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# Investigation of the hydro-mechanical properties of silty sand material from Topolnica tailings dam

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**Abstract.** This paper describes the investigation process of the hydro-mechanical properties of a material used in 134.0 m high tailings dam construction. The grain size analysis classifies the soil as silty sand – by product from the mining process. The soil water retention curve was determined for wetting cycle using direct measurements of suction and volumetric water content. To describe the relationship between these two variables, the Van Genuchten hydraulic model was used. The unsaturated hydraulic conductivity was obtained with Mini Disk Infiltrometer. These results will be used for physical and numerical modelling of the tailings dam Topolnica. The study analyzes the slope stability of unsaturated soil triggered by high intensity rainfalls.

*Keywords: Hydro-mechanical properties; SWRC; Suction; Unsaturated hydraulic conductivity; physical model*

## 1 INTRODUCTION

The investigated soil is a by product from the copper mine and flotation Buchim, which is used for construction of Topolnica tailings dam near the city Radovis, Macedonia. With 134.0 m (654.0 m a.s.l) it is one of the highest tailings dam in Europe (Tanchev et al. 2013). The dam is constructed by method of pulp hydro cycling. Namely, a downstream dam is created from the sand and the spillway from the hydro cyclones is realized in the upstream deposit lake. Figure 1 shows a typical cross section of the Topolnica tailings dam.

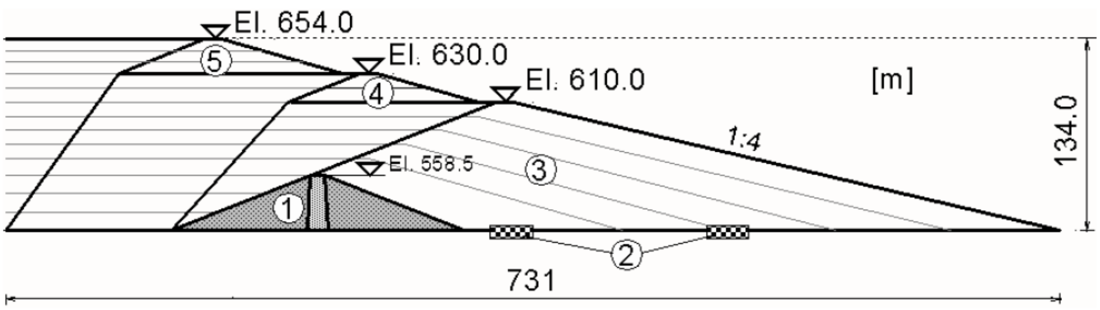


**Figure 1**. A cross section of Topolnica tailings dam. (1) Initial dam; (2) Longitudinal base drainages; (3) First phase sand dam constructed using downstream method; (4) Second and (5) Third phase sand dam constructed using upstream method;

Water movement through soil typically happens under saturated and unsaturated conditions. The hydraulic conductivity is the rate at which water moves through the soil under certain conditions and hydraulic gradients. Flow through an unsaturated soil is more complicated than flow through fully saturated pore spaces. Macro pores generally fill with air, leaving only the finer pores to accommodate water movement. Therefore, the hydraulic conductivity of the soil is strongly dependent on the detailed pore geometry, water content, and diferences in matric potential. (Rose 1966; Brady and Weil 1999).

The soil water retention curve (SWRC) provides a conceptual understanding between the mass (and/or volume) of water in a soil and the energy state of the water phase (Fredlund et al. 2012). It represents the relationship between suction (in kPa) and water content and constitutes the primary soil information required for the analysis of seepage, shear strength, volume change, air flow and heat flow problems involving unsaturated soils.

## 2 MECHANICAL PROPERTIES

Many laboratory tests have been made to determine the physical and mechanical properties of the soil according to the national standards. In this case around 128 samples were collected from the dam at different locations and depths. The analyzed results show that the soil has average values $Gs$=2.72 of specific gravity of the solid, dry unit weight $\gamma_d$=14.7 kN/m$^3$ and natural moisture content $\omega$=22.6 %. The strength and compressibility parameters were obtained through the direct shear and Oedometer test, respectively. The average value of the angle of internal fiction is $\varphi$=32.5° and cohesion $c$=9.0 kPa. The modulus of compressibility for different normal stresses is $Mv_{25\text{-}800\ kPa}$=1459.3-16814.7 kPa. Figure 2 shows the grain size distribution curve of the investigated soil.

