DESIGN, CONSTRUCTION AND PERFORMANCE OF THE MOUNT THORLEY CENTRAL RAMP TAILINGS DAM

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ABSTRACT

This paper covers the investigation, design, construction and performance of a tailings dam at Mount Thorley Warkworth ("MTW"), a Coal and Allied operated open-cut coal mine in the Hunter Valley, NSW. A tailings disposal site was identified in one of the ramps through the mine-spoil piles. The "foundations" and abutments comprise uncompacted mine spoil to a depth of 40m below the haul road surface. The Stage 1 embankment at this site has a height of 70m.

The dam is a zoned rockfill embankment, constructed from mine spoil. It was designed as a "leaky" dam. An innovative method of work packages was developed for construction. The rockfill was delivered to the site by the mine. Spreading and compaction was carried out by a separate external contractor. Construction of the embankment was completed in a period of 5 months.

Filling of the storage commenced before the end of construction. Monitoring has included measurements of very large settlements, plus tailings level and piezometric surface. The monitoring results are presented and discussed.

1 INTRODUCTION

The planning, design, construction and filling/operation of tailings dams is always carried out in a climate of change. Mine production rates may vary from time to time, and therefore remaining life of existing storages, and the time available to develop new ones is never an absolute. Management of the program of raising and/or development of new storages requires continued attention. In addition, at any time during operation the conditions in a tailings dam undergoing active filling are unique. That particular combination will never be repeated.

This paper covers the investigation, design, construction and performance of a tailings dam at Mount Thorley coal mine, NSW, and will illustrate some of the items listed above.

The mine is jointly owned and operated by Coal and Allied Operations.

2 BACKGROUND

Mount Thorley is an open cut mine using drag-line and truck and shovel methods. The mine operates with a face length of about 2 km (Figure 1). A number of different seams are mined, predominantly to produce export quality coal. The coal seams dip west at an average slope of about 5%. Initially three separate haul roads or ramps were left through the spoil piles to provide for access and coal haulage.

In common with most mines of this type, the coal preparation process produces two waste streams: a coarse reject of predominantly sand and gravel sizes, and fine reject or tailings.

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Figure 1: Locality Plan

Because of surface constraints during the early life of the mine, there was limited available space for a conventional tailings dam, and the tailings disposal method used mechanical de-watering, based on either solid bowl centrifuges or belt-press filters.

The method used was to direct the dewatered product (filter cake) onto the coarse reject conveyor. This discharged to a temporary stockpile from where the combined rejects were loaded and trucked for disposal in the mine spoil piles. The belt-presses were found to be more efficient, and the centrifuges were phased out (McKee, 1989). The belt presses operated until 2000.

However, there were some significant disadvantages with this arrangement, including:

- high operating cost (flocculant, and loading and trucking costs)
- problems with dewatering the high plasticity tailings from some seams
- the negative effect of we filter cake on slope stability in the spoil piles
- the need to maintain back-up storage (which had limited capacity) for by-pass of the belt presses when processing the more difficult seams

3 RE-APPRAISAL OF METHODS

Tailings dam disposal was re-assessed in 1999-2000. A number of options were considered. Eventually the mine concluded that the central haul road could be re-aligned, and the existing ramp could be considered as a potential storage site.

Studies showed that a tailings storage at this location could provide significant savings over the existing disposal system, and investigation and detailed design commenced.

The storage required a major embankment at the west side, with a height of around 70m (for Stage 1) and a smaller embankment at the east

side. This paper focuses on the west embankment.

4 SITE CHARACTERISTICS

4.1 Staging and Capacity

The Centre Ramp haul road formation was 40m wide, with "V" drains on each side. It had a gradient of about 8% - 10%, and the spoil piles on each side of the ramp were end-dumped mine spoil, at the natural angle of repose, typically 36^0 to 37^0. Hence an embankment of significant height was required to obtain any reasonable storage.

