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Přírodovědecká fakulta
Ústav hydrogeologie, inženýrské geologie a užité geofyziky

MT OWEN LOW WALL FAILURE

Bakalářská práce

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Praha, červenec 2006

GEOTECHNIKA
SESUVY
SANACE
STABILITA
MONITORING
DŮL MT OWEN
AUSTRÁLIE

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Hana Šantrůčková

Praha, 4.7.2005

Abstract

MT OWEN LOW WALL FAILURE:

Mt Owen is an Open-cut mine located in the Hunter Valley in New South Wales, Australia. It is a successful open-cut operation with Thiess Pty Ltd as its contractors. In January 2005, geologists and geotechnical engineers from Mt Owen complex had to deal with a large low wall failure. The stabilising procedures were based on stability analysis results and extensive monitoring. Whole area was monitored by a Slope Stability Radar, which was installed due to the insufficiency of survey monitoring. This thesis is a case study, which solves stability issues, interprets monitoring data and describes post-failure remedial works.

SESUV VÝSYPKY V DOLE MT OWEN:

Povrchový důl Mt Owen leží v Hunter Valley v Novém jižním Walesu v Austrálii. Těžba je řízena společností Thiess Pty Ltd. V lednu roku 2005 se zde sesula velká část výsypky. Sanace sesuvu se opírala o analýzu stability a rozsáhlé monitorování oblasti. Poté, co se ukázalo geodetické monitorování za nedostačující, byl nainstalován radar zachycující pohyb svahu. Bakalářská práce je studií, která se zabývá sesuvem výsypky v dole Mt Owen. Řeší problémy stability, interpretuje data z monitorování a popisuje sanaci sesuvu.

CONTENT

My special thanks to David Mašín who helped me as my supervisor and Darren Pisters who helped me acquire the knowledge used in my thesis.

1. Introduction

The following thesis is based on my experience which I gained during a Full time Vacation Student Training Program with Thiess Pty Ltd. Thiess is Australia's largest mining contractor and is one of the leading integrated engineering, construction and mining services provider with 70 years of experience. It operates throughout Australia, South East Asia and the near Pacific, and employs more than 8,000 people (*www.thiess.com.au*). I was fortunate to be employed at Mt Owen mine located in the Hunter Coalfield (Figure 1) in New South Wales, Australia. Mt Owen is a highly successful open-cut mine operation with the production of 9 million tonnes of coal per annum (internal database, Mt Owen Complex, Thiess Pty Ltd). My duties at Mt Owen included providing assistance to the Mine Geologist Darren Pisters and developing a geology database. I also conducted research on a low wall failure which occurred at Mt Owen in January 2005. This has since become a major topic of my thesis.

The aim of my thesis was to do a case study of the low wall (landfill) slope failure which occurred in the B4 block.

Most of the used data and information were gained from personal communication with Darren Pisters and, as an employee of Thiess Pty Ltd, I had access to internal database of Mt Owen complex. This database has become my main information source. I was also provided with software used at Mt Owen which gave me the chance to interpret survey data, radar data and mainly do slope stability analysis. For survey and radar data interpretation I used Ground Probe Software (*www.groundprobe.com*), Vulcan and Excel, and for stability analysis I used Galena Software (*www.galenasoftware.com*). Thanks to this I was able to perform all stability analyses, and all monitoring interpretations contained in my thesis.

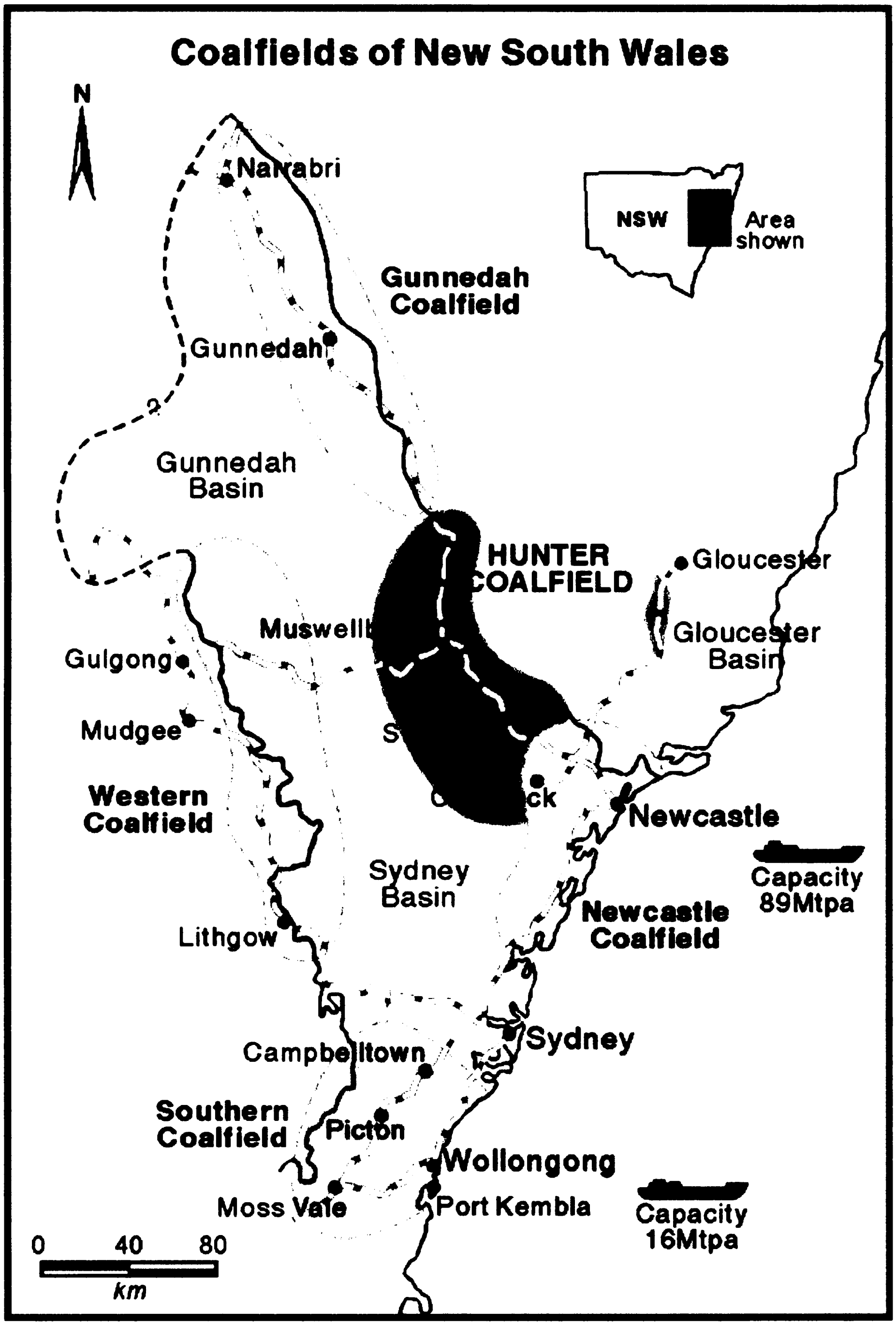


Figure 1: Hunter Coalfield, Mt Owen mine is located 20 km SW of Singleton (internal database)

2. Geology, Failure and triggering mechanism

2.1. General Geologic Setting of Mt Owen complex

Mt Owen complex is located in the Upper Hunter Valley within the western edge of Hunter Coalfield. It's part of the Permo-Triassic Sydney Basin, which covers an area of 49000 km^2 and is considered to be the major coal producing region in New South Wales (internal database). All coal seams at Sydney Basin are part of Permian Upper Coal Measure sequence and are covered by a Triassic sandstone layer. The thickest coal seams of Sydney Basin are within the Hunter coalfield and are incorporated in a so called Singleton Supergroup. Singleton Supergroup comprises Wittingham and Wollombi coal measures (Figure 2).

Neither of Wollombi Coal Measures or Upper Wittingham seams occurs in the vicinity of Mt Owen complex. This leaves Mt Owen mine with a part of Wittigham measures, which can be further divided into uppermost Jerrys Plains Subgroup and basal Vane Subgroup.The Vane Subgroup is undelayed by Mulbrig siltstone, and Archefield sandstone separates the two coal formations from each other.

Mt Owen complex has two active pits and two abandoned pits. Mt Owen Pit (sometimes also called North Pit) and West Pit (also known as Ravensworth Pit) are actively mined for coal, one abandoned pit is used as a tailings pit and the other one forms a dam. Mined coal is of Late Permian age.

