Proceedings of the 7th World Congress on Civil, Structural, and Environmental Engineering (CSEE'22)
~~Lisbon, Portugal~~ Virtual Conference– April 10 – 12, 2022
Paper No. ICGRE 222
DOI: 10.11159/icgre22.222

A Preliminary Insight into the Water Retention Response of Sand-Silt Mixtures of Stava Tailings

Gianluca Bella[1,2]
[1]Politecnico di Torino
Corso Duca degli Abruzzi 24, Torino, Italy
[2]Presently: Pini Group SA
Via Besso 7, Lugano, Switzerland
gianluca.bella@pini.group

Abstract - This research provides the main outcomes of an experimental investigation into the water retention behaviour of unsaturated tailing wastes collected after the failure of the Stava tailing dams. The water retention response of Stava tailings is studied by carrying out tests which apply different techniques where the water content was measured and the suction was imposed, and tests where the water content was imposed, and the suction was measured. The dependency of the Water Retention Curve (WRC) on the grain size distribution, and on the initial void ratio/density was investigated to account the in-situ heterogeneity of tailing wastes. As for standard soils, looser tailing specimens showed a lower water retention capability than that given in the denser ones. Similarly, the reduction of the fine content showed to decrease in the water retention capability of tailings. A microstructural interpretation in terms of the cumulative value of pore size density (PSD) is also provided. The in-depth knowledge of the hydro-mechanical response of the soils proposed by the current research finds its practical application as a fundamental tool to reliably assess the stability of the tailing storage facilities which the high rate of recent collapses poses unacceptable fatalities with environmental and economic damages.

Keywords**:** tailing dams; Stava; Water Retention Curve; unsaturated soil; void ratio; fine content.

1. Introduction

Mechanical and hydraulic response in unsaturated conditions is coupled, therefore the accuracy in predicting the hydraulic soil behaviour is essential for determining the mechanical soil response. The shear strength is affected by the pore fluid via its suction but also its degree of saturation so, different degrees of saturation associated to the same suction will lead to different values of shear strength. Moving from this reason, the current research is aimed at providing a preliminary insight into the range of hydraulic response of tailing materials by considering the variation in the void ratio and the fine content which could reasonably be expected in situ.

2. Testing material and experimental apparatus

The hydraulic behaviour was investigated by means of water retention tests carried out at Politecnico di Torino (Italy) on the tailing samples collected from the Stava upper embankment, which remained in place after the failure occurred in 1985. Tailings studied in the current research are composed of two grain sizes: a silt fraction passing through a sieve n°200 that seemed to be deposited inside the basin, and sand fraction made up of particles retained by sieve n°200 that was part of the embankment. The D_{10}, D_{50} and D_{90} of the sand fraction are equal, respectively, to 0.08 mm, 0.20 mm and 0.35 mm, ([4]), with a specific gravity equal to 2.721. Liquid (w_L), plastic limits (w_P) and specific gravity (G_S) of the silty fraction are 27.4%, 18.0% and 2.828. X-ray diffraction analysis showed that both fractions were made up of quartz, with a significant amount of calcite and fluorite, especially within the silty fraction ([1]; [3]), with an absolute permeability equal to $9.5 \cdot 10^{-6}$ m/s (sandy fraction) and 10^{-7}m/s (silty fraction). All specimens were prepared at different initial void ratio or fine content (Table 1), and statically compacted. The hydraulic behaviour was investigated in terms of Water Retention Curve by means of different methods (details are given in [1] and [2]):

- axis translation technique applied into a suction-controlled oedometer (Fig. 1, suction range: 0-500 kPa) on samples having initial size of 50 mm diameter and height of 20 mm, and vapour equilibrium technique (suction values up to 70 MPa) applied in closed box on samples having initial size of 20 mm diameter and height of 10 mm;

- dew point technique (suction range: 0-300 MPa) applied by a chilled mirror psychrometer (WP4C) on samples having initial size of 20 mm diameter and height of 10 mm.

