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Evaluating the dry stacking performance of commingled waste rock and filtered tailings

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Abstract

Dry stacking of filtered tailings is becoming an increasingly widespread approach to tailings management. Dry stacking can potentially offer some significant advantages over traditional tailings deposition, such as lower geotechnical risk, greater water return, much lower overall waste volume, and ease of reclamation and closure, thereby enabling a higher level of post-closure land use. However, filtration and compaction costs, and the operational complexity of dry stacking, can make it challenging. It has been shown that commingling of filtered tailings and waste rock can improve the geotechnical performance of the stack, and it has the potential to allow stacks to be constructed more rapidly in higher lifts, making dry stacking more economical for large operations.

This paper presents an overview of recent research into the geotechnical properties of filtered tailings and waste rock blends. Results from a series of shear strength and consolidation tests are also presented. It is shown that the addition of waste rock to filtered tailings stacks significantly increases the shear strength and reduces the pore pressure response during placement. This could potentially allow higher and faster lifts to be stacked safely.

Keywords: *filtered tailings, commingling, dry stacking*

1 Introduction

Waste management and its associated problems provide arguably the biggest environmental challenge facing the mining industry. Mining is an inherently waste-producing activity; in open pit mining, large quantities of overburden material are often stripped before ore can be mined. Furthermore, the vast majority of the ore also becomes a waste product; even high grade deposits contain only a few grams per tonne of recoverable metal. In typical metal mining operations, ore is recovered in a wet extraction process. The byproduct, tailings, is discharged from the mill in the form of a fluid slurry, typically about 20–40% solids by mass. Conventionally, these are stored behind dams often constructed from the tailings themselves. These structures can present a challenge for reclamation and closure, and are a long-term geotechnical risk and liability. As large, high-profile failures continue to occur, such as the recent Fundão (Morgenstern et al. 2016) and Córrego do Feijão disasters, tailings dams are increasingly becoming seen as unacceptable by many stakeholders.

A promising new approach is dry stacking: deposition of tailings in a self-supporting pile that has the potential to eliminate or reduce the need for a dam. This has now been successfully demonstrated in many commercial-scale metal mining operations (Wickland & Longo 2017). In the vast majority of cases, creating stackable tailings is achieved by using filtration techniques. Another technology that is gaining traction in dry stacking is waste rock and tailings co-disposal. Combining these techniques offers an attractive solution to mine waste management. Adding commingled waste rock to a filtered tailings stack can improve stability and reduce overall waste volumes.

2 Background

2.1 Filtered tailings

Densified tailings technologies are broadly divided into 3 categories based on mechanical properties and the method of dewatering: thickened tailings (TT), typically around 50–65% solids, paste tailings (PT), typically 70–80% solids and filtered tailings (FT) (>80% solids). Figure 1 summarises the properties, and pros and cons, of different densified tailings technologies.

