Tailings deposition management plan – design and implementation including operational aspects and case history

B Batchelder[1] and A Uz[2]

1. Senior Technical Director, Geotechnical, Tailings and Mine Water Management Dams, GHD, St Leonards NSW 2120. Email: bob.batchelder@ghd.com
2. Senior Geotechnical Tailings Engineer, GHD, Sydney NSW 2065. Email: attila.uz@ghd.com

ABSTRACT

The tailings deposition management plan (TDMP) provides the methodology for optimal deposition of tailings slurry. It forms an integral part of the design of a tailings storage facility (TSF). This paper focuses on subaerial (air-dried) tailings deposition, which is extensively utilised within Australia.

The correct implementation of the TDMP determines the condition of the tailings deposit in terms of trapped moisture, deposited dry density (which directly affects storage capacity), saturation/excess pore pressure (which influences static liquefaction), strength/stability (risk), the deposited beach slope and the difficulty/cost of rehabilitation. Correct design and implementation of the TDMP is necessary to achieve the design requirements, to reduce risk, and to enable cost-effective rehabilitation.

Once implemented, the TDMP is validated by observation and adjustment of spigot discharge duration (per spigot in some cases) and the number/location of spigots to provide the required beach shape to minimise the pond area in the TSF. This in turn maximises deposited dry density and hence TSF storage, increases flood routing capability, reduces risk of static liquefaction, non-compliant discharges/overtopping and high rehabilitation costs.

Other aspects of the deposition which are recorded during this process include channel erosion and incorrect beach slope which are often due to spigot type, the number of spigots open and/or decrease in percent solids of the tailings. The first two aspects are handled by operator training, the third will require a revision of the TDMP as a ‘change management’ measure.

This paper presents the testing conducted and typical results for a metalliferous mine in western NSW (site unnamed) showing the most recent implementation of the TDMP design. This TDMP is about to be implemented. The paper also presents a case study for a coal tailings TSF in the Western Coalfields of NSW west of Lithgow (site unnamed), which has successfully been implemented and achieved deposited subaerial beaching meeting the required (estimated density) as per the TDMP design.

Introduction

The tailings properties utilised in the design of the tailings deposition management plan (TDMP) are determined by careful laboratory medium to large scale simulation testing, comprising column/permeability/consolidation undrained settling tests combined with air drying tests (in buckets under lights with a reference water sample) for a range of deposited layer thicknesses. These results, informed by the Australian Bureau of Meteorology (BOM) data for a site, are used to model the tailings deposition for the TSF geometry under the site-specific climatic conditions, in order to optimise the deposition layer thickness and cycle time for the emplacement of tailings at the maximum achievable dry density for the site.

The requirement for TDMP

Tailings storage facilities (TSF) employ subaerial discharge under a carefully prepared TDMP in order to achieve significant gains in deposited dry density and strength in a cost-effective manner with acceptable risk for the planned subaerial discharge operations. In particular, the TDMP is used to inform and assess the potential for upstream/centreline raising that can be achieved by optimising the combination of ‘layer’ thickness and air-drying time, in combination with managing the tailings geometry and deposition flow management, in order to: maximise storage, assist in upstream staging, reduce operational and long-term risks; and to reduce rehabilitation costs.

Once implemented, the TDMP will be conducted using the ‘Observational Approach’ (OA), whereby aspects of the deposition are recorded and adjusted as necessary during the deposition process, including:

- Avoiding beach channel erosion by adequate number of spigots open, addressing dysfunctional discharge from the spigots, and keeping the percent solids as high as is reasonably practical (minimum 44 per cent as per the supplied tailings sample).
- Achieving the correct beach shape to minimise the decant pond, by keeping it to a minimum area centred around the gravity decant inlet. This is achieved through positioning and varying the length of discharge time across the spigots, for each deposition segment.
- Ensuring proper operation of the decant by adding short riser pipes (150 mm to 300 mm length) to prevent tailings ingress whilst keeping the length of riser pipe/pipes to a minimum. In order to minimise the decant pond depth. Noting that any areas covered by water will remain saturated and thus not gain density increase through air drying, thus subaqueous not subaerial deposition will be occurring with corresponding increase in risk and much lower strength and deposited density.

