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Unsaturated soil behaviour in thickened and filtered tailings

P Simms *Carleton University, Canada*

Abstract

Proper application of unsaturated soils to thickened or filtered tailings has substantial potential to optimise such tailings deposition. Unsaturated behaviour bears on both the geotechnical and geo-environmental performance of these deposits. Geotechnically, there is an increase in strength through both additional densification, and the presence of suction, as well as a stress history effect. The latter is especially important to understand in situ measurements in previously desiccated deposits; geo-environmentally, unsaturated behaviour strongly bears on seepage generation, as well as management or mitigation of acid generation. This paper summarises a body of work on experimentation, numerical simulation, and field data relating to different aspects of unsaturated behaviour and their relevance to practical outcomes for design of thickened or filtered tailing deposits. An important new outcome from this summary is the suggestion to characterise the extent of the stiffness imparted by drying, especially due to the possible risk of strength loss in thick deposits when the tailings eventually yield under self-weight.

Keywords: *unsaturated, volume change, dewatering, desaturation, strength, desiccation, drying*

1 Introduction

The role of desiccation in tailings deposits seems to be experiencing somewhat of a renaissance or perhaps an overdue recognition of its importance and utility for tailings management. Here we define desiccation as the past inducement of matric suction in the tailings (as opposed to simply an acceleration of consolidation by drying). This impression of the author is gathered from conversations with consultants and mine operators, but also some 'facts', such as the recent proposal from The University of Western Australia to use air-drying as part of a standard sample preparation technique for element testing (Reid et al. 2022), discussion of CPT through desiccated tailings (Robertson et al. 2017), and some statements made by authors of public reports on tailings dam failures that allude to the positive impact of, e.g. rendering hard rock tailings dilative that are contractive before desiccation. Drying has long been occurring by nature or by design in deposits of thickened or filtered tailings. Desiccation is a necessary part of thin-layer deposition in both hard rock mines and overburden-derived tailings (such as the atmospheric fines drying (AFD) and tailings reduction operations (TRO) used in the Oil Sands), and is considered 'standard of practice' for strengthening tailings supporting upstream dam construction, e.g. South Africa, where sun drying was required for upstream construction, and in Australia, where the standard of practice requires desiccation of tailings that will support the dam (Reid, pers comm, 2022). Even in quite northern and wet climates, drying can play an important role in strength development in thickened or filtered tailings impoundments, provided the rate of rise is not too high; e.g. one site in Northern Ontario rates of rise up to 3 m/year still allowed for desiccation to influence strength behaviour (Qi & Simms 2018b).

There appear, however, to be some misconceptions and over-generalised beliefs among practitioners concerning drying and its effects. The goal of this paper is to review, very briefly, key elements of unsaturated soils, and then show application to specific problems in managing subaerial deposits. These elements include estimating an evaporation rate, quantifying the distribution of water content and density in a particular tailings deposition scheme, and how to quantify the contribution of desiccation to strength. The last is particularly important given recent proposals to use desiccation in laboratory preparation methods. These are done in the context of laboratory and field data from both hard rock and oil sands tailings.

2 Elements of unsaturated soils applicable to tailings drying, consolidation and desaturation

A good starter reference for applying unsaturated soils to tailings is Bussière (2007). In the present paper, key concepts of unsaturated soil behaviour are briefly reviewed, with some 'twists' important for tailings management highlighted.

The key state parameter for unsaturated soils is suction, which has a number of formal definitions (Fredlund & Rahardjo 1993). One useful definition for conceptual understanding is 'the work required to bring a unit volume of water to a reference state'. The type of suction changes with the reference state; for example, if the reference state is pure water at atmospheric pressure, this gives 'total' suction. Total suction is the sum of matric suction and osmotic suction. Matric suction is the pore-air pressure (u_a) less porewater pressure (u_w). In nature, the pore-air pressure is almost always atmospheric pressure (0 gauge pressure); hence, matric suction is equal to the negative porewater pressure. Matric suction is the relevant parameter for mechanical behaviour. It arises due to the capacity of pores to retain water under negative pressure due to the capillary phenomena. Osmotic suction arises due to the presence of dissolved mass in the porewater, and it is important to consider for tailings in the context of evaporation. For example, under equilibrium conditions, the vapour pressure at the tailings surface is a function of the total suction (sum of both suctions) in the liquid phase; hence, the accumulation of dissolved mass at the surface can limit evaporation through increasing osmotic suction, and therefore total suction at the surface.

The soil-water characteristic curve (SWCC), also called the water retention curve, is the primary material property of unsaturated soils. Conventionally, this is presented in terms of water content or degree of saturation versus matric suction. An example of a SWCC for a hard rock tailings is shown in Figure 1, expressed in terms of geotechnical gravimetric water content *(w)* or degree of saturation (S_r) versus matric suction. Most but perhaps not all practitioners realise that the shape of these two functions is different, and to capture the correct degree of saturation versus matric suction curve requires measurement of volume change during the SWCC test. The air entry value (AEV) is associated with the onset of substantial desaturation and is correctly determined from the saturation–suction curve. The lower suction range (<500 kPa) can be obtained by the axis translation technique, while the higher range can be reliably obtained using paired measurements of total suction and water content of small (~50–100g) air-drying samples. Total suction can be measured conveniently on grab samples using dewpoint hygrometers. Not shown here is the well-known hysteresis of the SWCC – when the curve is measured starting at a dry state (the 'wetting' SWCC), the curve shifts to the left, and the same degree of saturation is achieved at the lower matric suction than for the drying curve. The magnitude of hysteresis does not vary substantially within different hard rock tailings, nor among clayey tailings (Qi & Simms 2018a, b), and it is probably not necessary to measure the wetting curve for most applications in tailings.

For subaerial deposition of tailings, more important is the variation of the SWCC as a function of the degree of consolidation or compaction experienced by the tailings. The lower the void ratio at the start of drying, the higher the air entry value, and the flatter the slope of the water content–suction curve before the AEV. The consequences of a lower void ratio before drying are generally beneficial: a larger suction at the AEV means that the degree of suction hardening will be larger, and the same value of suction can be achieved for less drying, as less water needs to be consumed by drying for the same value of suction to be reached. Of course, initial drying itself may shift the SWCC, leading to an important behaviour: a layer of tailings, after desiccation, undergoes a substantial amount of irreversible volume change. In practically all tailings, this irreversible volume change will be much greater than any swelling. This is particularly important for understanding the drying of tailings in wetter climates. Rain can re-saturate tailings, but it will not erase most of the gains in volume reduction, stiffness, or in strength due to suction history. This is likely why robust strength increases due to drying are reported in some sites in relatively wet and cold climates.

The shifting of the SWCC is evident in Figures 2 and 3. Figure 2 shows the shrinkage curve (void ratio versus water content) as determined from bench tests from a thin single layer dry box test (~1 by 1 m in plan), and a thicker dry box test. For the dry box tests, the volume and mass measurements pertain to the whole layer, reflecting dewatering both from consolidation and drying. This is why the water content at which desaturation (the point at which the shrinkage curve deviates from the linear portion) occurs is lower for the thicker layer. For the case of hard rock tailings, the change is somewhat less, but still significant, as shown for the two drying SWCCs in Figure 3 where the onset of desaturation occurs at a higher suction for the initially compacted specimen.

