Hydraulic Dewatered Stacking (HDS): Effects of fines content in the drainage performance of the sands.

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ABSTRACT

Efficient management of tailings storage facilities (TSFs) stands as a cornerstone for fostering sustainability and environmental stewardship within the mining industry. There is an increasing need to ensure both physical stability and efficient resource utilization in the mining industry, with a specific focus on water management.

Anglo American has pioneered Hydraulic Dewatered Stacking (HDS) technology, leveraging principles of soil mechanics to expedite tailings consolidation and bolster water recovery efforts. The HDS method involves engineered co-disposal of fines-free sand and tailings creating a 3-dimensional drainage system to promote in-situ dewatering of the wet tailings and consolidation of the materials.

The coarser materials in the HDS can be derived from coarse particle flotation (CPF or CPR) rejects which correspond to sands free of fines (<5% passing 75um), with high permeability and draining capacity. If no CPR plant is in place, sand can be delivered from the tailings themselves via classification. In the latter, the permeability and suction characteristics of the materials need to be carefully studied as to ensure dewatering performance of the HDS.

This study explores the effects of increased fines content on the resulting permeability and suction characteristics of CPR sands. The study conducts a series of laboratory tests and develops seepage numerical models (utilizing Seep/W calibrated with laboratory data from Musso et al. (2023)) to investigate the performance of tailings dewatering and consolidation under simplified HDS configurations. The flexible wall permeability tests showed that increases in fines content for CPR sands, in the range from 0 to 10%, resulted in a decrease of two order of magnitude in the coefficient of hydraulic conductivity. Considering Seep/W results, for models that tried to mimic the Large Consolidation Cell available at UTFSM, it was observed that desaturation occurred at a different pace depending on sands fines content. The greater the fines content of sands, the higher the saturation observed in the tailings mass, for simulations periods over 15 days.

INTRODUCTION

Efficient management of tailings storage facilities (TSFs) is essential for the mining industry, with recent guidelines emphasizing the importance of both physical stability and resource optimization, particularly water usage. Despite thickening processes improving solid content in tailings, discharged material remains saturated, releasing significant water due to sedimentation and consolidation. The water balance and management within TSFs involves multiple factors such as evaporation, retained water in tailings, collected seepage, and infiltration. Water recovery from tailings entrainment is challenging, with limited options available. Some technologies, like electrokinetics and controlled blasting show promise but scalability and cost-effectiveness remain uncertain.

In this context, Anglo American has developed a system called Hydraulic Dewatered Stacking (HDS) that increases the rate of consolidation of fresh tailings and the rate of recovery of the resulting drained water.

The HDS method involves engineered co-disposal of fines-free sand and tailings creating a 3-dimensional drainage system to promote in situ dewatering of the wet-tailings. Using the rejected sand as draining material within an HDS approach, it delivers key benefits as enhanced drainage and consolidation, improved safety, reduced strength loss risk, better water recovery, and cost efficiency compared to filtration methods. The resulting saturation of the tailings stack falling below 100%, offers significant operational benefits:

- Safety: Reduced risk of liquefaction failure and minimized consequences if such an event occurs.
- Water: Efficient water recovery demonstrated in proof of concept and full-scale trials at El Soldado.
- Legacy: HDS allows rapid repurposing of the tailings facility post-deposition.

The HDS has been commissioned at a large-scale trial at the El Soldado Mine in Chile (150,000 m^3 capacity greenfield tailings facility) where promising findings and outcomes have been observed, e.g. desaturation capacity of the materials, suction development, benefits of promoting horizontal drainage paths, among others. The results of the first 9 months of operation of the facility are reported in Newman et al. (2023).

In the context of previous research (e.g. Musso et al. 2023), it has been found that Coarse Particle Recovery (CPR), which delivers a coarse well graded sandy reject prior to final flotation in base metal sulphides, produce a “perfect” near 0 fines content sands which promote quick desaturation of tailings in the HDS (Newman et al, 2022). However, CPR is sometimes not part of the existing operation and the required sands for HDS implementation may need to be obtained through a classification process. This can result in increased fines content in the sand and lower resulting overall hydraulic conductivity of the HDS.