Preparation of the TDMP

The TDMP is prepared based on large scale laboratory simulation testing to model the settling/consolidation behaviour of the deposited tailings layer using typically at least two different layer thicknesses. The assessment of multiple layer thickness is required in order to model supernatant production and the time to achieve end of primary consolidation (start of the air drying portion of the slurry sample in the ‘cycle time).

Large scale air drying tests are commenced on the 150 mm and 300 mm slurry thickness samples after they have reached the end normal consolidation. The air drying simulation test is conducted in order to model the density and strength gains achieved by over-consolidation through the air drying process ie achieving an unsaturated state. The site climatic data is used in combination with the results of this test, to estimate site evaporation potential.

Laboratory simulation testing

The laboratory simulation testing conducted includes:

- **Settling and Consolidation Test Phase 1** – settling and consolidation tests – top and bottom undrained.
- **Settling and Consolidation Test Phase 2** – top undrained, base drained.
- **Air drying under lights –** with a water container for correlation to BOM Class A Pan Factor.

Soil Classification results are also conducted in order to classify the tailings and to estimate the specific gravity (SG) of the slurry sample. An SG of 2.79 was adopted as part of the example TDMP. The tailings test samples are taken from the throughput to the TSF.

Slurry settling and consolidation tests

Large scale undrained deposition settling and consolidation tests (see Figure 1) are carried out to evaluate the rate of settling and to estimate the initial deposited dry density likely to be achieved in the layer deposition. An in-house laboratory test procedure is used to assess the settling and consolidation behaviour for tailings deposition. This test simulates placement of a tailings layer over underlying low permeability tailings deposits, prior to air drying.

Duplicate sets of samples (Samples A and B) are tested for repeatability, for each of deposited tailings slurry layer thicknesses assessed (150 mm and 300 mm). These samples are placed into cylinders at the solids concentration of mine throughput.

The method for optimising the deposited dry density includes division of the TSF depositional area into a number of portions, and assessing the cycle time for the sequential deposition over each portion ie how thick a slurry layer is placed in the portion and how long the drying time is for each layer until a recurrence of deposition (end of cycle time) occurs. The implementation of this technique is conducted in conjunction with the OA, as described above.

The times for settling and consolidation for the above test samples are recorded in the settling and consolidation test shown in Figure 1. This is achieved by recording the decrease in slurry height at suitable time intervals, from layer placement until secondary consolidation (creep) is established. This enables the time for effective completion of the primary consolidation to be established for each sample.

Figure 1 ***Column settlement and consolidation test.***

Following completion of Phase 1, the sand filter drainage layer beneath the sample is drained via a drainage tap, located near the base of the test cylinder, thereby decreasing the pore pressure at the base of the sample and enabling a second stage of consolidation testing for the sample to be assessed from the data collected (if desired).

The sample permeability is recorded during this second stage. The seepage and supernatant water quality can be assessed during the test, if desired. The interpreted tests results for the settling and consolidation tests on the subject samples are presented graphically in Figure 2

