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THE INFLUENCE OF THE INPUT DATA ON UNSATURATED HYDRAULIC SOIL PARAMETERS AND ON UNSTEADY SEEPAGE RESULTS FOR EARTHFILL DAMS

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Abstract: *Calculation of seepage on small earth fill dams inevitably involves modelling flow through unsaturated zones. The parameters that influence the flow through unsaturated environments are important for the rain water that seeps through the unsaturated slopes, or when we refer to unsteady flow with rapid variations of water level. Obtaining these parameters involves pricey and time consuming laboratory measurements. Different stages of calculations require different precision of seepage modelling. These parameters can be estimated using existing databases obtained over time, the results are influenced by the quality and quantity of input data available at the moment. The unsaturated hydraulic parameters can be predicted from previously estimated soil hydraulic parameters (the forward problem), from observed retention data and quantifying the hydraulic properties by simultaneous analysis of a limited number of soil water retention data points. The present paper shows differences in seepage calculations using different parameters obtained for three different input data.*

Key words: *unsaturated soils, parameter estimation, axis translation.*

1. Introduction

Earth fill dams are the most common types of dams all over the world. Designing earth dams involves some logical stages. The first step to identify the correct location for an earth fill dam is finding the right material to build with and on, meaning that we know the type of soil available on the site: fat clay, low or high plasticity clay, silty sand, clayey sand or high plasticity silt. Estimation of parameters influencing seepage for this type of input data is available using specialised software like RETC, Hydrus-1D [17]. This software is using existing databases created during long period of time in order to offer satisfying estimated results. With the first set of data engineers can estimate the shape of the cross section for the most economic type of dam. If the solution is earth fill dam, based on the geometrical recommendations available [11] we run the first estimations

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considering the seepage behaviour and stability calculations for the upstream and downstream slope. If the results are in the economic efficiency limits the initial study follows its path.

Next step the first geological tests are made and we can already know the content of clay, silt and sand, the bulk density, saturated permeability and a number of other strength related parameters. The designers can already make first estimations considering seepage behaviour, slope stability factors and shape the filling for the dam.

Moment when the construction starts, earth, which will be used can be tested on the field and number of compaction tests will be made in order to find the correct method of capacitation to obtain the estimated characteristics used in the designing phase. Samples can be tested in the laboratory in order to find the seepage characterising parameters [12].

After finishing the construction, the dam starts its operation stage; the behaviour of the filling is monitored using specific devices, placed in sensible sections of dam. If the results predicted in the designing and construction stages are not obtained, more tests are conducted regarding the exact characteristics of the earth fill [13].

The present paper will try to show the influence of available input data on the seepage behaviour. After the floods registered in Romania in 1970, large number of small dams [4], most of them earthfill [4], were raised in order to control and limit flow on small water streams. Being small height and with not important storage capacity, most of them were constructed with just a few calculations and many times using cross sections recommended [11]. Small dams are characterised by small storage and fast raising levels of water during floods.

The present paper shows some results obtained for such dam. All the calculations and tests are made on the Calinesti Oas homogenous earth fill dam. Raised between 1971-1973 the Calinesti Oas dam is situated on River Tur, 8 km upstream of river Talna; Tur, Valea Alba and Valea Rea are the main water sources for the lake. Dam is homogenous earth fill made of fat clays, 9.50 meters high, crest width of 4.40 meters and slopes of 1:3.5 upstream and 1:3 downstream. Maximum water storage capacity is around 20 million cubic meters. The dam's site is characterized by the presence continuous layers of fat clays of 4 to 5 meters laid over a thick layer of river deposits. Same material was used in the earth fill.

In this paper are analysing two of important floods recorded in the lake, in the year 1998 and 2001, trying to show if any difference on results of seepage calculations can be observed if the parameters for the conductivity and storage capacity for the material used are estimated or measured. The calculations of seepage curves were performed using MNPNS.exe software [3], and the post-processing of results using GMSH.exe [9].

2. Parameter Estimation

The equation of the unsteady seepage through unsaturated porous media is:

$$\frac{\partial}{\partial x}\left(k_x(\psi)\frac{\partial \psi}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y(\psi)\frac{\partial \psi}{\partial y}\right)= = C(\psi)\frac{\partial \psi}{\partial t} \tag{1}$$

For the definition of permeability functions are numerous examples in the scientific literature [1,2,5,6,14,15].

For the estimation of permeability function is used the Burdine model [6]:

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

where:
k_r - relative permeability;
S_e - the effective saturation defined as:

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \tag{3}$$

θ_s is the saturated moisture content and θ_r is the residual moisture content of the soil.