This study explores the effects of increased fines content on the resulting permeability and suction characteristics of CPR sands following laboratory a numerical modelling approach.

BACKGROUND: CPR SANDS

The concept stemmed from Anglo American's research on Coarse Particle Recovery (CPR), pioneered through pilot trials since 2015, leading to the successful operation of the largest CPR unit at El Soldado Mine, Chile (Arburo et al, 2022). CPR, traditionally used for tailings scavenging, now integrated into the mill circuit, yields coarse barren tailings (CPR sands) reducing ball mill energy consumption and enhancing flotation circuit capacity.

At El Soldado, CPR surpassed expectations, doubling planned production increase via SAG mill with marginal plant recovery improvement. CPR's placement within the flowsheet varies based on deposit metallurgy, project type, and mine objectives, consistently produces fines-free reject sand. Additionally, Hydraulic Dewatered Stacking (HDS) or separate stacking of CPR sands enhances water recovery and reduces tailings liability. Recognizing fines-free reject sand's water recovery potential, Anglo American conducted small-scale piloting, hypothesizing its role in tailings filtration when placed in a 3-dimensional drainage matrix within the tailings storage facility (TSF). This finally led to conception of the HDS.

LABORATORY HDS CELL

In order to replicate the application of Hydraulic Dewatered Stacking (HDS) in practical settings, in 2021 a large consolidation cell was assembled and adapted in the geotechnical facilities at the Universidad Técnica Federico Santa María (UTFSM), following the work of Torghabeh (2013), and Bruton and Newman (2021). The potential benefits of CPR sand layers among fine-grained tailings to enhance material consolidation have been investigated in recent years using instrumentation within the cell for different configurations of CPR sands and Tailings. The materials have been sourced from Anglo American’s El Soldado and Los Bronces Mines.

A schematic of the chamber setup is presented in Figure 1. The chamber comprises three square compartments made of transparent Perspex, each measuring 1.0 m x 1.0 m with a height of 0.5 m, stacked to create a 1.5 m chamber. A scale of approximately 1/10th was chosen, featuring interbedded layers of CPR sands (150 mm thick) and tailings (350 mm thick), with three 500 mm layers planned. The compartments are interconnected via steel beams and bolts supported by a steel frame, ensuring assembly stability while facilitating visual monitoring of tests. Thirty-two horizontal outlets are positioned on the chamber walls, with four holes located at its base. Drainage is regulated through valves equipped with porous stone and filter paper for protection.

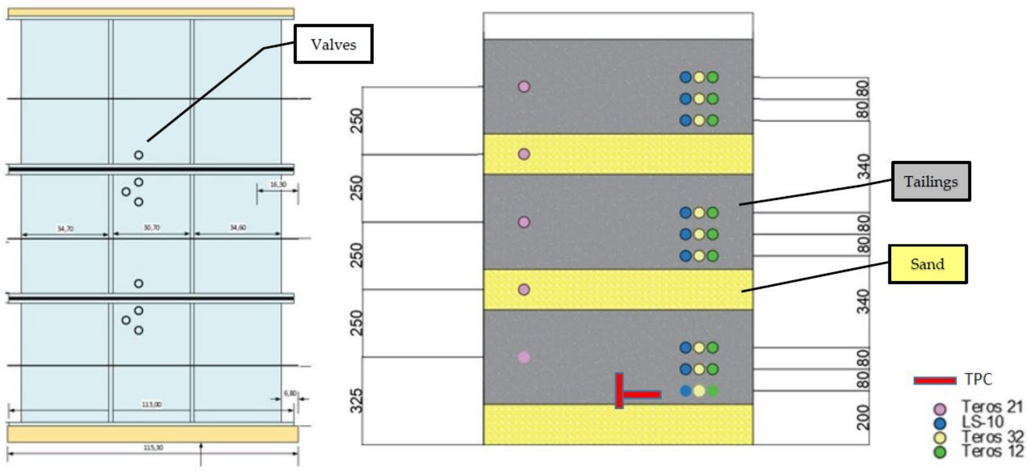

Figure 1 Schematic representation (elevation) of large cell apparatus.

