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Capping of Tailings Deposits: Analysis, Design and Implementation

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ABSTRACT

Un-rehabilitated, large coal tailings deposits present a safety and environmental risk to current and ceased coal operations. Capping of tailings deposits, involving the spreading of granular mine waste over the surface of the tailings using heavy machinery is often undertaken to rehabilitate such sites. There is often uncertainty about the risks associated with the capping works due to a lack of understanding of the condition and strength of the tailings at depth, as well as likely failure mechanisms. This paper presents a design methodology for final capping of deep, unconsolidated soft coal tailings deposits. The approach outlines a testing, analysis and construction sequence to minimise risk during capping works. A case study of the method is presented for a coal mine in the Hunter Valley of New South Wales (NSW), Australia. The design process presented in this paper outlines the significance of appropriate site investigation works required to assess the undrained shear strength profile of the tailings, which often varies considerably with depth, location and time. The results of the investigation form the basis for analysing the stability of the capping works, where heavy machinery pushing material across the surface of the tailings creates a short-term unbalanced load. Global stability due to unbalanced loads as well as local bearing capacity are considered. The analysis is then used to develop limiting fill thickness and machinery loads for the works, with consideration given to subsequent capping layers. Implementation of the capping methodology is also discussed.

Keywords: tailings dam, coal tailings, capping

1 INTRODUCTION

Following the processing of run-of-mine coal, the fine-grained residual “tailings” are typically deposited in surface storages or into available mining voids in a high moisture state. As such, the tailings often take many years to reach a state of normal consolidation. Mining voids are generally deep and large, making tailings deposited into them a considerable safety and environmental hazard until they can be rehabilitated. Rehabilitation by “capping” of these areas comprises heavy machinery spreading fill material on the surface of the tailings in layers, until a final landform height is reached. There is often little consideration given, during deposition and storage of the tailings, to the time taken for the tailings to reach a normally consolidated and desiccated condition adequate to facilitate the capping works.

Figure 1 shows a deep slip failure at a NSW coal mine which occurred during the capping of a surface Tailings Storage Facility (TSF). It is understood that the slip occurred during the placement of the third layer of capping fill due to excessive out of balance loads from the second and third layers. Insufficient investigation works also led to uncertainty about the shear strength of the tailings at depth.

Figure 1. Large scale slip failure during capping works at a NSW coal mine

2 BACKGROUND

The specific coal tailings deposit discussed in this paper is located at a coal mine in the Hunter Valley of NSW and is referred to as Tailings Dam 'A'. Tailings Dam 'A' is a surface TSF and covers an area of approximately 330,000 m^2 with a depth of tailings of generally greater than 20 m.

Tailings deposition ceased in June 2010. Since that time the tailings have undergone consolidation due to overburden pressures, and desiccation within the surface material due to evaporation.

Rehabilitation of the TSF is a requirement of the ongoing operations of the coal mine. As such, a capping design that would facilitate placement of readily available granular mine waste on to the surface of the tailings was required. The development process for the capping design is presented in the following sections.

3 INVESTIGATION

The saturated, fine grained tailings are subjected to rapid loading during capping works and so an understanding of the undrained shear strength of the tailings was required for stability analysis.

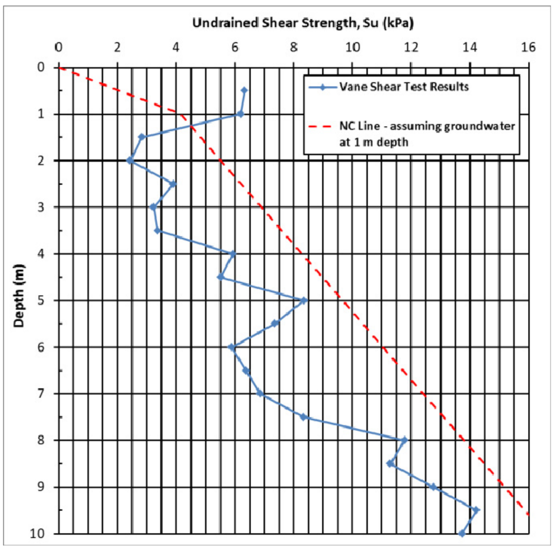
The generally "soft" nature of the deposited tailings limits the loads that can be placed directly onto the surface of the tailings, making it difficult and dangerous to traverse vehicles across the deposit. This ultimately limits the investigation techniques to either hand-held tools or machinery specifically designed to access soft areas. The latter is expensive and so simple hand-held vane shear tools were used within Tailings Dam 'A'. Vibrating wire piezometers and a soil sampler were also used.