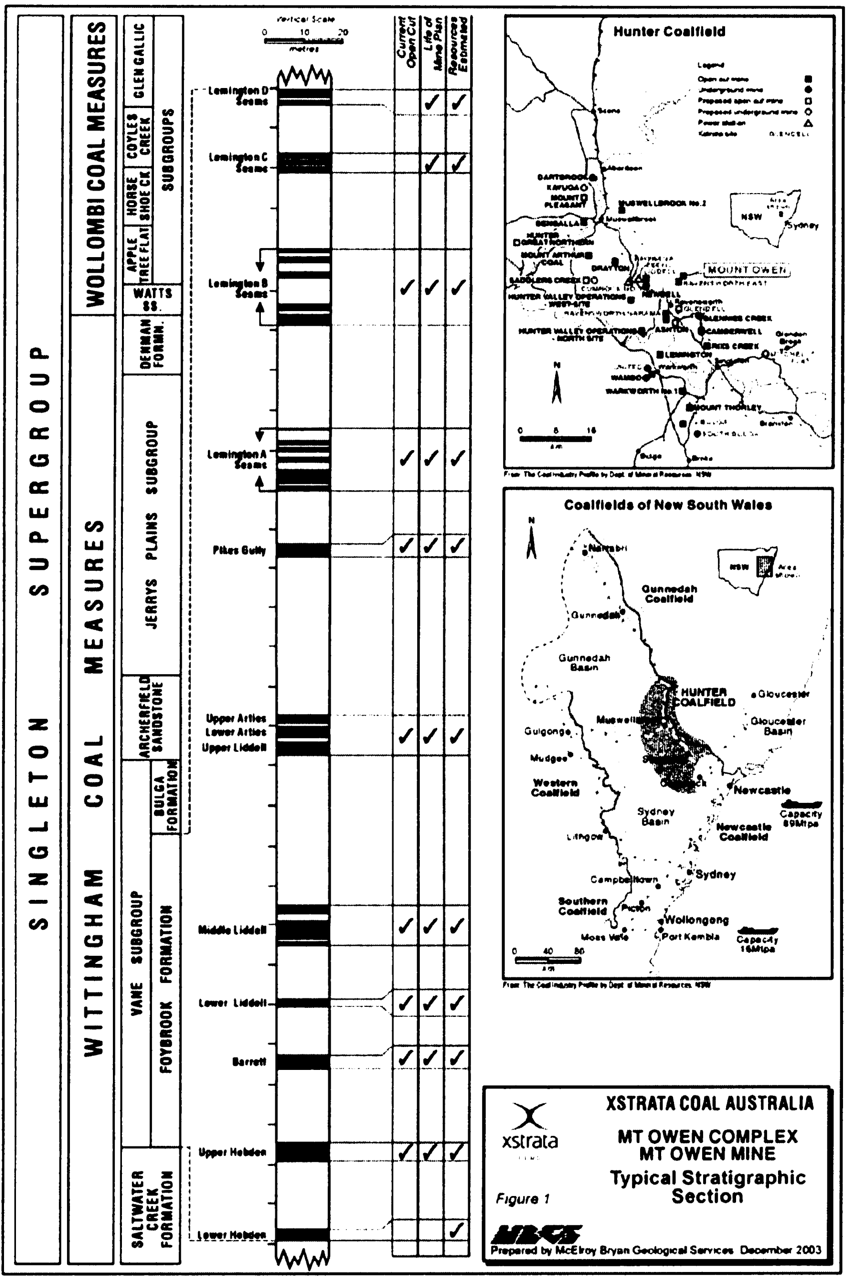


Figure 2: Coal seams within Singleton supergroup (internal database)

Structural features

Mt Owen is situated between two major faults, both trending in north-west direction- Hebden and Hunter Thrust (Figure 3). Couple of smaller faults can be recognised but are of a minor significance.

- Hunter Thrust: Mt. Owen is located south west of Hunter thrust. The plane of Hunter Thrust dips at approximately 30° to the northeast and elevates Carboniferous strata to the surface. Therefore Carboniferous strata lie at some places higher (closer to the surface) than Permian coal strata.

- Hebden Thrust: Hebden Thrust is a reverse fault, striking at approximately 130°. It's a low angle fault dipping at 22° to the northeast.

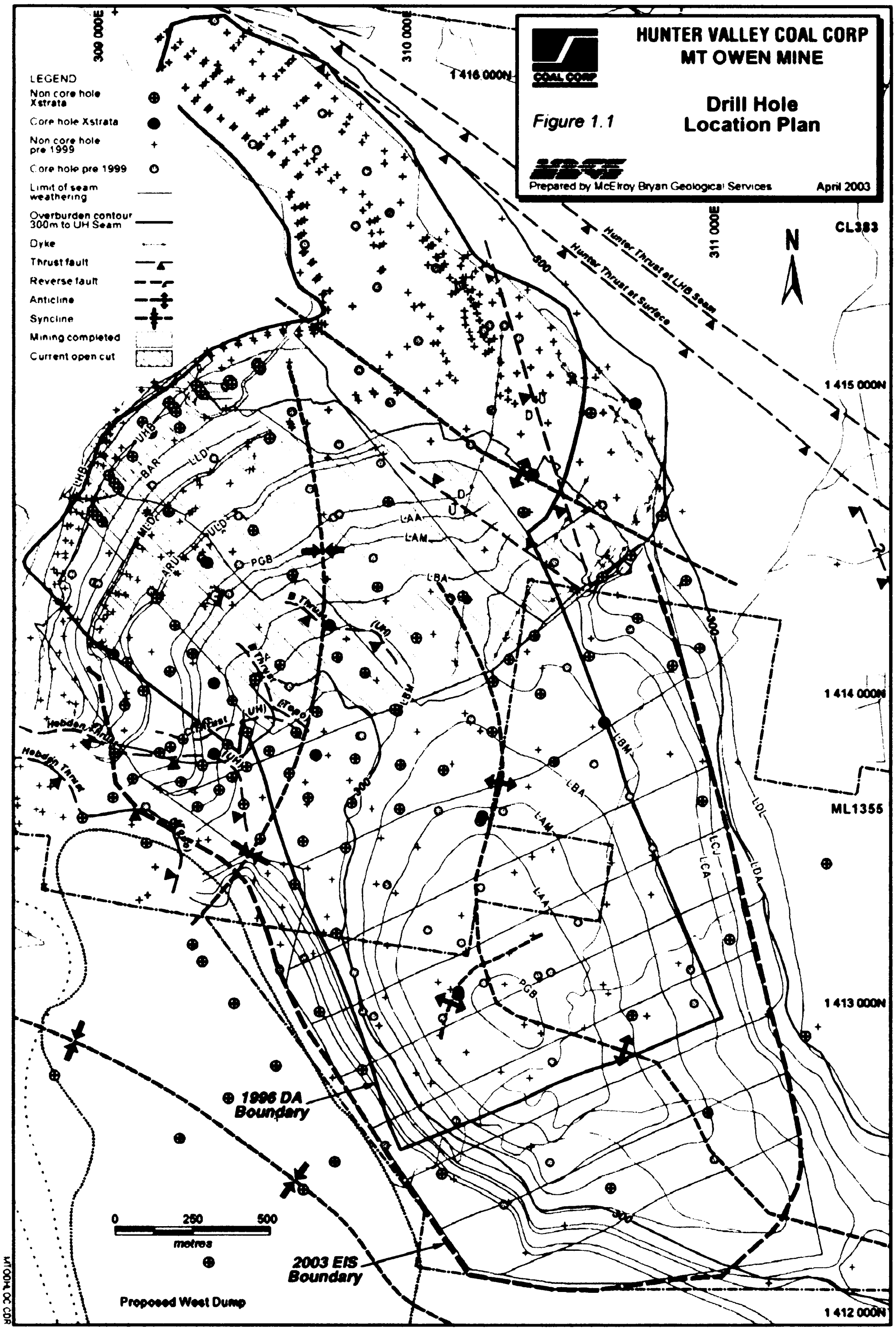


Figure 3: Hebden and Hunter Thrust, Mt Owen pit (internal database)

2.2. Geology of Mt Owen pit

Mt Owen Pit is considered as one of the biggest pits in Australia. It's intersected by number of coal seams of Vane Subgroup, which were formed in Late Permian age (Figure 4). The seam dip is very steep and because of numerous faults it can range from 10° to 45°. This steep angle makes the mining more difficult and so special approach has to be used.

Interseam sediments are mostly siltstone and lithic sandstone with sporadic claystone units.

Structural features:

- Hebden Thrust
- A, B, C Thrusts: These reverse faults influence the coal sequence and the stability of the North Pit (Figure 4).
- Dykes: There is number of volcanic dykes intersecting the pit. Dykes are predominantly made of Dolerite.

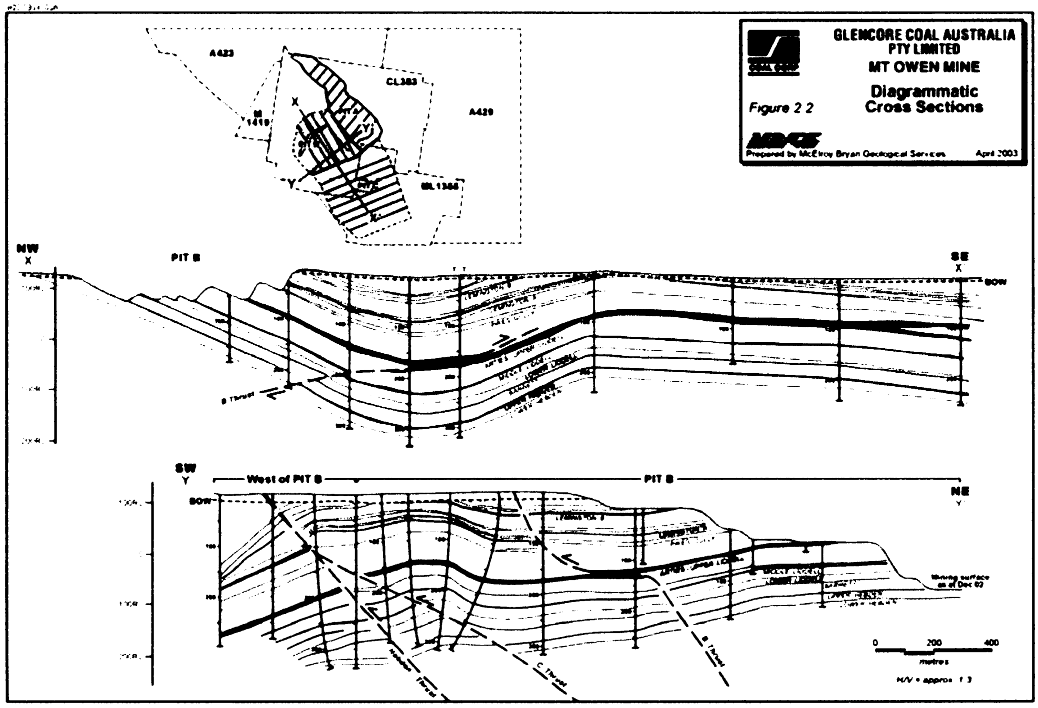


Figure 4: **Stuctural features of Mt. Owen Pit** (internal database, Mt Owen complex)

2.3. Geology of B4 low wall

Overburden is mainly composed of sandstones and siltstones. Underneath the overburden dump is *in situ* rock material which was once covered with an Upper Hebden Coal Seam. Beneath the rock material is a Lower Hebden coal seam, which lies in a 20m depth. All seams coincide in their inclination of 12° to14°. Two major discontinuities, dyke and a fault, appear in the B4 block and as later shown, both of them participate in the failure mechanism.