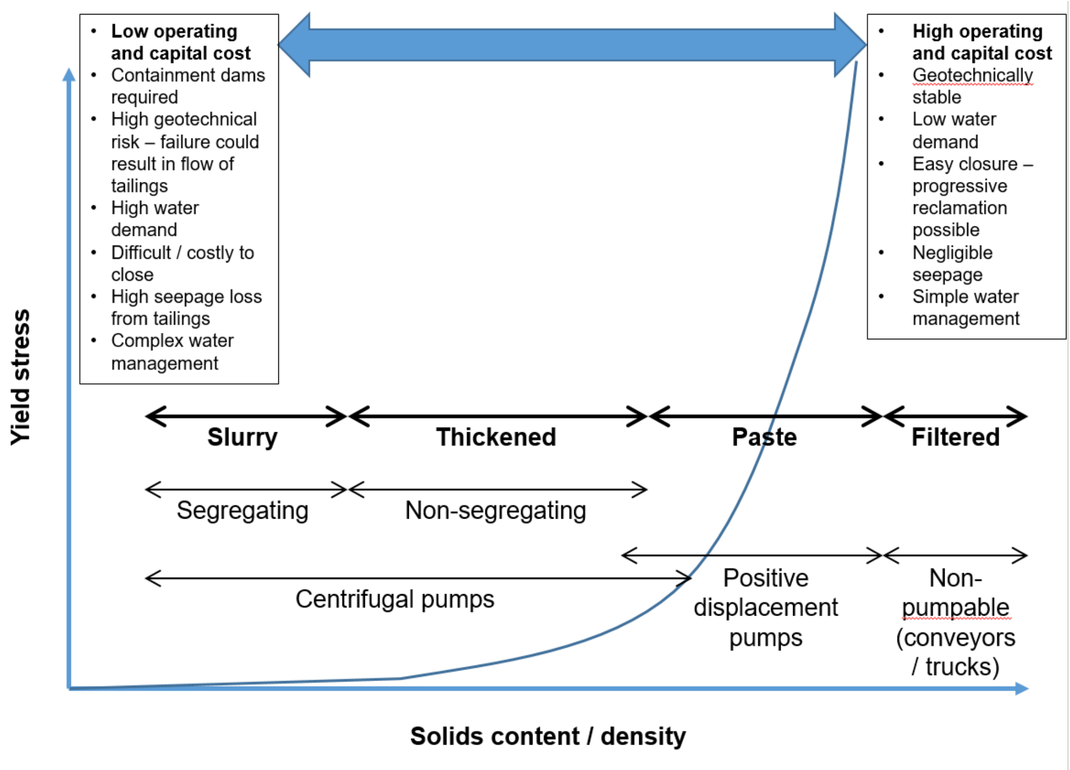

Figure 1 The tailings continuum (after Davies & Rice 2001; Jewell & Fourie 2006)

TT and PT technologies have many potential benefits; namely reduced water consumption and waste volumes, and improved geotechnical stability, whilst maintaining relatively low operating costs and good geochemical performance (Jewell & Fourie 2006). However, some form of containment structure is still required for deposition of TT or PT alone. Construction of a stable, self-supporting deposit requires filtration or co-disposal technologies.

FT dry stacking is becoming an increasingly popular alternative to traditional methods of tailings disposal and is now widespread in practice (Davies & Rice 2001; Jewell & Fourie 2006; Wickland & Longo 2017). Pressure- or vacuum-filtration is used to rapidly dewater the tailings. In a typical operation, filter cakes are transported to the impoundment by truck or conveyor, and then spread and compacted using equipment. Some drying of the filter cakes post filtration is typically required, such that they are in the unsaturated condition and amenable to compaction. This can be a costly and time-consuming process. Perhaps as a result, FT technologies have only been successfully applied at small- to medium-scale operations. The largest mines currently using FT technologies have a throughput of around 20,000 tonnes per day.

2.2 Co-disposal

In general terms, co-disposal refers to the disposal of waste rock and tailings in the same place. Co-disposal has been applied in many forms with varying degrees of mixing. These include pumped co-disposal, waste rock inclusions in a tailings impoundment, deposition of tailings into waste rock cells and layered co-disposal.

A good overview of these techniques is given by Bussiere (2007); a summary of several co-disposal case histories is given by Habte & Bocking (2017). More recent research has focused on producing homogenous blends to create an engineered material which has favourable properties and is known as paste rock (Wickland et al. 2006; Wilson et al. 2008). Blended co-disposal is the focus of this paper.

The principle behind paste rock blends was to create an engineered material which retained the high shear strength and low compressibility of the waste rock skeleton, combined with the low permeability and high water retention properties of the tailings. The focus was more on mitigation of acid rock drainage from waste rock dumps or its use as a cover material rather than for dry stacking. Any non-segregating tailings, typically paste or thickened, could be used. However, the need for a prescriptive ‘optimum’ mix ratio which is often not compatible with the mine plan, and the high costs compared to traditional methods of tailings disposal, have generally been prohibitive to the commercial application of this technology.

An alternative approach currently under development is the co-disposal of filtered tailings and waste rock. Filtered tailings and waste rock blends have the potential to be geotechnically stable at a much wider range of mix ratios, since they do not rely upon a continuous waste rock skeleton. This makes it a more viable and robust technology than thickened or paste tailings and waste rock blends. In practice, mines do not usually produce waste materials in the perfect ratio, and the ratio of waste rock and tailings produced usually varies throughout the life of the mine.

The addition of waste rock has the potential to improve the stability of a filtered tailings deposit by increasing shear strength and reducing the build-up of pore pressures during stacking. This may enable the material to be stacked rapidly in high lifts without prior drying of the filter cakes, which could make large-scale dry-stacking economical at mines with throughputs exceeding 100,000 tonnes per day. Blending could be achieved using the same system of conveyors that is used to transport the materials, although it should be noted that the transport and blending of waste rock typically requires the rock to be crushed to some degree, which may incur increased operational costs.

3 Geotechnical properties

This section gives a brief overview of some of the results of a program of laboratory tests on filtered tailings and waste rock blends. All mix ratios are given as rock:tailings by dry mass. Samples were blended using a concrete mixer to produce homogenous mixtures. Whilst it is recognised that this is not always representative of field conditions, ‘perfect’ blending is targeted for laboratory trials in order to produce good quality, repeatable results. Due to constraints in equipment size, shear strength tests were scalped to -37 mm and compression tests were scalped to -19 mm. Further details on blending procedure is given by Burden et al. (2018).