3.1 Vane Shear Testing

Vane shear testing comprised the use of a Geonor H-70 vane shear tester and torque wrench. The Geonor H-70 incorporates a coupling system just above the steel vane, allowing a 180° turn with the torque wrench before the vane is engaged. This facilitates the recording of skin friction on the rods which is particularly useful at depth and prevents the over-estimation of shear strength values.

Testing was undertaken in 2014 at twenty-eight locations across Tailings Dam 'A' at 0.5 m depth intervals to a maximum depth of 10 m. The deep vane shear testing is considered to be vitally important for understanding the variability of shear strength with depth which reduces uncertainty and improves confidence in the design. Deep slip failures can and will develop as the height and extent of capping fill and machinery loads increase. Readings recorded by the torque wrench produced an undrained shear strength profile at each test location. Figure 2 shows the equipment used as well as the recorded undrained shear strength profile at one test location. The normally consolidated (NC) line also shown in Figure 2 adopts a groundwater depth of 1 m as measured at this location.

(a)



(b)

Figure 2. (a) Vane shear testing equipment; (b) Indicative undrained shear strength profile

3.2 Sampling

A piston soil sampler was used to obtain numerous samples at varying depths and locations across Tailings Dam 'A'. The retrieved samples were tested in the laboratory to obtain information on specific gravity (G_S), moisture content (w), and dry density (ρ_d).

Moisture content results were correlated with recorded undrained shear strength values. Figure 3 shows an indicative relationship between gravimetric moisture content and undrained shear strength for the tailings sampled from Tailings Dam 'A' and other coal tailings deposits within the mine.

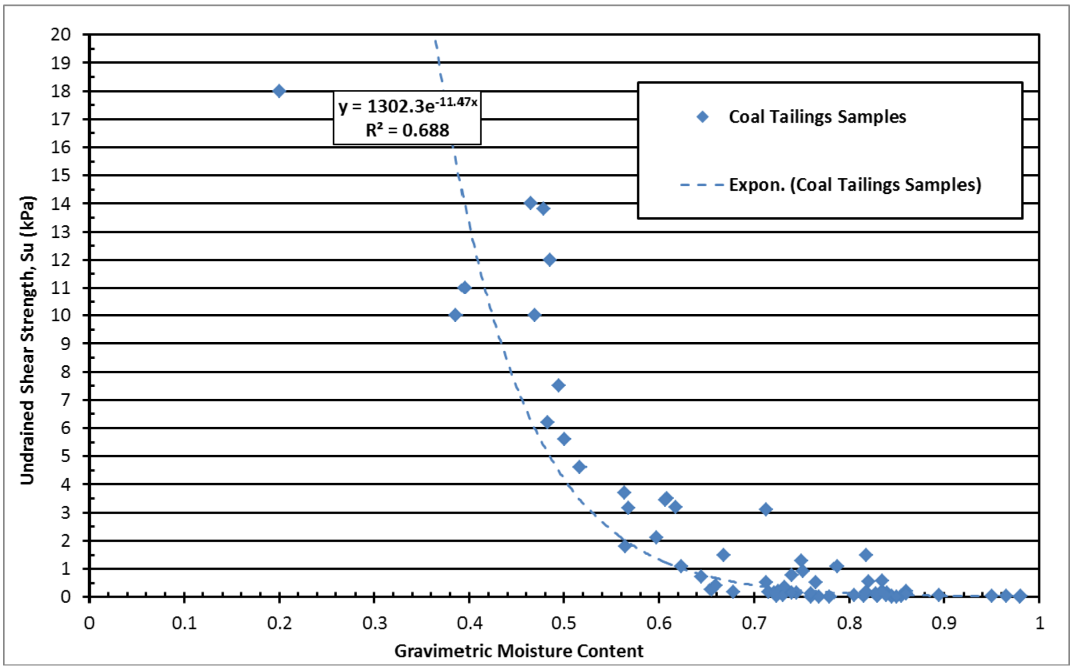


Figure 3. Undrained shear strength vs gravimetric moisture content plot

3.3 Vibrating Wire Piezometers

Vibrating wire (VW) piezometers were installed at three locations to assess the distribution of pore pressures with depth. The results indicated that at the locations examined the excess pore pressures due to overburden weight had not dissipated and the tailings had not reached normal consolidation.