The compression of the tailings induces a change in stiffness that remains even after re-saturation. However, the magnitude of the stiffness is greater than expected due to the change in density alone. Figure 4 shows an oedometer test on hard rock tailings, in which a tensiometer was installed through the base to monitor the sample during initial drying. The matric suction achieved before rewetting in this test was ~100 kPa, but the pre-consolidation pressure of the subsequently rewetted tailings is about 230 kPa.

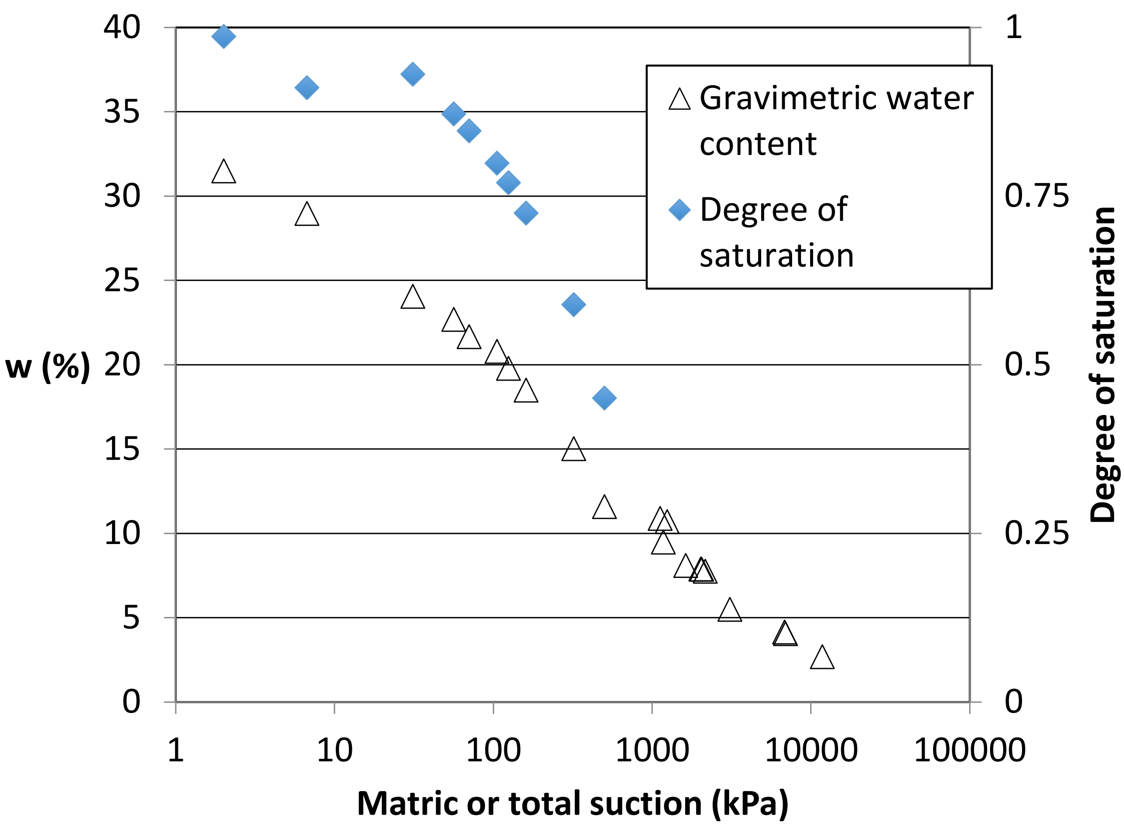

Figure 1 Drying SWCC in terms of water content and saturation (modified from Simms et al. 2019)

Figures 2 through 4 imply that the compressibility behaviour of the tailings depends on past desiccation and self-weight loading, while the SWCC itself will shift to past compression due to either consolidation or drying. Fortunately, these somewhat complex interactions have been conceptualised by several models in the field of unsaturated soils, and many of these models (Basic Barcelona, or BBM, state surface or SSM, and Glasgow coupled or GCM) have been implemented in geotechnical codes, although for small strain conditions. Qi et al. (2017a, 2020) reset these models into a large strain consolidation framework, the UNSATCON code, which has been applied to multilayer drying box tests (up to 1 m deep multilayer deposits, 1 by 1 m in plan), as well as field data from both hard rock and oil sands mines (Qi & Simms 2018a, Simms 2021).

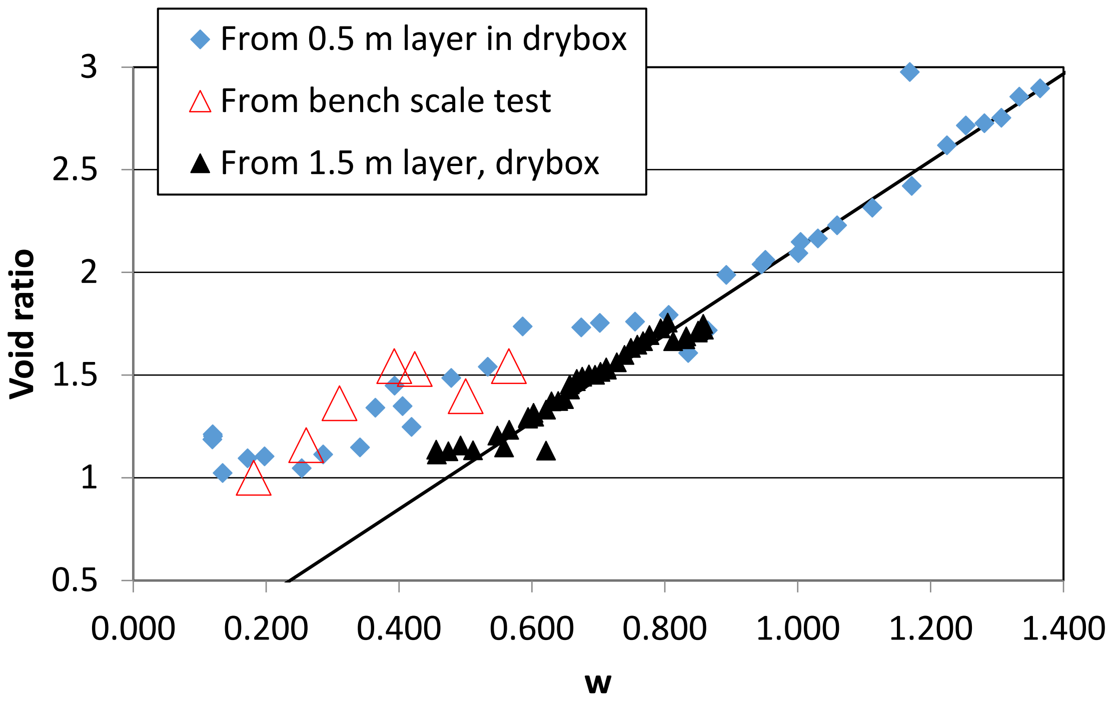

Figure 2 Shrinkage curves of a clayey tailings (data from Rozina et al. 2015)