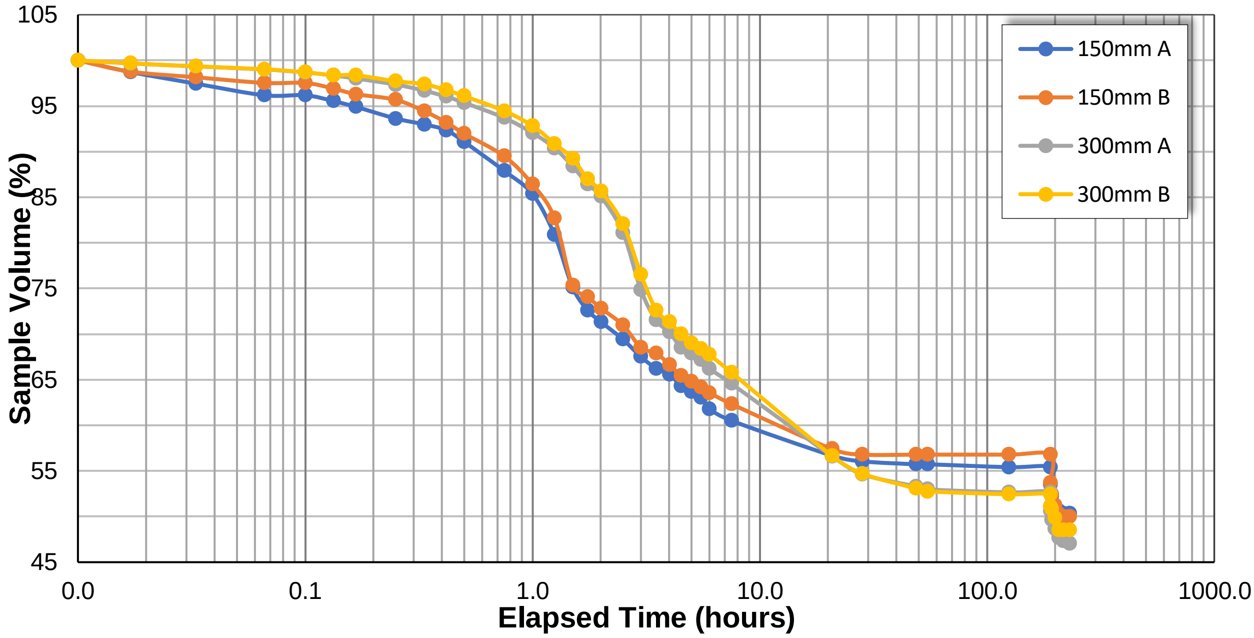

Figure 2 TSF tailings settling test – 150 and 300 mm slurry layer thickness (Samples A and B).

The settlement testing demonstrates three phases: mixed sedimentation and consolidation (the steeper portion of the curve); primary consolidation (less steep curve); then flattening out to secondary consolidation (creep) settlement until the termination of the test.

The steep section at the curve following completion of Phase 1 of the test, is the test Phase 2 where only permeability was calculated for the subject samples. Consolidation data, while able to be obtained from the recorded settlement and the small effective stress decrease from the draining (release of pore pressure) from the base, is relevant for subaqueous deposition and hence is not calculated for subaerial modelling.

The testing results, as included below for the two slurry thickness samples, provide performance data for the slurry layers as follows:

150 mm slurry layer

- A percent solids of 63–64 per cent (γ_d = 1.07–1.08 t/m^3) was recorded for the 150 mm thickness slurry layer samples at the end of primary consolidation, which took approximately one day.
- A percent solids of 63–65 per cent (γ_d = 1.07–1.11 t/m^3) was recorded at the end of testing (190 hrs) for the 150 mm thick layer sample.
- The permeability recorded in the Phase 2 testing ranged from 3.7 to 7.4 × 10^{-7} m/s.

300 mm slurry layer

- A percent solids of 55–57 per cent (γ_d = 0.86–0.89 t/m^3) was recorded for the 300 mm thickness slurry layer samples at the end of primary consolidation. Primary consolidation took approximately 1.5 days.
- A percent solids of 67 per cent (γ_d = 1.16–1.17 t/m^3) was recorded at the end testing for the 300 mm thick layer sample (190 hrs).
- The permeability recorded in the Phase 2 testing ranged from 4.7 × 10^{-7} m/s to 1.1 × 10^{-6} m/s for the 300 mm thick slurry samples.

Air drying tests

Large-scale air drying tests are conducted to simulate the air drying behaviour of the tailings in areas not covered by water eg beneath the (minimum sized) decant pond or other ponded water on the tailings surface (not recommended). Where water cover exists, only the NC density will be achieved.

Samples of tailings are placed into buckets and allowed to settle, with supernatant water being removed, until NC conditions are reached, prior to conducting the air-drying test.