4 ANALYSIS

The results of the investigation techniques discussed in Section 3 were used as the basis of the analysis for the stability of potential capping works. Two failure mechanisms likely to impact the heavy machinery spreading the capping fill were considered:

- Global stability – failure along a circular slip surface due to short-term unbalanced loads.
- Local bearing capacity – bearing failure through the capping layer into the soft tailings.

The failure mechanisms were analysed separately. Each analysis technique is discussed below.

4.1 Global Stability

The global stability of heavy machinery placing the capping fill on the surface of the tailings was analysed using the limit equilibrium computer program Slide. The input components were as follows:

- Design undrained shear strength profile of tailings derived from vane shear testing.
- Mass of the capping fill. Analysis indicated that an initial capping layer of no more than 0.5 m thickness could be placed onto the tailings surface.
- Loading from the machinery used to place the capping fill, with consideration given to the possible 3-dimensional load spread through the overlying capping material.

The stability assessment considered two types of machinery – a D6R Bulldozer and a tracked bobcat. A critical Factor of Safety (FoS), taken as the first circular failure surface extending through the tailings and impacting the machinery, was computed at each test location. Figure 4 shows a contour plot of FoS for the D6R bulldozer at the southern end of Tailings Dam 'A', computed from the limit equilibrium analysis completed at each test location.

It is noted that management protocols for Tailings Dam 'A' required the minimum FoS for the works to be 1.3. The results of the analysis indicated that the capping works could not be undertaken (FoS less than 1.3) at the northern end of the deposit with the current methodology.

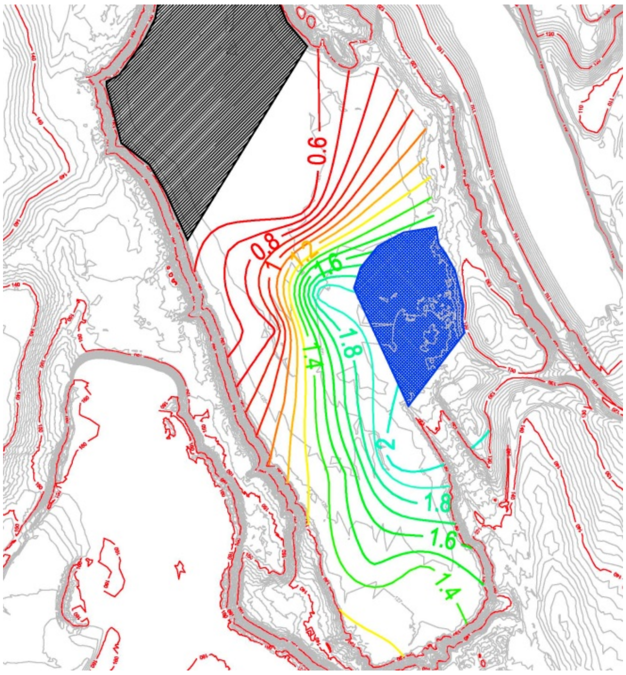


Figure 4. FoS Contour Plot – D6R Bulldozer and 0.5 m Capping Layer

4.2 Bearing Capacity

The bearing capacity of the tailings profile beneath the machinery was also considered. This is a difficult failure mechanism to analyse quantitatively due to the layered ground profile (granular material overlying soft tailings) with significantly different strength and stiffness properties.

A number of analytical methods to compute the local stability of the works in bearing were considered:

- Bearing capacity of clays with increasing shear strength profile, as presented by Davis and Booker (1973)
- Bearing capacity of granular material overlying soft clays, as presented by Hanna and Meyerhof (1980)
- Axi-symmetric modelling using the finite element analysis program Phase^2

Singularly, the computation methods above were not considered to provide a definitive answer. However, a combination of the methods gave an indication of whether the proposed machinery would be suitable for the capping works, in conjunction with the results of the global stability assessment.

The results of the analyses generally indicated global stability to control machine size and fill height.

5 DESIGN

The results of the stability analysis indicated that the capping works at the northern end of Tailings Dam 'A' could not be completed with the current methodology. This resulted in the approach where the southern end would be capped first, and various other options examined to improve the density and shear strength of the tailings at the northern end.

