Paste 2024 – AB Fourie & D Reid (eds)

doi:10.36487/ACG_repo/2455_15

Farmed tailings stacking

H Li *Rio Tinto, Australia*

J Hinton *Rio Tinto, Australia*

J Navarro *Rio Tinto, Australia*

Abstract

Recent catastrophic high-profile tailings dam failures such as Fundão and Brumadinho have regenerated interest in tailings dewatering and dry stacking as risks of catastrophic failures or runout associated with wet tailings disposal or conventional tailings storage facilities are dramatically reduced or totally eliminated. Dry stacking is normally achieved using filtered tailings which has low moisture content and cannot be pumped. Filtered tailings is generated by high-rate thickeners followed by filtration. An alternative method to filtered tailings is to dewater tailings and accelerate consolidation in situ through mud/tailings farming, especially in regions where evaporation rates are high and rainfall is relatively low. Mud farming is not a new technology and has been applied in the alumina industry for decades. It can be used to generate tailings with solids content as high as those that can be achieved by filtration and create structural zones for safe and stable tailings storage facilities. The method requires low capital and operational expenditure, substantially less than that required by the filtration process.

This paper presents an alternative approach for dry stacking using farmed tailings. Key aspects for farmed tailings stacking, including water management, tailings farming, and disposal area/tailings cycle time are discussed. Water management is to ensure the decant pond in a tailings storage facility is minimised such that tailings in the structural zones can be farmed at all weather conditions. In order to achieve required tailings density and strength in the structural zones for safe and stable facilities, proper farming equipment, methodologies and assurance are needed and tailings cycle time between two consecutive tailings depositions should be adequate for tailings air drying and farming. In this stacking, dam safety relies on the farmed tailings in the structured zones and thus, only small bund walls are required for tailings containment and surface water management.

Keywords: *mud farming, filtration, tailings stacking, tailings, water management*

1 Introduction

Recent catastrophic failures of high-profile tailings dams, such as the Fundão incident in 2015 and the Brumadinho disaster in 2019, have reignited interest in tailings dewatering and dry stacking. This renewed focus is driven by the substantial reduction or complete elimination of risks associated with catastrophic failures or runouts, which are often linked to the wet disposal of tailings or conventional tailings storage facilities.

Dry stacking, a method gaining prominence, is typically achieved through the use of filtered tailings characterised by low moisture content, making them non-pumpable. Filtered tailings are generated through a process involving high-rate thickeners followed by filtration. An alternative approach, apart from filtered tailings, involves dewatering tailings and promoting consolidation in situ through mud/tailings farming. This method is particularly applicable in regions with high evaporation rates.

Mud farming is not a novel technology; it has been successfully employed in the alumina industry for decades. It offers the advantage of producing tailings with a high solids content comparable to filtration and establishing structured zones conducive to safe and stable tailings storage facilities. Importantly, this method demands lower capital and operational expenditures, significantly less than what is required for filtration processes.

2 Mud farming

Mud farming, a well-established practice in the alumina industry, involves the systematic ploughing of hydraulically deposited tailings using mechanical equipment to enhance density and strength through water drainage, solar and wind drying, and compaction. This technique has found application in numerous alumina production sites including Alcoa, Aughinish, Gove, Queensland Alumina Limited Worsley and Yarwun, as documented in various studies (Cooling 2007; Willan & Ghataora 2015; Li et al. 2011; Munro & Smirk 2012).

The mechanical equipment employed in mud farming includes bulldozers, amphibious excavators, and amphirols. A similar technology known as progressive trenching has been utilised in the dredging and reclamation industry since the 1970s, pre-dating its adoption in the alumina industry by at least a decade (Haliburton 1978).

2.1 Mud farming operations

Farming operations encompass several key steps, including surface preparation, tailings deposition, mud curing and drying, and mechanical working.

Surface preparation: this initial step ensures a properly sloped and firm floor, facilitating even tailings distribution, quick drainage of bleed water, and high farming productivity. Inadequately dried or compacted tailings can impede subsequent layers, reducing productivity.

