ANALYSIS OF Flexural Toppling at Australian Bulk Minerals Savage River Mine

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ABSTRACT

The Savage River Iron Ore Mine, located in northwest Tasmania, was opened in 1968 to produce iron ore pellets from a magnetite orebody. Over the years four pits have been developed; South Centre Pit, Centre Pit, South Lens and North Pit. On the western walls of Centre Pit and North Pit flexural toppling failures have restricted overall slope angles to 37°. This paper discusses the geology, history and stability analyses of these toppling failures. The computer software programme UDEC has been successfully used to model excavation history, groundwater depressurisation and slope movements. The model is now being used to predict the future behaviour of the slopes to assist in mine planning

ANALYSIS OF FLEXURAL TOPPLING AT AUSTRALIAN BULK MINERALS SAVAGE RIVER MINE

The Savage River Iron Ore Mine, located in northwest Tasmania (refer to Figure 1), was opened in 1968 to produce iron ore pellets from the magnetite orebody. The magnetite is crushed at the mine and then sent via an 85km long slurry pipeline to Port Latta on the northwest coast for processing into hematite pellets. The original owners shut down operations in 1996 but in 1997 Australian Bulk Minerals (ABM) recommenced mining after relocating the crusher and installing a 1.3km conveyor.

Figure 1 : Site Locality Map

Over the years four pits have been developed; South Centre Pit, Centre Pit, South Lens and North Pit. The mine has had a history of flexural toppling failures in Centre Pit and North Pit that have restricted a major portion of the western walls to overall slope angles of 37°, with vertical slope heights in the order of 150m. This paper discusses the history of the toppling and the recent use of Itasca's (2000) UDEC computer programme to model the phenomena, i.e to back analyse previous failures. Detailed geology, excavation histories and dewatering aspects have successfully been incorporated into the UDEC model. The model is now being used to predict behaviour of the slopes to assist in mine planning.

GEOLOGY

The magnetite deposit is located within and near the eastern margin of the Proterozoic, north-east to south-west trending structural corridor, known as the Arthur Mobile Belt. The orebodies are enclosed within a highly sheared and strike faulted, 0.5km wide belt of mafic and ultramafic schist and mylonite; all enclosed

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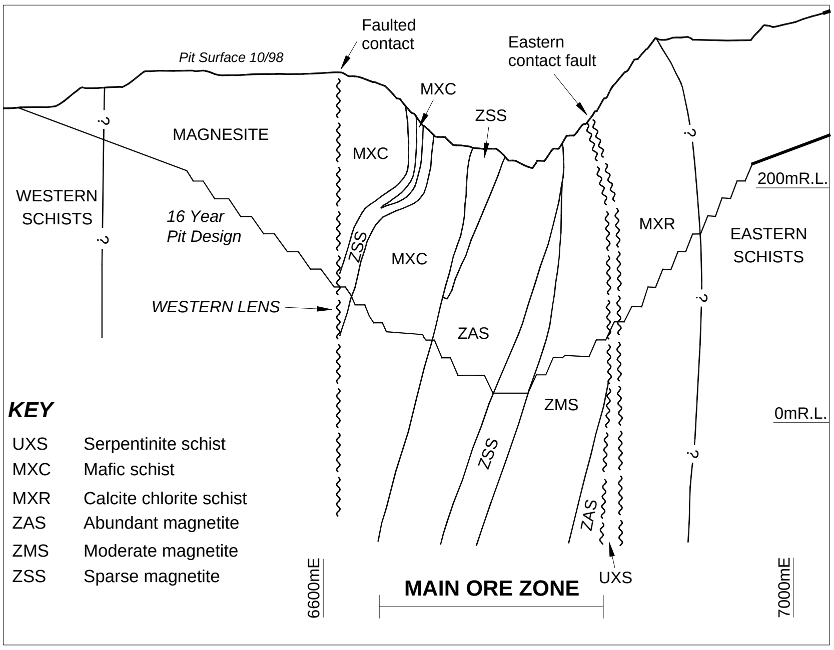

Figure 2 : North Pit N9400 Geological Section

within thick sequences of quartz – white mica schist, the Eastern and Western Schists (refer to Figure 2).