Staged construction was proposed for the storage. The initial Stage 1 was designed for construction to a maximum crest level of 92.5mRL, which gave a storage volume of around 4 Mm3. This provided capacity to store tailings from three years of production. Provision was made for a second stage crest raise of 5m to a final level of 97.5 m RL, to provide storage for a further year.

4.2 Foundation and Abutment Material

The foundations and abutments of the site are comprised totally of mine spoil, as a result of the mining operations. The spoil is derived from coal-measures sedimentary rock, consisting of sandstone and siltstone, with some conglomerate and carbonaceous shale layers. The near surface overburden material is weathered, and may be "free-dig", but the majority of the material is blasted prior to excavation. The resulting spoil comprises a mix of angular to sub-angular cobble/boulder sized fragments in a finer matrix, typically a clayey or silty/sandy gravel.

As a consequence of the method of mining, the lower section of the spoil is formed by drag-line, with layers of truck-dumped spoil placed over the top. Because of the height of the dumps and the method of placement, a feature of drag-line spoil is the potential for major segregation to occur during placement. Larger rock particle tend to roll to the bottom of the pile, and form semi-continuous zones containing macro-voids (Richards,1998). The site investigation was directed towards assessment of these conditions.

5 SITE INVESTIGATION

Nine boreholes were drilled in the mine spoil, using RC air coring. All holes were stage tested for permeability using water inflow methods, and two holes were completed as short term monitoring bores to provide a better indication of the groundwater level in the spoil piles.

Two holes were continued by coring into the "basement" rock to provide an indication of the spoil to rock contact, and the type, strength and weathering of the rock.

Investigation Results:

Permeability: The water inflow tests confirmed that the average in-situ permeability was high. Test inflow rates of between 12 l/sec and 15 l/sec failed to fill any of the holes. Lower bound permeability values (averaged over each test interval) were calculated to be of the order of 10^5m/sec.. The actual average values could easily have been an order of magnitude higher.

Further, it was considered probable that out-flows were not in fact averaged over test lengths, but were most likely concentrated in specific zones of large open voids. This was interpreted as confirmation of the existence of "macro-voids" within the spoil.

Base Conditions: The holes drilled into the basement rock indicated competent rock, without the presence of any low-strength claystone bands which may have had a deleterious influence on stability. This was confirmed by the overall mine experience, which was that the site is not prone to significant "base-failures" in the spoil piles.

The groundwater level in the spoil was close to bedrock level.

6 TAILINGS PROPERTIES

A standard range of laboratory testing was carried out on representative samples of tailings to provide design parameters. A Rowe cell consolidation test was carried out to provide input parameters for large-strain consolidation modelling of the filling and self-weight consolidation process (Murphy and Williams, 1990).

The tailings properties are summarised as follows:

Slurry Solids Content:		40-44% (w/w)
Particle Size Distribution (percent minus 75 um):		69 – 91 %
Plasticity	LL:	40 - 45
	PI:	15 - 24
Unified Soil Classification:		Clay (CI)
Soil Particle Density (SG):		1.81 – 1.88
Initial Settled density:		0.55 t/m3

The consolidation modelling indicated an end of filling density of 0.65 t/m3 (dry). This is a relatively modest increase over the initial settled density, and reflects the high rate of rise in the storage, and the low permeability of the clay tailings.

7 DESIGN

7.1 General

The dam was designed on the basis of a HIGH B consequence category (ANCOLD, 2000), reflecting the fact that mining was to be carried out in the pit, down-slope of the dam, during its operational life.

The dam was designed as a zoned rockfill embankment, constructed from mine spoil. The design cross section is shown in Figure 2. It was designed as a “leaky” dam, with an upstream zone intended to retain tailings but not water.

For Stage 1 the aim was to use spoil sourced directly from overburden removed as part of ongoing mining operations, not to reclaim it from the already placed spoil piles. The mine uses mostly 220t Komatsu 830E haul trucks. Considerations of the turning circle and safe operating requirements for these vehicles dictated a minimum crest width of 40m. Eventually, considering the requirements for placement of individual zones, a crest width of 51m was adopted.