Tailings deposition: tailings is deposited in layers, with layer thickness determined by drying characteristics, production rates, and climatic conditions. In general, layer thickness for amphirols and swamp dozer operation is approximately up to 1,000 and 400 mm, respectively. Maintaining discipline in tailings pours is an important factor in the success of mud farming.

Curing and drying: after deposition, tailings undergo a curing period, allowing bleed water to drain and consolidate under its own weight. Once the desired solids content is achieved, mechanical working begins. Some slurry tailings may skip the curing period due to particle segregation.

Mechanical working: machines such as swamp dozers and amphirols plough, scarify, dry, and compact the residue. This process:

- Improves drainage, squeezing water to the surface. The drainage channels that are created by the amphirols also significantly reduce the impact of rain as it runs straight off (toward the decant pond) and does not delay the drying time except for the period of the rain
- Breaks up surface crust, enhancing solar drying
- Roughens the surface, increasing evaporative area
- Provides a compactive force, densifying the tailings.

At Gove, mud farming achieved in situ solids contents of 72% and dry density of 1.49 t/m^3, reducing volumetric storage requirements by over 20% (Li et al. 2011). It also enhanced slope stability and significantly reduced groundwater contamination and liquefaction risks.

Willan & Ghataora (2015) reported that on Aughinish Island, Ireland, in general, dry density within the farmed residue ranged from between 15.6–18.5 kN/m^3, with a mean value of 16.8 kN/m^3, whilst within non-farmed residue it ranged from between 14.3–17.9 kN/m^3, with a mean value of 15.5 kN/m^3. This demonstrated an average dry density increment of 8.3%, indicating varied effectiveness based on climatic conditions. At Worsley, Western Australia, Australia, farmed bauxite residue has achieved a dry density of 1.84 t/m^3, similar to that achieved via filtration (Woolston & DiDonna 2020).

Mud farming can also result in dilatant behaviour. McPhail et al. (2021) reported that mud farming resulted in dilative residue while unfarmed residue was contractive, as shown in Figure 1.