2.4 Failure

The B4 low wall failure occurred in the morning on the 29th of January 2005. The radar alarm went off and warned the personnel approximately 5 hours before the major failure. The B4 dump slipped 40 m into the pit and heave barrier rose up to 10 meters height.

<u>Triggering mechanism</u>

There are two major mechanisms to be considered as triggering mechanisms- blasting and water impact

Blasting

When blasted, a large amount of energy is released and hence the structural strength of rock can be reduced. Discontinuities can be opened up or new fractures and planes of weakness can be formed.

It is assumed that one of the triggering mechanisms of the B4 failure was blasting. This theory is supported by survey monitoring data, which show the increase of slope movements after two particular blast shots. First blast was done at the toe of the failure in late December and caused a slight increase of movement rate. The major second shot took place on January 14. Because it was an overburden blast, it was very strong and so a lot of energy was released. This caused extensive vibration and hence, the failure movement increased even more.

Water

In December and January high rainfalls occurred. In early January, the water level was measured to be 1 meter above the failure surface. This factor makes us consider a saturated failure surface, which together with blasting impact decreases the stability of the slope.

Failure mechanism

Slope geometry, material properties and major discontinuities have fundamental impact on the failure mechanism. A major issue is to recognize the most critical slip surface.

Slope material

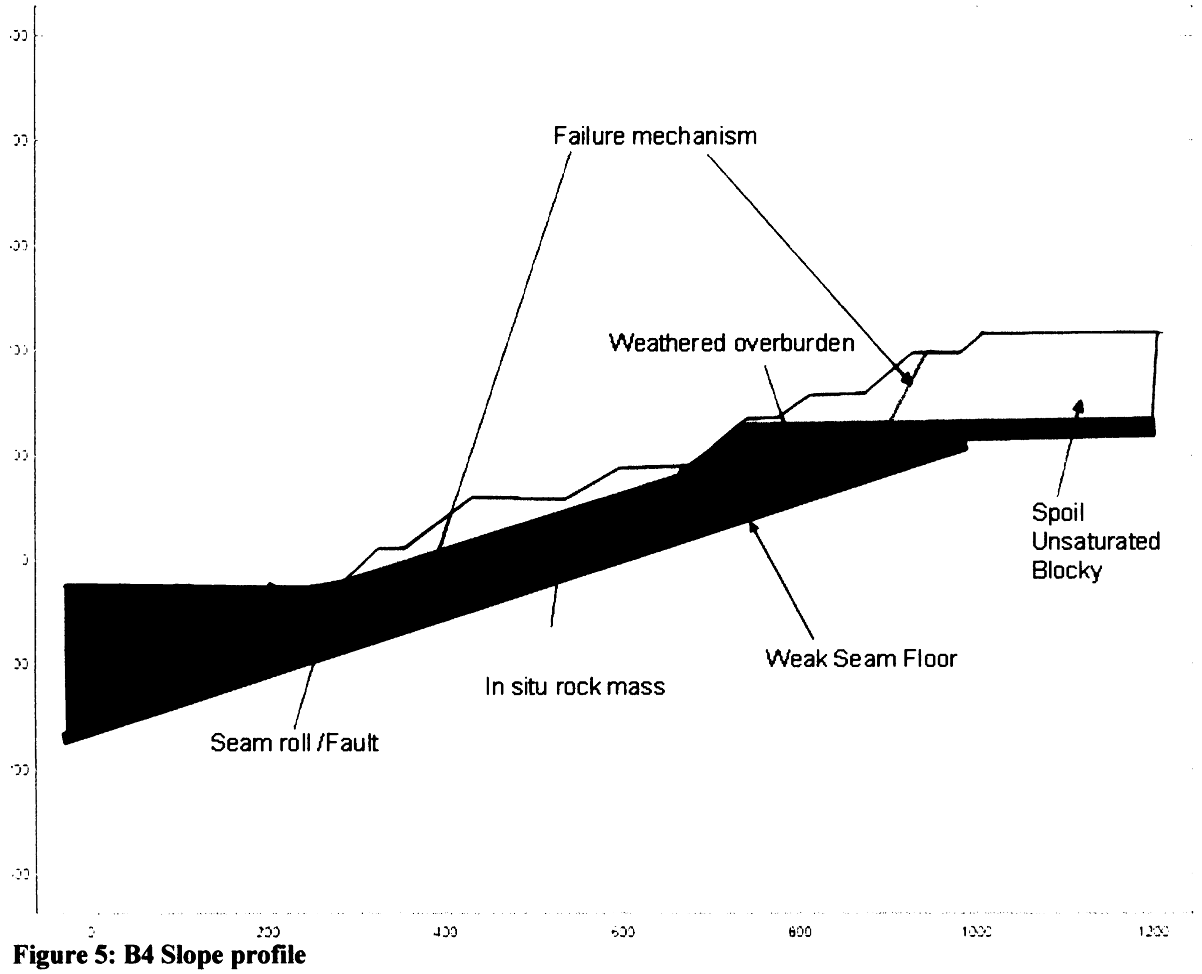


Figure 5: B4 Slope profile

- *Spoil Unsaturated Blocky*: The majority of the dumping spoil material consists of sandstones and siltstones.

- *In situ rock mass:* Consolidated siltstones and sandstones.

- *Seam roll/Fault*: The fault that causes a seam roll.

- *Weak Seam Floor:* Represents weak horizons somewhere within Lower Hebden coal seam or its surrounding, located 20 m below the slope surface. Weak clay horizons were found in this area and hence, it was assumed that partly sheared clay bands made the slip plane.

- *Weathered overburden*: Former surface lies at 125 meters above the reference level (RL). Rock material from125 metres above RL down to 110 metres above RL has "weaker" material properties due to weathering. Majority of the weathered rock are siltstones and sandstones.

Slope geometry

The B4 block is a low wall block with claystones and siltstones as its overburden. It was dumped at an overall angle of 15° (Figure 6). Interwall angles range from approximately 30° to 40°. Benches are close to horizontal and vary in their lengths.

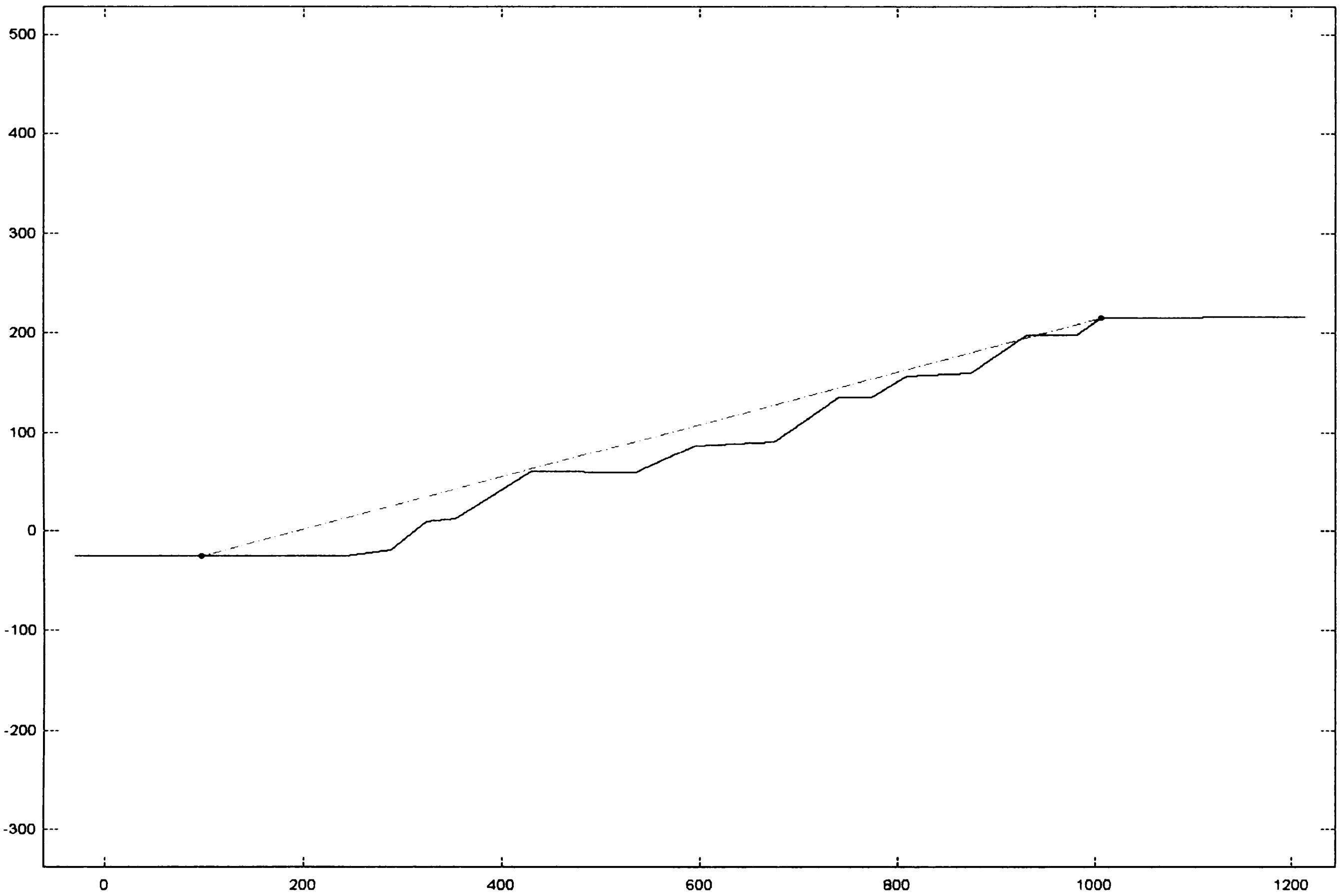


Figure 6: Overall angle of 15° (green dashed line), Interwall angles from the top: 37°, 35°,31°, 35°, 25°, 32°, 41°.