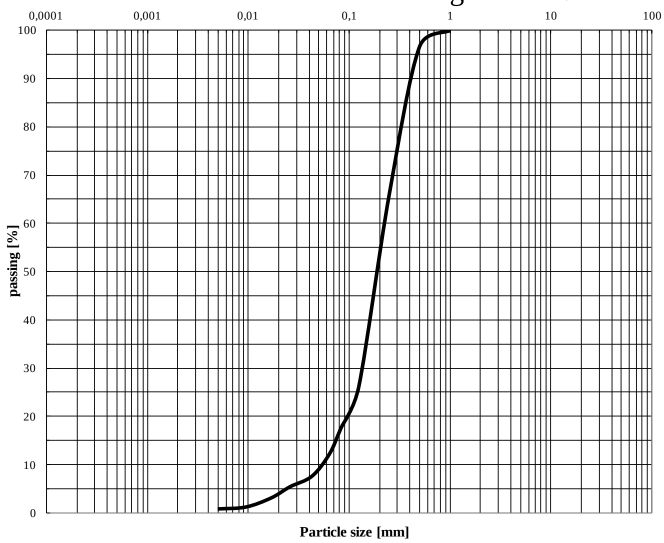


**Figure 2**. Grain size distribution curve

It contains 82.5% sand and 17.5% silt which classify this soil as silty sand. The coefficient of uniformity $Cu$=4.29 and the coefficient of curvature $Cc$=1.51.

## 3 UNSATURATED HYDRAULIC CONDUCTIVITY

The unsaturated hydraulic conductivity can be measured with Mini Disk Infiltrometer. It is manually operated device consisted of two chambers filled with water, one for suction control and one as a water storage. The infiltrometer ends with porous, sintered, stainless steel disk for interaction with the soil sample (Figure 3). The sample was oven dried and prepared in CBR mould with dry density $\gamma_d$=16.89 kN/m$^3$. Good hydraulic contact between the infiltrometer disk and the infiltration surface is essential for correct measurements. Once the infiltrometer is placed on a soil, water begins to leave the chamber and infiltrate into the soil at a rate determined by the hydraulic properties of the soil. The suction rate depends on the soil type. By applying the suction (from -0.5 to -7.0cm), the infiltration is controlled and the water does not enter the macro pores. Thus, the infiltrated water under tension gives the unsaturated hydraulic conductivity of the soil matrix. It is recommended to apply suction rate of -6.0 cm for such sandy soil. Usually, the volume change time interval for manual reading is 2 to 5 seconds for sands (Decagon Devices 2016).

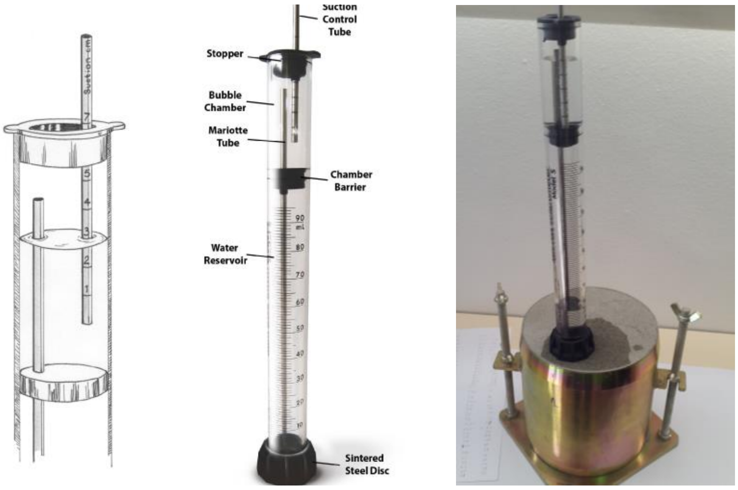


**Figure 3**. Infiltrometer diagram and test set up

Figure 4 presents the relationship between the cumulative infiltrations versus the square root of time.