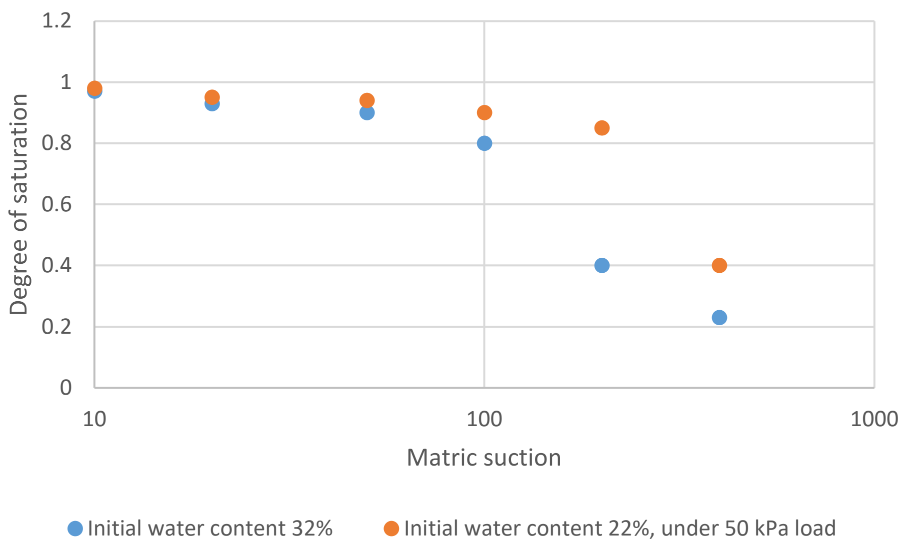

Figure 3 Drying SWCCs for the same hard rock tailings, different degrees of initial consolidation (data from Heidarian 2012)

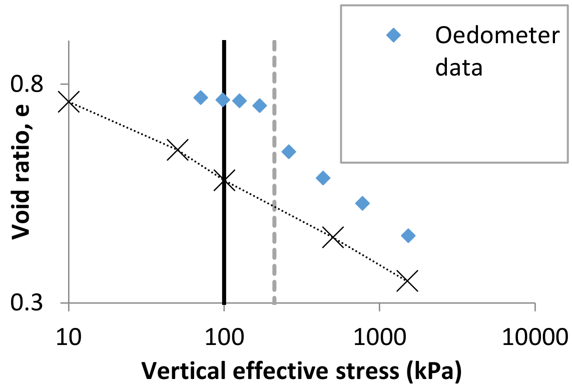

Figure 4 Changes in compressibility in hard rock tailings due to past suction history in a rewetted sample

Here we do not focus on the details of the particular soil models (e.g. BBM, GCM) but rather hope to explain the data requirements and how aspects of desiccation in tailings deposition can be explained or framed using generic results from codes like UNSATCON. Figure 5 shows the data requirements with respect to compressibility and the SWCC. Figure 5a shows a typical compressibility relationship for saturated soft soil – the blue lines indicating the unload–reload line. With the presence of suction, this relationship gets expanded to three dimensions, as shown in Figure 5b, where the normal consolidation line is now a surface, delimited by the large strain compression curve along the total stress axis, and the shrinkage curve along the matric suction axis. The rebound line is now an elastic surface with a different slope along the suction and the total stress axis. The drying SWCC, shown in Figure 5c, depends on the void ratio.

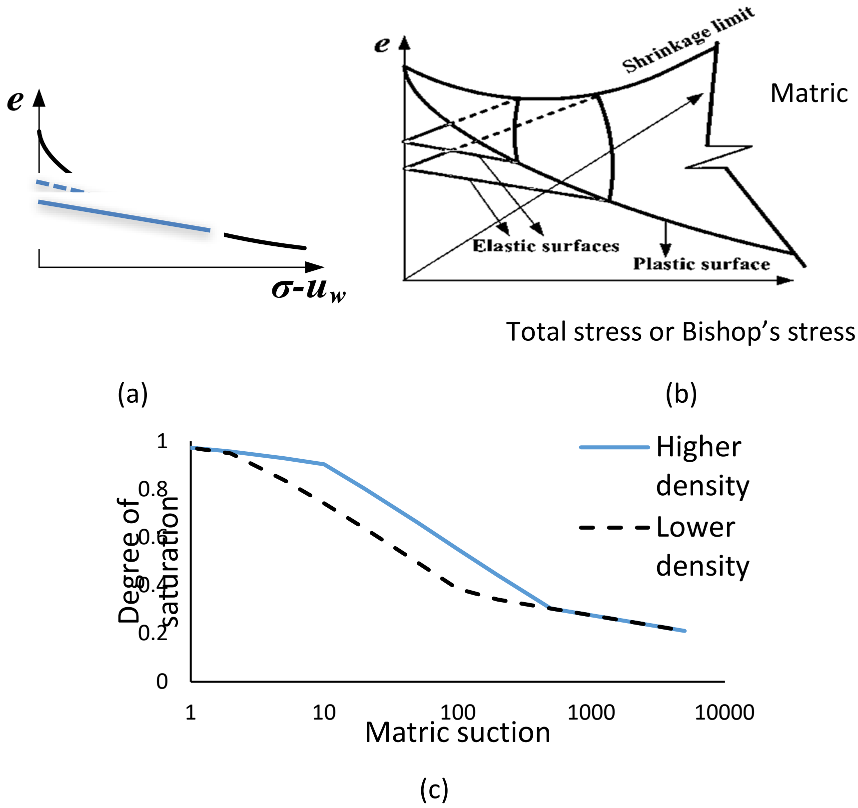

Figure 5 Data requirements for elasto-plastic unsaturated models. (a) Conventional compressibility; (b) Compressibility as a function of stress and suction; (c) Dependency of SWCC on void ratio

Our own group's experience has shown that the plastic surface in Figure 5b and the susceptibility of the drying SWCC to void ratio can be determined by measuring the compression curve and a standard drying SWCC test with volume change measurement (which would also give the shrinkage curve). From this data the parameters of the relevant soil model (e.g. BBM, GCM) for the void ratio dependency of the SWCC and the shape of the plastic surface can be determined analytically (Qi et al. 2020). The data requirements for determining the slopes of the elastic surface in Figure 5b, require a compression test on a previously desiccated sample, such as the test in Figure 4. This last test is important, as it is required to determine additional volume change resulting from the burial of desiccated tailings by fresh tailings. In other words, how much volume change will the first few layers of a deposit experience after desiccation, and after their burial by 10s of metres of additional tailings and/or cover soil?

Figure 4 is also important for interpreting field tests on tailings that may have experienced past desiccation. Not only the stiffness, but the strength of such tailings, even after re-saturation, may be substantially higher at a given void ratio than for tailings that have never experienced drying. Therefore, knowledge of the likely stress history of a given deposit is very important to properly interpret field data.