On the western side of the orebody the rocks are a sequence of mafic schists and banded mylonites. The schists are weak rocks; occasionally being completely sheared and friable. The mylonites, on the other hand, are moderately strong rocks. Intrusions such as dolerite or magnesite lenses are also encountered in various locations. These intrusions vary in thickness from a few metres to several tens of metres and have also influenced toppling as discussed later in the paper.

The dominant structural features of the rock units are steeply dipping, north-south striking foliations and foliation shears. In the area of the UDEC modelling in North Pit there are two sets of pervasive discontinuities, in addition to the foliation and foliation shears, as shown on the stereographic projection plot in Figure 3.

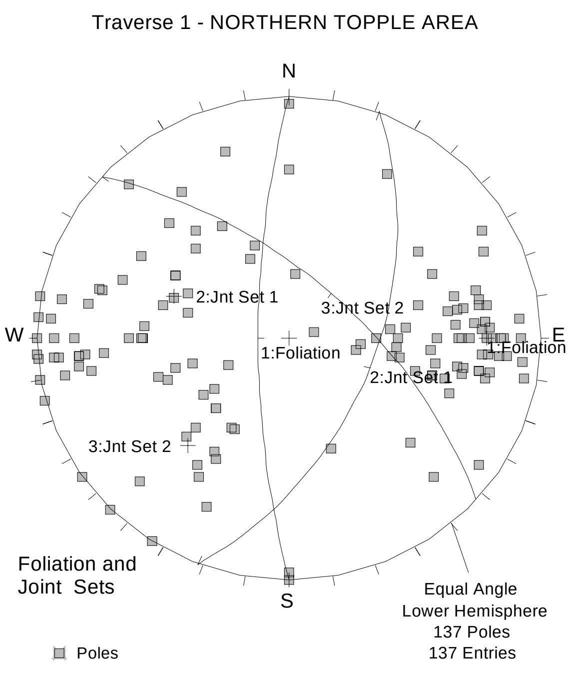

Figure 3 : Typical Major Plan Stereonet of West Wall

FLEXURAL TOPPLING HISTORY

The dominant structure that allows toppling to occur at Savage River are discontinuities that strike parallel or semi-parallel to the pit walls and dip steeply (typically 60°-85°) into the slope. The majority of the movement occurs along the relatively thin (20 to 150 mm thick) foliation plane shears, that are spaced in the order of 5 to 15 m apart.

In some locations the existence of thick competent meta-volcanic units have prevented toppling, despite having the same structural orientations.

The original operators experienced the onset of a major toppling failure on the west wall of Centre Pit in 1989. At the time the slope had been excavated at 44-45° over a vertical height of 107 m, above a 35m wide berm. A further 30m of excavation had previously occurred below and in front of the berm. Prism monitoring indicated previous horizontal displacement rates averaging at 5 mm/day that accelerated to 16 mm/day when a major portion of the berm was removed. Large tension cracks opened up 60 m behind the crest of the slope with this increased displacement rate. Horizontal displacements at the crest of the slope reached values in the order of 10 m.

The slope was re-designed to an overall 37° slope with a two stage development (Stage 1 being an upper slope cut-back) to allow ore previously left behind to be extracted early, after partially unloading the upper slope.

In June 1990 Stage 1 had been completed with 50 vertical metres of the upper slope being excavated back to 37°. During removal of lower toe material, in August/September 1990, the upper slope displacement rates increased from 1 mm/day to 4 mm/day. Horizontal drainholes were being used to depressurise the slopes. In

May 1991 the upper 37^o slope was at a vertical height of 80 m when the next 10 m high final wall blast caused a 100-200 mm horizontal jump in the prisms and an increased daily rate of 13 mm/day.

Mining from this point onwards was severely restricted due to the gradual toppling which produced horizontal displacements in the order of 13 m to15 m. With careful mining and monitoring all of the ore was eventually extracted back to the final 37^o overall slope. Two weeks after completing the ore extraction a further major topple event reportedly occurred, although the extent of this is not known to the present operators.

The photo in Figure 4 shows the classic toppling reverse scarp development that eventually occurred. In late 1999 the height of the reverse scarps reached 2-3 metres, easily enough to prevent observation from the other side of the pit of a person standing upright in the trough. Recent mapping indicates that left lateral strike slip movement occurs along the discrete foliation shears at the back of the reverse scarps.