The equipment is to monitor the following variables: settlement, pore water pressure, matric suction, water and volumetric water content, and horizontal and vertical stresses. The original test results were presented by Musso et al. 2023. This experimental setup and results obtained are used in this article to calibrate numerical models and explore the effects of CPR fines content in HDS performance.

MATERIAL CHARACTERIZATION

The CPR and fine-grained tailings for this research were obtained from the El Soldado copper mine, Region of Valparaíso, Chile. The main characteristics of the materials are summarised in Table 1. The initial void ratio in the table was obtained from small-scale column tests.

Table 1 Summary of material's index properties

Parameter	Tailings	CPR Sands
Specific Gravity	2.796	2.728
Plasticity Index	Non-Plastic	Non-Plastic
USCS Classification	ML	SP
Fines Content (%)	51	3.5
Initial Dry Density, γ_d g/cm^3	1.56	1.49
Initial Voids Ratio, e_0	0.79	0.83
Permeability at e_0 K m/s	4.3×10^{-8}	9.3×10^{-5}

From as-received CPR sand, the fines content was increased from 0% to a maximum of 19% of the resulting material. The added fines were obtained from sieving of tailings. The particle size distribution (PSD) for all mixtures are shown in Figure 2.

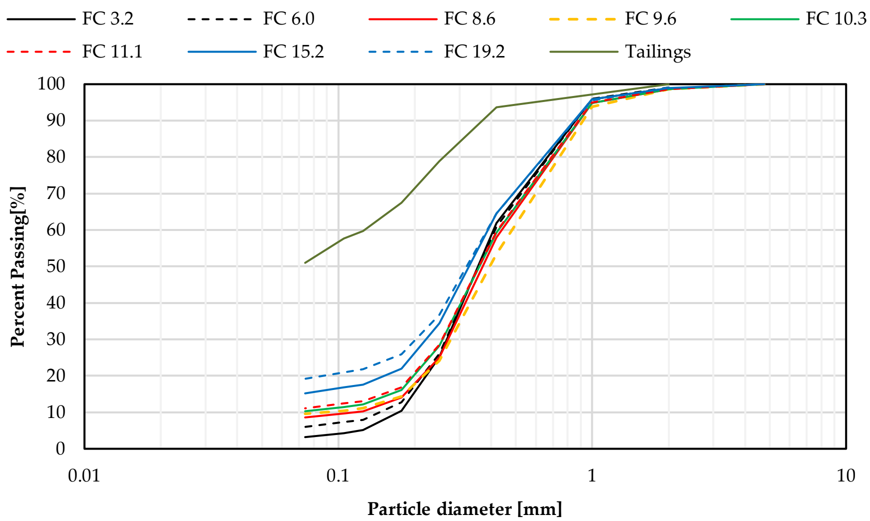

Figure 2 PSDs of resulting sand mixtures and tailings.

Initial testing considered flexible wall permeability tests at confining pressures of 50, 100 and 150 kPa which results are shown in Figure 3. The results show that coefficient of permeability can decrease in up to two order of magnitude when the fines contents are increased from to 0% to 19%. A significant drop in the conductivity is observed in the 0 to 10% fines content range.

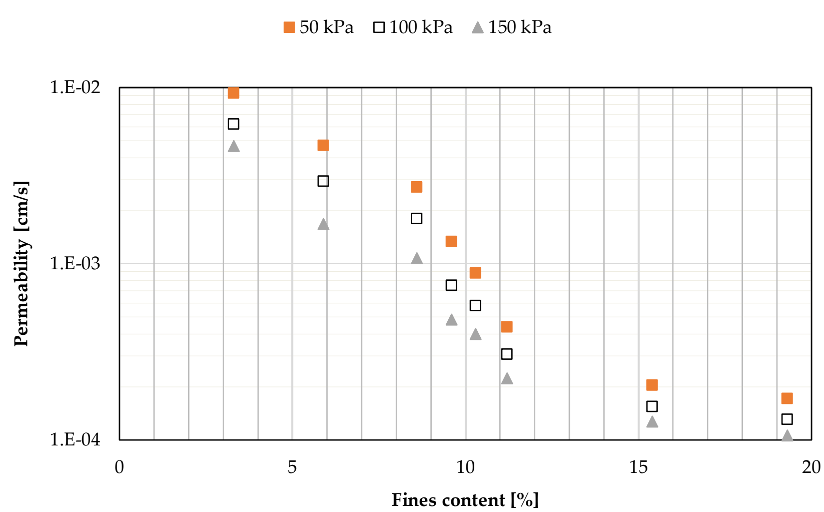

Figure 3 Flexible wall permeability tests for sand mixtures.