Discontinuities

Two major discontinuities were recognised in B4 block:

- Fault: North-westerly trending fault intersects the B4 block in its southern part (Figure 7). It dips towards the north-west at an angle of approximately 25 degrees and causes a seam roll. The fault comes up to the surface at a point where a low wall face meets with a pit floor.

- Dyke: A dolerite dyke is situated in the west flank of B4 block. It's 0.6 – 0.7m thick and is slightly weathered. It dips north-easterly at an angle of 80 degrees.

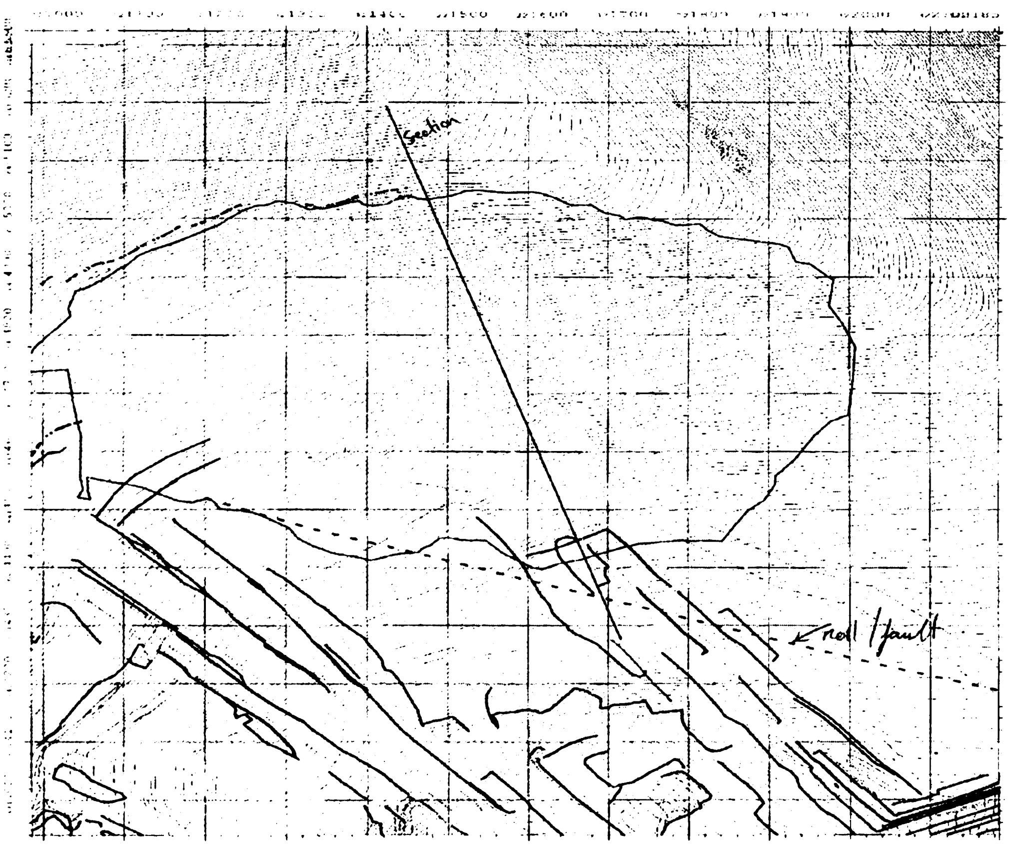


Figure 7: Fault (dashed line) and the potential B4 failure (contoured line)

3. Slope stability analysis

3.1. Sarma Method

Sarma method is a stability analysis method based on the principal of limiting equilibrium and the method of slices (Sarma, 1973). It calculates a seismic coefficient from an assumed value of Factor of safety (FS). Usually the value of FS is assumed to be 1 and the calculated seismic coefficient then represents a seismic coefficient required to cause sliding of a mass of soil bounded by a slip line and the free surface (Duncan and Wright, 2005). Effective stress strength parameters are used (Sarma, 1973).

3.2. Analysis of the low wall failure

Pre-failure stability analysis was done using strength properties listed in Table 1 and setting the water level to 1 meter above a slip surface. Running the stability analysis with Sarma Non-Vertical Slice Single Method calculated Factor of safety (FS) was 1.01 (Figure 8). This result was satisfactory because the tension cracks implied that the failure is imminent and so the FS close to one. This calculation was done without considering underground water flow or any other kind of disturbance and hence FS 1.01 had to be considered as the highest possibility.

After the failure occurred, slope geometry (Figure 9) was changed and strength of the slip surface decreased to residual strength. Running Sharma Non-Vertical Slice Single analysis, FS 1.11 was received.

Table 1: Material properties of slope material (values according to Darren Pisters, pers. com., Mt Owen)

Material	Prefailure		Postfailure	
	Cohesion [kPa]	Friction Angle [deg]	Cohesion [kPa]	Friction Angle [deg]
Spoil Unsaturated Blocky	30	28	30	28
In situ Rock Mass	200	45	200	45
Seam roll/Fault	30	22		
Weak Seam Floor	10	12.5	0	12.5
Weathered Overburden	5	17		
Remoulded rock-Breakout			0	12.5