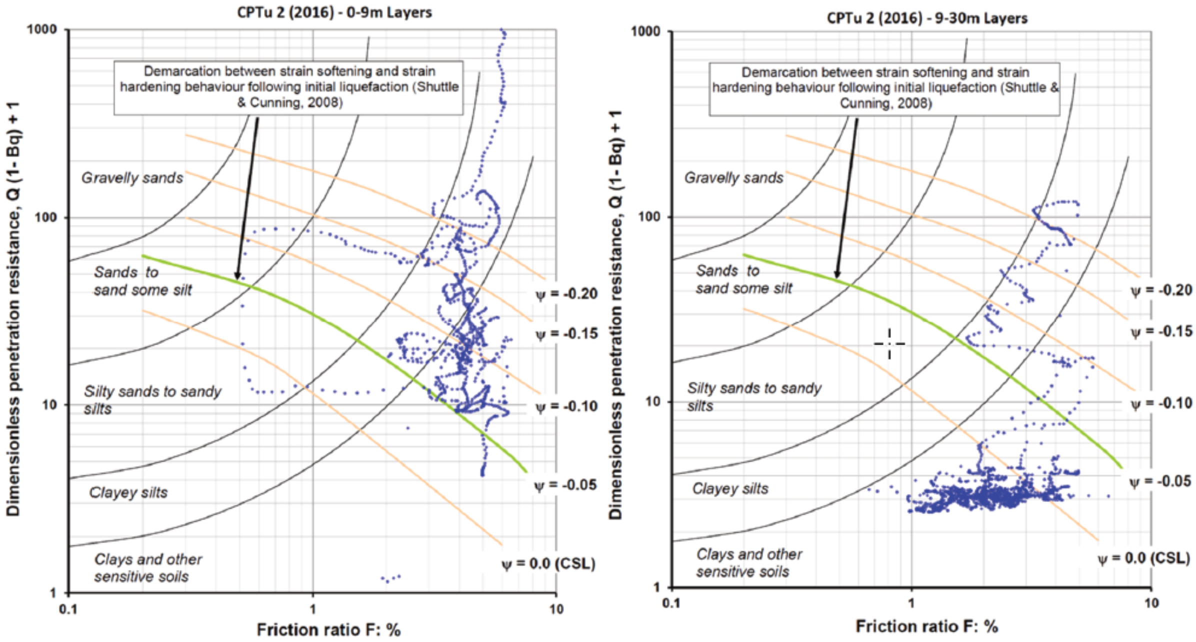

Figure 1 Mud farming resulting dilatant residue on the left and mud remaining contractive without farming on the right (McPhail et al. 2021)

2.2 Farming to enable construction of upstream raises

At Queensland Alumina Limited, mud farming was introduced to support the upstream raising of embankments (Li & Richter 2010). A designed farmed zone of tailings, integral to raising, ensures storage facility integrity under maximum design earthquake (MDE) loading conditions. This approach eliminates the need for expensive ground improvement in the future.

In the slope stability analysis, the post seismic strength with a strength ratio of 0.08 was used for unfarmed bauxite residue in the potentially liquefied zone, the strength of the farmed bauxite residue was taken as 80% of the peak strength. Based on slope stability analysis for MDE conditions, the required red mud zone width is approximately 100 to 120 m, with tests indicating a necessary density equivalent to 70% solids content to prevent liquefaction. This conditioned or structural zone, achieved through mud farming, forms a crucial part of the long-term upstream raising strategy, gaining regulatory approval and enhancing the company's reputation for safe mud disposal. Figure 2 illustrates the integration of a farmed zone into the upstream raising design.

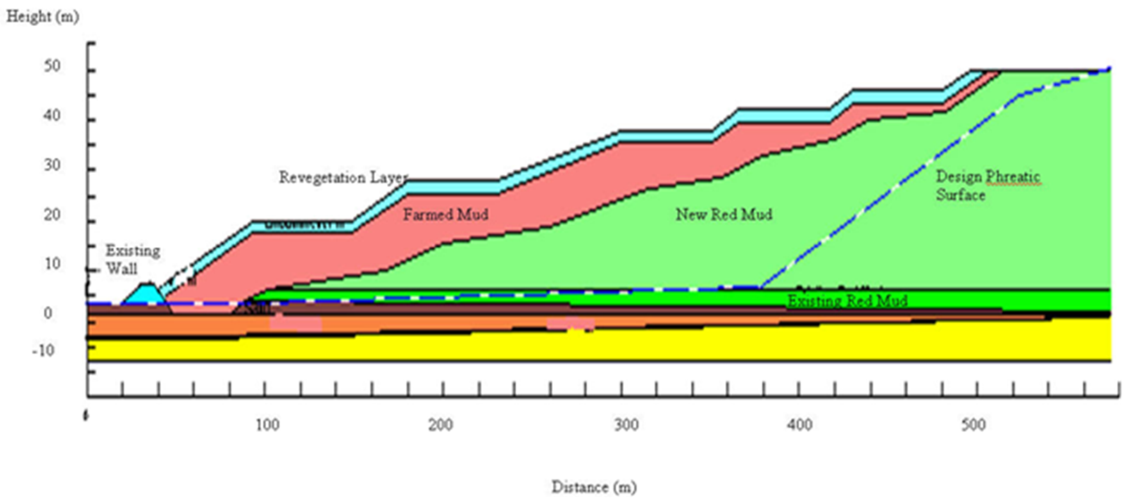

Figure 2 A farmed zone as an integral part of raising (Li & Richter 2010)

3 Farmed tailings stacking

The disposal method presented here is an enhanced upstream raising technique coupled with mud farming, aiming to create an extensive dilatant farmed structural zone, as depicted in Figure 3. The extensive nature of the farmed zone confines potential failure surfaces occurring within the boundaries of the farmed structure. The primary objective is to induce dilative characteristics within this designated farmed zone, thereby pre-empting liquefaction and restricting the failure mode to slumping. Notably, McPhail et al. (2021) observed that farmed bauxite residues at Worsley in Western Australia exhibited no contractive behaviour, as shown in Figure 1.

