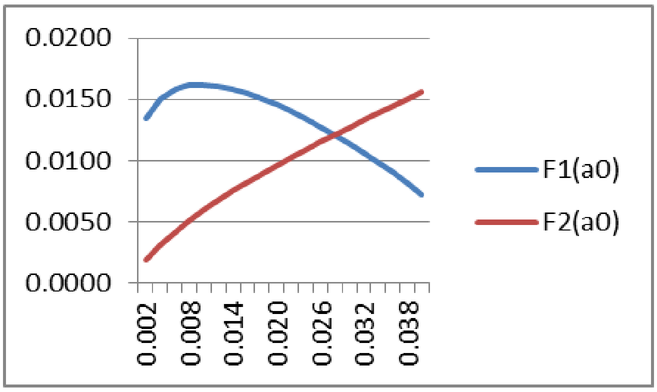

Figure 3. Graphical analytical solution

3. NUMERICAL SOLUTION

SEEP/W is a module of GEO SLOPE software [7], produced by GEO- SLOPE International Ltd., dedicated for seepage and infiltration through porous media analysis in the case of steady state flow, in situations covered by confined/ unconfined aquifers. In comparison with others models as Modflow [ ] most specific characteristic of the model is the possibility to take into consideration also the unsaturated flow.

The model is based of finite element method by using triangular or rectangular mesh elements in discretisation process which is automatic permitting refine the mesh in the points of interest.

A groundwater flow model with complex geometry can be the object of groundwater flow study, this geometry being created by a graphic editor (CAD product). The boundary conditions consisting in constant water head on downstream and upstream slopes (figure) was applied for the model.

As a material parameter, the hydraulic conductivity was set for whole flow domain in spide of the fact than in natural conditions, layer with fine or coarse sand can't exist.

After runing the model there an many possibilities to interrogate the results in terms of contour lines, head values and shapes, flow directions shown by vectors and values or, infiltration flow rate.

It must be mentioned than in this study the interest was focused on infiltration curve shape in order to compare it with the Pavlovsky solution and the results obtained in the lab experience.

As a results of modeling, the Figure 3. shows the infiltration curve and flow direction.

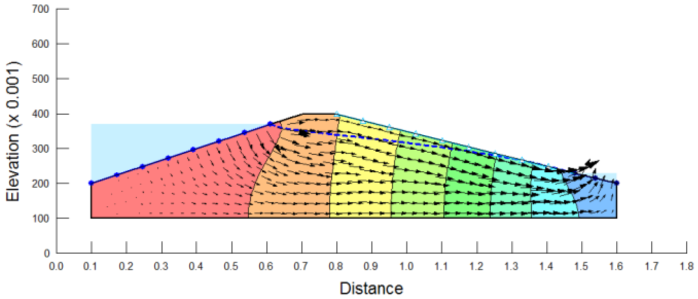

Figure 4. Results in the numerical solution

4. LAB EXPERIENCE

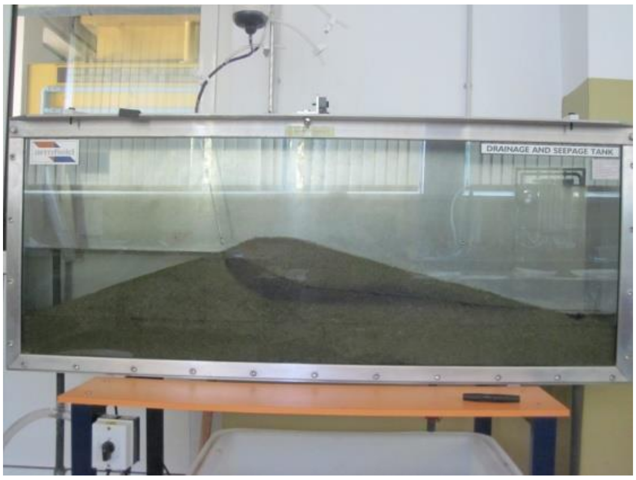

Figure 5. Lab experience with ARMFIELD

In the lab the studies were performed by using an ARMFIELD product [8], Figure 5. The bench consists in an acrylic tank which can be filled with different porous materials having various shapes and geometry. The tank is supplied with water in closed circuit by using a pump and two overflow located on upstream and downstream sides of the sand structure. On the upstream side of the constructed sand dam is possible to inject a colored dye from a high level reservoir and by this way to observe the infiltration process parameters (duration, shape of the infiltration curve, the location of the exit point from the dam). The goal of the study was to observe and register the infiltration curve shape on the front side of the acrylic tank.

5. CONCLUSION

As presented above, there are multiple ways to study the infiltration phenomenon in porous media: analytical solution, numerical modeling and lab studies. The results for a_0 parameter in the three solutions were: 2.8 cm (Pavlovsky), 3.2 cm SEEP/W and 2.2cm in the lab. Each of these solutions has its advantages and disadvantages, depending on input data, theoretical basis and user skills.

In the analytical solution the parameter with great importance on the results is the permeability of the material, knowing than in situ this parameter is not constant. Not in the last row, the experience and computational skills of the researcher have their effects.

In the numerical solution the most important aspects are given by knowledge on numerical methods and models modeling parameters with restrictions, convergence criteria, results interrogation. Even if these models are up to date techniques, the experience and skills in numerical modeling can be achieved after a long period practice.

In the lab studies the most important aspects is the scale of the model, knowledge in the physical models and similitude techniques.

These three different solutions revealed close results of the shape and infiltration parameters

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