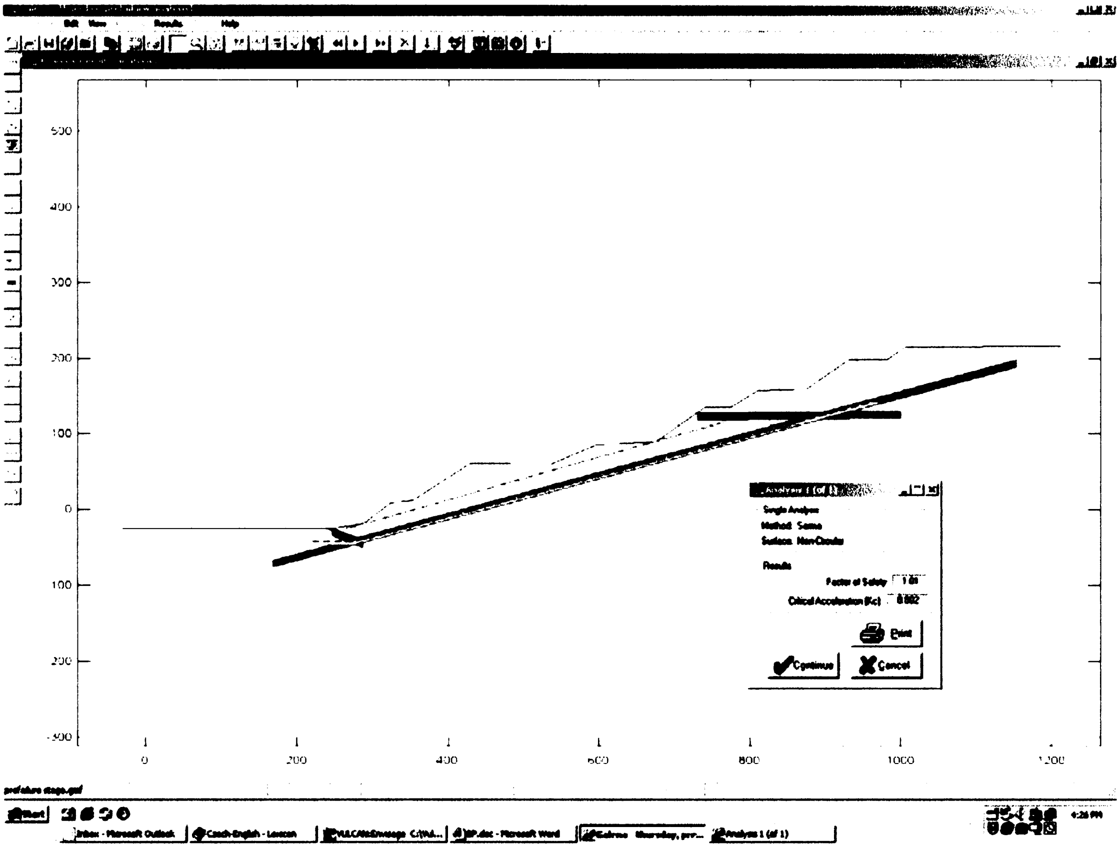


Figure 8: Pre-failure stability analysis plotted in Galena

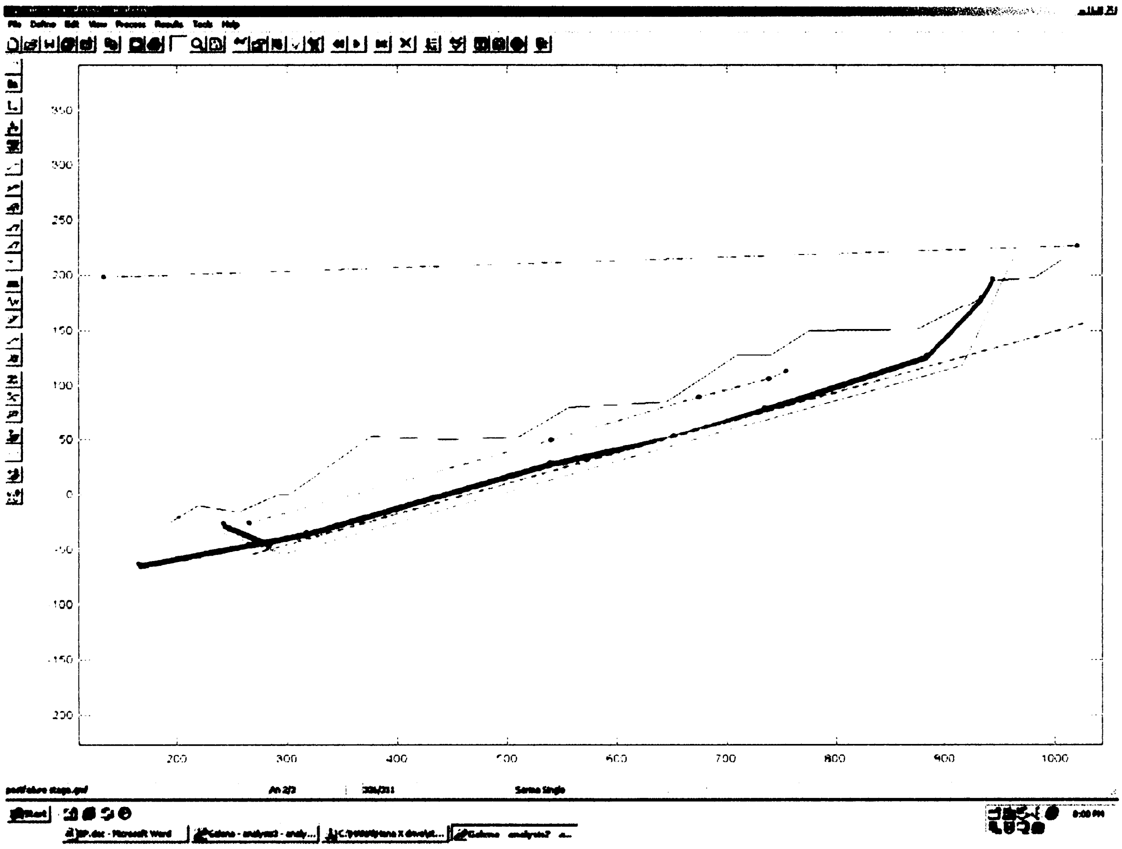


Figure 9: Post-failure stability analysis plotted in Galena

4. Monitoring

Peg monitoring

The width of a crack is a useful monitoring factor. It allows us to not only study the movement rate but also helps us to calculate the pressure produced by water in the cracks. A very simple system of placing two pegs on crack edges – each peg on one side of the crack- was used. The distance between the pegs was frequently measured and corresponded with the slope movement.

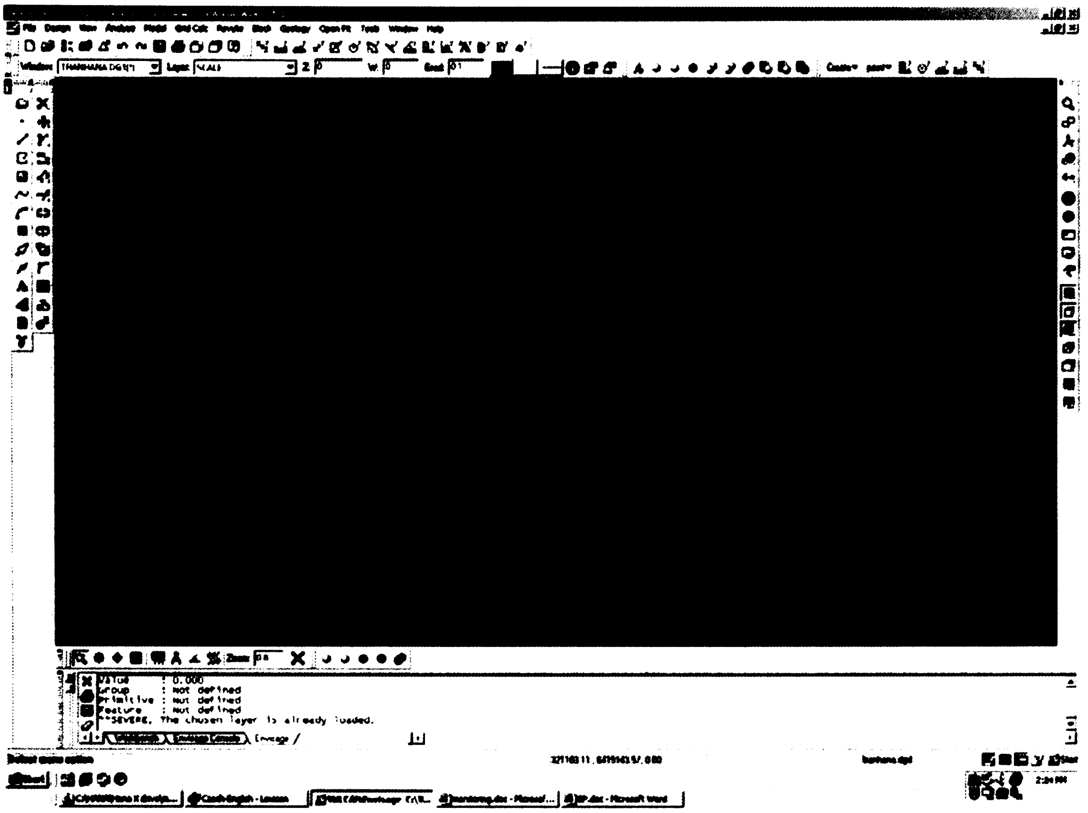
Water monitoring

In order to locate the underground water level, holes were drilled through the B4 block. Using piezometer the water table was detected 19 meters under the surface, which was one meter above the LHB coal seam.

Survey monitoring

Six major monitoring stations were created upon the B4 block. Even though the monitoring period differs for each of them, all except one record the period from 24.12 2004 up to the failure (29.1.2005). This is the most important period as the movement accelerated just around Christmas time.

To be able to predict the behaviour of a moving slope, we have to know the direction of major displacement and its velocity. Together with the knowledge of geology of particular area, we can make statements about the causes of certain behaviour and possibly predict the failure progress.



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Value     : 0.000
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Figure 10: Monitoring stations within the pre-failure area (vectors elongated twenty times their size). Dyke marked in green.

Knowing the survey data we are able to plot vectors, which inform us about the direction and the amount of displacement for each monitoring station at a certain time (Figure 10). Each monitoring station produced data for a different time period. Therefore comparing lengths of vectors in order to see which station moved the most can not be done.

It can be surprising that the failure wasn't sliding straight down dip. From looking at position of local discontinuities (Figure 10) it can be seen that the displacement vectors are parallel with a dolerite dyke intersecting the failure. Therefore it can be assumed that the failure mechanism was influenced by the dyke and the slope started to slide parallel to it.

Radar monitoring

Ground Probe Slope Stability Radar

Slope Stability Radar is capable of detecting rock movements and further data evaluation in order to set off an alarm. The radar can be set up to scan a particular area of which it takes photos every 2 hours and collects data every 2 minutes.

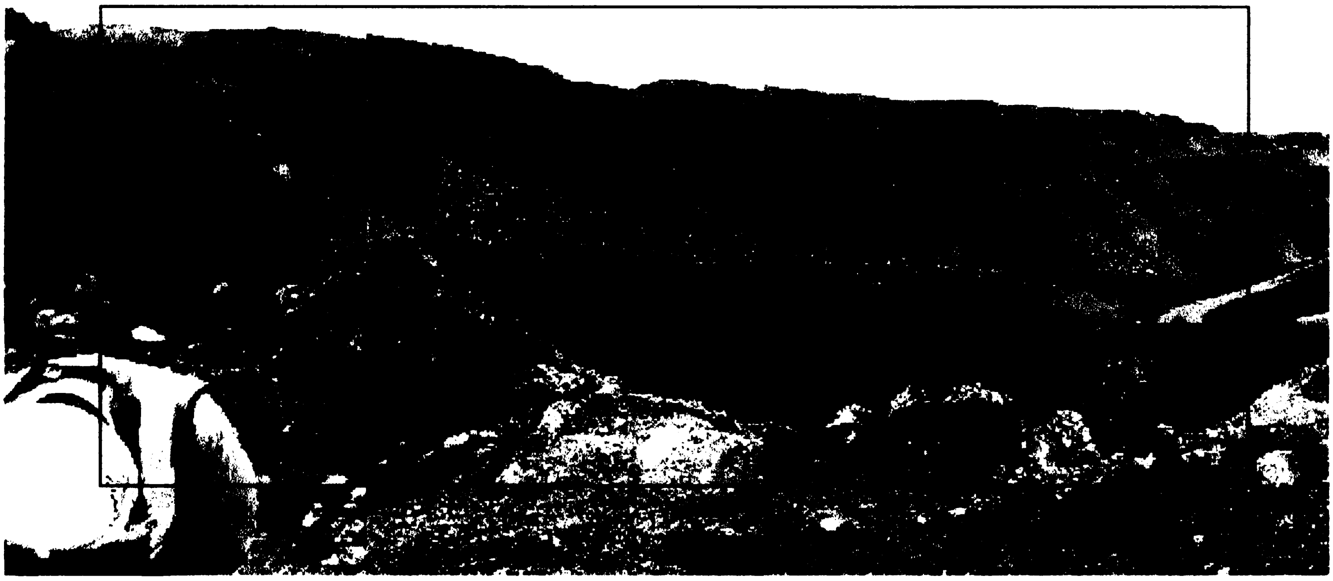


Figure 11: Scan set up

After detecting evident physical signs of instability in early January, Slope Stability Radar was installed. Some advantages of using radar include:

- Scans a wall 24 hours a day
- Monitors the whole area
- Easy access to the data
- Quick data evaluation

The rate and acceleration of slope movement is of the most interest as it makes it possible to predict the failure. A long-term movement trend of the B4 failure was 5 mm/hour. This is graphically shown in Figure 12, where the area moving 5 mm/hour is coloured in dark red.

