Available online at www.sciencedirect.com

ScienceDirect

Procedia Earth and Planetary Science 1 (2009) 1067–1071

Procedia Earth and Planetary Science

www.elsevier.com/locate/procedia

The 6th International Conference on Mining Science & Technology

Preventing catastrophic failures and mitigating environmental impacts of tailings storage facilities

Andy Fourie

School of Civil & Resource Engineering, University of Western Australia, Perth 6009, Australia

Abstract

Mine tailings are usually deposited hydraulically, resulting in very large volumes of contaminated water having to be managed in a safe and economical manner. Poor operational practices often result in the release of contaminated water to the environment, sometimes resulting in catastrophic consequences. Even more of a concern is the potential hazard to communities living and working in close proximity to these facilities. There have been a large number of failures of TSFs internationally, with at least two failures in 2008 resulting in fatalities. Recent technological developments mean it is now possible to prepare, transport and place tailings at a much higher solids content than previously, leading to significantly reduced water consumption. The TSF can also be constructed more safely, potentially preventing catastrophic failures. This paper discusses these recent advances, and describes some of the mining operations around the world, which are now in excess of twenty, where the technology is being used. It highlights some of the operational difficulties, and some of the evolving design principles that must be considered when planning a thickened tailings deposit.

Keywords: tailings; environmental; high-density; thickened

1. Introduction

The vast majority of above-ground tailings storage facilities (TSF's) today are constructed using the tailings material itself to raise the height of the retaining perimeter of the TSF. The manner of construction may differ, e.g. downstream, upstream or centreline. Common to all these techniques is the deposition of high water content slurries into the storage facility. The reason for pumping low density slurries to tailings storage facilities has inevitably been one of cost; firstly the lower cost of pumping low viscosity material and secondly by avoiding the need to dewater the tailings after the mineral extraction process has been completed. Upon deposition, the tailings tend to segregate, with the coarser fraction settling out first, near the point of deposition, with the finer fraction of the total tailings stream being carried towards the centre of the impoundment.

As the tailings elevation rises, the potential for an instability to occur increases. Water is usually stored on the top surface of these facilities, either intentionally, with a view to reclaiming the water as and when required for processing operations, or unintentionally, when inadequate provision has been made for water re-use. Either way, operation of the storage facility requires that the area occupied by the tailings water pond is minimised and preferably confined to the centre of the facility. It should also be confined to an area

doi:10.1016/j.proeps.2009.09.164

immediately around the penstock or decant facility, in order that control of the location of this pond is possible. It is also required (sometimes by legislation) that adequate freeboard be provided to ensure that, even in the event of a major rainfall event, the resulting runoff towards the centre of the facility is safely retained.

By keeping the tailings pond away from the perimeter of the facility, solar drying of the tailings occurs, accelerating densification and strength gain. Particularly in arid and semi-arid climates this results in the perimeter tailings reaching a relatively high density quite quickly, usually producing a deposit that is dense enough to not be susceptible to sudden, static liquefaction. To ensure that a tailings disposal facility is always operated strictly within the design parameters, ensuring for example that adequate freeboard is always maintained, or that the tailings pond is always as small as possible and centrally located, requires a high level of management commitment. It is likely that for many tailings facilities, less-than-ideal management will occur sometime during the life of the facility, potentially resulting in the development of a zone (or zones) of inherent weakness.

As discussed by Brzezinski[1], virtually all failures of tailings storage facilities between 1980 and 1996 occurred as a direct result of water action, whether by seepage and internal erosion of the containment facility, or overtopping due to blockage or inadequate capacity of decant or spillway systems. It is thus the presence of large quantities of stored water that is the primary factor contributing to most of the recent tailings storage facility failures.

2. Failures and catastrophic releases of tailings.

Catastrophic failures of tailings storage facilities are nothing new. For example, in 1928 the Barahona tailings storage facility in Chile failed during a large earthquake, killing more than 50 people in the ensuing flow failure. In 1976 the Bafokeng platinum tailings storage facility in South Africa collapsed after a period of above average rainfall, releasing more than 3 million tonnes of tailings during the resulting flowslide, causing the deaths of 12 people. It is thus not the occurrence of failures that has changed, but rather the access that otherwise unaffected people around the world have to details of each failure that might occur. In the era of instant global communication, it is the evening news television coverage of a failure anywhere in the world that moulds public perceptions. An example of this is the Baia Mare catastrophe in Romania, which resulted in the release of 100 000m^3 of cyanide contaminated liquid into the Lapus stream and the subsequent lodging of a $179 million compensation claim by the Hungarian government against the mine owners. It is an inescapable reality that all tailings disposal facilities, even those in the most remote and hostile terrains, will become the subject of international scrutiny should any failure (particularly if loss of life results) take place.