3.1 Index properties

The specific gravity of solids for both the tailings and waste rock used in this study were measured to be 2.73 and 2.67, respectively. Moisture contents (defined as mass of water/mass of solids) were measured to be 19.3 and 2.1%. Particle size distributions for the filtered gold tailings and waste rock used in the study are given in Figure 2. Waste rock was scalped in the field to -100 mm.

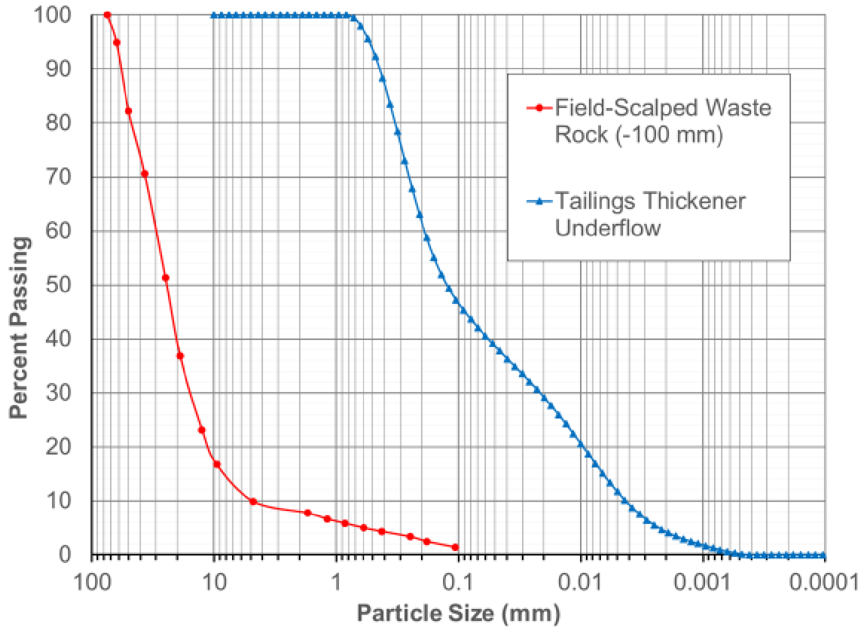

Figure 2 Particle size distributions of waste rock and filtered tailings

3.2 Shear strength tests

For large-scale direct shear tests on blends at a range of mix ratios, as well as filtered tailings and waste rock alone, a 300 × 300 mm shear box was used. The materials were scalped to a maximum particle size of 37 mm to allow for the best possible characterisation of the rock whilst remaining broadly consistent with the recommendation that the maximum particle size should be 1/6 of the box size per ASTM International standards. Further discussion on the influence of maximum particle size is given in Burden (2021). The blends were tested at their natural moisture contents. A low strain rate of 0.1 mm/min was used to ensure fully drained conditions. Tests were carried out at normal stresses of 250, 500 and 1,000 kPa. Results are plotted in Figure 3. One test was carried out for each data point.

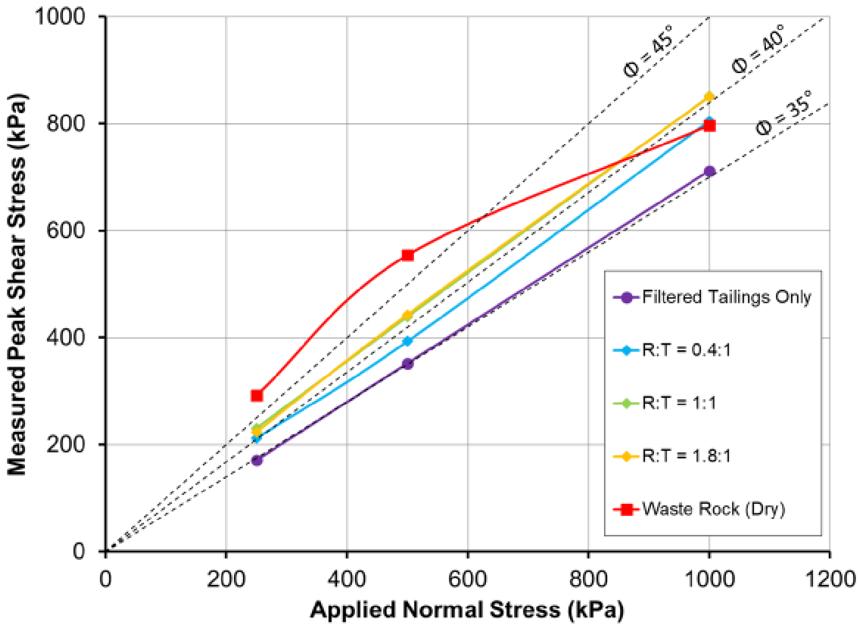

Figure 3 Large-scale direct shear test results for filtered tailings and waste rock blends