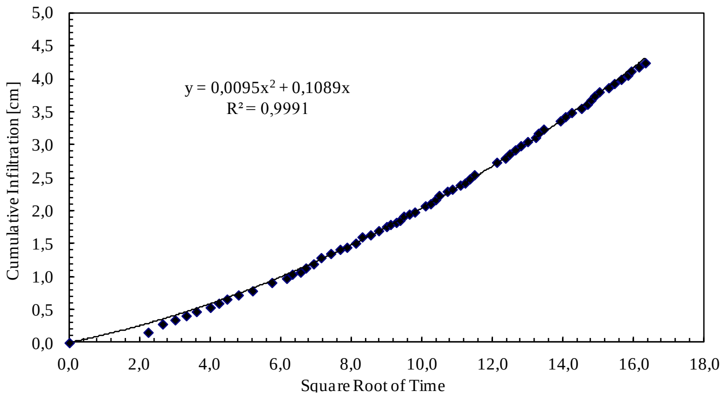


**Figure 4**. Cumulative infiltration – square root of time relationship

To determine the soil hydraulic conductivity from the measured data, a method for dry soils proposed by (Zhang 1997) was used. The method requires measuring cumulative infiltration versus time and fitting the results with the following function:

$$I = C_1 \cdot t + C_2 \cdot \sqrt{t} \tag{1}$$

Where $C_1$ [ms$^{-1}$] is parameter related to hydraulic conductivity and $C_2$ [ms$^{-1/2}$] is the soil sorptivity. The hydraulic conductivity ($k$) of the soil is computed as:

$$k = \frac{C_1}{A} \tag{2}$$

Where $C_1$ is the slope of the curve in Figure 4 and $A$ is a value relating the van Genuchten parameters for a give soil type to the suction rate and radius of the Infiltrometer disk:

$$A = \frac{11.65 \cdot \left(n^{0.1} - 1\right) \cdot exp\left[2.92 \cdot (n - 1.9) \cdot \alpha \cdot h_0\right]}{\left(\alpha \cdot r_0\right)^{0.91}} \tag{3}$$

Where $n$ (2.68 for sands) and $\alpha$ (0.145 for sands) are the van Genuchten parameters for the soil obtained from (Carsel and Parrish 1988), $r_0$=2.25 cm is the disk radius and $h_0$=-6.0 cm is the suction at the disk surface. Thus, the value of $A$ is calculated $A$=0.4611 and $C_1$=0.00954719 [cm/s]. Finally, k=0.0207 [cm/s].

## 4 SOIL WATER RETENTION CURVE

The construction of soil water retention curve is essential when analyzing rainfall triggered slope instabilities. The amount of water in the soil can be defined as degree of saturation *S*, volume of water $V_w$ referenced to the original volume of the specimen $V_0$ ($V_w/V_0$), gravimetric water content *ω=mass of water / mass of soil solids* or volumetric water content $\theta$ (used in this study):

$$\theta = \frac{Volume\,of\ water}{Volume\,of\ voids + Volume\,of\ solids} \tag{4}$$

Many methods are used to determine the SWRC such as pressure plate method which uses axis – translation technique, filter paper method, tensiometers, thermal conductivity sensors, chilled – mirror hygrometer technique etc. A system of two sensors (Figure 5), one for suction and one for volumetric water content (VWC) direct measurement was used in this study to determine the relationship between the soil suction and water content during the continuously wetting process.


**Figure 5**. MPS-6 suction sensor and EC-5 VWC sensor

The MPS-6 (TEROS 21) is a Meter Group, calibrated matrix water potential sensor that provides long term, maintenance – free soil water potential and temperature measurements without sensitivity to salts. It has wide range from field capacity to air dry (-9 to -100000 kPa). EC-5 measures the volumetric water content via the dielectric constant of the soil using capacitance technology. Is has range from 0% (dry air) to 60% (pure water) VWC and high accuracy. The sample was oven dried and prepared in cylindrical mould with D=20 cm and H=7.3 cm with dry density $\gamma_d$=15.7 kN/m$^3$ (Figure 6). The sensors were placed in the middle of the sample.