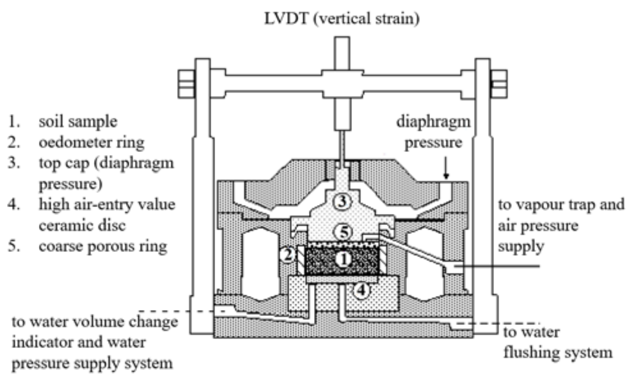

Fig. 1: Schematic view of the suction-controlled oedometer (modified from [7]).

Table 1: Initial state of Stava samples: void ratio (e_0), water content (w_0), degree of saturation Sr (%), dry density (γ_d), net stress (p_{net}), percentage of sand/silt.

Sample	e_0 (-)	w_0 (-)	Sr (%)	γ_d (kN/m^3)	p_{net} (kPa)	Sand/Silt (%)
SILT-0.70	0.70	17.3	70.0	16.6	100.0	0/100
SILT-0.60	0.60	15.0	70.0	17.6	100.0	0/100
SILT-0.50	0.50	15.9	90.0	18.9	100.0	0/100
7030-0.70	0.70	17.8	70.0	16.2	100.0	70/30
3070-0.60	0.60	17.2	80.0	17.4	100.0	30/70

3. Experimental results

Figure 2 shows the experimental results (main drying branches, SILT-0.60) obtained from the three adopted techniques. The black diamond marked as "s_i?" represents the assumed initial state of the specimen in terms of suction and degree of saturation value. Indeed, the initial degree of saturation has been imposed (70%) while the initial suction was unknown. Due to the wetting response of the sample at the imposed suction 50 kPa at the first step of the water retention test, the initial suction of SILT-0.60 was higher than that suction value. By assuming Sr^{res} = 0.05, the experimental points were fitted by the van Genuchten model ([6]). The effective degree of saturation was defined as $Sr_{eff} = (Sr\text{-}Sr^{res})/(1\text{-}Sr^{res})$ allowing to obtain the main drying and the main wetting branches of the Water Retention Curves.

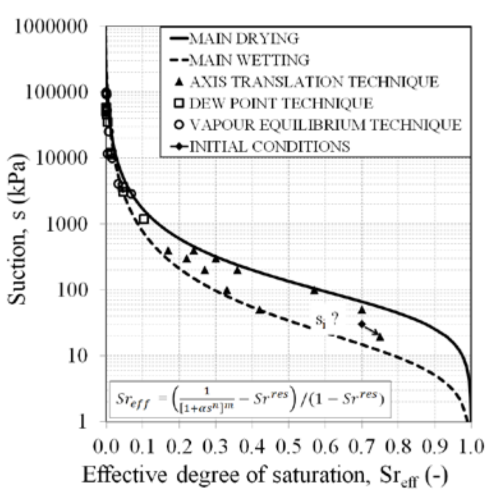

Fig. 2: Sample SILT-0.60, experimental points, fitting Van Genuchten curve for the three applied methods.

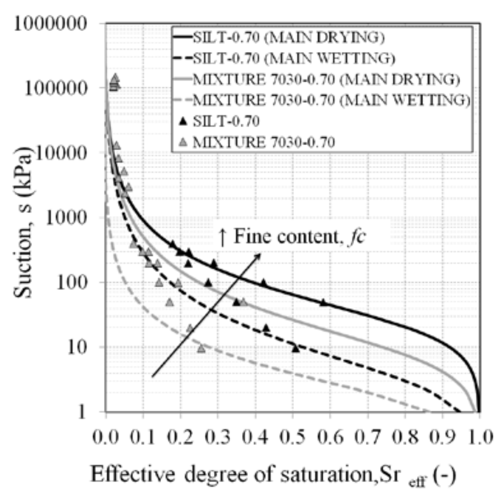

Fig. 3: Influence of the fine content on the water retention behaviour.