NUMERICAL MODELLING

Materials Properties

The Seep/W software was used to complete simplified numerical models for the consolidation cell using sand mixtures (the same tailings-sands configuration but different sand's fine contents). A Saturated/Non-Saturated constitutive model was used in all the models. The Soil Water Retention Curve (SWRC) for the material were found from laboratory data set from pressure plate testing and the van Genuchten function best-fitted to data points. The unsaturated permeability (K_{uns}) was then estimated with the Fredlund-Xing-Huang method considering the saturated conductivity from flexible wall testing (Figure 4). The resulting curves are shown in Figure 4 for SWRC and Figure 5 for K_{uns}. The air entry value (AEV) of the sand slightly increased as the fines contents were increased (i.e. AEV increased in the range 0 to 3 kPa).

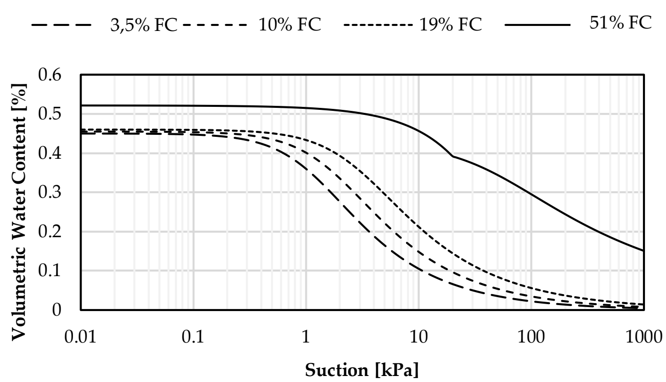

Figure 4 Fitting curve obtained to SWRC.

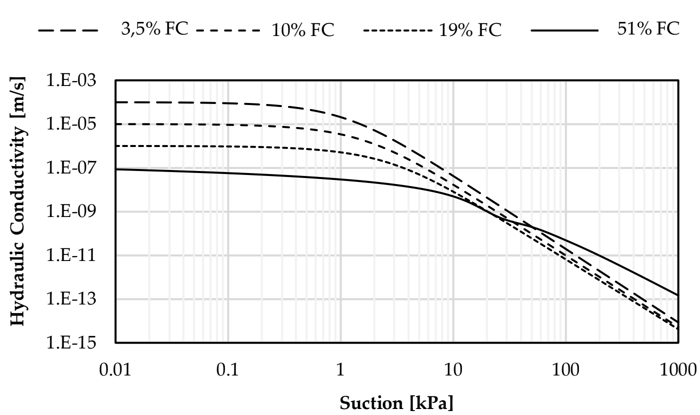

Figure 5 Fitting curve obtained to unsaturated hydraulic conductivity.

Model

The geometry consists of three layers of tailings (35 cm each) and three layers of sands (15 cm each) as shown in Figure 6 a). A permanent regime is initially considered considering hydraulic load lines on the sides of the model as shown in Figure 6 b), then a transient regime (of 15 days) is considered where water is allowed to exit at the level of the sand layers as shown in Figure 6 c). The fines content of the sand layers is modified leaving 4 case studies with 3.5, 10 and 19 % fines content in addition to the case with no sand layers, i.e., pure tailings (51%FC). The model was calibrated using the base case of 3.5% fines content (CPR sand) and the data sourced by Musso et al. (2023).

