GEOTECHNICAL CONSULTING SERVICES

MILLENNIUM MINE

RESIDUAL VOID SLOPE STABILITY STUDY

For

MILLENNIUM COAL PTY LTD

Report No. 170
August 2017

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Geotechnical Consulting Services Pty Ltd | Barry Ward
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1. INTRODUCTION

Mining commenced at the Millennium Mine complex in 2005, with a current projected finish to opencut truck and shovel mining in late 2018, after which it is proposed to conduct highwall scavenging using highwall augering or highwall mining methods.

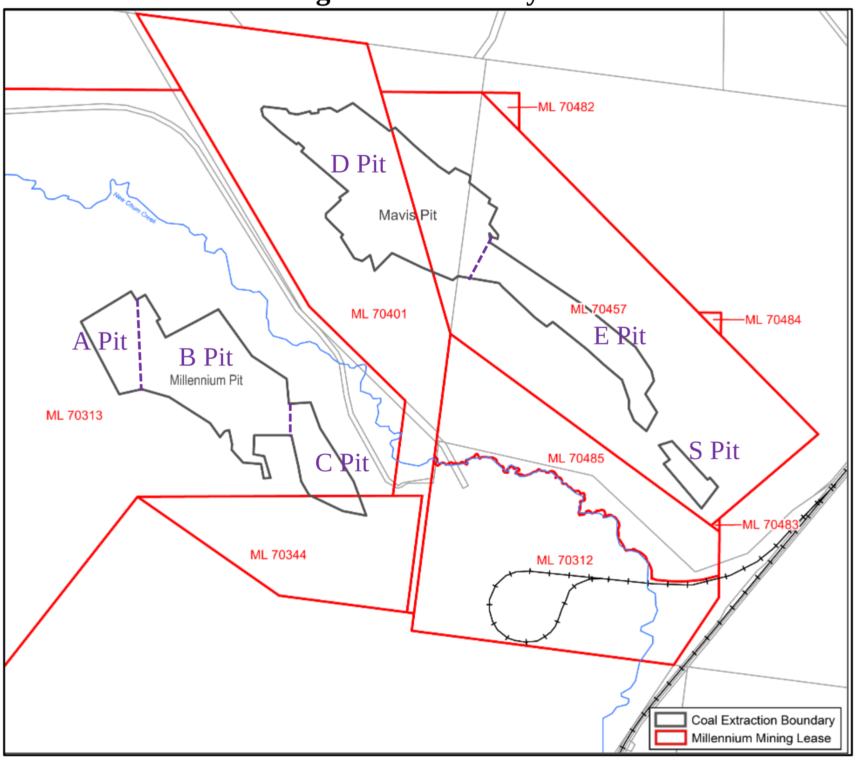
Under the conditions of Environmental Authority Permit No.EPML00819213, Clause F7 (d), a pit wall stability study must be undertaken with proposals for meeting the residual void design. A geotechnical site inspection was accordingly undertaken during the period 8 to 12 May 2017 to assess the stability of the pit walls and dumps with respect to final void conditions.

This report presents an assessment of the geotechnical stability of highwall and low wall slopes and provides an indication of the remedial measures needed to achieve geotechnical stability. It is based on the site inspection, discussions on site and slope stability calculations where appropriate.

2. MINE LAYOUT

Figure 1 shows the general layout of the Millennium Mine complex, with mining leases and opencut pit areas. The mine site comprises two opencut mining areas, Millennium Pit and Mavis Pit, which are separated by a major fault system. Mining is by truck and shovel in both cases. New Chum Creek runs between the two mining areas.

Figure 1: Mine Layout



Millennium Pit was originally developed as three conjoined pits, A Pit, B Pit and C Pit, the mining areas being separated by major fault systems. B Pit and C Pit have been mined out with current mining confined to A Pit. Mining is on a block basis against advancing highwalls on two sides with an advancing in-pit spoil dump on the south-east side.