The influence of the fine content (fc) on the WRC was investigated (Fig. 3). In the pure silt (SILT-0-70) and mixtures samples (7030-0.70), the main drying was affected by changes in grading: at a decrease of the fc, correspond a movement of the WRC to low suction values. Indeed, when decreasing the fine content, the pores between the sandy grains get emptied with the small silty particles resulting an overall higher permeability, and so a lower retention behaviour. Indeed, a comparison of the air entry values (AEV) of the two samples show that the AEV of sample 7030-0.70 (8.3 kPa) is lower than that of SILT-0.70 (23.8 kPa). The influence of the initial density/void the ratio on the WRC of silty samples was studied by fitting the experimental point using the van Genuchten model (Fig. 4). Both the main drying and wetting branches are influenced by initial void ratio of the samples. An increase in the void ratio moves the WRC to a lower suction because as the size of the pores increase, a lower suction is required to empty the pores. For this reason, the WRC of SILT-0.60 rest above the curve of SILT-0.70. Table 2 gives the van Genuchten fitting parameters for silty samples and mixtures. Figure 5 gives the main drying WRC at different compaction states for more standard soils (speswhite kaolin specimens), highlighting a good agreement with the experimental results obtained in this research on Stava tailing specimens at different void ratios. Within the suction range investigated for both cases, the Water Retention Curves were shifted upward with decreasing the initial void ratio of compacted soil.

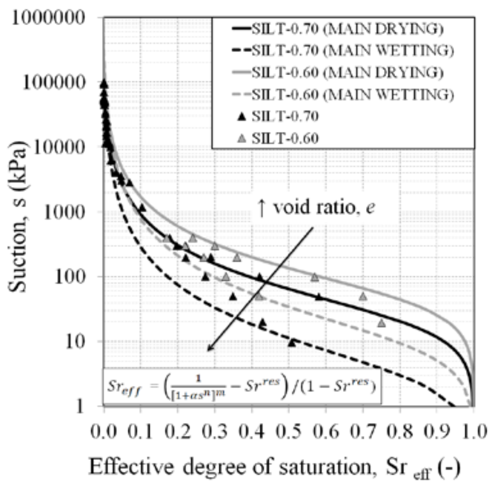

Fig. 4: Influence of the initial void ratio on the water retention behaviour.

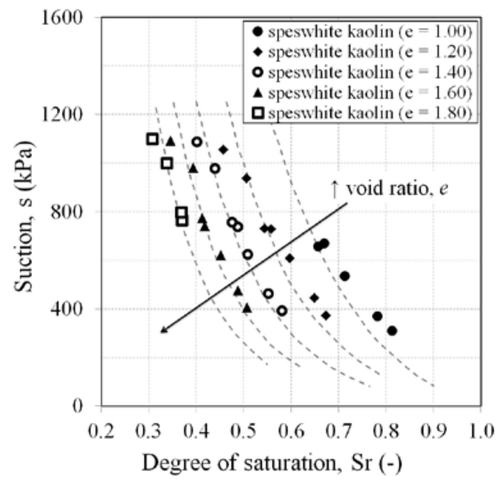

Fig. 5: Water Retention Curves for speswhite kaolin specimens (modified from [5]).

A microstructural interpretation of the WRC of Stava tailings at different initial densities and grading can be performed by assuming that the water retention is due to the capillary mechanism described by Washburn-Laplace equation (contact angle α between water and pore's wall equal to 0°, water tension T_S equal to 72 Nm/m at temperature of 20°C) given in Eq. (1). The cumulative value of the pore size density is represented in Fig. 6. A comparison of the effect of the initial void ratio in terms of cumulative PSD (Eq. (2)) allows one to observe that sample SILT-0.7 has a bigger cumulative curve than samples SILT-0.60 and SILT0.50: this means that the first one has a higher number of large size pores that can be firstly intruded by water. A comparison of the effect of fine content in terms of cumulative PSD allows one to observe that, even if the two samples have the same initial cumulative value of the PSD (at r = 1 nm) due to their same initial void ratio (e_i = 0.7), cumulative PSD of sample 7030-0.70 is bigger than those of SILT-0.70. This means that the 7030-0.70 has a higher number of large size pores that can be firstly filled by water. Similar considerations could be made by comparing the cumulative PSD of sample SILT-0.60 with those of sample 3070-0.60.