Figure 3 ***Air drying test.***

In the air-drying test (see Figure 3), the evaporative loss of water and settlement/shrinkage of the tailings sample is recorded, and used to calculate the dry density increase in the tailings sample. The evaporative water loss from the tailings surface is compared to that from a similar bucket of free water, in order to calculate the Class A Pan evaporation Factor for the tailings, by correlation to evaporation rate from the free water surface.

The tailings samples are periodically weighed and measured, in order to estimate moisture content, dry density and incremental evaporation losses. The water sample is periodically weighed at the same time as the tailings samples. From this data it is possible to calculate the variation of Pan Factor within the tailings versus the sample moisture content.

The Class A Pan Factor for the soil typically reduces with the drying time of the tailings sample, due to increased soil suction.

This test models the air drying performance potential for the slurry deposition with varying slurry layer thickness and cycle time. The expected dry density and rate of rise of the tailings deposit can be calculated based on the tailings throughput and subaerial deposition area. This also enables the assessment of ‘change management’ for differing throughput values or an extended periods of ponding (other than that the minimum decant pond area). and provides understanding as to whether the tailings are likely to achieve sufficient drying to sustain upstream or centreline construction.

From this data it was possible to calculate the variation of pan factor with the tailings sample moisture content, as illustrated in Figure 4, for 150 mm and 300 mm thickness slurry deposition layers.