Figure 2: Design (Typical) Cross Section

7.2 Embankment Design Features

7.2.1 Zoning

The design provided for four separate embankment zones, all of mine spoil (Figure 2).

The material requirement for each of these zones was:-

Zone 2A: the original intent was for this to be constructed using lower permeability, weathered mine spoil, preferably selected from one of the upper benches being mined. This proved to be impracticable, as the mine plan provided for only one bench to be extracted at a time. Limits were placed on the maximum particle size and the overall grading of this zone to ensure a well graded material, which would act as a "filter" to retain the tailings solids. A low permeability zone capable of retaining water was not considered to be necessary. The zone was constructed in 1m thick layers.

Zone 2B and Zone 2C: these were constructed using general mine spoil, but excluding weathered material from the upper benches. Zone 2B was placed in 1m thick layers. Zone 2C was placed in 5m thick layers.

Zone 3: this was to comprise a free-draining rockfill of selected mine spoil, sourced from one of the sandstone / conglomerate layers in the overburden sequence, and placed in 5m thick layers..

7.2.2 Compaction

The design required Zones 2A and 2B to be compacted, and was based on the use of an impact roller. Specifications were prepared for both 4 sided and 5-sided types of roller. The contractor elected to use the 14t, 5 sided roller.

Zone 2A was compacted by 8 passes of the 5 sided roller. Zone 2B required 4 passes.

7.2.3 Stability

The embankment was analysed for both static and seismic stability.

Initial analysis was based on an adopted friction angle of 36^{o}, based on observations of the angle of repose of the existing spoil piles, and data suggested by Richards (1998). The design assumed that the spoil would remain free draining under conditions of rapid loading, and separate undrained parameters were not used. Subsequent design recognised the possibility of non-linear strength envelopes, and adopted design strength values as proposed by Simmons (1995), originally for Bowen Basin mine spoil.

A site specific seismic risk analysis was commissioned to provide seismic design values. A peak ground acceleration of 0.38g was adopted, for a Maximum Design Earthquake having a return period of 5000 years.

Acceptable factors of safety were calculated for all cases.

7.3 Seepage and Leakage

Design measures to address the issue of potential leakage of tailings (both solids and decant water) through preferred seepage paths in the abutments included:

- flared abutments
- wide crest
- relatively flat (overall) downstream slopes
- location of the tailings discharge points on the west embankment so that the decant pond formed at the east end of the storage.

The selected site is totally contained within the mine pit envelope. Any seepage losses will report to the pit sump, and there is no possibility of an off site discharge.

7.4 Settlement

It was recognised that post-construction settlements as a result of progressive loading and creep, and "collapse" settlements following

wetting-up of the mine spoil would be significant. Rainbow (1990) indicates settlements of the order of 1% of the saturated thickness for compacted mine spoils in UK. Data on post construction settlements of rockfill dams were also reviewed. Data presented by Clements (1984) indicates that for central core dams constructed using sedimentary rock, post construction settlements of up to 0.75 – 1% have been recorded. These values were supported by laboratory tests carried out by ATC as part of a previous design study on another site.

In the current case, similar values were expected in the compacted embankment zones, and higher values in the existing uncompacted spoil piles, and in the embankment zones where compaction was not specified.

7.5 Water Management

The storage has been designed so that air space is available to retain the runoff from a PMP storm event. The storage has a catchment area of just under 80ha, and the required storage capacity is 700ML. This volume requires a freeboard of 2m at FSL.

Bleed water from the tailings, which would normally be expected to report to the decant pond, was calculated to be around 1.3 Ml/day. Because of the high permeability of the spoil piles, it was accepted that much of the decant water would be lost from the storage area. The slope of the pit floor indicated that lost water would eventually report as seepage from the base of the spoil piles, in the south west corner of the pit. This is the lowest point in the mine, and seepage due to rainfall infiltration into the dumps was already exiting at this point. Nevertheless, provision was made in the design for the installation of a pump-set to recycle decant and stormwater to the plant from the storage.