The relationship between pressure head and effective saturation derived from the van Genuchten model [15]:

$$S_e = \frac{1}{\left[1 + (-\alpha\psi)^n\right]^m} \tag{4}$$

For van Genuchten model the equation of specific moisture capacity becomes:

$$C(\psi) = \frac{\partial\theta}{\partial\psi}$$
$$C = (\theta_s - \theta_r)mn(-\alpha\psi)^{n-1}\left[1 + (-\alpha\psi)^n\right]^{-m-} \tag{5}$$

In order to run any seepage calculation with the available measured water levels in the lake for the major events recorded in the dam's section, all this parameters are needed. The saturated and unsaturated permeability and the unsaturated storage capacity must be measured or estimated for the existing soil in the dam and foundation.

Measuring in the laboratory these parameters is time consuming [10],[12], involves skilled personal and the results can be obtained with a number of direct or indirect methods. Many times is recommended the automated or semiautomated methods for this kind of slow process over long periods of times [13]. Based on the soil-water characteristic curve (SWCC) the indirect methods are offering satisfying results on the unsaturated conductivity or on the storage capacity. The SWCC can be used or estimated based on the grain size distribution, bulk density and void ratio [8], [17].

The parameters for unsaturated parameters for our study were obtained using RETC.exe software [17] for three different types of data:

1. Known type of soil in foundation and inside the dam: fat clay;

Earth fill: Fat clay
θ_r=0.068; θ_s=0.38; α=0.74;
n=1.09; K_s=5.55x10^{-7} m/s

2. Measured grain size distribution. according to a study conducted by the Polytechnic Institute of Cluj-Napoca in eighties, the dam's body filling is a mixture of clays in a proportion of 17.97%, 70.02% clayey silts and clay sands at a rate of 12%;

Earth fill: 25.5% Clay; 46.7% Silt; 27.8% Sand
θ_r=0.0743; θ_s=0.4314; α=0.74;
n=1.5338; K_s=1.51389x10^{-6} m/s

3. Measured SWCC for the material extracted from the dams body.

Two undisturbed probes were extracted from our dam in order to perform laboratory measurements. Considering the low estimated conductivity parameter the material was tested using falling column technique. The saturated conductivity obtained during the tests was 1.35x10^{-9} m/s. Axis translation was performed to obtain a number of retention points. We used pressure cells with HAE plates with the bubbling pressure of 3 bar.

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Fig. 1. *Pressure cell with 3 bar HAE*

Table 1

Pressure	θ	Pressure	θ
[bar]		[bar]	
0	0.413	0	0.458
0.70	0.300	0.30	0.345
0.90	0.289	1.00	0.264
1.40	0.266	1.50	0.249
2.00	0.246	2.00	0.225
2.50	0.209	2.50	0.200

The retention data was used in the RETC [17] software in order to fit the shape parameters m, n and α for van Genuchten and Burdine retention and conductivity functions.

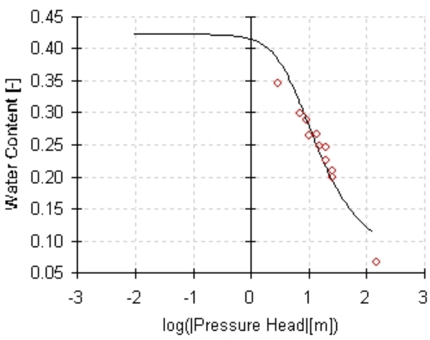

Fig. 2. *Retention data: θ vs. log h*

Results:

Earth fill:
$\theta r=0.068$; $\theta s=0.462$; $\alpha=0.1822$;
$n=1.649$; $Ks=1.35x10^{-9}$ m/s