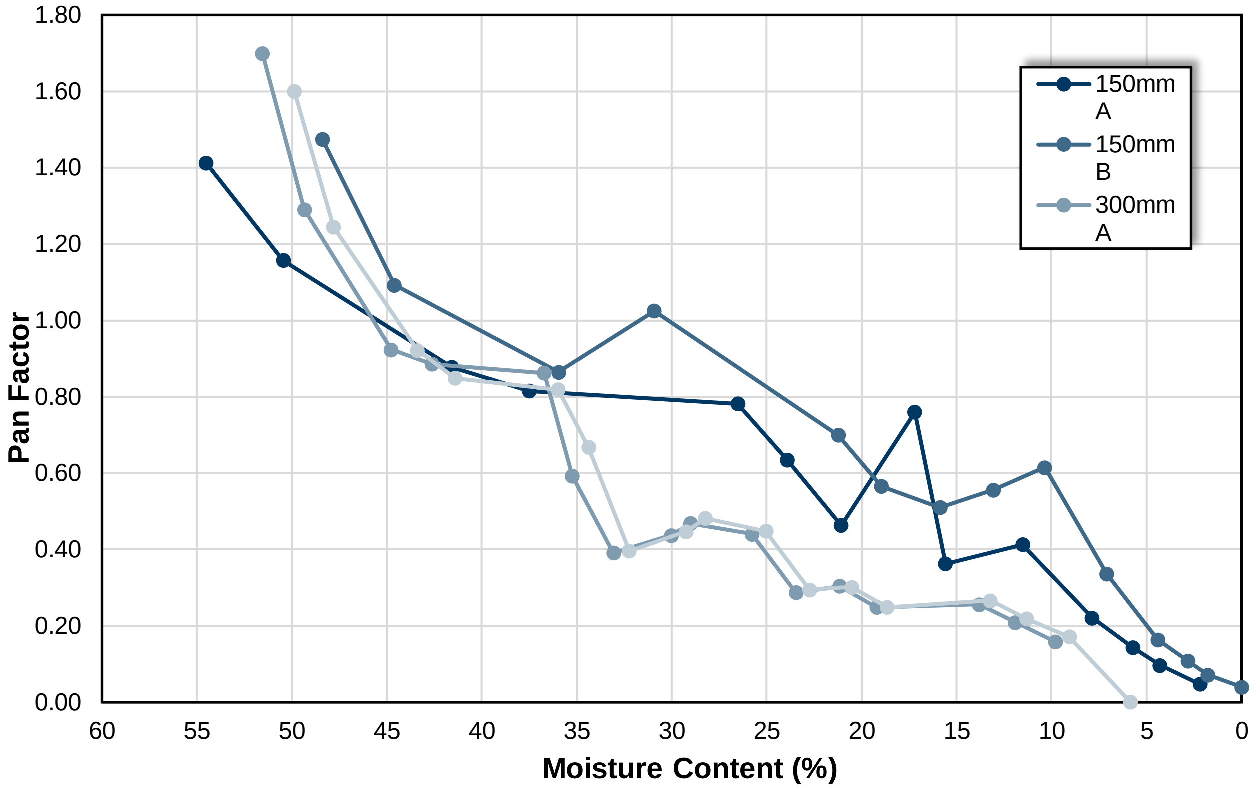

Figure 4 *Tailings air drying tests – pan factor versus moisture content.*

The results of these tests inform the estimation of the tailings air dried density that will be attained through the use of site based evaporation data and hence the expected rate of rise of the tailings beach deposit for the throughput. It also provides an understanding as to whether the tailings are likely to achieve sufficient strength to sustain upstream or centreline construction.

The quantified evaporative loss, using the site evaporation data, results in a revised moisture content with corresponding dry density for the slurry layer, which allows choice of the optimum cycle time and layer thickness combination for the planned deposition. The results as plotted in Figure 5 show the advantage of the 150 mm layer for air drying, even though the 300 mm layer has a marginally higher density at end of primary consolidation.

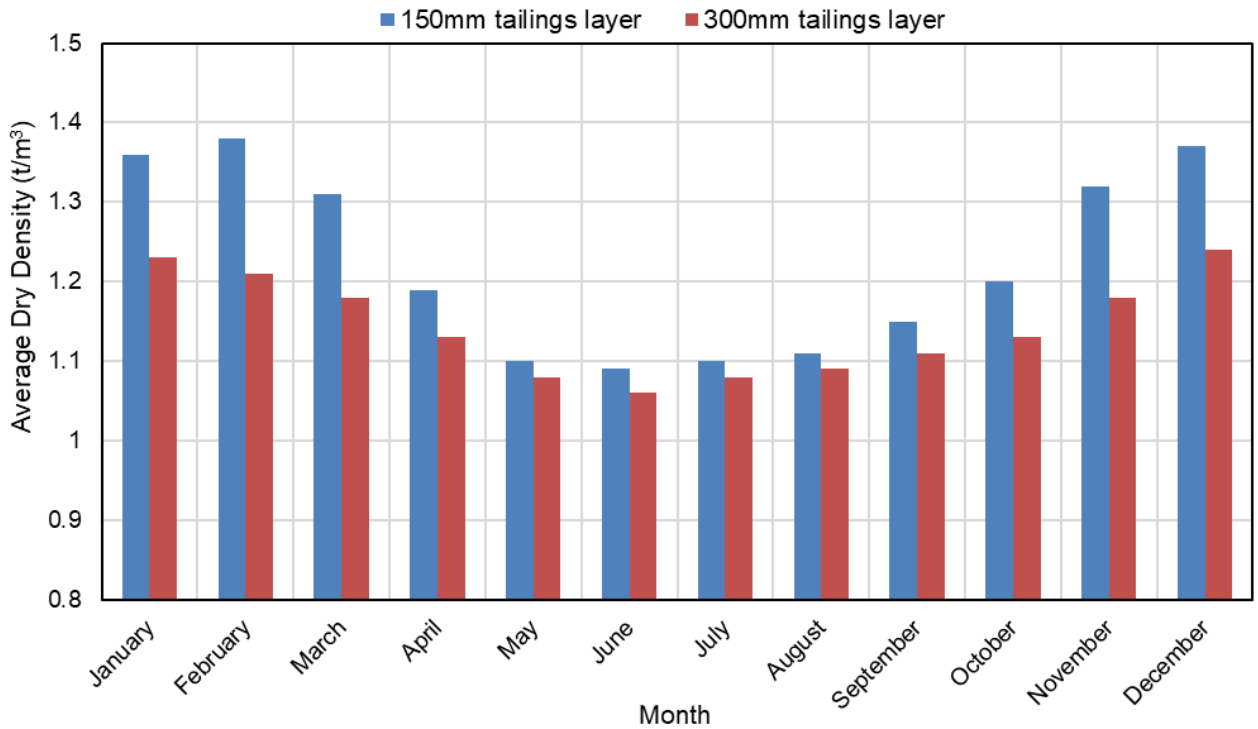

Figure 5 *Tailings air drying tests – average monthly dry density calculated for the 150 mm and 300 mm slurry layer thicknesses based on the air drying test data.*