Addition of waste rock to filtered tailings resulted in a significant increase in shear strength. The results appear to suggest that, at higher stresses where rock breakage may occur, the strength of the blended materials is greater than rock alone. This may be because the tailings occupy void space between rock particles, reducing the stress at clast-to-clast contacts and resulting in less rock breaking. The significance of this effect would be dependent upon the strength of the waste rock used. However, 1,000 kPa would typically be considered a low stress for significant particle breakage to occur in most waste rock types. Further investigation of this effect for a range of rock types and confining stresses is recommended.

It should be noted that for the materials under consideration, the 'just-filled' point, defined as the mix ratio in which all of the voids in the waste rock skeleton will be fully occupied with tailings, occurs at a mix ratio of around 1:8. Thus, it can be seen that the addition of a relatively small amount of rock increases the shear strength significantly, even when the blend is still in the 'floating' condition, i.e. a continuous matrix of tailings with discontinuous, floating rock particles. An increase in strength at the just filled point may be expected, however, in the tests here, no improvement in shear strength is evident for mix ratios above 1:1.

3.3 Compression tests

The objective of the compression tests was to simulate the stacking of the material at a constant rate and measure the settlement and pore pressure response. Controlled rate of loading (CRL) tests were employed using an incrementally increasing load rate to account for the increasing drainage path length as the stack rose. Preliminary results are presented here, but detailed analysis and discussion of the method is beyond the scope of this paper.

The consolidation cell used in this study was a slurry consolidometer, custom built to the specifications of the University of Queensland. The cell has an internal diameter of 150 mm and is capable of accommodating samples up to 300 mm high. Sample heights used in the tests presented here were approximately 250 mm. Axial load is applied via a 10 kN high precision electromechanical load frame. It is equipped with top and base load cells, a base pore pressure transducer and further pressure transducers located throughout the height of the cell. Settlement is measured via a linear variable differential transformer (LVTD). The device is computer controlled and any combination of load steps and load rates may be applied. Drainage is from the top of the sample only. The slurry consolidometer is shown in Figure 4.

The cell is rigid walled and connected to the base. Wall friction was quantified by the use of a base load cell in addition to the load cell on the loading piston. For the tests presented here, maximum wall friction losses were approximately 60%. Detailed discussion on this topic is given by Burden (2021).

Figure 4 Slurry consolidometer

Figure 5 shows the base pore pressure response normalised with respect to vertical stress measured at the base. The samples were loaded up to a peak stress of 560 kPa using an initial seating load of 100 kPa, and thereafter the rate was incrementally increased over approximately 2 hours. The peak stress was selected based on the maximum capacity of the testing apparatus and corresponds to a loosely placed stack approximately 30 m high and compacted under self-weight. The load was then maintained and dissipation of excess pore pressure was monitored. Applied stress is plotted on the secondary axis. Actual measured pore pressure is shown on the first plot.