Figure 4 : Centre Pit West Wall Reverse Scarps

An area directly south of this main Centre Pit topple has the same structural configuration, with the exception that a dolerite lens rapidly thickens from 5-10 m, in the topple area, up to 50–60 m wide. This wider, more competent dolerite intrusive appears to have acted as a stabilizing feature as no toppling has been observed in this southern area of the west wall.

In North Pit ABM experienced similar toppling episodes in their west wall 37^o cutback, in geological conditions similar to the N9400 section in Figure 2. After 90 m of vertical excavation, horizontal movement rates accelerated; from background values of 1-3 mm/day, up to 30 mm/day. The slope was "stabilised" back to the background rates with the installation of horizontal drainholes, 110 m long and spaced at 35-50 m apart.

Excavation continued leaving a 25 m wide berm but with a steeper lower slope of 42^o, thereby retaining the overall 37^o slope. Horizontal drainholes were then drilled at 30m vertical intervals. When the slope was approximately 120 m high horizontal movement rates again accelerated, with the development of reverse scarps along the foliation shears. At the top of the slope a large slump block dropped 600 mm, along a fault bounding the magnesite lens to the west. The toppling was bounded along the northern and southern extents by smaller slump scarps along the two joint sets shown on the Figure 3 stereonet.

Once again the ore at the base of the slope was fully extracted but only after close monitoring and careful retreat mining, restricted to daylight hours.

STABILITY ANALYSES AND COMPUTER MODELLING

During the previous owner's operations the analysis of the toppling failures was severely curtailed by budget restraints as the mine was in a closure phase. BFP Consultants Pty Ltd (BFP) carried out limiting equilibrium analyses, using their computer software version of the Hoek and Bray (1977) toppling analysis. The use of realistic variations of rock strength properties and structural configurations (block thickness) continually gave factors of safety greater than 1.0, which obviously was misleading due to the visual observations (see Figure 4).

For the current work BFP, M.A. Coulthard & Associates and ABM considered using either Itasca's FLAC or UDEC programmes to model the observed phenomena in North Pit. Due to the three dimensional nature of the topple (with the bounding slump features) and the discrete structural features along which the topples occurred, the decision was made to use UDEC. The intent was to initially use the 2-dimensional program leaving the option to change to the 3-dimensional version, if realistic calibrations to the observed conditions could not be met. As modelling progressed the 2-dimensional program proved to be very successful.

The program UDEC is a 2D distinct element code, designed to analyse the stress-strain behaviour of blocky rock masses. In addition to treating slip and separation along discontinuities within a rock mass and large relative displacements and rotations of blocks, UDEC also allows the block material to deform and yield. A range of standard constitutive models is provided – eg Mohr-Coulomb (M-C) and ubiquitous joint (ubi) – but these can also be modified using the in-built programming language FISH to represent more complex material behaviour. In this work, the underlying M-C and ubi models were modified so that the isotropic yielding behaviour stimulated a generalised Hoek-Brown yield criterion (Hoek, 1999). Values of GSI, UCS and m_i were estimated for each rock unit, as listed in Table 1, then the Hoek-Brown parameters $m_{b,}$ s and a computed.

TABLE 1
ROCK MATERIAL PARAMETERS FOR SECTION 9400 MODEL

								Ubiquitous Joints		
Unit (See Fig. 2)	**Model type**	**Density (kg/m^3)**	**E (Gpa)**	**Poisson's Ratio**	**GSI**	**UCS (Mpa)**	**m_1**	**Dip (degrees)**	**Shear Strength (kPa and degrees)**	**Tensile Strength (kPa)**
MXR	M-C	2850	32	0.24	70	125	20	-	-	-
Fault 1	Ubiq	2500	0.7	0.25	25	10	4	90	c = 6, ϕ = 26	8
OH	M-C	3350	2.9	0.25	30	87	15	-	-	-
OS	M-C	3350	1.7	0.25	15	20	15	-	-	-
MXC (c)	Ubiq	2830	5.2	0.26	50	25	8	75 (East)	c = 50, ϕ =26	3
MYF	Ubiq	2830	10.3	0.25	55	55	6	75 (East)	c = 20, ϕ =30	10
MXC(a)	Ubiq	2830	5.2	0.26	50	25	8	80 (West)	c = 50, ϕ =26	3
MXC(b)	Ubiq	2830	5.2	0.26	50	25	8	45 (West)	c = 50, ϕ = 26	3
Magnesite	M-C	3000	22	0.25	60	100	20	-	-	-
Clay	M-C	2000	0.01	0.40	10	10	5	-	-	-

The elastic parameters and ubiquitous joint strengths that were used in the final models are also given in Table 1. Groundwater pressures were computed for each stage of mining from estimated phreatic surfaces. These pressures were set in both the joints and in the block material, so full effective stress analyses could be performed.