Case study

The above illustration of the preparation and implementation of a TDMP relates to a metalliferous mine site in Central Western NSW. It is the latest refinement of presentation for the TDMP, but is as yet to be implemented at the site.

The case study was chosen to illustrate the advantages of this methodology, relates to an earlier application of the methodology, for an unnamed coal tailings site west of Lithgow.

The coal tailings site was using subaqueous deposition into an old Open Cut (OC) named ‘A’ Pit, which lies to the north of the current TSF, and which was at the time rapidly becoming unsustainable, due to the site’ available area constraints and the rate of rise of the tailings deposit.

It was assessed from TDMP design for the site, that the use of the maximum possible site area was needed for the subaerial deposition, given the throughput combined with the site rainfall and evaporation characteristics resulted in a rate of rise of some 3 m per annum. It was considered unlikely that the site would support upstream construction and potentially problematic, at least in the early stages, to support centreline construction.

Based on the TDMP testing, a design chosen for what was for a co-disposal of Coarse Coal Reject (CCR) to be used as material for by downstream construction of the TSF ‘turkeys nest’ embankment. With subaerially deposited coal fines placed under a detailed TDMP into the TSF. The TSF deposition area ranged from some 10 ha initial footprint, to approximately 13 ha footprint at the final TSF height. The previous TSF, ‘A’ Pit, had a maximum 4 ha available.

Using the methodology described in the simulation testing above, a cycle time and ‘slurry’ layer thickness were obtained, to target the optimum number and positions of spigots, in order to maximise the deposited dry density for the slurry type, throughput and site characteristics. This comprised varying the number of ‘12 hour’ shifts per deposition point, and the sequence of deposition over 11 deposition points, while maintaining a beach that sloped towards the decant (in the west), without low points or ponding away from the decant occurring. The deposition was modelled as a series of deposition cones emanating from each spigot point, the diameter of which were dependent on the number of shifts per spigot point. This deposition pattern is shown in plan on Figure 6.