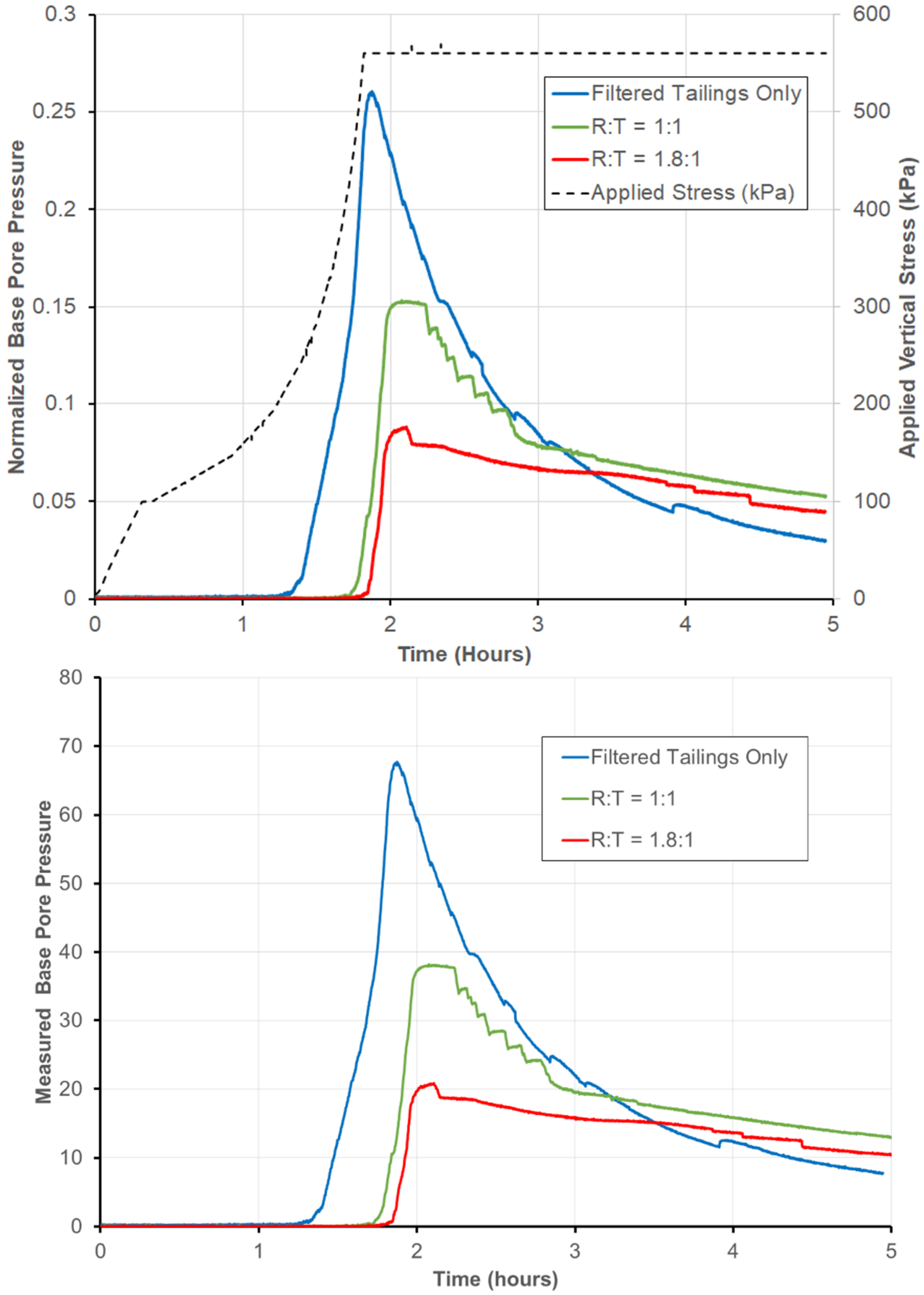

Figure 5 Pore pressure response for filtered tailings, and filtered tailings and waste rock blends, in a CRL test

One trial was performed for each blend ratio. The samples were placed loose in the cell at their natural blended moisture content. Initially, the sample underwent compaction and removal of large air voids. When a continuous water phase formed, excess pore pressures develops. Initial bulk densities of the samples were

1.38 g/cm^3 of filtered tailings, 1.31 g/cm^3 for the 1:1 blend and 1.33 g/cm^3 for the 1.8:1 blend, whilst final bulk densities were 2.1, 2.2 and 2.2 g/cm^3, respectively.

The results show that increasing rock content reduces the build-up of excess pore pressures under compressive loading. This suggests that the addition of rock to a filtered tailings stack has the potential to reduce the build-up of pore pressures at the base of the stack during placement. This could potentially allow for faster placement in higher lifts.

4 Discussion and conclusions

A dry stack consisting of commingled waste rock and filtered tailings has the potential to be more geotechnically stable than filtered tailings alone. Based on the limited laboratory-based testing presented in this paper, it appears that increasing rock content increases shear strength and reduces the build-up of pore pressure during stacking. This may allow dry stacked tailings to be placed rapidly in high lifts. Most mines currently employing filtered tailings technologies operate by spreading and compacting the material in thin lifts, which is equipment-intensive and difficult to scale up, so this new technique may make dry stacking more economically viable, especially at large mines. However, the practicality of transporting the two materials to the same site and achieving a blend requires careful consideration as it impacts the costs of achieving this improvement in strength and pore pressure response.

Generally the stacking of waste rock is straightforward because the rock is dry and extremely permeable, and pore pressures are not an issue. During the dry stacking of tailings, pore pressure generation due to compaction is paramount and may result in failure due to undrained loading and liquefaction. Predicting the performance of a dry stacked tailings blend at a given mix ratio and initial water moisture content is a critical design question. The slurry consolidometer provides a robust test method to address this question. A range of blends produced by any filtration system or tailings and waste rock types may be quickly and easily evaluated.

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