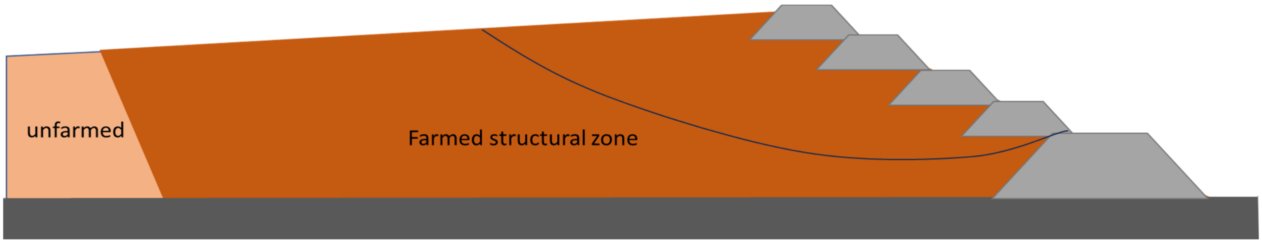

Figure 3 Schematic cross-section of farmed tailings stacking

The attainment of dilatancy in farmed tailings is dependent on various factors, including the type of farming equipment used, the characteristics of the disposal area, and the efficacy of water management. In this section, we delve into the influence of farming equipment and disposal area, reserving the discussion on water management for the subsequent section.

In general, relying solely on amphirols may prove insufficient, necessitating the incorporation of dozers and other equipment to impart dilative properties to the tailings. Amphirols, characterised by their low ground pressures, may not be efficient or suitable for working on tailings with undrained strength exceeding 20 kPa. Conversely, dozers are adept at working on sandy tailings, contributing to compaction, especially when the moisture content of the tailings approximates its optimum level. Therefore, the general farming process is to have amphirolling first followed by dozer farming.

The creation of dilatant conditions post tailings deposition is contingent on allowing adequate time for settlement, consolidation, and drying before the application of new layers. This temporal requirement underscores the importance of having a sufficient disposal surface area and implementing effective water management practices. The adequacy of the disposal surface area is crucial to facilitate the deposition of thin layers, ensuring ample drying cycle times. Estimations of the requisite disposal area can be derived by establishing relationships between average settled dry densities and loading rates, as illustrated in Figure 4. The figure provides a basis for determining the limiting loading rate for a target dry density. Once this rate is determined, the necessary disposal area can be estimated based on tailings production rates. Drying time, duration needed to achieve a target density, can vary from three weeks to four months, depending on a number of factors including drying characteristics of tailings and climatic conditions.