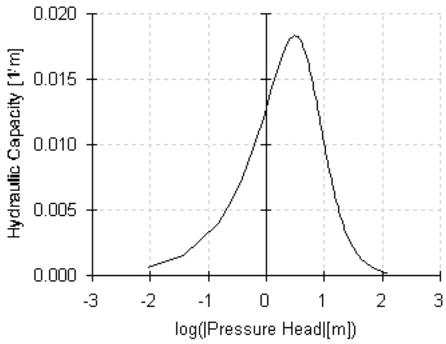

Fig. 3. *Hydraulic properties: C vs. log h*

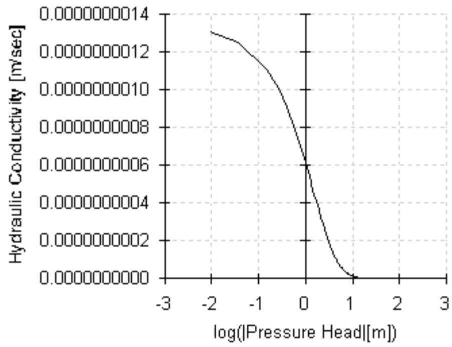

Fig. 4. *Hydraulic properties: K vs. log h*

3. SEEPAGE Results

Two major floods were analyzed according to the available data. The input was the water level measured during the floods recorded in year 1998 and 2001. The floods were considered following a long period of time before with levels of water close to normal operations condition. This detail will permit us to consider that initial seepage conditions are steady. The measured data at the piezometers could not be used in our study because wrong response caused by low permeability and faulty response.

3.1 Flood Wave Registered Between 14.06.-22.06.1998

The period preceding this flood is characterized by water levels in the lake close to the normal and not major changes in time. The water level in the lake recorded on 14.06.1998 is considered the level at which the seepage is steady.

During the study period the water level in the lake raised slowly over a period of six of days, from 142.43 to 145.05 meters maximum registered on 21.06.1998. This type of flood is recorded in the rainy periods of the year. June is known in terms of rainfall as one of the richest months. Boundary conditions used were the measured water levels in the lake for the upstream face and the downstream toe was considered drained (given that we have no water at downstream toe).

If at the downstream toe of the dam nothing changes during floods for the initial conditions, the difference on permeability shows some important changes at upstream slope, differences that can change substantially the stability factor for the upstream slope. The seepage curves obtained during the recorded flood are presented in the following figures and are numbered accordingly to the numbers used for the corresponding hypothesis used to estimate parameters.

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Fig. 5. *Recorded water levels. June 1998*

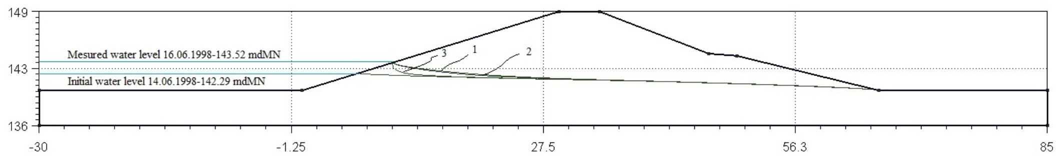

Fig. 6. *Seepage curves 16.06.1998*

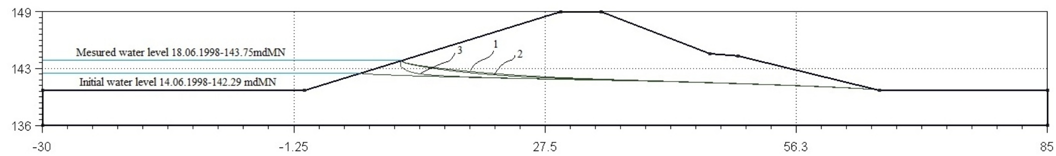

Fig. 7. Seepage curves 18.06.1998

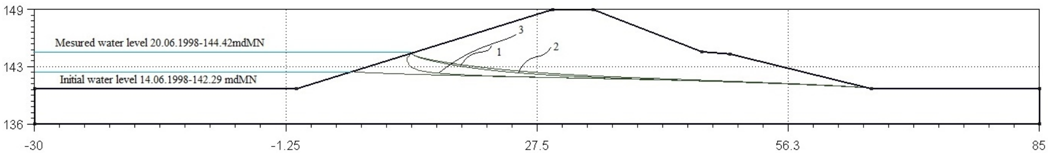

Fig. 8. *Seepage curves 20.06.1998*

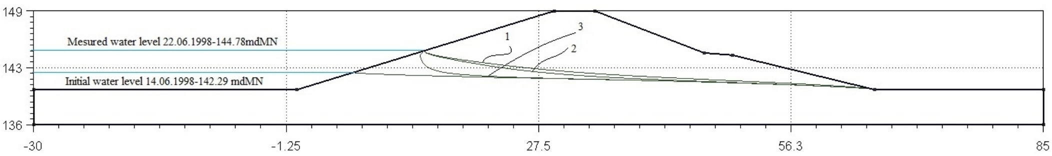

Fig. 9. *Seepage curves 22.06.1998*

3.2 Flood Wave Registered Between 02.03.-12.03.2001

The flood is characterized by a sudden increase during first two days from the normal water level value of the 146.11 meters, well above the warning level; followed by a slow decrease of water levels over a week.