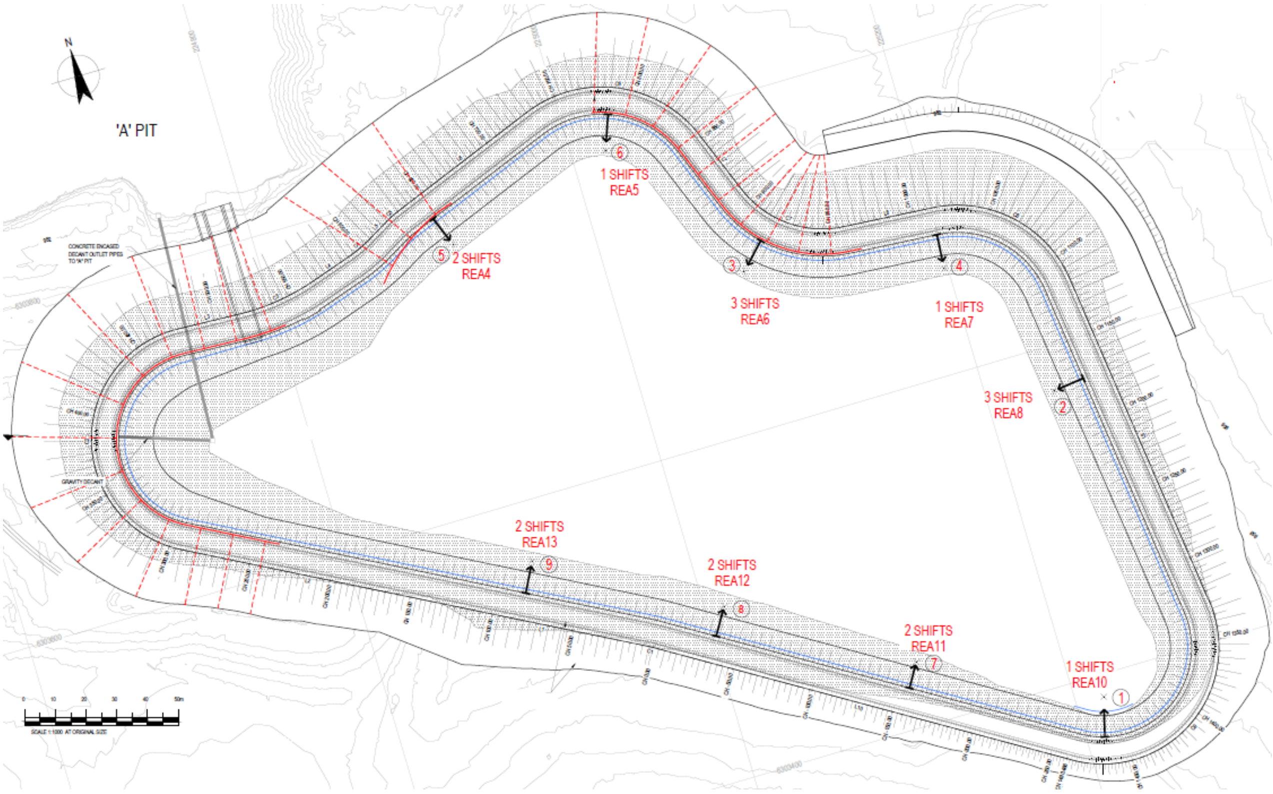

Figure 6 ***Tailings deposition plan spigot arrangement.***

Modelling in the TDMP showed that if managed correctly under the TDMP, there would be approximately 60 per cent to 70 per cent increase in the deposited dry density (from 0.6 t/m3 to 1 t/m3) in the placed coal tailings, after being over-consolidated by air drying rather than placed under water cover in the OC. Achievement of this air dried density was borne out by subsequent LIDAR and in situ testing.

The spigot shift times, sequencing, variation of spigot positions (addition/subtraction) was conducted using daily observation of the deposition.

During the deposition, a significant increase in coal fines production occurred for an extended period of time. The anticipated deposited density (with higher throughput) was modelled in the TDMP for contingency action planning which informed the 'change management' contingency action requirements. One such contingency action was to deposit back into the old OC (now settled/shrunk by about 2 m by consolidation and air drying) by including a further three spigot points, and thereafter to include it in the TDMP sequence to further improve the achieved deposited dry density.

Figure 7 Case study – typical deposition condition, winter.

Conclusions

Careful modelling and simulation testing is required for the planning and design of a TSF. This paper provides an example of the such preparation and implementation by illustration of the methodology in a recent application for a metalliferous mine and by way of a case study from an earlier TSF design for coal tailings.

The correct implementation of the TDMP determines the condition of the tailings deposit in terms of trapped moisture, deposited dry density (which directly affects storage capacity), saturation/excess pore pressure (which influences static liquefaction), strength/stability (risk), the deposited beach slope and the difficulty/cost of rehabilitation.

Correct design and implementation of the TDMP is necessary to achieve the design requirements, to reduce risk, and to enable cost-effective rehabilitation.

The TDMP forms an integral part of the design of a tailings storage facility (TSF). If not implemented correctly, the performance of the TSF will be adversely impacted ie it may not fulfil the performance requirements of the design, nor have the flexibility to respond to changes in tailings composition nor produce an acceptable risk profile for such items as flood routing and static liquefaction potential.

The TDMP is in summary science backed modelling for deposition management planning.

Acknowledgements

The authors acknowledge the most useful assistance of Vivian Byrne in assistance with the compiling and the formatting of this document.

REFERENCES

Batchelder, A R, 1989. Development of a Tailings Deposition Consolidation Test Using Water Pressure, Master's Thesis, Sydney University.