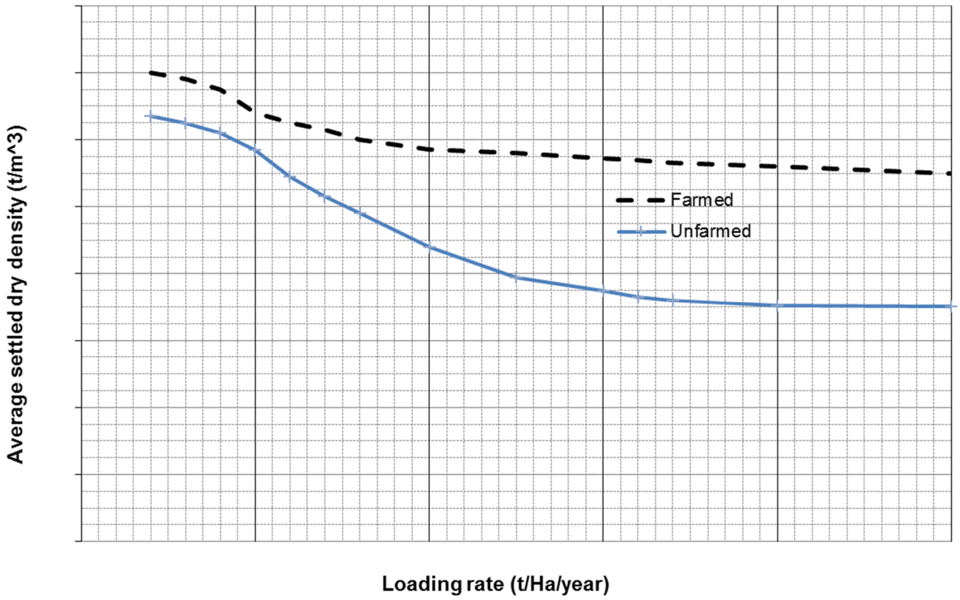

Figure 4 Demonstrated relationships between average dry density and loading rate

To verify if tailings have achieved dilatant conditions, a monitoring and testing system will be required. This includes field moisture content and density testing, laboratory tests including critical state lines and consolidation tests, and in situ tests such as cone penetration tests with porewater pressure measurement (CPTu). Figure 1 shows the contractive/dilative behaviour of farmed and non-farmed bauxite residue based on CPTu test results

In conventional upstream raising, the embankments are designed and constructed in line with conventional earth embankments for water dams. However, as shown in Figure 3, the overall slope stability is achieved through the farmed tailings density rather than the upstream raised embankments. Subsequently, future design and construction for the upstream embankments can be optimised.

4 Water management

Effective water management is a pivotal factor for the success of farmed tailings stacking. In the realm of farmed tailings stacking, the primary focus of water management revolves around minimising ponded water on the impoundment surface and preserving tailings beaches to prevent ponded water from encroaching upon the upstream slopes of the embankments and facilitating the utilisation of mud farming machinery in the structural zone. Achieving this delicate balance is facilitated by an adequate decanting system through the incorporation of GoldSim water balance modelling into the design.

GoldSim, as a modelling tool, possesses the capability to conduct Monte Carlo simulations based on climate data. This involves running numerous ‘realisations’ throughout the simulation period, with each realisation representing a potential climatic condition. By generating a substantial number of realisations, the ranking of simulation results can be interpreted as the probability of occurrence corresponding to each value.

The insights derived from water balance modelling encompass several crucial aspects, including predicting the maximum water levels within the contained pond for various storm events in relation to the tailings levels at the perimeter wall of a typical tailings dam. Additionally, the model provides information on the duration required for the decant system to effectively remove water, ensuring the attainment of the necessary dry beach length.

Illustrated in Figure 5 is a water management criterion that emphasises the necessity of achieving the required dry beach length under 1 in 100 annual exceedance probability storm events. If the predicted pond levels encroach upon the required dry beach length, it signifies an inadequacy in the decant system which will impede mud farming activities. Conversely, if the decant system successfully prevents flooding of the required beach length, it indicates its effectiveness in swiftly removing stormwater as needed. This systematic approach contributes significantly to the overall resilience and safety of tailings dam structures, ensuring optimal water management under varying climatic conditions.