Whilst it is probably true that the vast majority of tailings storage facilities around the world are well managed and pose little or no threat to the environment or to surrounding communities, it is the occasional, catastrophic failure that drives public and media perceptions of the dangers associated with these facilities. It would thus appear to be both a moral and an economical necessity for the mining industry to seriously reconsider whether their current approaches to tailings disposal are appropriate and sustainable.

3. The emerging technology of thickened tailings.

It is now more than three decades since Robinsky[2] suggested improving tailings management by thickening it to a consistency such that no free water (or ‘bleed’ water) separated from the tailings upon placement. He suggested that the tailings would be non-segregating upon placement and no retaining embankments or dykes would be required. For almost two decades after this initial suggestion, very little development of the concept occurred, although the Kidd Creek operation in Canada persevered with Robinsky’s concept. During this time, a number of technological advances occurred that improved our ability to produce high density tailings at relatively consistent densities, at costs that are not entirely prohibitive. These developments included:

3.1. Improved flocculant performance

Synthetic flocculants are now available in anionic, cationic, or non-ionic form, and extremely high molecular weight flocculants are common, providing a relatively inexpensive way to bind together ultrafine clayey tailings particles that eventually become large enough to settle under their self-weight. Choice of appropriate flocculants to use with a particular tailings material is still largely an empirical approach, often being based on a series of comparative jar tests. Although the cost of flocculant addition is still considered too high for many mining operations (where required concentrations can be in excess of 200g per tonne), the benefits of providing a means of binding ultrafine particles together and inducing rapid settlement often outway these costs.

3.2. New generation thickeners.

Unlike conventional tailings thickeners, which are typically shallow (of the order of one metre deep), the new generation high density and paste thickeners are of the order of 20m deep, or more. Extensive research has been completed to improve the feedwell (zone in which flocculants are introduced) area of these thickeners (Fawell et al.[3]) and very good contact between the flocculant and the feed tailings is now achievable. As the flocculated tailings settles through the thickener, it becomes denser, until the final density achieved at the outlet (the underflow density) is equal to that required for pumping to the TSF. Recent improvements to increase the rate of settlement include vertical rakes (also called pickets), which disturb the sedimenting tailings, providing drainage paths for the escaping water. Until recently a restriction to the widespread adoption of the technology has been the inability to handle very large volumes of tailings, such as that which is produced in the copper mining industry in Chile, where volumes of 100 000 tonnes per day are common. The thickener manufacturers have started producing ever-larger thickeners, with those proposed for the Esparanza project in Chile being 60m diameter.

3.3. Transportation of high density tailings

Conventional tailings is usually transported by pipeline to the receiving TSF, with flow in the pipeline being turbulent. The turbulence keeps the solid particles entrained in the water, with separation only occurring when tailings are deposited onto the TSF beach. Transportation of high-density tailings by pipeline usually results in laminar flow with the pipe, presenting a new set of challenges to designers of these systems. For some time, the perception seemed to persist that the pumping requirements of this material were so onerous that positive displacement (p.d.) pumps would be the norm. The very high capital cost of p.d. pumps meant that many operations automatically disregarded the option of high density tailings. Once again, targeted research has provided some solutions to this problem, with it being demonstrated that conventional centrifugal pumps may often be used, even to transport high-density tailings that has a yield stress in excess of 100Pa. A useful resource in this field is that given by Paterson[4].

4. Adoption of thickened tailings technology.

With many (but certainly not all) of the technological challenges being addressed, more and more mining operations decided to experiment with high density thickened tailings, such as the bauxite industry (see Cooling[5] as an example) and some of the benefits began to become apparent. An annual series of seminars on the topic was initiated by the Australian Centre for Geomechanics, and the 12th in the series was recently held in Chile. Many operations have reported positive outcomes from implementing thickening schemes, although some difficulties have also emerged, such as the need in some cases to cover (or cap) a greater surface area of tailings when the Central Thickened Discharge (CTD) technique is used. The technique has been applied to a complete range of tailings, including diamond, gold, bauxite, mineral sands, coal and copper (see Williams et al.[6]), although the more fine-grained materials appear to be better suited to management using this approach than very coarse grained tailings.