Figure 3 Zone 2A Grading Curves

8 STAGE 1 CONSTRUCTION

An innovative method of work packages was developed for construction. The rockfill was delivered to the site by the mine, as an extension of normal mining operations. Delivery rates of up to 20,000m3/day were achieved, being approximately 80% of total overburden removal. The logic of this was that the cost of load, haul and dump was already covered by the mining operation. The only incremental costs directly attributable to the embankment were overhaul, additional spreading, and compaction. However, the mine reported that the longer cycle times associated with the delivery operation had a negative effect on productivity, and that a lower proportion of overburden production delivered to the dam would have been desirable.

Spreading and compaction of Zones 2A and 2B was carried out by a separate external contract, let to local contractor Daracon Pty Ltd. Placement and spreading of Zone 2C and Zone 3 was carried out directly by the mine.

Construction of the embankment commenced in mid 2001, and was terminated after a period of 5 months, when the embankment reached a crest level of 90mRL. The decision to terminate Stage 1 at this level (ie 2.5m below the original design level) was because of the temporary completion of mining operations in a locality amenable to the supply of rockfill to the dam.

One relatively minor modification to the design was necessary during construction to provide for safety berms along the upstream side of the embankment, to comply with standard mine OHS requirements. The berms were formed by pushing up material with a dozer, and compaction was not possible. The berm material was obtained by a degree of over-placement, combined with a small decrease in the width of Zone 2A.

The final quantities of material placed in each zone were:

Zone 2A:	400,000m3
Zone 2B:	650,000m3
Zone 2C and Zone 3:	1,700,000m3

Grading curves obtained from samples of Zone 2A material, after placement and compaction, are shown in Figure 3 These results reflect both a) the generally well graded nature of the initial rockfill, and b) a degree of mechanical breakdown of the relative weak rock fragments during placement and compaction.

9 OPERATION & PERFORMANCE

9.1 Storage

Filling of the storage commenced in the last quarter of 2001, about half-way through the construction period. Filling continued until March 2005, when tailings deposition was switched to another storage pending the completion of the East embankment. The tailings level at that time was around 78mRL.

The storage filling curve is shown in Figure 4. This shows the actual filling curve (tailings surface level v time), and the theoretical curve, based on actual plant production values, together with the predicted “end-of-filling” density. It is apparent that the actual curve is up to 10m -15m lower than the expected curve for most of the duration of filling. Put another way, the predicted curve shows the tailings reaching 80mRL in a time of 24 months after commencement of filling. In fact the actual tailings surface was still 2m below this level some 18 months later. Part of the discrepancy is due to settlement of the base of the storage (see Section 11), but at most this can only account for around 2m of the 10m-15m difference.

Figure 4: Storage Filling Rate

The explanation of the remaining difference is that a significant proportion of the input tailings slurry has simply flowed into the macro-voids in the surrounding mine spoil. An examination of the filling curve (Figure 4) shows periods of time when the tailings level remained constant, whilst deposition into the storage was occurring. Sometimes it was possible to see the point where the tailings flow into the mine spoil was actually taking place. Flow into the spoil appears to continue into a defined void until it "blocks up". Tailings are then confined to the storage whilst the level rises and access to a new void is obtained. (This behaviour had been observed at other sites, but had not previously been quantified). At no time during the filling to date did any tailings solids daylight on the surface at points downstream of the storage.

No appreciable decant pond ever formed on the tailings surface, and the decant return pump was never installed. Throughout the period of active filling, a flow estimated to be about 25 l/sec emerged from the toe of the spoil piles, near the mine face, and was collected and recycled from the pit sump. This water was always clear, with no suggestion of tailings fines.

Some of this seepage water originates from rainfall infiltration into the top of the spoil piles, but it is not possible to quantify the proportion

9.2 Embankment Performance

There have only been minor issues relating to overall embankment performance. There has been a small amount of erosion on the upstream face where the tailings delivery stream discharges down the face, but this was expected.

Some local areas of the downstream Zone 2C were initially over-placed, and left at a steep slope. Some erosion and slumping was observed on this face due to stormwater run-off. This slope was actually outside the Stage 1 design envelope, but it was decided that it should be bulldozed down an angle closer to the design slope (Figure 8).