$$r = \frac{2 \cdot T_s \cdot \cos(\alpha)}{s} \quad (1)$$

$$PSD = \Delta \left[\frac{e\left(1 - Sr_{eff}\right)}{Gs}\right] / \Delta \log(r) \quad (2)$$

Table 2: List of the van Genuchten parameters α, n, m

Sample	Main drying branch			Main wetting branch		
	α (kPa^{-1})	n (-)	m (-)	α (kPa^{-1})	n (-)	m (-)
SILT-0.70	0.042	1.620	0.380	0.320	1.500	0.330
SILT-0.60	0.019	1.650	0.390	0.100	1.520	0.340
SILT-0.50	0.009	1.670	0.400	0.065	1.520	0.340
7030-0.70	0.120	1.550	0.350	0.600	1.700	0.410
3070-0.60	0.021	1.680	0.400	0.150	1.540	0.350

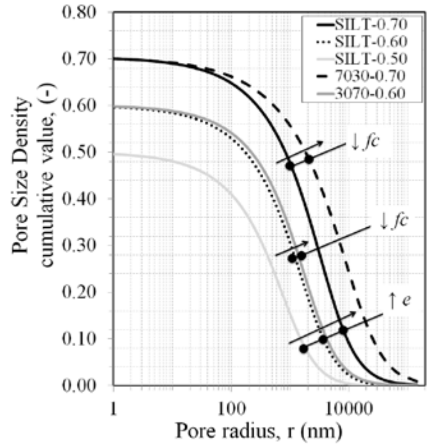

Fig. 6: Cumulative value of the PSD for all tested samples.

4. Conclusion

This research has provided an insight into the effects of the initial density and fine content on the water retention behaviour of unsaturated Stava tailings. The reduction of void ratio was proved to shift the hydraulic response to a higher suction range because the size of the pores decreases. The experimental results were successfully compared with those described in literature on more standard soils. The water retention response of different sand-silt mixtures with the same initial void ratio were studied by analysing their WRC. A reduction of the fine content was proved to move the water retention to lower suction values as the big pores between sandy particles get emptied with silty particles, leading to a lower water retention capability of silt-sand mixtures than pure silt samples. A preliminary microstructural interpretation of the water retention behaviour of Stava tailings was given in terms of pore size density. The experimental results find their practical application as relevant aspects for a reliable assessment of performances and stability of tailing dams.

Acknowledgements

The Author wishes to thank Prof. G. Musso, M. Barbero and F. Barpi (Politecnico di Torino) for their valuable inputs.

References

[1] G. Bella, “Hydro-Mechanical Behaviour of tailings in Unsaturated Conditions,” Ph.D. dissertation, Dept. Struct. Build. and Geotech. Eng., Politecnico di Torino, Italy, 2017a.
[2] G. Bella, ”Water retention behaviour of tailings in unsaturated conditions”, *Geomechanics and Engineering, An Int'l Journal*, vol. 26, no. 02, pp. 117-132, 2021.
[3] G. Bella, F.S. Lameiras, T. Esposito, M. Barbero and F. Barpi, ”Aging Simulation of the Tailings from Stava Fluorite Extraction by Exposure to Gamma Rays”, *Revista Escola de Minas*, vol. 70, no. 04, pp. 483-490, 2017b.
[4] A. Carrera, M. Coop and R. Lancellotta, “Influence of grading on the mechanical behaviour of Stava tailings”, *Géotechnique*, vol. 61, no. 11, pp. 935-946, 2011.
[5] G. Della Vecchia, “Coupled Hydro-Mechanical Behaviour of compacted clayey soils,” Ph.D. dissertation, Dept. Struct. Eng., Politecnico di Milano, Italy, 2009.
[6] M.T. van Genuchten, “A closed-form equation for predicting the hydraulic conductivity of unsaturated soil”, *Soil Science Society of America Journal*, vol. 44, no. 05, pp. 892-898, 1980.
[7] E. Romero, “Thermo hydro-mechanical behaviour of unsaturated Boom Clay: an experimental study”, Ph.D. dissertation; Universidad Politecnica de Catalunya, Spain, 1999.