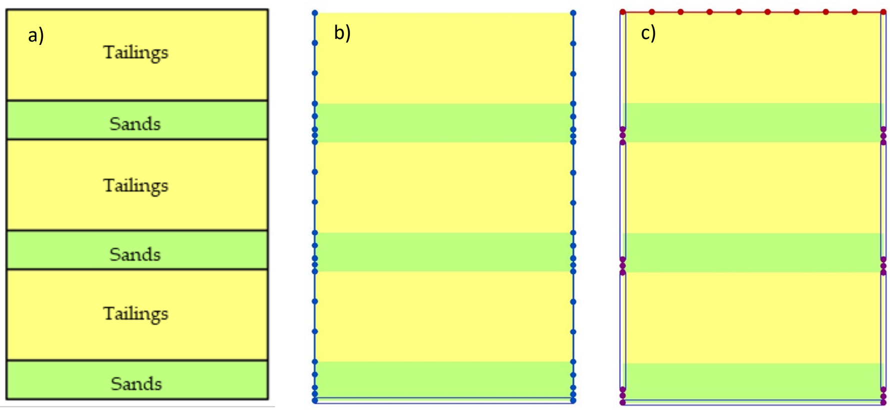

Figure 6 a) Material distribution, b) Permanent regime condition and c) Transient regime condition.

Results

Figure 7 shows the evolution of pore water pressures in materials after 15 days consolidation. The general behaviour shows that central tailings develop lower suction as fines contents are increased. This may be counterintuitive regarding the air entry value of material and evolution of suctions as shown in their respective SWRCs. However, this can be attributed to larger desaturation of the more permeable materials (especially near to 0% fines contents)

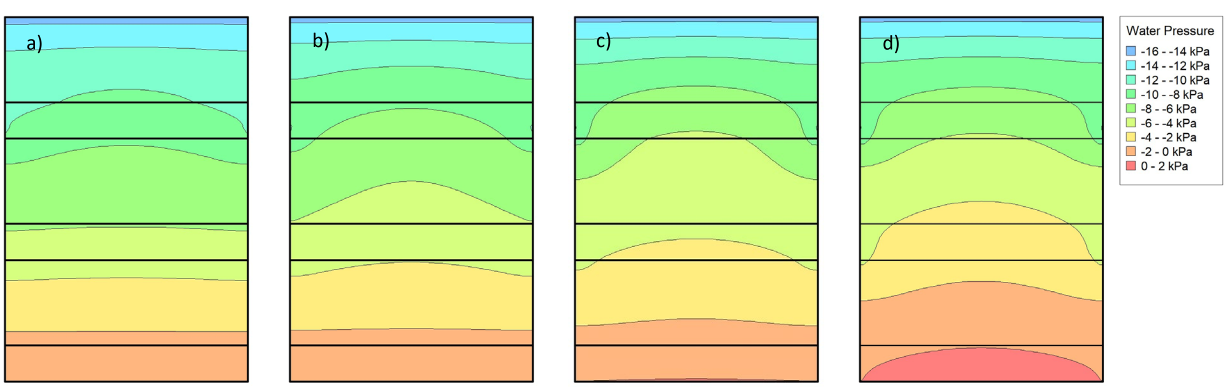

Figure 7 Suction model response for fines contents in the sands of a) 3.5%, b) 10%, c) 19% and d) 51%.

Figure 8 shows the degree of saturation for the scenarios modelled after 15 days consolidation. As expected, the lower the fines content the faster the materials desaturated. The lowest degree of saturation attained in the models for tailings is near to 80%. This is expected to decrease in larger periods, especially once materials are exposed to ambient condition and volumetric changes occur (not thoroughly considered in the simplified models)