Figure 6 shows an example of a simulation using UNSATCON of a two-layer deposit of clayey tailings, showing outputs of void ratio (left) and degree of saturation for different time periods. The sign of the slope of the void ratio profile changes multiple times. The sign changes arise at the end of the drying period for the first layer because total stress is largest at the bottom but decreases with elevation, whereas the opposite behaviour is present with matric suction, which is maximum at the top, but decreases towards the bottom. Therefore, there are two different minimum void ratios: the one at the bottom due to compression, and the one at the top due to drying. The profile at the end of the second layer is due to the differences in compression in the first layer due to the additional self-weight of the second layer. The tailings at the top of the first layer are stiffer than the tailings at the bottom of the first layer due to the additional stiffness due to drying. The resulting profile is seen in some of our drying box tests on clayey tailings, as illustrated in Figure 7. Detailed comparisons of the model output with a gold tailings dry box test are presented in Qi et al. (2020).

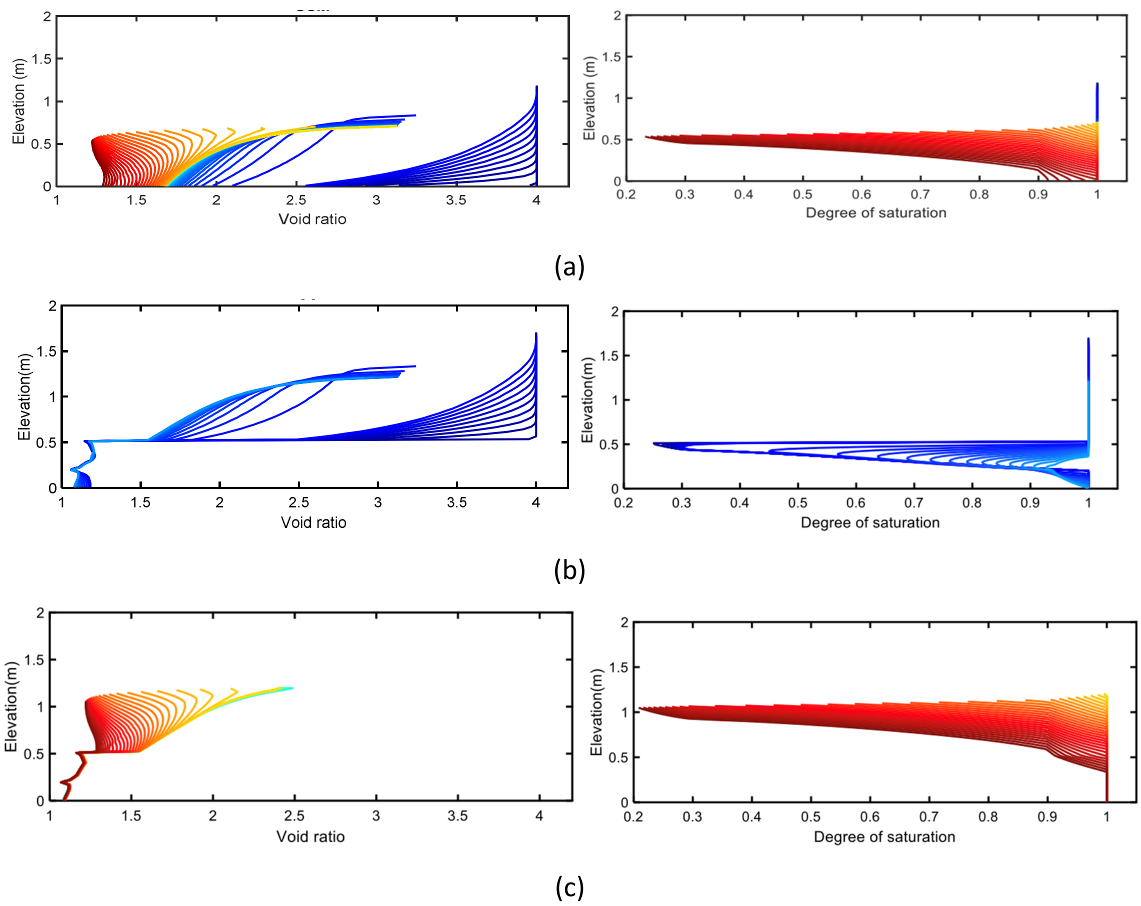

Figure 6 Simulation of subsequent deposition of two layers of clayey tailing using the UNSATCON model. (a) First layer consolidation and drying; (b) Consolidation of the second layer and rewetting of the underlying layer; (c) Subsequent drying of both layers

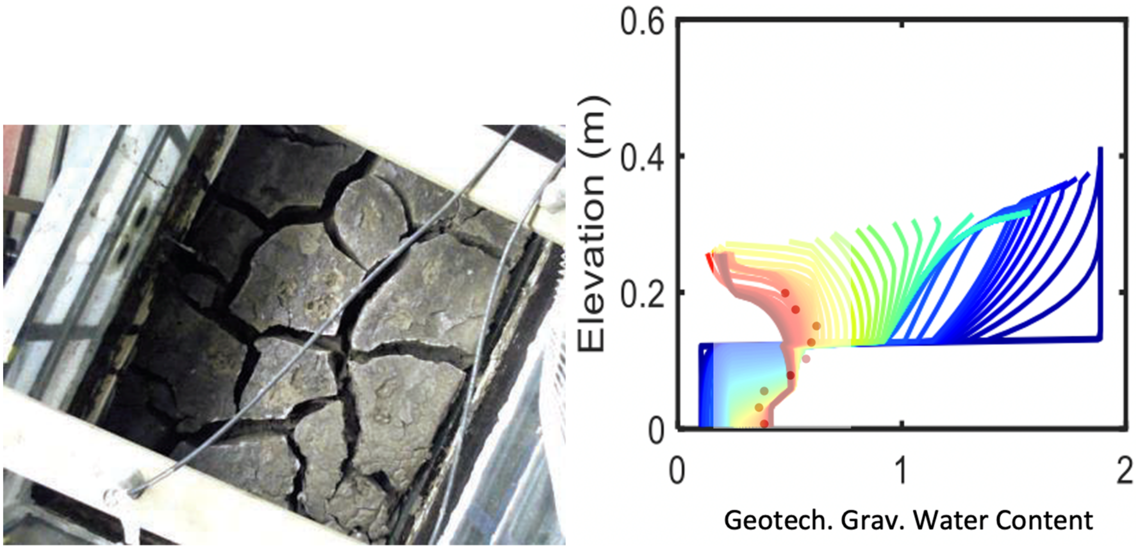

Figure 7 Comparison of a core from a two-layer dry box with UNSATCON simulation in a clayey tailings

As shown in various 'what if' simulations using this model (e.g. Qi & Simms 2018a, b), the correct characterisation of when a previously desiccated tailings yields (experiences new plastic deformation) may be important, not just to correctly estimate the volume change evolution of a given tailings deposit, but for consequences of stability. Therefore, testing to provide the information shown in Figure 4 is likely important to the safety and performance of deposits that experience drying.