Due the important variation of water level at the upstream face of dam, differences at the downstream toe for the seepage curves are also important in case of this flood. The stability of slopes in this case can be significantly influenced for the upstream downstream slope.

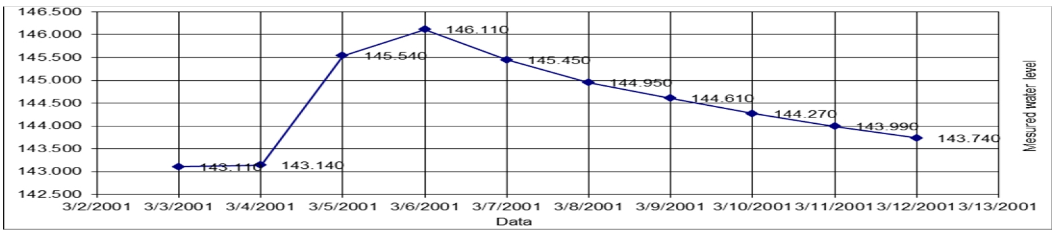

Fig. 10. *Recorded water levels. March 2001*

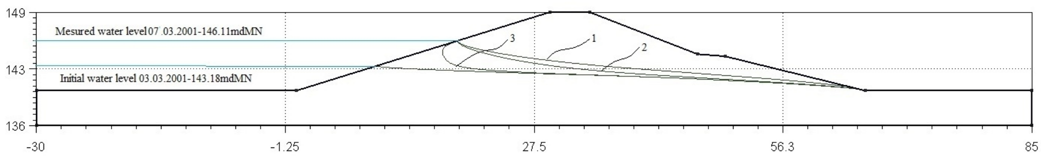

Fig. 11. *Seepage curves 07.03.2001*

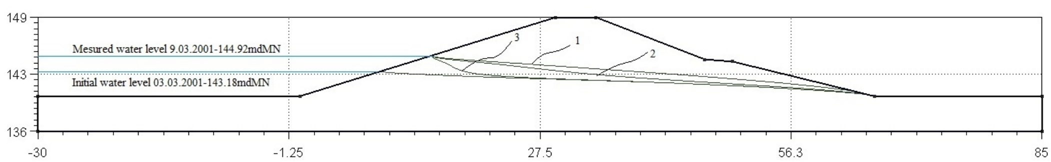

Fig. 12. *Seepage curves 09.03.2001*

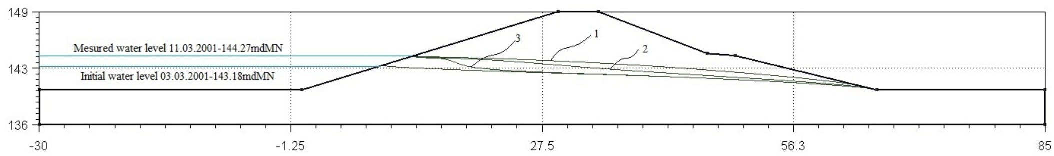

Fig. 13. *Seepage curves 11.03.2001*

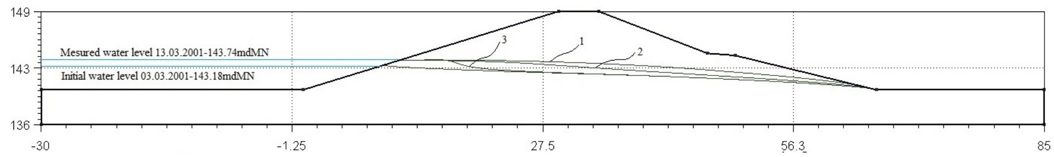

Fig. 14. *Seepage curves 13.03.2001*

4. Conclusions

The constant need of new water resources, exploiting the hydropower potential of river streams, tourism, fisheries, and financial constraints that we face, force us to become more creative, when it comes to find new places to make permanent reservoirs. In Romania a huge development potential is represented by dams built over time in order to attenuate flooding in the upper basins, dams with non permanent reservoirs. These dams have non permanent reservoirs and it is a category, which due to their small size somehow were neglected. Using of optimal design solutions according to new operating conditions will permit increased efficiency of such investment.

Small earth fill dams with permanent or non permanent lakes usually were designed using charts with recommended slopes and crest width. Even if luckily these small dams (constructed mostly after the 1970's floods) were designed considering seepage and slope stability calculations, seepage was considered steady so they slope stability reserve, and luckily this grows same time with the height of the dam.

Results are showing that using estimated parameters and not measured parameters for seepage analysis will lead to less favourable results when it comes to verify the stability of slopes, meaning that earth fill dams in operation have more safety reserve.

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