10 MONITORING RESULTS

10.1 Instrumentation and Monitoring

Monitoring has included measurements of deformation (N-S, E-W and vertical, by periodic survey of settlement points), records of the tonnage of tailings delivered to the storage, measurements of the tailings level, and installation of standpipe piezometers on the crest of the dam and monitoring of the phreatic surface.

10.2 Settlement

A total of 37 deformation monitoring points has been installed. These points are located on the embankment, and on the spoil piles around the storage (primarily to monitor the safety of the haul road). For clarity, only selected representative results are presented in this paper.

The first monitoring results are from November/December 2001. Tailings disposal had already commenced at this time, and hence it is probable that the initial settlements have been missed. No corrections have been made to the reported results to reflect this, and therefore the values discussed below are likely to be under-estimates.

The monitoring results for vertical deformation (settlement) on the embankment are presented in Figure 5. This includes both embankment and foundation settlement, and shows settlements of up to 1.4m on the compacted, upstream zones. Settlements up to 2.4m have occurred over the dumped, uncompacted downstream zones.

The monitoring results for the abutments/ spoil piles are shown in Figure 6. The results are generally similar to the settlements obtained on the actual embankment. Points T74 and T76 show a delayed response. This is because of their location 400-500m east of the embankment, away from the initial zone of saturation formed by tailings deposition.

Some measure of the influence of foundation settlements on these results can be gained from points T85 and T89. These were located on the upstream bund at RL55m. The underlying spoil consisted of approximately 25m of compacted embankment material, and 40m of "old" spoil foundations. Up to the time that it was lost due to overfilling, T85 had a measured settlement of 1.36m. If this is split in proportion to the layer thickness, it gives about 0.55m for the embankment fill, and just over 0.8m for the foundations.

Figure 7 shows the settlement as a percentage of the saturated thickness of mine spoil beneath the monitoring point (assuming the spoil is saturated up to tailings level in the storage).

10.3 Horizontal Deformation

Horizontal deformations on the upstream face, and on the surrounding abutments/spoil piles showed a deflection towards the storage during filling. The general horizontal deformation was around 0.4m.

This is contrary to the behaviour of most dams, where the loads due to filling result in downstream deformation. The upstream deformation is considered to be due to softening (and a reduction in modulus) of the foundation mine spoil due to saturation effects.

10.4 Phreatic Surface

The phreatic surface at the end of the initial filling (ie when the tailings level reached around 80mRL) is shown on Figure 8.

This figure also shows the changes that have occurred in the downstream embankment profile.

Figure 5: Embankment Settlement v Time

Figure 6: Spoil Pile/Abutment Settlement v Time

Figure 7: Settlement v Time, as a proportion of Saturated Thickness

Figure 8: Phreatic Surface and Embankment Re-Shaping

11 FUTURE EXTENSIONS

The smaller, east embankment has now been completed, and further filling to complete Stage 1 is scheduled for 2006.

Additional raises to the storage are planned, and will result in a modification to the original design for the raise to 97.5m RL. The current plan is for a Stage 2 raise to 100mRL, followed by Stage 3 to 120mRL, both linked to scheduled mining activities in close proximity to the storage to facilitate delivery of mine spoil for embankment / spoil pile construction.

12 CONCLUSIONS

A zoned rockfill embankment was designed for this storage. It was constructed by an innovative mix of mine fleet and external contract.

From conception, the time for investigation, design, permitting, tendering and construction was around 18 months.

The period of active filling to the end of Stage 1 will be 4-5 years.

Significant settlements have been experienced in the embankment and spoil piles surrounding the storage, but these have not effected serviceability.

Significant losses of decant water into the mine spoil, for recovery from a sump down-dip have occurred, and were expected from the design stage. In addition, a significant proportion of the tailings solids has infiltrated macro-voids in the mine spoil, resulting in an increased storage life.

Further staged raising of the embankment is under consideration.

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