3 What is the appropriate rate of evaporation to assume from the tailings?

The answer to this is complex, but a general rule of thumb can be applied in most cases. Nevertheless, understanding the complex behaviour could be important for practitioners to identify cases where the rule of thumb could fail.

Three phenomena can complicate the evaporative behaviour of tailings: (i) the suppression of evaporation due to an increase in total suction at the surface, (ii) the suppression of evaporation due to the accumulation of dissolved mass, which increases suction (through osmotic suction) but also results in the formation of salt crusts through mineral precipitation (very commonly gypsum in tailings, for example), and (iii) the enhancement of evaporation, at least temporarily, by the formation of cracks. Phenomenon (i) is probably the best known, and is handled in many geotechnical software codes for unsaturated soils applications. Theoretically, the evaporation ratio (AE – actual evaporation, PE – potential evaporation) will decrease when suctions at the soil surface become sufficiently high to depress the vapour pressure of water at the soil surface, usually requiring a total suction in excess of 5,000 kPa for a substantial decrease in AE to occur (Wilson et al. 1997). Conversely, high salinity depresses evaporation by contributing to total suction, which is enhanced by the concentration of dissolved mass at the surface and the formation of precipitates (Simms et al. 2007; Fisseha et al. 2010). This depression of evaporation, however, is often countered by the formation of cracks which can, at least for a period, maintain high levels of AE. The influence of cracks to enhance AE, even to values temporality above PE, has been demonstrated in dry box tests, such as those shown in Figure 8. Figure 9, from the same experiment and a field test on similar tailings, shows that while the total suction becomes quite high at the surface, especially at crack edges (which dry out the most), total suction within the cracks remains quite low, indicating that crack surfaces can serve as a source of extra evaporation, at least for some time.

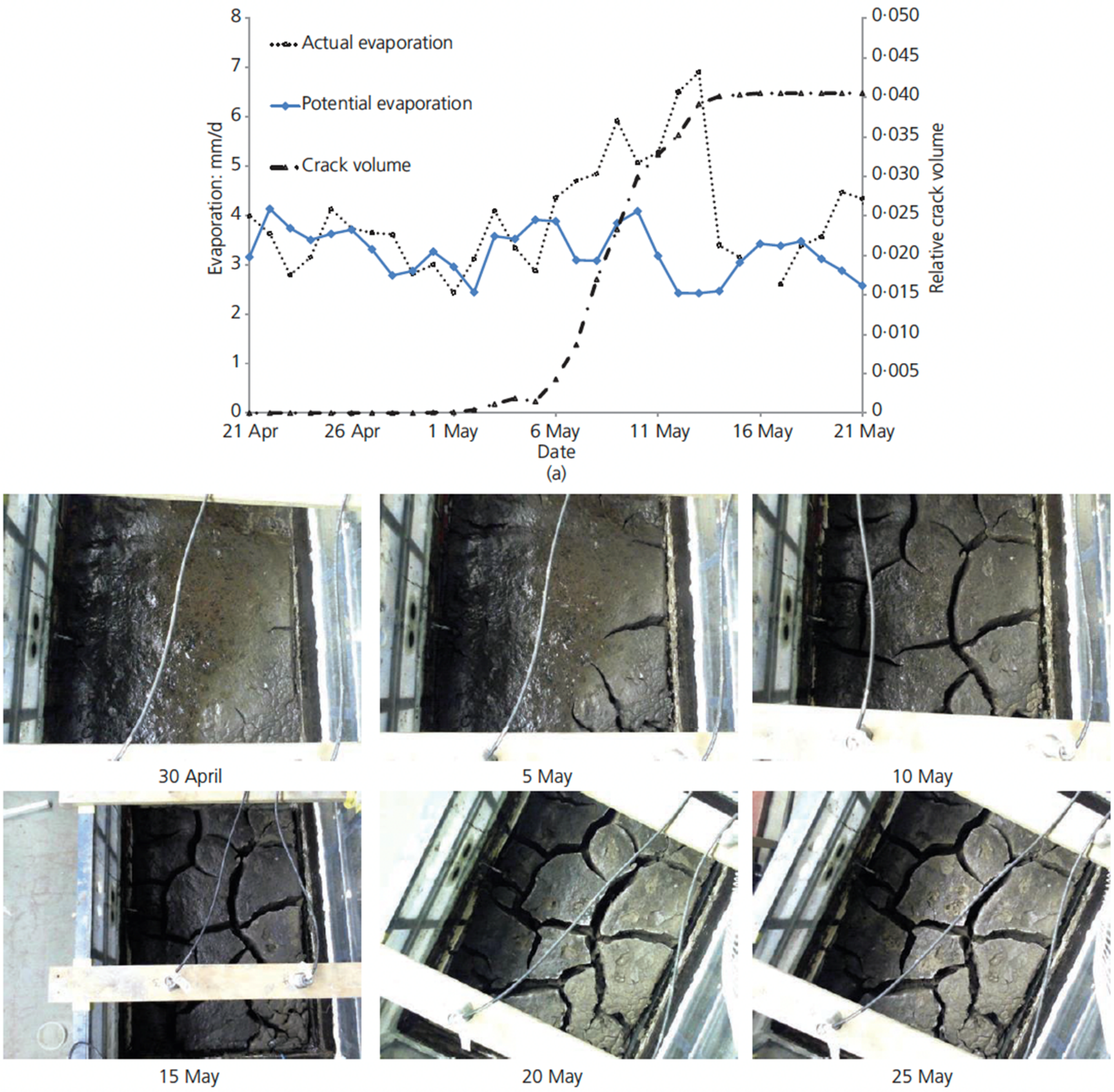

Figure 8 **Evaporation and crack volume in a 0.35 m layer of clayey tailings (modified from Simms et al. 2019)**

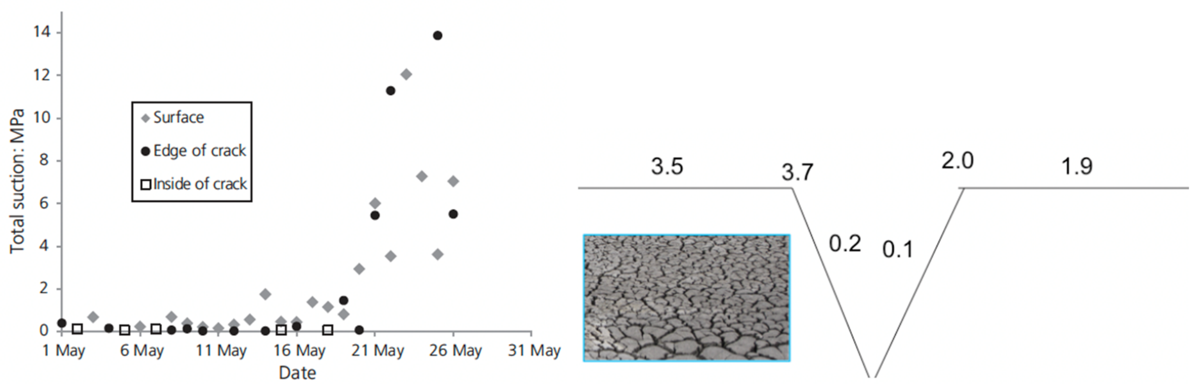

Figure 9 **Measurements of total suction in top 1 cm thick samples, at surface, edge of cracks, and insidecracks in a clayey tailings in (a) a dry box test; and (b) in the field**