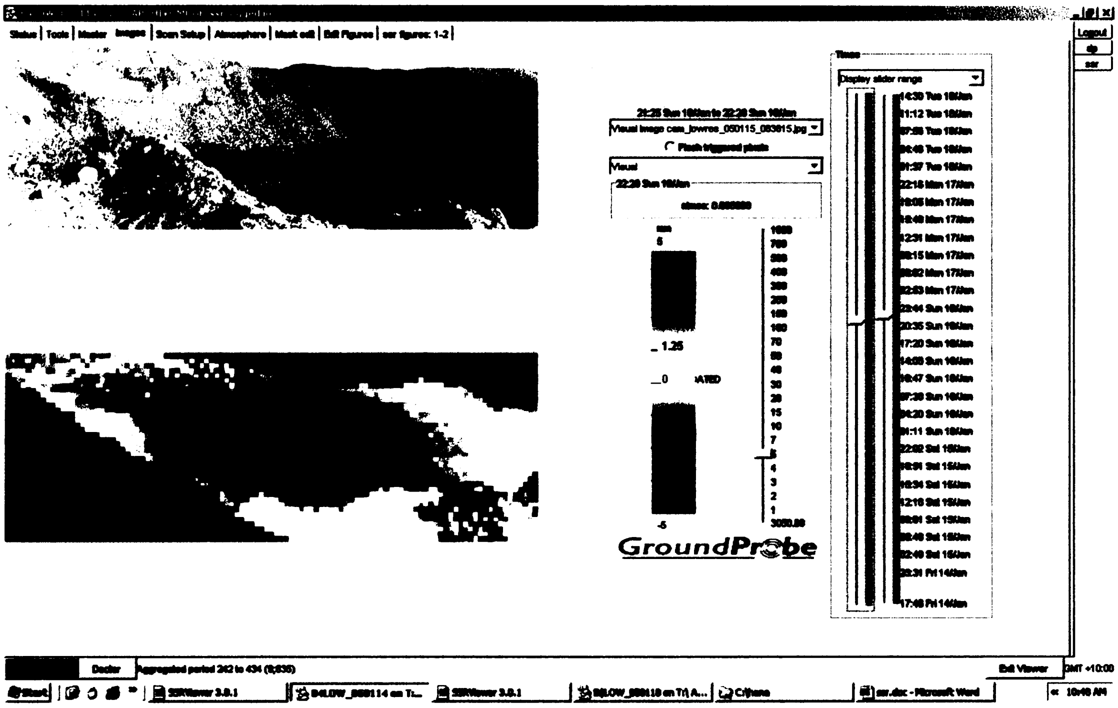


Figure 12: Displacement plot, Ground Probe Software

- **Coloured scale: Dark red marks movement of 5mm/hour (see scale)**
- **Date: 16.01.2005**
- **Shown time period: 9:25pm – 10:28pm**

Ground Probe software allows plotting monitored data into graphs, which demonstrate a relation between deformation (in mm) and time. This relation is shown for predetermined area, which is selected by plotting a rectangle at an area of interest (Figures 13, 14).

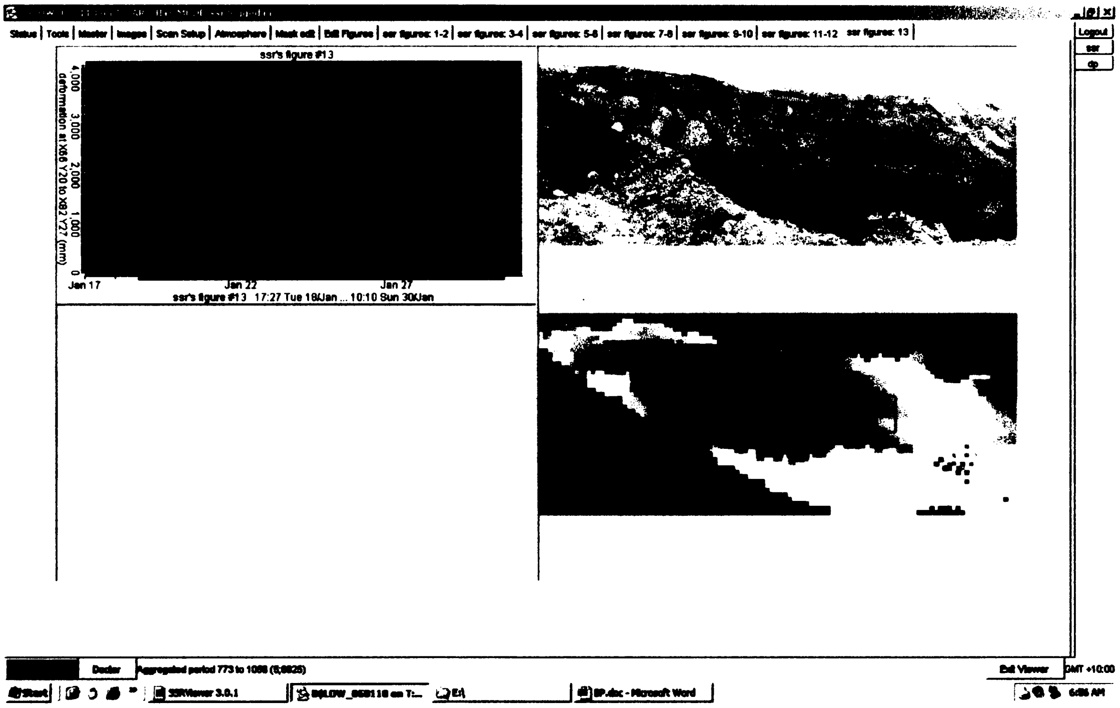


Figure 13: Visualisation of gradually increasing displacement, Ground Probe Software.

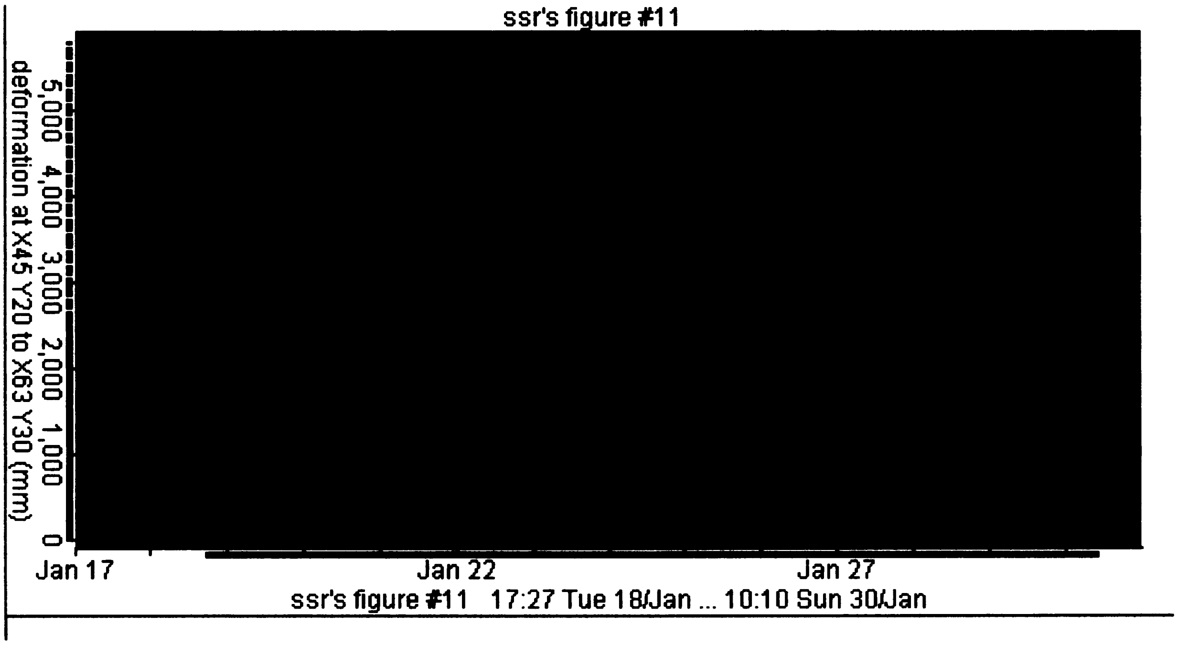


Figure 14: A relation between displacement (mm) and time of an area within the B4 block, Ground Probe Software.

As shown in Figure 14, the movement rate is gradually increasing. Acceleration was plotted for specific times on the 22nd, 25th and 27th of January. On the 22nd the measured rate value was approximately 4 mm/hour, on 25th 8 mm/hour and on 27th it was 15 mm/hour. Just before the failure, the acceleration was 114 mm/hour.

The critical slope movement acceleration was determined to be 70 mm/hour (Darren Pisters, pers. com., Mt Owen). This value was used as a trigger value to set off an alarm, which warned the personnel when a 1000 m² vast area started to move at 70 mm/hour velocity. This was about 5 hours before the failure, which occurred at 7:40 am on Saturday morning. The area was cleared soon enough to prevent any personnel injuries or damage to the equipment.

5. Stability measures, geotechnical issues in mining forward

Stability measures

It is very difficult to predict when an area is actually falling and when it just temporarily accelerated its movement. For this reason stability measures should be made as soon as there appear signs of increased movement even though it doesn't necessarily mean that a failure is coming up. This procedure is used for low walls in coal open cut mines where a slow low wall movement is considered as normal.

After detecting an increased movement of the B4 block, water level was measured. When realising that the potential slip plane was saturated with water, holes were drilled at the pit floor to release water from the Lower Hebden coal seam which formed a natural aquifer. Also in order to stop rain falls going down the crack, drainage was done at the top of the slope to steer the water away. This also prevented the water flowing down through the slope and mainly reduced pore pressure.