Initially a section at N9250 was modelled because of the simplified geometry and the restriction to smaller upper slope planar failures and slump failures on the lower slopes. This section was used to evaluate the strength characteristics of the more competent medium strength mylonite unit in the middle of the slope. After successfully modelling the excavation, drainage and failure mode history of this section the material properties, refer to Table 1, were applied to the N9400 toppling section. Figure 5 shows a series of some of the excavation and groundwater sequences used in the model. All of the excavation, drainage and failure mode sequences were successfully modelled and showed very good correlation with ABM's experience at North pit and, in particular the surface prism results.

Figure 6 shows a magnification of the modelled toppling failure, which corresponds very well to the observations. Actual displacements were in the right order of magnitude but this is partly a function of the number of calculation steps allowed in the modelling process. Of more importance is the relative displacements between different areas of the slope which corresponded very well to the field observations.

PREDICTIVE MODELLING

Following the successful calibration of the model with past experience the UDEC model has now been used to predict the future behaviour of the western slope under the next two cutback scenarios. The model has indicated relationships between toppling behaviour, slope height, slope de-watering and the inclusion of

Figure 5 : UDEC Modelling

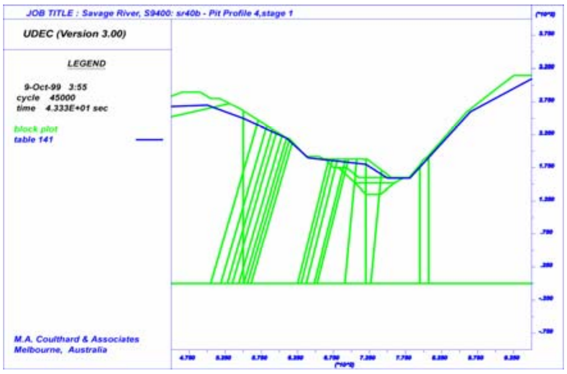

Figure 5a

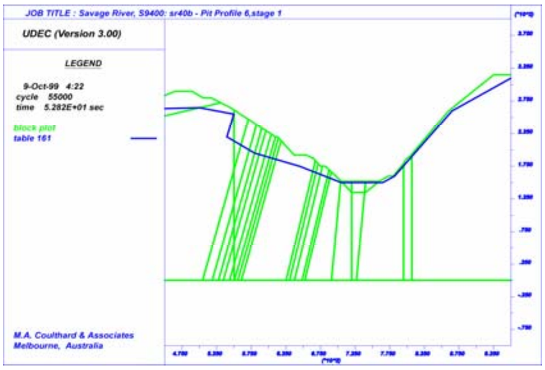

Figure 5c

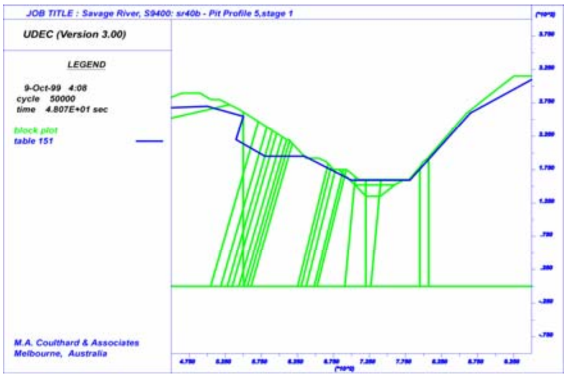

Figure 5b

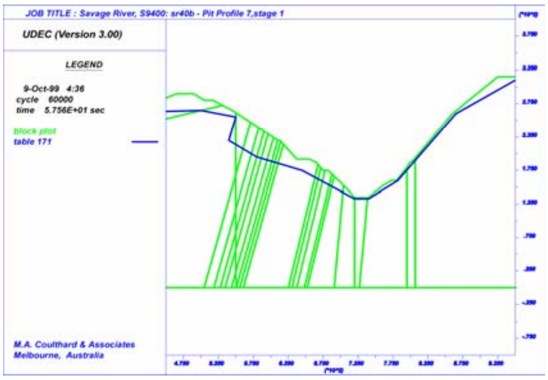

Figure 5d

mid-slope berms or ramps. The model has, for instance, indicated that permanent ramps can be removed with continued de-watering and the overall 37^{o} slopes achieved at the planned 160m slope height of the next cutbacks. The installation sequence of drainhole installation has also been evaluated and will greatly assist in mine planning and cost evaluation.