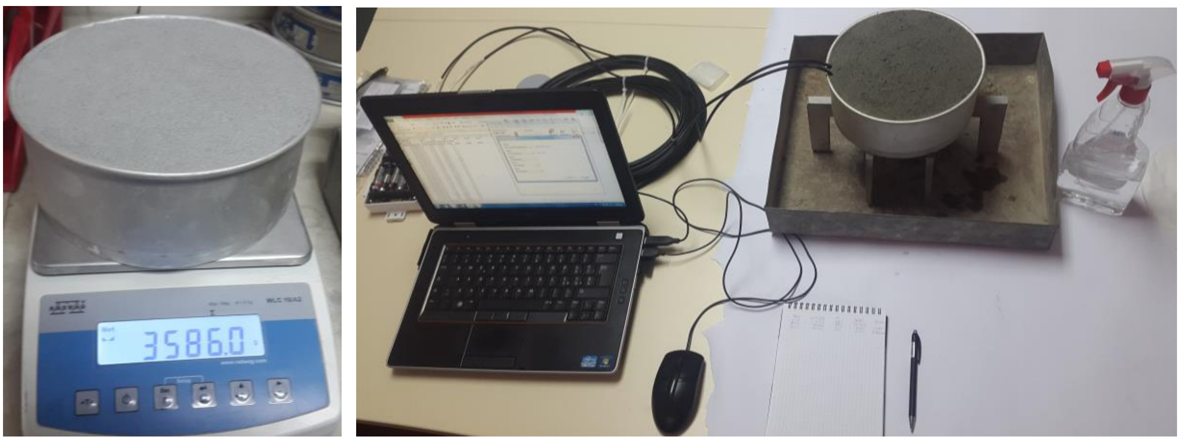


**Figure 6**. Preparation of the sample and test set up

The changes in suction, temperature and VWC are digitally recorded every one minute by the data acquisition system while the wetting process continues.

To give a wider picture of the hydraulic behaviour of the tested silty sand, the obtained results are plotted as a function of volumetric water content [m$^3$/m$^3$] and suction in log scale [-kPa] on Figure 7. It is seen that the suction sensor begin to response after the VWC reaches 0.038 m$^3$/m$^3$.

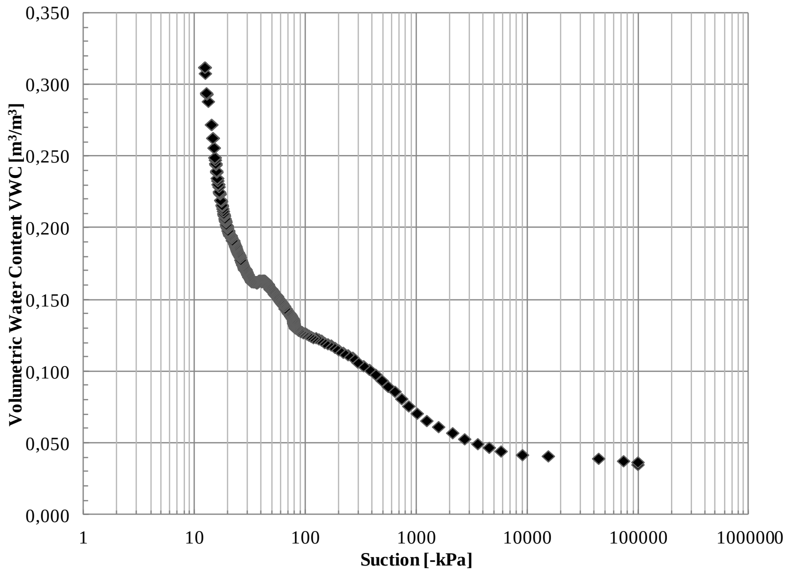


**Figure 7**. Measured data during the test

The Van Genuchten's method (1980) is widely used method to describe the soil water retention behaviour of soils. This hydraulic model uses the following equation (Van Genuchten 1980):

$$S_e = \left[ \frac{1}{1+(\alpha \cdot h)^n} \right]^m \tag{5}$$

Where $S_e$ is effective saturation related to pressure head $h$. On the other side, the dimensionless water content $S_e=(\theta-\theta_r)/(\theta_s-\theta_r)$. In this equation, $s$ and $r$ indicate saturated and residual values of soil-water content $\theta$, respectively. $\alpha$, $n$ and $m=1-1/n$ are parameters. According the measured data, this equation was solved online using the SWRC Fit – a nonlinear fitting program (Seki 2007). The results are presented in Figure 8 and table 1.

