Case Study – Outer batter slope profile design for the Beenup tailings storage facility.

Summary

Following the decision of BHP Billiton to close its Titanium Minerals mining operation at Beenup, Landloch was engaged to design an outer batter slope for the Mine Development Storage Area, (MDSA) that would remain stable over the long term.

The erodibility of two materials was tested in the laboratory: ferricrete and a sand. It was determined that, after some initial erosion, the ferricrete 'amoured' and its erosion rates diminished greatly. The sand displayed higher levels of initial erosion than the ferricrete.

Computer simulations using the Water Erosion Prediction Program (WEPP) assessed a variety of batter slope designs for the MDSA. The long-term erosion of the most suitable slope profiles was then assessed using the SIBERIA model. It was determined from the laboratory studies and computer simulations that the most effective batter slope design (to minimise long-term erosion and to provide maximum landscape stability) was a concave slope of ferricrete material.

The proposed design has now been constructed and a number of criteria have been set and agreed with government agencies for ongoing monitoring of surface erosion and depth of surface gullies, along with other factors such as slumping or sliding slip surfaces. Monitoring methods are now in place to track performance against design.

Closure Plan – Beenup Mine

Tailings from the Beenup mine were stored in three tailings dams. The Closure Plan considered transferral of the tailings from the existing dams into the dredge pond. As not all tailings material could be returned to the dredge pond (due to volume changes of the mining material and a slow consolidation process), some tailings needed to be stored above ground level. One of the tailings dams, the Mine Development Storage Area (MSDA) had been designed and constructed as a watertight facility. It was therefore chosen as the site for tailings storage and has been rehabilitated as a permanent structure.

View of MDSA. (Top revegetated.)

The structure is a circular dam, with an outer batter approximately 12 metres high. Design considerations took into account local features of the dam structure and as a result the batter gradients average 33-40%. Within the dam, tailings material has been covered by a cap of sand, with gradients of the cap surface being approximately 1%. Drains within the cap area provide for both infiltration of runoff from the cap and also for safe disposal of runoff water via spillways. A perimeter drain is designed to prevent runoff from the cap from discharging onto the outer batter slopes. This will reduce the potential for erosion of the crest and outer face of the embankment. Flow in the perimeter drain will be transferred to the natural land surface by three spillways down the face of the embankment.

Concave batter slope and spillway, also showing rock armouring of the top (steepest) section of batter slope.

Determination of Erodibility Parameters for Both Spoil Types

Erodibility of the two materials planned for use in the construction of the MDSA was tested in the laboratory. One was ferricrete (silty sandy gravel with cobbles) used in the MDSA outer batter; and the other was a medium sand containing some gravel likely to be used as a capping material.

Flume studies of the ferricrete showed that, after initial erosion removed fine particles from the surface, a rock armour developed that was extremely resistant to erosion by overland flows. Similar studies showed the erodibility of the sand was low relative to sandy agricultural soils, though still higher than that of the ferricrete even prior to armouring.

Laboratory Erodibility Testing of ferricrete erodibility in flumes, showing visible armouring of the ferricrete.

The parameters measured in the laboratory on these two materials were subsequently used to determine input parameters for the two erosion models.

Erosion Modelling

Two erosion models were used to determine the most appropriate batter slope profiles for the MDSA.

The Water Erosion Prediction Program (WEPP) was developed by the United States Department of Agriculture (USDA) to predict runoff, erosion, and deposition for both hillslopes and watersheds. For ferricrete batter slopes, WEPP simulations indicated very low rates of erosion. In the longer term, rates of erosion will probably become even lower than predicted, due to continuing depletion of fine particles in the armoured surface.

The SIBERIA model simulates runoff and erosion from landforms that evolve in response to predicted erosion and deposition for periods up to thousands of years. Simulations using the SIBERIA model showed the proposed MDSA landform likely to remain stable for periods of at least 1000 years. This is consistent with the very low erodibility of the ferricrete material used to construct the batter slopes, and the extremely low erosion rates likely on the low gradient cap material.

The SIBERIA simulations also highlighted the importance of the perimeter drain on the MDSA cap, as the drain prevents runoff from the cap discharging over the batter slopes throughout the life of the landform.

Four slope profiles were considered in the erosion simulations. The Option 1 slope was the current linear slope profile. The other three slopes were variations on concave slope designs. Predicted erosion from Option 1 was considerably higher than all other designs (Table 1).

Table 1: *Mass and depth of peak and average erosion on MDSA batter slopes, WEPP model output*

Profile option	Peak erosion (t/ha/year)$_1$	Peak erosion (mm/year)	Average erosion (t/ha/year)	Average erosion (mm/year)
1	31	1.7	8.86	0.49
2	10.6	0.59	5.06	0.28
3	6.2	0.34	4.7	0.26
WEPP concave	4.6	0.25	4.6	0.25

Final Design Recommendations

Outer batter slope

Based on the results from the two erosion models, and from associated considerations of earthquake stability carried out by GHD and independently reviewed by Guria Consulting, the Option 3 slope was considered the most suitable slope design. The Option 3 slope is a concave slope with gradients ranging from 50% (top of profile) to 25% at the toe of the slope. It displayed minimal erosion in all erosion model simulations and is expected to remain stable for a minimum period of 1000 years.

During construction of batter slopes of ferricrete material, some provision has been made to deal with the erosion that will occur during the initial armouring phase. This has been achieved by setting the toe drain well back from the slope to cater for deposition of eroded materials. As part of the criteria, survey measurements will be taken to calculate the tonnes of eroded material to ensure the slope is performing according to modelling. (Figure below.)

Perimeter drain set well back from the toe of the slope

Cap

While the low gradients planned for the MDSA cap will ensure that rilling and incision by overland flows will not occur, vegetation of the cap is still desirable. This will reduce erosion rates on that area and minimise the sediment amounts being transported into the drains on the cap.

The cap surface has been treated with hydromulch to protect against short term wind erosion and a mix of 8 species of reeds, rushes and ground covers has been added with the mulch to afford long term protection of the cap.

For other information on the Beenup site:

http://www.ea.gov.au/industry/sustainable/mining/booklets/mine/cs1.html