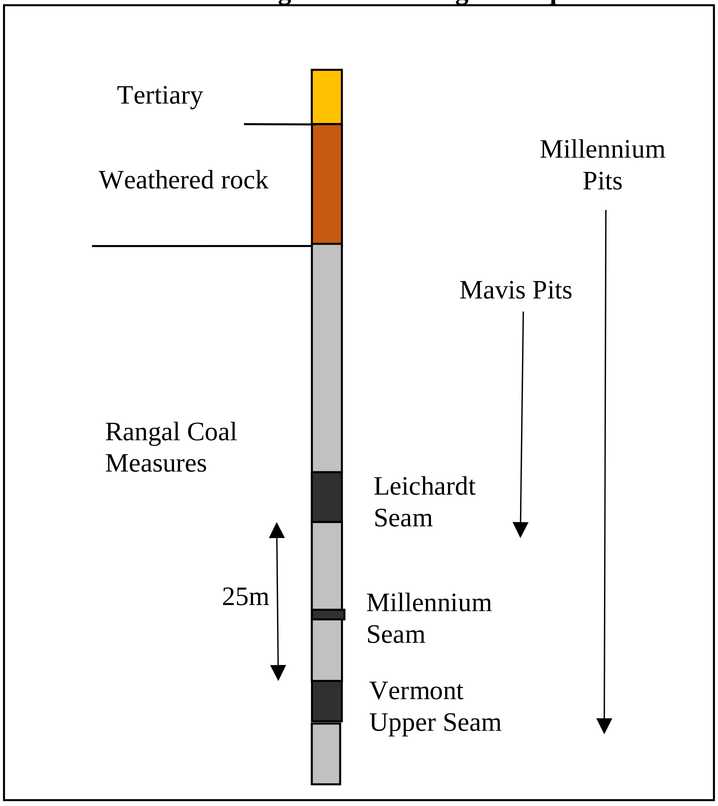
Mavis Pit comprises the conjoined D Pit and E Pit, with the small S Pit at the southern end of the strip, now combined with E Pit. Mining is in down-dip strips with a highwall advancing towards the north-east and with spoil dumping on the low wall side and externally out-of-pit. S Pit was excavated as a boxcut which was then used for water storage between 2013 and 2017. It has since been dewatered with another two strips currently being excavated. Opencut mining has ceased in E Pit, except for the southern end which is being linked up to S pit. D Pit has reached its down-dip limit but there is a possibility of extending the pit to the north depending on arrangements with the adjacent leaseholder (Carborough Downs Mine).

Highwall augering has been undertaken at Millennium Mine on three occasions in 2008, 2011 and 2015/6, and is currently underway in D/E Pits. Further augering or highwall mining is under consideration for remaining exposed highwalls in both Millennium and Mavis Pits as a post opencut mining operation.

3. GEOLOGY

Millennium coal mine is situated in the Rangal Coal Measures in the northern part of the Bowen basin. A generalised succession of strata is illustrated in Figure 2 below.

Figure 2: Lithological Sequence



The main units forming the overburden are:

Tertiary/residual soil:	mostly sand and silt, with some clay
Weathered rock:	weak to moderately strong brown sandstone, siltstone
Coal Measures:	moderately strong to strong grey siltstone and sandstone

The sandy superficial deposits are generally between 2m and 10m thick, beneath which is weathered rock to a depth (base of weathering) of between 20m and 30m. These layers are generally mined as free-dig benches.

Fresh rock comprises thinly interbedded sandstone and siltstone typical of Rangal coal measures overburden. The main overburden down to the Leichardt Seam contains thicker beds of stronger sandstone, with finer grained laminite forming the interburden between the seams. The rock overburden is up to 70m in the highwalls.

The main target seam for both mining areas is the Leichardt Seam, which is typically about 4.5m thick. The 2.0m thick Vermont Upper Seam occurs 20m to 30m below the Leichardt Seam and is mined in Millennium Pit only. The lesser 0.7m thick Millennium Seam, which occurs at a variable location within the interburden, is also a possible target seam but is not normally taken during mining operations.

The seams generally dip at less than 10^0 (between 3^0 and 10^0) within the pits in a direction generally between south-west and north-northwest but the strata are interrupted by large scale reverse faults with local steepening of the dip. The main structural disturbance at Millennium is the A/B Fault which runs NNW-SSE and separates A Pit from B Pit. This fault dips at between 25^0 and 35^0 to the west and has a vertical displacement of about 80m. There are however numerous lesser faults at various orientations.

Mavis Pit is highly disturbed with a number of major faults intersecting the highwalls plus strike faults along the pit. Local steepening of the pit floor in association of these faults is not uncommon.

The groundwater table varies from 17m to 54m below ground level, with an average depth of 32m for the mining areas.