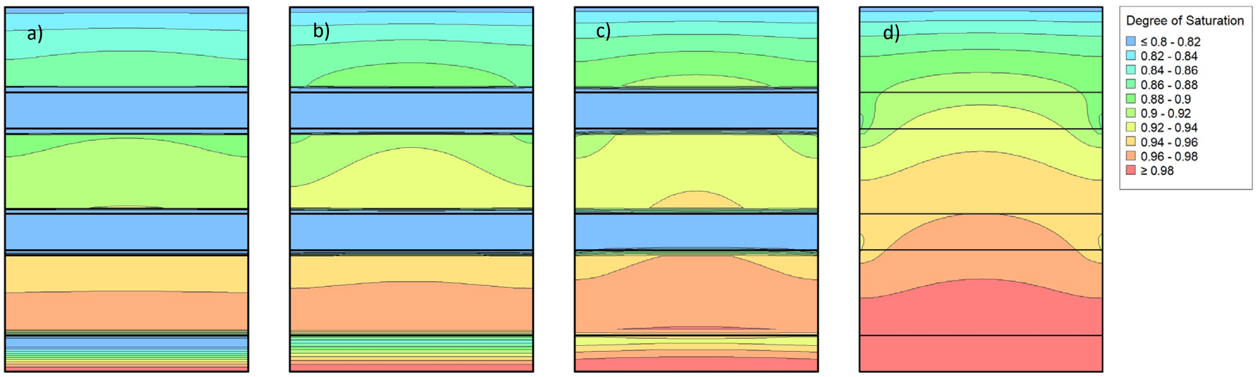

Figure 8 Saturation model response for fines contents in the sands of a) 3.5%, b) 10%, c) 19% and d) 51%.

The water recovered over time is shown in Figure 9. As the fines content in the sand layers increases, the volume of water recovered decreases due to increased retention capacity of mixtures showing increased fines contents. Differences in water drained out of the system may reach 15% for the sand mixtures considered.

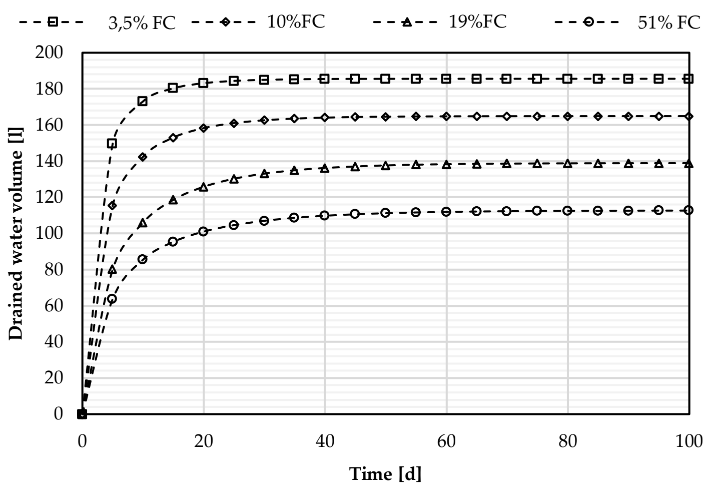

Figure 9 Drained water volume.

CONCLUSIONS

The effects of increased fines content in draining-sands were studied experimentally in the Laboratory. The flexible wall permeability tests showed that increases in fines content for CPR sands, in the range from 0 to 10%, resulted in a decrease of two order of magnitude in the coefficient of hydraulic conductivity. On the contrary, the changes in the AEV were small and SWRC and K_{unsat} (over suction) showed minor changes as fines contents were increased from 0 to 19%.

Considering Seep/W results, for models that tried to mimic the Large Consolidation Cell available at UTFSM, it was observed that desaturation occurred at a different pace depending on sands fines content. The greater the fines content of sands the higher the saturation observed in the tailings mass, for simulations periods over 15 days. Similarly, suction developed slowly in the tailings where larger contents of fines were considered. Finally, as the sand fines content were increased to a maximum of 19%, the volume of water recovered in the cell decreased up to a 15% in comparison to CPR sands for a period of 15 days.

This study allows to observe the benefits of using CPR sands (clean sands) in comparison to classified sands with increased fines content. Nevertheless, if CPR sands are not readily available, the counteracting effects of increased fines content (as observed in this article) in the HDS can be managed with appropriate design of drains, spatial arrange of materials (such as cells) and appropriate rate of rise of tailings.

ACKNOWLEDGEMENTS

The authors would like to thank Anglo American for their financial support in the development of the HDS laboratory large cell and support to this investigation.

NOMENCLATURE

HDS	Hydraulic Dewatered Stacking
TSF	Tailings Storage Facilities
CPR	Coarse Particle Recovery
CPF	Coarse Particle Flotation
K	Hydraulic Conductivity
FC	Fine Content (Particle percentage <75 μm)
S	Saturation
e	Voids Index
SWCC	Soil Water Characteristic Curve
SWRC	Soil Water Retention Curve
UTFSM	Technical University Federico Santa María

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