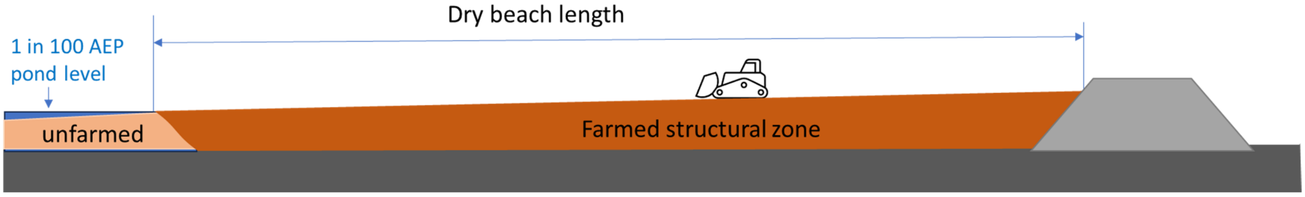

Figure 5 Schematical water level control for farmed tailings stacking

5 Conclusion

Farmed tailings stacking presented here is an enhanced upstream raising method coupled with mud farming, aiming to create an extensive dilatant farmed structural zone upstream perimeter embankments. The primary objective is to induce dilative characteristics within this designated farmed structural zone, thereby limiting the potential for liquefaction and restricting the failure mode to slumping. The attainment of dilatancy in farmed tailings hinges upon various factors, including tailings deposition regime, type of farming equipment used, the characteristics of the disposal area and tailings, and the efficacy of water management. In general, relying solely on amphirols may prove insufficient, necessitating the incorporation of dozers and other equipment to impart dilative properties to the tailings. The creation of dilatant conditions post tailings deposition is contingent on allowing adequate time for settlement, consolidation, and drying before the application of new layers. This temporal requirement underscores the importance of having a sufficient disposal area and implementing effective water management practices. The primary focus of water management is to minimise ponded water on the impoundment surface and preserve tailings beaches to facilitate mud farming as well as preventing ponded water from encroaching upon the upstream slopes of tailings dams.

References

Cooling, DJ 2007, 'Improving the sustainability of residue management practices — Alcoa World Alumina Australia', in R Jewell & AB Fourie (eds), *Paste 2007: Proceedings of the Tenth International Seminar on Paste and Thickened Tailings*, Australian Centre for Geomechanics, Perth, pp. 3–16.

Haliburton, TA 1978, *Guidelines for Dewatering/Densifying Confined Dredged Material*, technical report DS-78-11, U.S. Army Engineer Waterways Experiment Station, Vicksburg.

Li, H & Richter, P 2010, 'Case studies — integrated approach to design, construction and operations for tailings storage facilities', in R Jewell & AB Fourie (eds), *Mine Waste 2010: Proceedings of the First International Seminar on the Reduction of Risk in the Management of Tailings and Mine Waste*, Australian Centre for Geomechanics, Perth, pp. 35–47, https://doi.org/10.36487/ACG_rep/1008_04_Li

Li, H, Pedrosa, S & Canfell, A 2011, 'Case study – bauxite residue management at Rio Alcan Gove, Northern Territory, Australia', in RJ Jewell & AB Fourie (eds), *Paste 2011: Proceedings of the 14th International Seminar on Paste and Thickened Tailings*, Australian Centre for Geomechanics, Perth, pp. 203–212.

McPhail, GI, DiDonna, P & Ugaz, R 2021, 'Dam break analysis for BRDA 5 at Worsley Alumina Refinery', in AB Fourie & D Reid (eds), *Paste 2021: Proceedings of the 24th International Conference on Paste, Thickened and Filtered Tailings*, Australian Centre for Geomechanics, Perth, pp. 177–200, https://doi.org/10.36487/ACG_repo/2115_16

Munro, LD & Smirk, D 2012, 'Optimising bauxite residue deliquoring and consolidation', *Proceedings of the 9th International Alumina Quality Workshop*, pp. 269-275.

Willan, MB & Ghataora, GS 2015, 'Management of bauxite residue in a temperate climate using mud-farming techniques', in R Jewell & AB Fourie (eds), *Paste 2015: Proceedings of the 18th International Seminar on Paste and Thickened Tailings*, Australian Centre for Geomechanics, Perth, pp. 209–222, https://doi.org/10.36487/ACG_rep/1504_14_Willan

Woolston, JS & DiDonna, P 2020, *A Case Study Comparison of Best Available Technology for the Stacking of Bauxite Residue: Accelerated Mechanical Consolidation (AMC) and Filtration & Stacking (F&S)*.