SWRC interpretation of iron ore tailings blends focusing on saturation assessment of filtered tailings piles

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Abstract

Blending slime tailings with coarser materials, such as flotation tailings, has gained popularity to overcome the problems of fine-grained material dry stacking. The problem is the maintenance of high degree of saturation, particularly at the base of these stacks, due to the water retention capacity. However, there is little information about the unsaturated hydraulic performance of these blends. Basic geotechnical characterization, compaction, oedometer and soil water retention tests were carried out on itabirite iron ore slime tailings, flotation tailings and their blends. The soil water retention curves (SWRC) and the unsaturated hydraulic conductivity functions, obtained using Fredlund and Xing's (1994) method, are analysed in an equilibrium situation over the depth of a hypothetical filtered tailings deposit. The paper assesses the effect of capillary rise in blends using water retention curves. Through the proper interpretation of the SWRC, it is verified that the pile thicknesses with a saturation degree above 80% of the blends are close to pure flotation tailings and significantly smaller than pure slime tailings. Therefore, for itabirite iron ore tailings, adding slime to the flotation tailings, up to 30% in mass, is a viable solution to minimise the effect of high degree of saturation in slime tailings.

Keywords: Dry-stacking; Filtered iron ore tailings; Soil Water Retention Curve; Saturation; Slope Stability; Unsaturated Soil Mechanics.

1 Introduction

In a dry stacking of filtered tailings from mineral concentration, the soil water retention curves (SWRC) and hydraulic conductivity parameters play fundamental roles in the stability. The determination of the SWRC and its proper interpretation positively contributes to understanding the distribution of water in the embankment and, thus, allows us to assess whether there is the possibility of saturation of the material and how to circumvent the possibility of liquefaction. The finer the gradation of the tailings, the greater the challenge of stacking safely. An alternative to mitigate the difficulty of disposing of fine tailings is blending them with coarse tailings in proportions that do not significantly alter the geotechnical hydraulic performance of the resulting blend compared to pure coarse tailing. The risk this process incurs is a high degree of saturation within the stack. Thus, in the design of dry stacking of varied filtered materials, it is necessary to evaluate how the blend of different materials will affect the SWRC and its hydraulic conductivity function (HCF). The materials were prepared by

mixing slurry tailings (silty clay) and flotation tailings (silty sands) in different proportions. The tests were carried out at the Technological Research Institute (IPT) of the State of São Paulo. This paper presents geotechnical data of tailings to be used in a dry stacking project of iron ore in the region of Minas Gerais (Brazil) and the analyses resulting from the interpretation of these data.

2 Conclusion

The geotechnical characterisation of the materials indicates no plasticity, except for one of the samples: the pure slime (100%SL). The content of particles smaller than 2 μm ranged from 1% to 29%, with all blends showing that over 5% particles are smaller than 2 μm. For the pure slime, the percentage of particles smaller than 2 μm was 29% and presented an optimum water content of 16.5%.

The blend of pure flotation (100%FL) with pure slime induced a reduction in the optimal moisture content, generating materials with optimal moisture content values of the order of 11% for all blends, a value very similar to the total tailings (TT). The maximum dry density of the blends ranged from 2055 kg/m^3 to 2195 kg/m^3; the total tailings presented a maximum dry density value of 2220 kg/m^3.

The consolidation test indicated that adding pure slime in the pure flotation reduces the compression index for 10% slime in mass but increases it for proportions of 20% slime or higher. The expansion index is strongly reduced in the blend with 10% slime in mass but slightly reduced in the blends of 20% and 30% slime.

The saturated permeability coefficient, Ksat, obtained during consolidation tests indicated little variation due to vertical stress. The pure flotation showed the highest Ksat, and the pure slime showed the lowest. The blends showed intermediate values, close to the one of pure slime tailings.

A fundamental aspect that emerged from the results obtained is the possibility of inferring the material's capacity to remain saturated or with a high degree of saturation. The value of the air entry suction, whether it is a real concept or a value derived from the adjustment of the retention curve data, controls the maintenance of a high degree of saturation in a capillary rise process, for example.

Regarding the degree of saturation maintained by the porous material, the results obtained indicate the following:

- The pure slime material has the greatest air entry suction and is, therefore, the one material that maintains a high degree of saturation in a capillary rise analysis. This material maintains a prejudicial degree of saturation above 80% up to a height of approximately 80 m, in an equilibrium state with no infiltration nor evaporation.

- The other materials tested have a thickness with a degree of saturation above 80% above the phreatic level lower than 1 m, although these thicknesses must be considered in the design.