The alumina industry has long recognised the potential benefits of storing tailings using some form of ‘dry’ disposal. The extremely alkaline nature of their process water means that control of water and ideally reduction of quantities produced has always been a priority. The operations of Alcoa World Alumina in Western Australia have pioneered many of these improvements. In 1985 ‘dry stacking’ of bauxite residue was adopted at Alcoa’s Western Australian refineries. This technique utilised a large diameter thickener to dewater the tailings that was spread in relatively thin layers that were then further dewatered through a combination of drainage and evaporative drying. In their process the coarse particles (>150μm) are separated from the fine tailings. The fines are pumped to a thickener that is generally 70 to 90m diameter, with a conical base and a central slurry depth of up to 10m. The tailings are flocculated with about 40 to 60g per tonne of tailings solids and the throughput from the thickeners is of the order of 500 tonne/hour. The underflow has a solids content of 48 to 50% (with associated yield stress values of 25 to 50Pa). This thickened material is pumped to long, narrow drying beds and placed in layers up to 500mm thick. It is then allowed to dry in the sun, which is very effective given the high ambient evaporation rates in summer. This drying produces a material with a solids content of about 70% by mass, which is more than adequate from an undrained shear strength point of view.

Results presented by Cooling[7], also illustrate the important effect that changes in the ore body can have on the characteristics of the thickened tailings. To ensure a relatively uniform slope upon deposition, the parameter over which control is exercised is the yield stress (by manipulating the solids content). He shows results where, in order to maintain a yield stress of 50Pa a decrease in solids content from 51% to 47% was required.

Another industry that is pioneering the use of thickened tailings is the mineral sands industry. In both South Africa and Australia, innovative work has been undertaken to determine the viability of the technique, with interest being driven by the enormous difficulties encountered with trying to dispose of their tailings material using conventional techniques. The Hillendale mineral sands mine in South Africa is planned to produce approximately 1.65 million tonnes/annum of tailings and began production in 2001. The fine tailings (<45μm) is thickened in three 12m diameter ultra high rate thickeners, with a design feed rate of about 2800 m^3/h. The feed tailings has a solids content of between 8 and 10% solids, to which is added flocculant at a dosage of between 150 and 200g/tonne feed. Preliminary testing produced an underflow with a solids content of 28 to 32%, but during pilot thickener trials the unavoidable inclusion of up to 15% material >45μm tended to result in target densities not being achieved. Field trials with this material produced beach slope angles of about 2%.

In South Africa, De Beers are utilising the thickened tailings option for the storage of diamond tailings in both medium and large operations. The Oaks mine, which produces about 0.3 million tonnes/year of tailings at a slurry density of 1500kg/m^3, deposits this material into purpose built impoundments made from waste rock. The Combined Treatment Plant in Kimberley, which started production in mid-2002, produces about 7 million tonnes of tailings per year. Using 5 thickeners, an underflow with a solids content of about 56% is produced and pumped to the storage facility using positive displacement pumps.

The Bulyanhulu gold mine in Tanzania, Africa, has a production rate of about 900 000 tonnes per year. Approximately 25% of the tailings is disposed of underground, after blending with crushed waste rock, whilst the remainder is disposed of on surface. The tailings has a d_{50} of about 25μm and after thickening is discharged from elevated towers into an impoundment constructed from waste rock. The tailings are deposited in thin layers and reliance is placed on evaporative drying to achieve the required shear strengths. To date, a maximum beach slope angle of about 5° has been regularly achieved. A comprehensive description of this project is given by Landriault[8].

In addition to the projects mentioned above, there are probably another twenty or thirty projects around the world that are using high-density thickened tailings in one form or another. Williams et al.[6] provide a useful summary of these projects. Even more recently, details were provided of plans to use high density tailings management for very large volumes (95,000 tonnes per day) of copper tailings at the Esparanza project in Chile (Luppnow and Moreno[9]).

5. Emerging issues

A significant aspect to emerge from the use of high density tailings is the need to better integrate the preparation and transport components of the process with the deposition component. Unlike conventional tailings disposal, where the TSF operator has to accept that the solids content of the material arriving at the TSF will be variable and to develop operational techniques for dealing with this variability, with high-density tailings the control of solids content (and more relevant, the control of rheological parameters, particularly the yield stress) is critical to the operation of a TSF. Relatively small changes in yield stress can result in very significant changes in beach slope, with severe effects on the impoundment operation. Management of high-density TSF facilities requires a greater understanding of preparation and transportation methods, and thus adds to the skills base required of a designer and operator of these facilities.