Figures 10 and 11 show cumulative evaporation data on dry box tests of both a gold tailings and a clayey tailings. Even for the gold tailings with a very high potential evaporation rate, the cumulative evaporation remains above 0.7 × PE. The clayey tailings remains close to the PE. Limited data from field experiments (Fujiyasu et al. 2000), pilots (Dunmola et al. 2013), and back-calculations using models such as UNSATCON (Qi et al. 2017b; Qi & Simms 2018b) support the rule of thumb that cumulative AE will vary between cumulative PE and 0.7 × cumulative PE. To simulate multilayer deposition, simple boundary conditions where the evaporation ceases when the surface suction achieves a certain value (usually between 5 and 10 MPa) are sufficient to conservatively characterise the contribution of evaporation to dewatering. Very saline tailings (Newson & Fahey 2003) may require special consideration due to a more rapid reduction in AE; the growing database of experiments and field cases should provide useful information to practitioners to make their own judgement on what level of salinity would trigger this extra analysis.

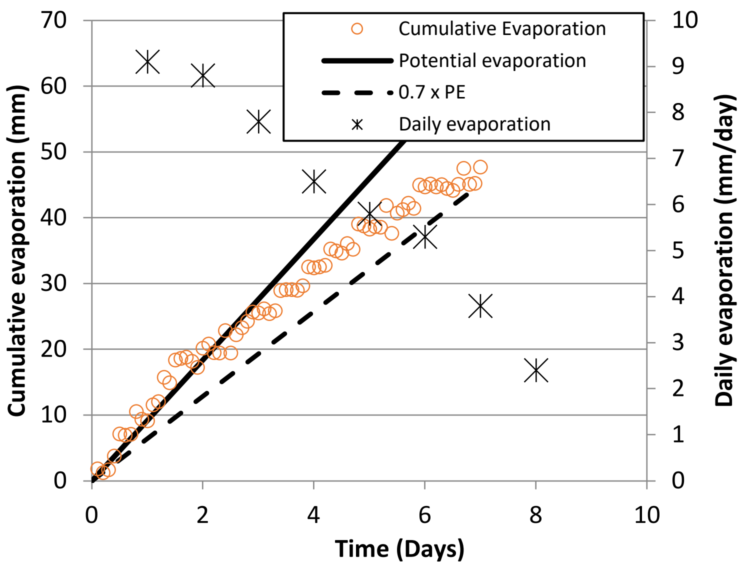

Figure 10 Evaporation in a gold tailings deposited at *w* = 40%, 0.2 m thick layer

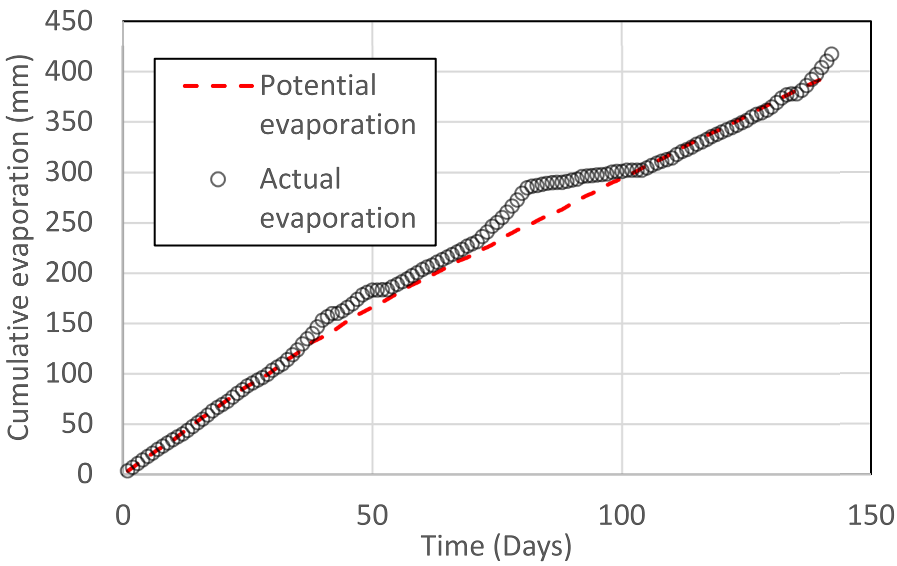

Figure 11 Evaporation in a clayey tailings deposited in three layers (deposited on 0, 60, 120 days), initial thickness 0.35 m

4 Contribution of drying to shear strength

Here we consider only the contribution due to the stress history beyond any additional densification and neglect contributions via matric suction to the current effective stress. For both hard rock and clayey tailing, a history of drying can increase strength at a given void ratio due to the stiffness imparted to the tailings (e.g. Figure 4). Additionally, for hard rock tailings, desiccation has been shown to increase the stiffness and dilatancy, resulting, for a given test, stronger and stronger samples at higher and higher void ratios (Figure 12). The samples in Figure 12 are air-dried, rewetted, and then consolidated before shear; results are reported in Daliri et al. (2014, 2016) and Simms (2017) on gold tailings, with some replication on a different gold tailings by Reid et al. (2022). It may be useful to note that it does not take drying all the way to the shrinkage limit (in the case of Figure 12, the shrinkage limit is at w = 18%) to induce dilative behaviour or, as shown in Figure 13, to induce a sizeable increase in shear strength measured by a vane. Indeed, the largest increase in strength in the element tests occurs from w = 30% to 25%; w = 30% being the post-settling water content for these tailings. A comparison of similar data in Figure 13 with some vane tests from the field is shown in Simms (2021). A mechanism for the increase in dilatancy was postulated by Daliri et al. (2014) based on SEM images of freeze-dried samples. The clayey tailings reported in Figure 14, by contrast, show little difference in terms of shear strength at a given effective stress, but there is a difference in terms of void ratio, with the previously dried tailings exhibiting substantially higher shear stresses at a given void ratio (as shown in Figure 15).

For both these tailings, it would be expected that the contribution of drying to strength would be removed at some level of consolidation, similar to the collapse of the compressibility curve of the previously dried sample back towards the 'never dried' curve. The Daliri (2013) results show that shear strength remains affected by drying history up to 400 kPa k0 loading, though the contribution of drying becomes less. How will a deposit behave when the tailings experience a substantial decrease in stiffness, coupled with a loss in dilatancy and strength? It is recommended that this be evaluated in any testing program to support the design of tailings deposited with desiccation.