- Thus, the blend of materials provides important improvements on the tailings' water retention performance compared to the pure slime tailings, reducing the thickness with the degree of saturation above the safe limit by capillary action.

The study demonstrated the usage of retention curves to assess possible capillary rise saturation. In a dry stacking of filtered tailings, to reduce landfill saturation problems, it is essential to carry out this analysis based on material retention curves, verifying the possibility of saturation by capillary rise or infiltration.

Pure slime tailings pose a challenge in this context; however, pure flotation tailings offer better results. Thus, a possible alternative for the disposal of slime tailings is to blend them up to 30% of slime in mass to the flotation tailings to dry stack the resulting blend. However, this article did not deal with evaluating the best compaction state of materials to guarantee not only an adequate saturation profile but also a material with a dilatant behaviour when saturated, which further research in the field can consider.

3 References

Bentley Systems. 2021. “PLAXIS LE SoilVision Soils, a knowledge-based database system for saturated/unsaturated soil properties”. In *Theory Manual*, p. 41–42.

Caldwell, J. A. and C. Crystal. 2015. “Filter-pressed tailings facility design, construction, and operating guidelines”. In *Proceedings Tailings and Mine Waste 2015, Vancouver, BC*.

Crystal, C., C. Hore, and I. Ezama. 2018. “Filter-pressed dry stacking: design considerations based on practical experience”. In *Proceedings Tailings and Mine Waste 2018, Keystone, Colorado, USA*, p. 209–219.

Da Silva, A. Q. N., L. C. M. Montenegro, R. Z. Galery, H. D. G. Turrer, D. B. Mazzinghy, and L. C. de Aquino Junior. 2015. “Concentração de minério de ferro itabirítico através de célula de flotação pneumática [Concentration of itabirite iron ore through pneumatic flotation cell]”. *Tecnologia em Metalurgia, Materiais e Mineração.* Vol. 12, no. 2: p. 129–133.

Daliri, F., P. Simms, and S. Sivathayalan. 2016. “Shear and dewatering behaviour of densified gold tailings in alLaboratory simulation of multi-layer deposition”. *Can. Geotech. J.* 53: p. 1246–1257.

Davies, M. 2011. “Filtered dry stacked tailings – the fundamentals”. In *Proceedings Tailings and Mine Waste 2011, Vancouver, BC*.

Ferreira, C. R. N. 2015. “Métodos de flotação de minérios de ferro [Iron Ore Flotation Methods]”. Graduation thesis. Belo Horizonte: Departamento de Engenharia de Minas, Escola de Engenharia da Universidade Federal de Minas Gerias, p. 33-42.

Fredlund, D. G. and A. Xing. 1994. “Equations for the Soil-Water Characteristic Curve”. *Canadian Geotechnical Journal* 31, no. 4: p. 521–532.

Fredlund, D. G. and H. Rahardjo. 1993. *Soil Mechanics for Unsaturated Soils*. New York: John Wiley & Sons.

Garino, L., G. Rodari, L. Oldecop, F. Zabala, and R. Rodari. 2012. “Almacenamiento de colas mineras filtradas. Primera experiencia en Argentina. [Dry Stacking of Filtered Mining Tailings. First Experience

in Argentina]". In *Congreso Argentino de Mecánica de Suelos e Ingeniería Geotécnica 2012, CAMSIG XXI, Rosario, Santa Fe, Argentina*.

Leonida, C. 2020. "How to make filtered tailings feasible". *Engineering and Mining Journal*, Vol. 221: p. 42.

Li, S., Q. Chen, and X. Wang. 2016. "Superiority of filtered tailings storage facility to conventional tailings impoundment in southern rainy regions of china". *Sustainability* 2016, Vol. 8, 1130.

Silva, J. P. S., P. P. Cacciari, V. F. N. Torres, L. F. M. Ribeiro, and A. P. Assis. 2021. Behavioural Analysis of Iron Ore Tailings through Critical State Soil Mechanics. Unpublished.

Ulrich, B. 2019. "Practical thoughts regarding filtered tailings". In *Paste 2019: Proceedings of the 22nd International Conference on Paste, Thickened and Filtered Tailings, Australian Centre for Geomechanics, Perth*, p. 71-79.

Xu, Y. 2013. "Unsaturated hydraulic conductivity of fractural-textured Soils." In *Hydraulic Conductivity*, p. 68-134. Rijeka: IntechOpen. http://dx.doi.org/10.5772/56716