Post-failure remedial works

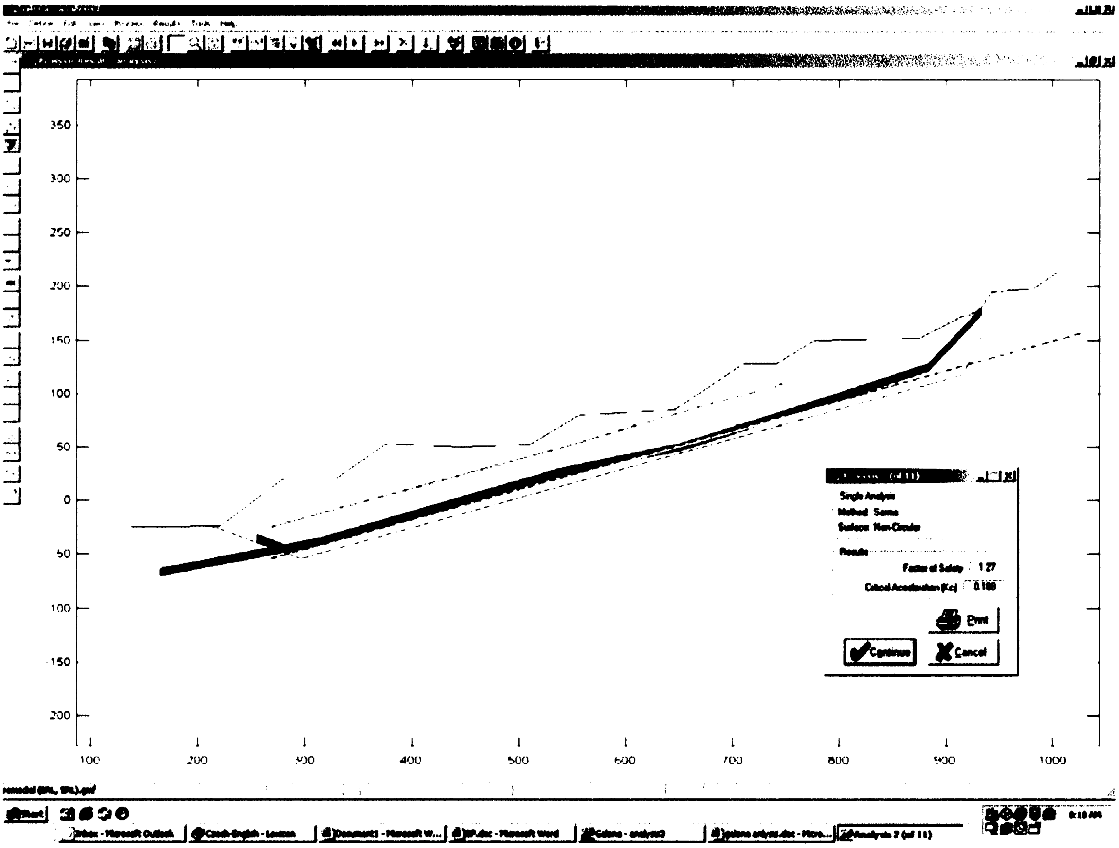
As can be seen from the post failure analysis, slipped area couldn't be considered as stabilised even after it failed to its post-failure position. The aim was to build up the FS up to 1.2. The difficult part was in making the slope stable and not burying too much coal while doing that. At Mt Owen it was even harder due to the position into which the failure slipped. The failed overburden buried part of the Upper Hebden seam which was to be mined. That made the remedial work even more complicated because there had to be thought of further geotechnical issues in mining forward.

To increase the stability, the following methods were used:

- Buttressing
- New access to the dump so it wouldn't go through the failure zone
- Sealing off the cracks to prevent further water ingress

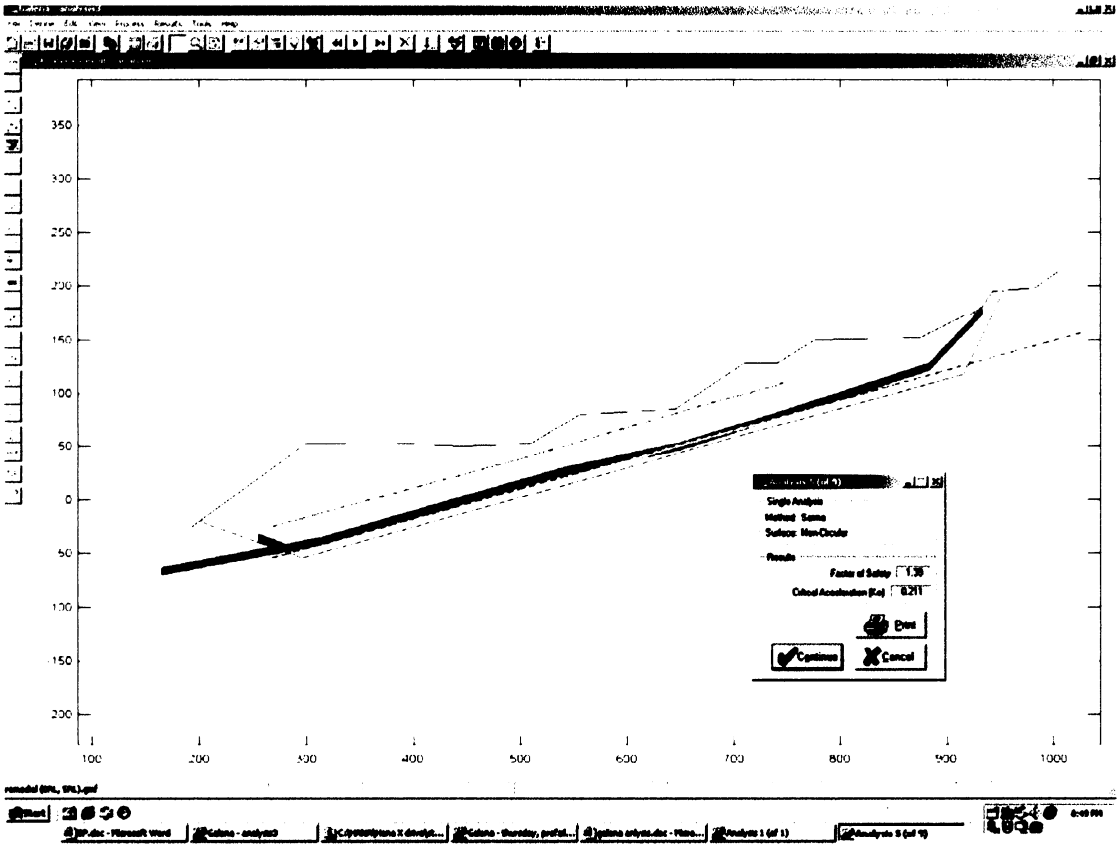
Buttressing

The basic idea of stabilising the slope consisted in buttressing the toe of the failure. Figures below show different stages and possibilities how it could have been done with corresponding FS.



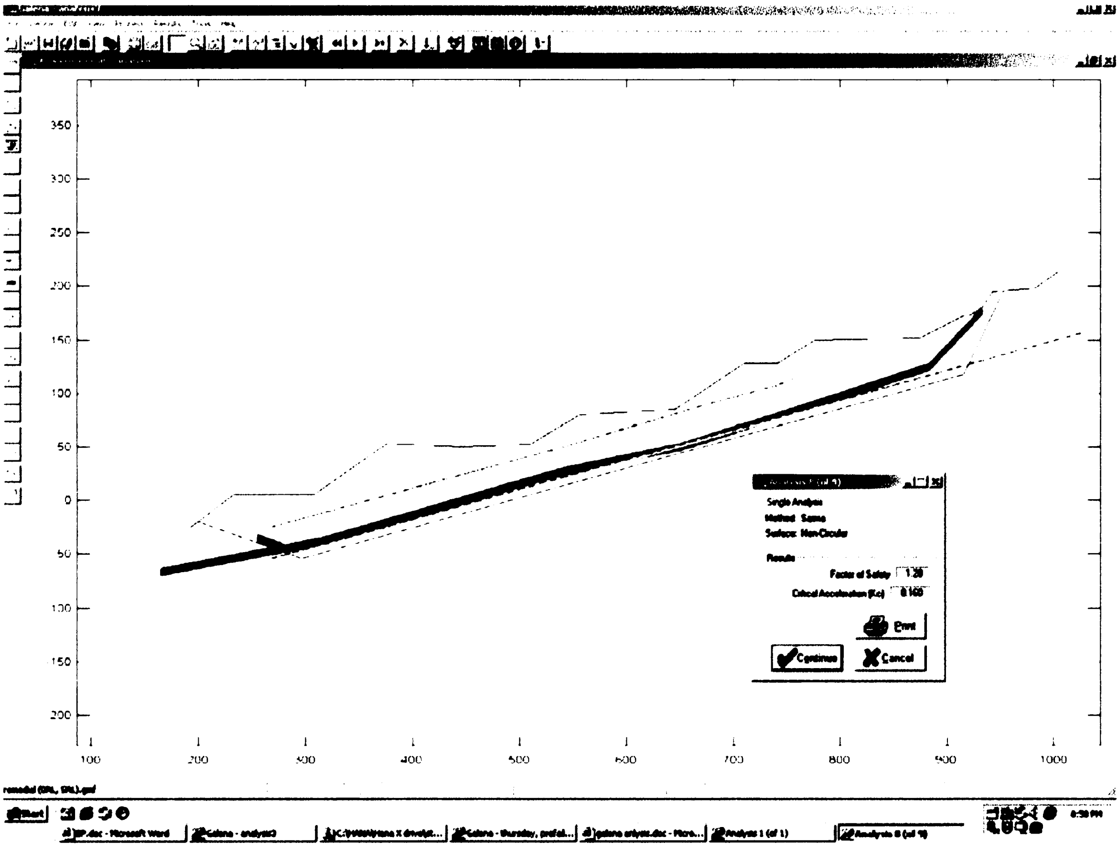
Single Analysis
Method: Sarma
Surface: Non-Circular
Results
Factor of Safety 1.27
Critical Acceleration (Kc) 0.188

Figure 15: 50 metres long buttress pilled up to 20 RL. FS 1.27



Single Analysis
Method: Sarma
Surface: Non-Circular
Results
Factor of Safety 1.38
Critical Acceleration (Kc) 0.211