The southern capping area was split into two zones based on the FoS plots produced by the analyses:

- Zone 1 – a D6R Bulldozer would be used to place a 0.5 m initial capping layer
- Zone 2 – a tracked bobcat (CAT 299D or similar) would be used to place a 0.5 m initial capping layer

The spreading of subsequent capping allows increasingly thicker fill layers and possibly larger machines as the initial layers of granular material provide additional confining stresses to resist slip failure development. It is important to ensure that the initial fill layer is sufficiently developed prior to commencing the secondary layer. The secondary capping layer design was as follows:

- Zone 1 – a D6R Bulldozer would be used to place a 1.0 m secondary capping layer no closer than 50 m behind the face of the initial layer.
- Zone 2 – a tracked bobcat (CAT299D or similar) would be used to place a 0.5 m secondary capping layer no closer than 50 m behind the face of the initial layer.

A D8 Bulldozer could be used in Zone 1 and Zone 2 to spread 1.5 m to 2 m thick fill layers to a final landform height of approximately 5 m, after a 1.5 m thick capping has been established.

5.1 Design Uncertainties

There is a number of uncertainties inherent in the overall analysis process, as discussed below:

- Use of a 2-dimensional analysis technique to model a 3-dimensional problem: A 3-dimensional load spread of the plant through the capping layer was adopted for the analyses as an attempt to incorporate 3-dimensional effects.
- Assumption of the plant load as a static, concentric load: The machinery loading will be subject to some eccentric effects during pushing, turning and movement on uneven ground. It is considered that the applied FoS will accommodate these effects.
- The extent of excess pore pressures in the tailings beneath the capping fill and their rate of dissipation: Review of monitoring results during the capping works will help develop a better understanding of pore pressure reactions to loading.

6 IMPLEMENTATION

The implementation of the capping design requires the analytical design to be incorporated into real-world construction procedures. The following sections discuss the factors considered to be important for the effective implementation of the design, including hazard training of personnel, an appropriate monitoring regime, and ongoing inspections and review of the capping works.

6.1 Hazard Training

Operators and supervisors undertaking the works need to be aware of the inherent risks and hazards as well as the limitations put in place to prevent failures developing. A training document was developed prior to the commencement of capping works to outline the specific limitations to the works and the visible signs for the onset of failure. A few key points are as follows:

- Tolerances on capping fill thickness:
    1. + 200 mm
    2. – 50 mm
- Signs of instability:
    1. Look for cracks parallel to the advancing face behind the capping crest
    2. Look for heaving or mud-waves in the tailings in front of the advancing face
- Operation of plant:
    1. Maintain separation of plant a minimum of 20 m
    2. Do not push out material more than 2 plant lengths from the advancing face
    3. Avoid working on wet spots following rainfall
- Monitoring:
    1. Use survey pegs in tailings to monitor movement for onset of failure
    2. Use spotters to monitor plant movements and to look for signs of cracking

6.2 Monitoring

VW piezometers were installed at three locations prior to commencement of the capping works as a way of assessing the pore pressure response during placement of the capping fill and the rate of dissipation of the excess pore pressures. PVC pipes of 100 mm diameter were placed over the top of the piezometers to prevent them being damaged during the placement of the capping fill and allow access once the capping fill had been placed. Additional PVC pipes were installed adjacent to the piezometers to allow further vane shear testing to be undertaken in the tailings following placement of the capping fill.

Piezometer readings taken before, during and after placement of the first capping fill layer indicated rapid increase in pore pressures up to 4 m depth, with very slow dissipation of excess pore pressures.

6.3 Design Review and Inspections

Additional vane shear testing was undertaken at the beginning of 2016 and indicated improvement in the undrained shear strength profile at a number of test locations. Review of the capping design with the new test data, in conjunction with inspection of the current capping progress, allowed the extent of the D6R zone and the overall works to be extended, improving the efficiency of the project. A D4K LGP Bulldozer was also recommended to replace the tracked bobcat within Zone 2.

At the time of writing this paper the capping works at the southern end of Tailings Dam 'A' are still in progress. The works are at approximately 50% completion of the second capping layer. Inspection of the works indicated no signs of heaving or displacement of the tailings or cracking of the capping fill.

Figure 5. Capping works progress - secondary 1.0 m capping layer (August 2016)

7 CONCLUSION

The investigation, analysis and design process discussed in this paper presents a systematic approach to developing and implementing a suitable capping works design that minimises the risks and hazards associated with spreading fill on the surface of deep coal tailings deposits. The author considers that a successful capping design is reliant on all steps of the discussed process.

The initial investigation works should be completed to an appropriate depth and density to capture possible deep slip failure mechanisms and zones of weaker/softer tailings. Suitable hazard training of the machine operators completing the works, as well as monitoring and review of the ongoing capping works are also considered vital to the success of the project.

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