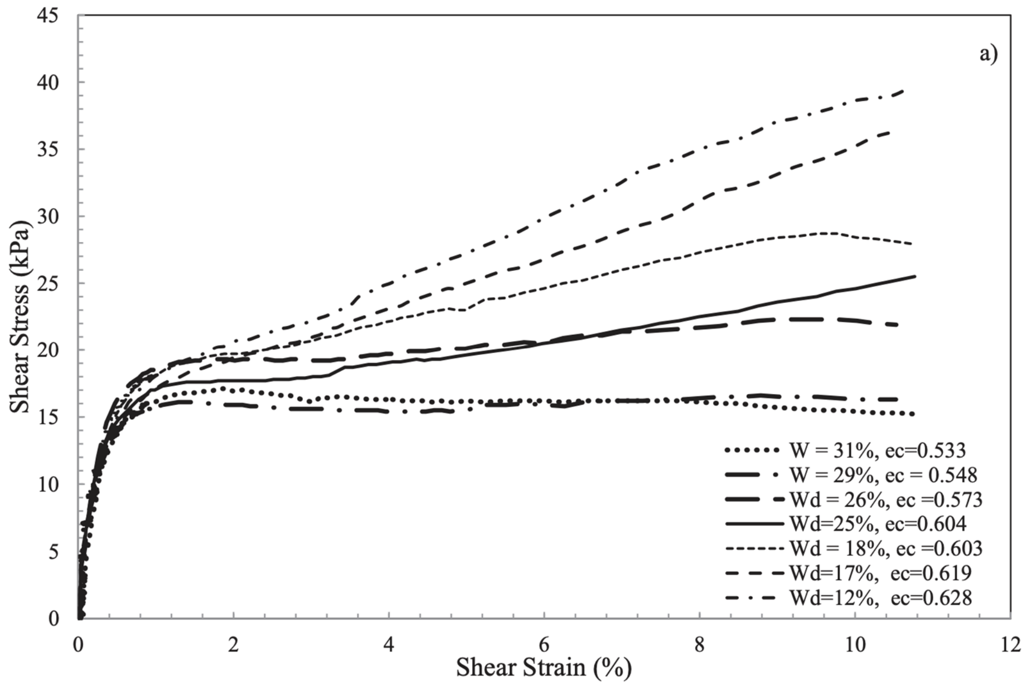

Figure 12 Shear strength in simple shear, consolidated to 100 kPa, of a gold tailings desiccated to different water contents (Wd), subsequently rewetted, consolidated, and sheared (Daliri 2013)

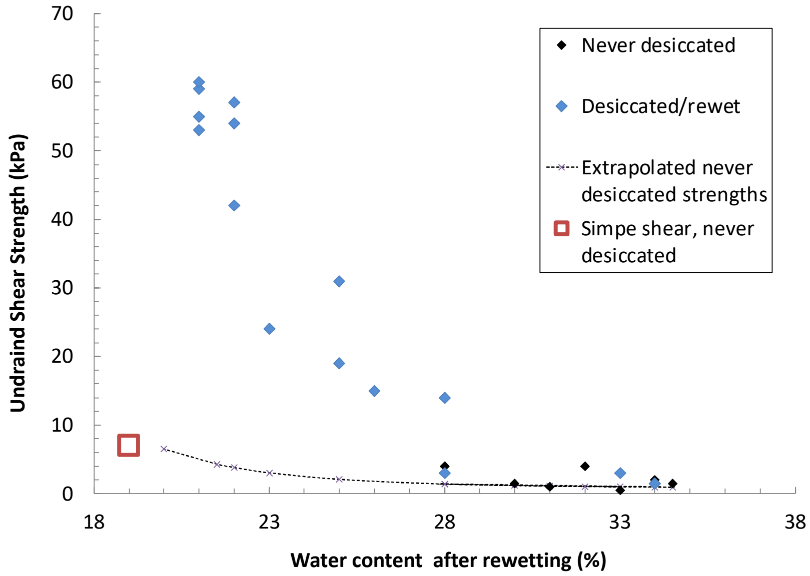

Figure 13 Vane shear tests in a gold tailings with initial water content of 40%, bench scale or dry box tests

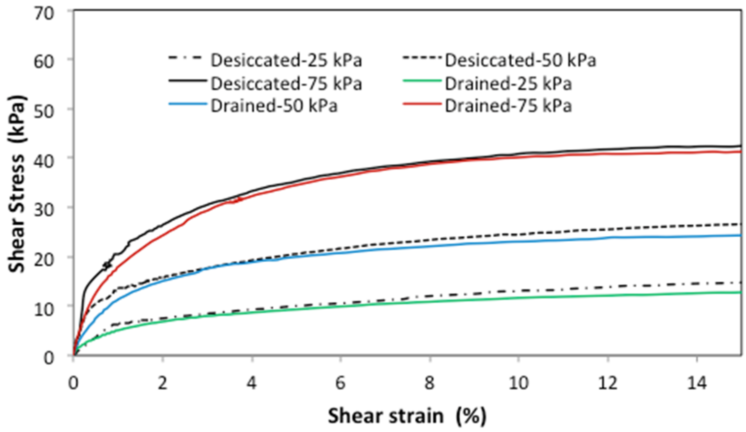

Figure 14 Shear strength in simple shear tests on a clayey tailings, either desiccated–rewetted–consolidated, or consolidated only (denoted by 'drained') Rozina et al. 2015)

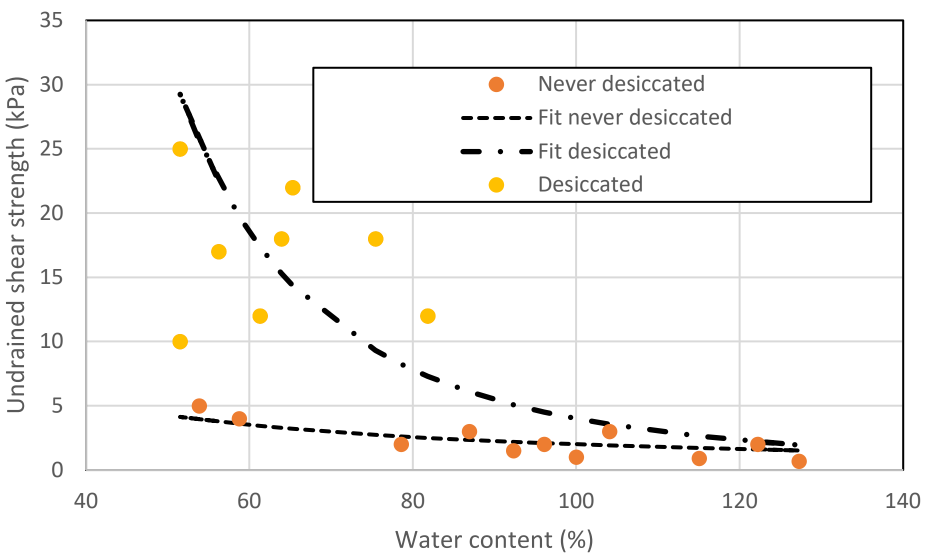

Figure 15 Vane shear tests from field data in a clayey tailings

5 Conclusion

The following important learnings are obtained from this summary of experimentation, numerical analysis, and field data on the desiccation of tailings in a multilayer deposition scheme:

1. The void ratio dependency of the SWCC, and the influence of desiccation on the tailings' compressibility are important to explain how volume change and saturation evolve in a multilayer deposit.
2. These effects can be handled by current elasto-plastic unsaturated soils models, coupled with large strain consolidation. This requires measurements of a standard drying SWCC including measurements of volume change, and the compression curve of a previously desiccated and subsequently rewetted tailings of the type shown in Figure 4.
3. The compressibility of the desiccated samples may be particularly important, as the yielding of the desiccated tailings may be associated with a reduction in deposit stability.
4. Despite evaporation being influenced by many phenomena, an estimate of AE = 0.7 PE seems to be a conservative estimate of the evaporative boundary condition, as seen in several experiments and field cases. Cracking will extend the contribution of evaporation beyond what is anticipated from small column tests on drying. For hypersaline tailings, actual evaporation could be substantially lower (see Newson & Fahey 2003).
5. The stress history or suction hardening due to past desiccation is substantial, although of a different nature in hard rock and clayey soil-based tailings. In hard rock tailings, substantial strength is developed well before the tailings are dried to their shrinkage limit. Therefore, the eventual erasure of the benefits of desiccation at high stress levels needs to be evaluated through testing, if such erasure threatens deposit stability.

Acknowledgement

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References

Bussière, B 2007, 'Colloquium 2004: hydrogeotechnical properties of hard rock tailings from metal mines and emerging geoenvironmental disposal approaches', *Canadian Geotechnical Journal*, vol. 44, no. 9, pp. 1019-1052, https://doi.org/10.1139/T07-040

Daliri, F 2013, *The Influence of Desiccation and Stress History on Monotonic and Cyclic Shear Response of Thickened Gold Tailings*, PhD thesis, Carleton University, Ottawa.

Dunmola, A, Cote, C, Freeman, G, Kolstad, D, Song, J & Masala, S 2013, 'Dewatering and shear strength performance of in-line flocculated mature fine tailings under different depositional schemes', in GW Wilson, DC Sego & NA Bier (eds), *Proceedings of the Seventeenth International Conference on Tailings and Mine Waste*, University of Alberta Geotechnical Center, Edmonton.

Daliri, F, Kim, H, Simms, P & Sivathayalan, S 2014, 'Impact of desiccation on monotonic and cyclic shear strength of thickened tailings', *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 140, no. 9.

Daliri, F, Simms, P & Sivathayalan, S 2016, 'Shear and dewatering behaviour of high density gold tailings in a laboratory simulation of multi-layer deposition', *Canadian Geotechnical Journal*, vol. 53, no. 8, pp. 1246–1257.

Fisseha, B, Bryan, R & Simms, P 2010, 'Evaporation, unsaturated flow and salt accumulation in multilayer deposits of a 'paste' gold tailings', *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 136, no. 12, pp. 1703–1710

Fredlund, DG & Rahardjo, H 1993, *Soil Mechanics for Usaturated Soils*, John Wiley & Sons Inc., New York.

Fujiyasu, Y, Fahey, M & Newson, TA 2000, 'Field investigation of evaporation from freshwater tailings', *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, vol. 126, no. 6, pp. 556-567, https://doi.org/10.1061/(ASCE)1090-0241(2000)126:6(556)

Heidarian, P 2012, *Effect of Initial Water Content and Stress History on the Tailings Water-retention Curve*, MASc thesis, Carleton University, Ottawa.

Newson, TA & Fahey, M 2003, 'Measurement of evaporation from saline storages', *Engineering Geology*, vol. 70, no. 3–4, pp. 217–233, https://doi.org/10.1016/S0013-7952(03)00091-7

Qi, S, Simms, P & Vanapalli, S 2017a, 'Piecewise-linear formulation of coupled large-strain consolidation and unsaturated flow. I: model development and implementation', *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 143, no. 7, https://doi.org/10.1061/(ASCE)GT.1943-5606.0001657

Qi, S, Simms, P Vanapalli, S. & Soleimani, S. 2017b, 'Piecewise-linear formulation of coupled large-strain consolidation and unsaturated flow. II: testing and performance', *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 143, no. 7.

Qi, S & Simms, P 2018a, 'Hydro-mechanical coupling in dewatering simulations for mine tailings management', in C Ng, A Leung, A Chiu & C Zhou (eds), *Proceedings of the 7th International Conference on Unsaturated Soils*, vol. 2, pp. 1157–1162, Hong Kong University of Science and Technology, Hong Kong.

Qi, S & Simms, P 2018b, 'Analysis of dewatering and desaturation of generic field deposition scenarios for thickened tailings', in RJ Jewell & AB Fourie (eds), *Proceedings of the 21st International Seminar on Paste and Thickened Tailings*, pp. 401–412, Australian Centre for Geomechanics, Perth.

Qi, S, Simms, P, Daliri, F & Vanapalli, S 2020, 'Coupling elasto-plastic behaviour of unsaturated soils with piecewise linear large-strain consolidation', *Géotechnique*, vol. 70, no. 6, pp. 518-537, http://dx.doi.org/10.1680/jgeot.18.P.261

Reid, D, Simms, P, Sivathayalan, S, Fanni, Ricardo & Fourie, AB 2022, 'The "air-dried" specimen reconstitution technique - review, refinements, and applications', *Proceedings of Tailings and Mine Waste 2022*.

Robertson, P, Viana de Fonseca, A, Ulrich, B & Coffin, J 2017, 'Characterization of unsaturated mine waste: a case history', *Canadian Goetechnical Journal*, vol. 54, pp. 1752–1761.

Rozina, E, Mizani, S, Malek, M, Sanchez, M & Simms, P 2015, 'Dewatering in a laboratory simulation of a multilayer deposit of inline flocculated mature fine tailings', *Proceedings of Paste 2015* Cairns, Australia, pp. 81–94.

Simms, P, Grabinsky, M & Zhan, G 2007, 'Modelling evaporation of paste tailings from the Bulyanhulu mine', *Canadian Geotechnical Journal*, vol. 44, pp. 1417-1432.

Simms, P 2017, 'Geotechnical and geo-environmental behaviour of high-density tailings', *Canadian Geotechnical Journal*, vol. 54, pp. 455-468.

Simms, P, Soleimani, S, Mizani, S, Daliri, F, Dunmola, A, Rozina, E & Innocent-Bernard, T 2019, 'Cracking, salinity, and evaporation in mesoscale drying experiments on three types of tailings', *Environmental Geotechnics*, vol. 6, no. 1, https://doi.org/10.1680/jenge.16.00026

Simms, P 2021, 'The role of unsaturated soil mechanics in unconventional tailings deposition', *Soils and Rocks*, vol. 44, no. 3, https://doi.org/10.28927/SR.2021.066721

Wilson, GW, Fredlund, GW & Barbour, SL 1997, 'The effect of soil suction on evaporative fluxes from soil surfaces', *Canadian Geotechnical Journal*, vol. 34, pp. 145–157.