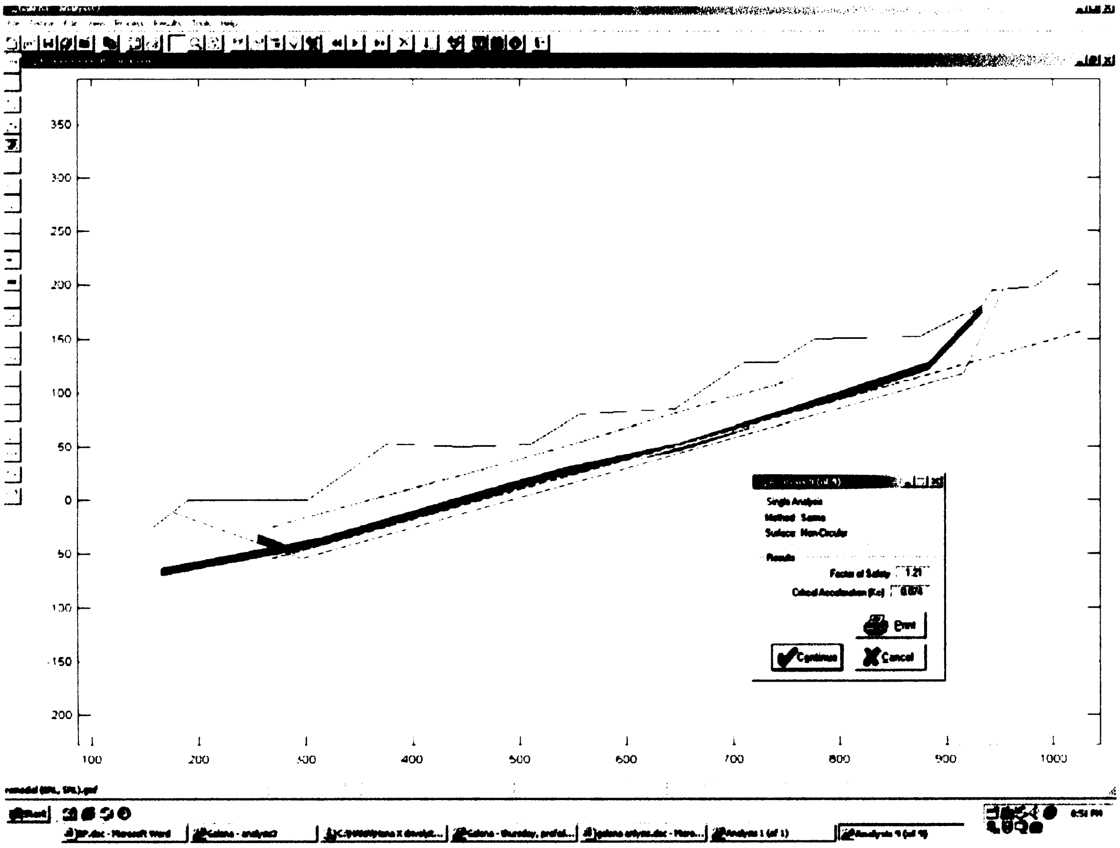
Figure 16: Material pilled up to 52 RL; FS 1.38



Single Analysis
Method: Sarma
Surface: Non-Circular

Results
Factor of Safety 1.28
Critical Acceleration (Kc) 0.100

Figure 17: 70m long buttress pilled up to 5 RL, FS 1.28



Single Analysis
Method: Sarma
Surface: Non-Circular

Results
Factor of Safety 1.21
Critical Acceleration (Kc) 0.076

Figure 18: 210m long buttress pilled up to 0RL; FS 1.21

The buttressing could have been done either by piling waste material to higher RL (Figure 15) or by extending the buttress to a vast area but lower RL (Figure 17). Even though each of these possibilities gives a satisfying FS for the B4 post failure, there is a very important issue that must not be neglected. While trying to stabilise the first failure by field works, new instabilities can occur due to changing of slope geometry. That's why before stockpiling large amount of material, it is essential to examine the potential situation and search for potential instabilities. This was done for the B4 buttressing. Looking at the stability of buttresses alone it was discovered that if a waste material was pilled up to a high RL, a new failure mechanism could develop. That's why in the end a buttress pilled up to 5 RL (Figure 17) was chosen as a satisfying one for it didn't initiate a new failure.

Geotechnical issues in mining forward

3 options to address the issue

- Step up to Barret Seam
- Mine down to Upper Hebden seam in small slots
- Upper Hebden seam blasting before mining forward

Due to financial reasons, an effort was made to be able to mine buried coal of the Upper Hebden coal seam. All possibilities were thoroughly examined. In theoretical point of view it was possible to mine forward thanks to blasting stabilisation but there was a high level of uncertainty due to unknown strength parameters after blasting and impact of blasting on a low wall slope. Proceeding in small slots proved to be a method for recovering the most coal with the highest FS. Local instabilities within small slots were not excluded but this problem was considered as manageable with stability radar.

Proceeding in small slots was based on excavating small slots of the buttress and backfilling them straight after coal extraction. Opening and backfilling should be done in a very short time so the buttress wasn't "unsupported" for too long. To raise the FS while extracting a slot, two 25 m wide *in situ* pillars were placed on each end of buttress. This made the buttress supported from each side by the dump material, which significantly raised the FS.

6. Conclusion

Low wall failures are quite frequent in open-cut mine operations. This summarised case study shows how Australian mining industry generally deals with failures such as Mt Owen B4 low wall failure. Analysis and data interpretation shown, correspond with the real situation. This suggests that the used methods give valuable results which can be applied in geotechnical practice for prevention and/or prediction of low wall failure events.

7. References

Duncan, J. M., and Wright, S. G. (2005), Soil Strength and Slope Stability, John Wiley&Sous, New Jersey, 297 pages

Internal database, Mt Owen complex, Thiess Pty Ltd

Sarma, S. K. (1973) Stability analysis of embankments and slopes. Géotechnique 23, No. 3, 423-433

8 Appendix

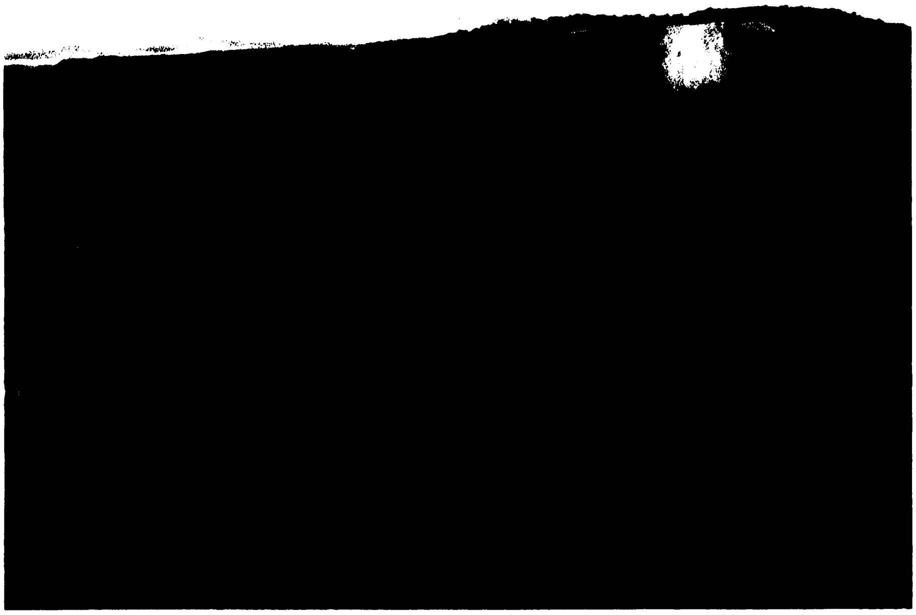


Photo 1: B4 low wall

Photo 2: Contoured B4 low wall failure

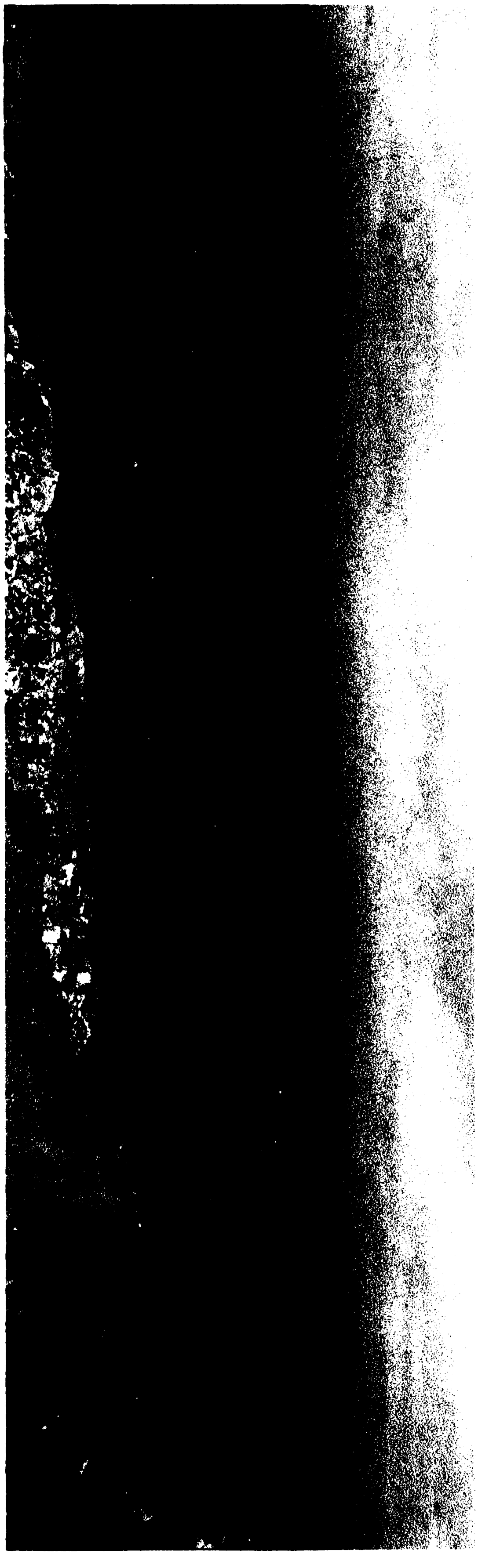


Photo 3: Mt Owen mine