The next stage of the work will involve modelling of the Centre Pit failures and steeper overall slope angles. Of most interest will be the potential formation of deep seated failure planes which might lead to catastrophic slope failure, rather than the slow progressive toppling movements experienced to date.

SUMMARY

The Savage River Iron Ore Mine has a history of major toppling failures that have restricted overall slope angles to 37^{o} on many of the western walls of the various pit operations. Modelling of the historic excavation and drainage sequences utilising the UDEC computer programme has successfully replicated the observed toppling failure modes. The model has greatly assisted in mine planning and risk assessment to ensure that current mine plans are viable. Future modelling is intended to assess options for steepening of overall wall angles with the combination of de-watering and artificial ground support. It is hoped to reduce stripping ratios and hence mining costs without increasing the risk of slope failures and the safety of mine personnel.

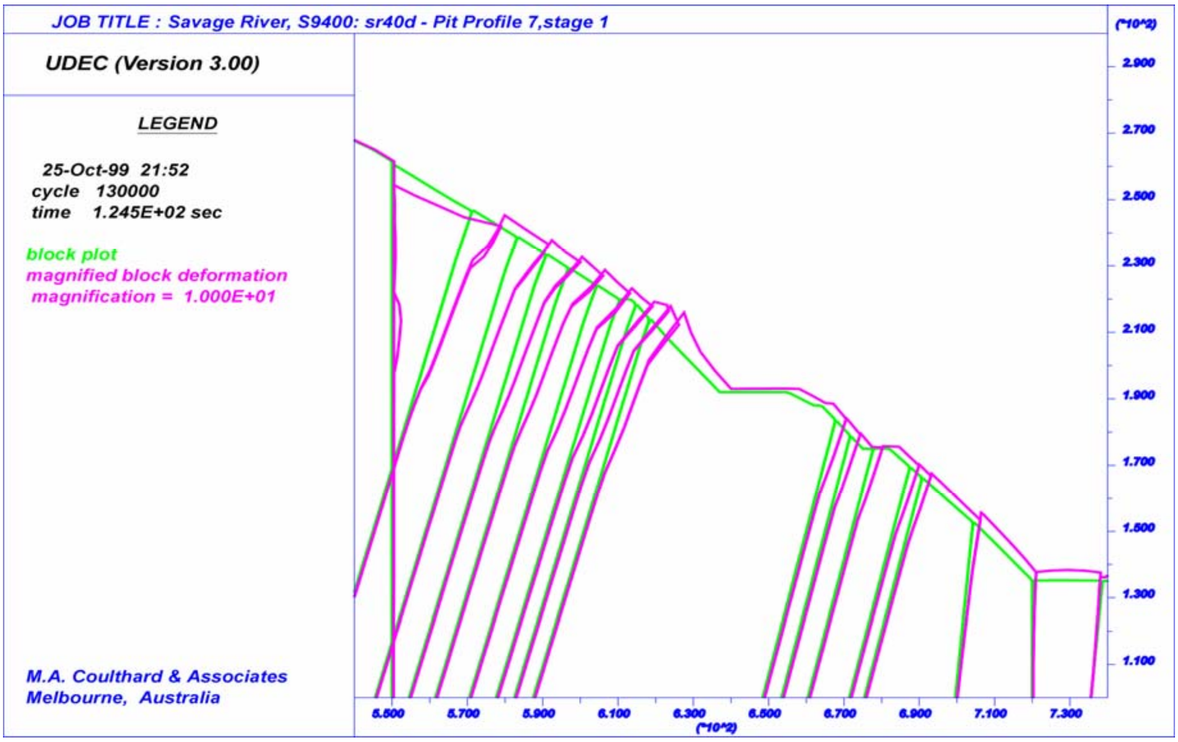

Figure 6 : N9400 UDEC Topple Mode

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