A disproportionately large percentage of thickened tailings operations deal with tailings that has a high clay content (note this refers to true clay minerals, not just material that is clay-sized and may be nothing more than rock flour). This is probably because dealing with this material (such as mineral sand slimes, smectitic diamond tailings and coal tailings) using traditional techniques is becoming increasingly difficult. Management of high-density clayey tailings has emphasised the importance of careful deposition strategies, with the deposition of relatively thin (less than 0.5m) layers being highly desirable. Even though there is no development of a decant pond, which means the surface of the TSF appears relatively dry, there is a significant danger of raising the elevation of the TSF too quickly, ultimately causing an instability.

The large surface area of some thickened tailings facilities, such as the Mt Keith operation in Australia, which has a diameter of approximately 4km, results in large volumes of stormwater having to be collected and managed. In the climate prevailing at Mt Keith, where annual rainfall is often less than 400mm, this problem is not too severe, but in a high rainfall area it could present major difficulties. A similar concern arises when closure of the TSF is considered. The large surface area that can result from use of thickened tailings means that closure costs can become prohibitively high. Clearly, although there are many benefits to be gained through the use of high-density tailings, great care needs to be taken when considering possible use of the technique, as there may well be undesirable outcomes along with the beneficial outcomes.

6. Conclusions

Perhaps it is inevitable with any new and relatively revolutionary technology that both proponents and opponents tend to take rather extreme viewpoints, and this is also unfortunately the case with high-density tailings. Proponents, such as some vendors, tend to advocate high-density (or indeed paste) tailings for almost all new and retrofit operations, irrespective of the real merits of the technology in each application. On the other hand, there are some who see the technology as just another fad and proceed to develop destructive counter-arguments to the use of the technology, based on unrepresentative hypothetical situations. Thankfully the majority of tailings practitioners have taken the pragmatic approach of dealing with each potential application on its individual merits, and many of the papers presented at the annual seminars on Paste and Thickened Tailings referred to earlier bear testimony to this assertion. This surely is the responsible approach to take, particularly as the use of high-density tailings certainly does provide significant water savings compared with conventional approaches (see McPhail and Brent[10]) and in the current climate of water scarcity in many mining areas of the world, this can only be a good thing.

As with many of the issues raised in this paper, the only truly rational way to deal with the viability of high-density tailings in a particular application is through appropriate and on-going training and education of those tasked with making these decisions.

References

[1] L.S. Brzezinski, Surface disposal of thickened tailings. Mining Environmental Management, (2001) 7-12.
[2] E. Robinsky, Tailings disposal by the thickened discharge method for improved economy and environmental control. Tailings Disposal Today, (1978) 75-95.
[3] P.D. Fawell, J.B. Farrow, T.V. Heath, 20 Years of AMIRA P266 “Improving Thickener Technology” – How has it changed the understanding of thickener performance? In: Proc. Twelfth International Seminar on Paste and Thickened Tailings, (2009) 59-68.
[4] A. Paterson, High concentration hydraulic transport systems. Chapter 8 in: Paste and Thickened Tailings: A Guide; 2nd Edition, Australian Centre for Geomechanics, 2006.
[5] D.J. Cooling, Improving the sustainability of residue management practices – Alcoa World Alumina Australia. Keynote address: In: Proc. Tenth International Seminar on Paste and Thickened Tailings, (2007) 3-15.
[6] M.P.A. Williams, K.D. Seddon and T.G. Fitton, Surface disposal of paste and thickened tailings – a brief history and current confronting issues. Keynote address: In: Proc. Eleventh International Seminar on Paste and Thickened Tailings,(2008) 143-164.
[7] D. Cooling, Thickened tailings storage as practiced by Alcoa World Alumina In: Proc. High Density & Paste Tailings 2001, Pilanesberg, South Africa. University of the Witwatersrand, (2001) 35.
[8] D. Landriault, In Chapter 10: Case studies – Bulyanhulu mine, Tanzania. Paste & Thickened Tailings. A Guide. Ed Jewell, Fourie and Lord. Australian Centre for Geomechanics, 2002.
[9] D. Luppnow and J. Moreno, Control and management of thickened tailings beach – a simplified approach. In: Proc. Twelfth International Seminar on Paste and Thickened Tailings, (2009) 245-250.
[10] G. I. McPhail and C. Brent, Osborne high density discharge – an update from 2004. In: Proc. Tenth International Seminar on Paste and Thickened Tailings, (2007) 339-350.