**Table 1**. Hydraulic data of Van Genuchten model obtained from SWRC Fit program

| Parameter | θs | θr | α | n | $R^2$ |
|---|---|---|---|---|---|
| Result | 0.2968 | 0.019849 | 0.080641 | 1.4802 | 0.85413 |

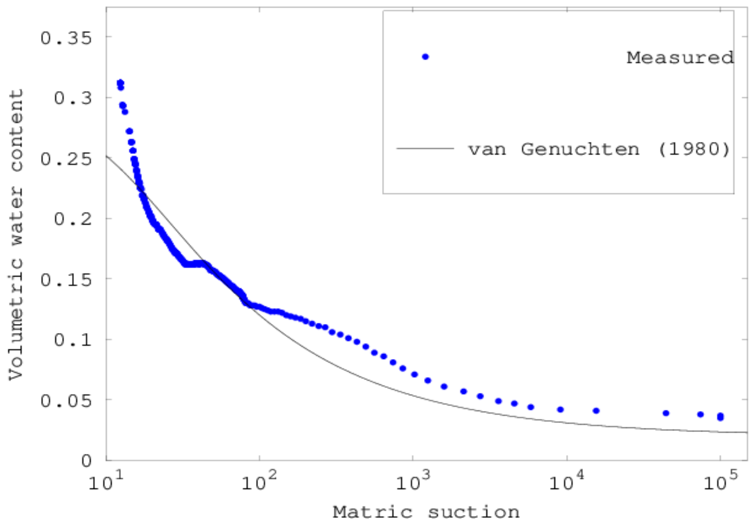


**Figure 8**. Soil water retention curve from Van Genuchten model

## 5 PHYSICAL AND NUMERICAL MODELLING

Having in mind the hydraulic properties of this silty sand, a physical model of the tailings dam Topolnica (Figure 1) will be built to analyze the hydro-mechanical behaviour of an unsaturated soil and slope stability during the intensive rainfall. The goal is to determine the influence of the intense rainfall and water infiltration on the suction and pore-water pressure build-up. Since this is a dynamic process, the analysis is to be transient. Model-wise, a fully coupled hydro-mechanical calculation will be used to simulate the processes measured in the physical model.
For calibration purposes before, another physical and numerical model of an ideal slope will be built to calibrate the hydro-mechanical behaviour of the soil measuring the changes in suction, VWC, pore and normal pressures recorded with integrated data acquisition system at five locations (Figure 9).

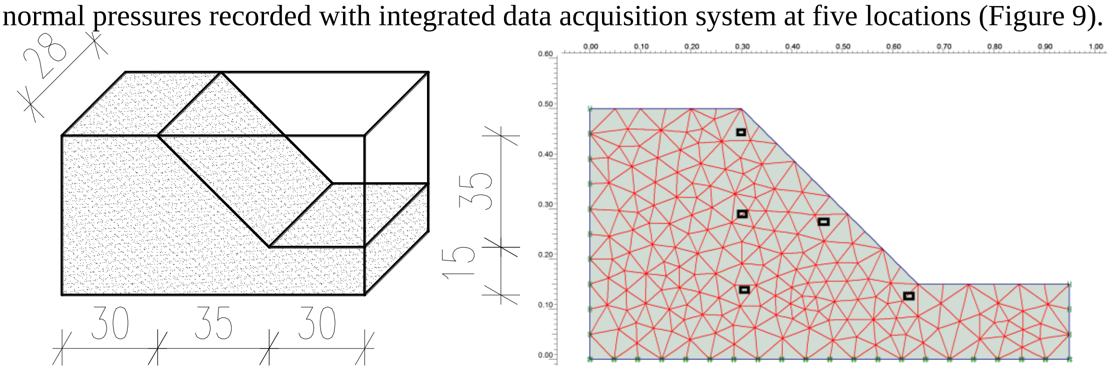


**Figure 9**. Slope model and finite element mesh with the position of sensor sets

## 6 CONCLUSION

The aim of this study was to determine the hydro-mechanical properties of the silty sand used in tailings dam construction as a by product of mining and flotation. Large number samples were subjected to laboratory tests to obtain the mechanical properties. The tests for hydraulic properties were mainly focused on unsaturated hydraulic conductivity and soil suction – water content relationship. The unsaturated hydraulic conductivity of the soil is k=0.0207 [cm/s] which is typical value for sands. The SWRC was obtained using the Van Genuchten hydraulic model through the SWRC Fit program. This leads to the main hydraulic parameters needed for fully coupled hydro-mechanical calculation dealing with unsaturated soil mechanics. These results will be used for physical and numerical modelling of slope instabilities caused by intense rainfalls.

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