4. SLOPE DESIGN

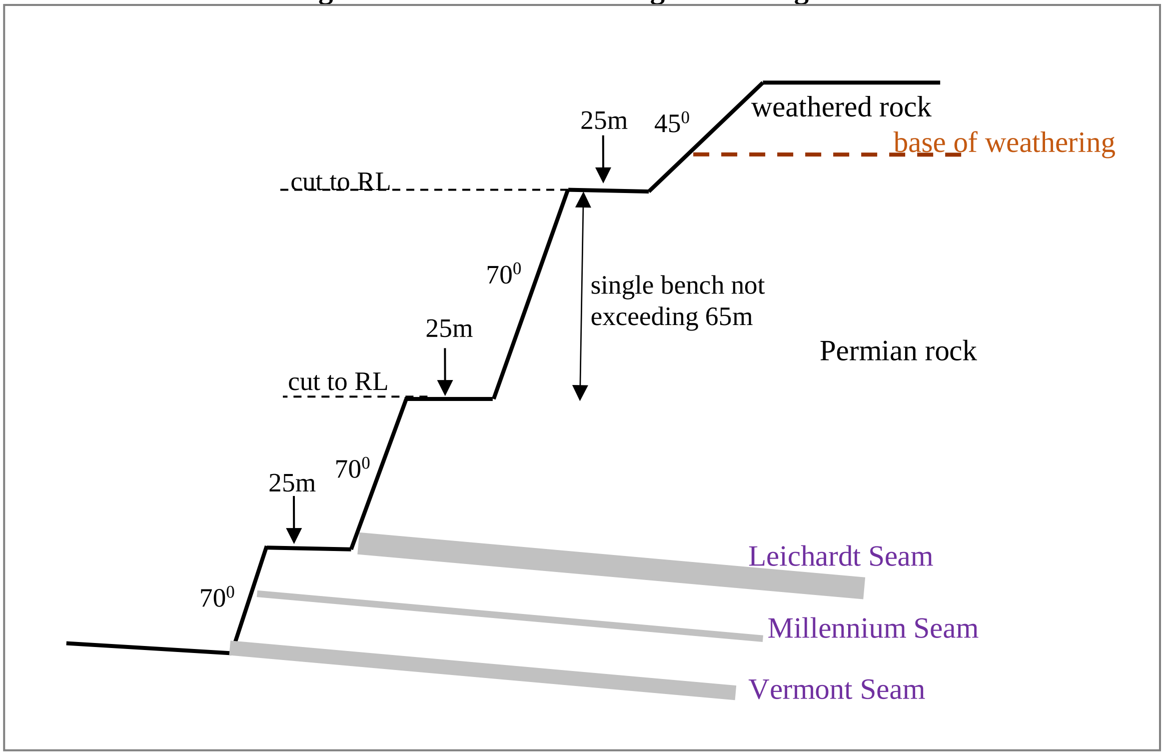
4.1 Highwalls and Endwalls

The standard slope design for insitu walls is illustrated in Figure 3 below. The main points are:

- Berms are designed to RL to ensure consistent drilling horizons, unless following a floor of coal;
- Batter angle in the superficials/weathered rock is 45^0;
- Rock benches are pre-split at 70^0;
- The maximum bench height in rock is 65m;

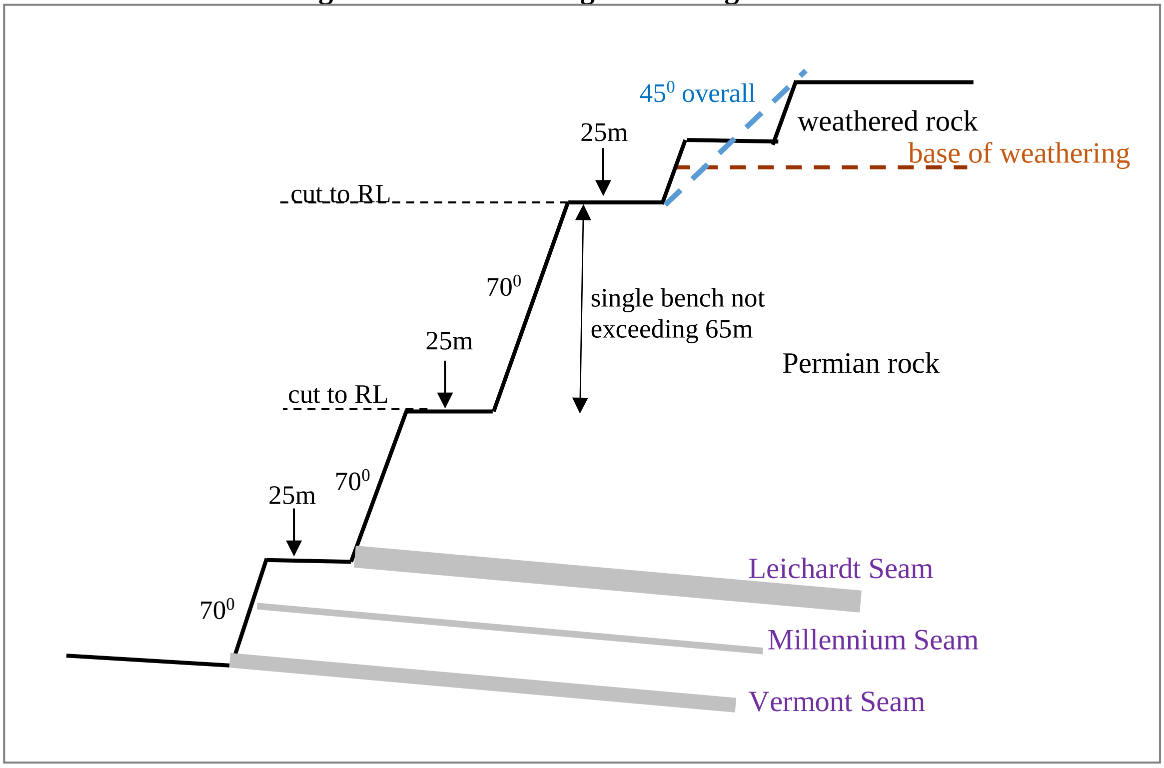
This design is used for all insitu side wall slopes in normal conditions; modifications may be made for local situations where fault zones intersecting the walls and could create conditions of instability.

Figure 3: Millennium Pit Highwall Design



A 'rough-cut' design variation is used in Mavis Pits where the soft overburden is dug by excavator. In this case the top bench through softer ground (soil/Tertiary/weathered Permian) is excavated as two individual benches cut to suit the excavator swing, with a berm of suitable width to ensure the overall slope angle of both benches does not exceed 45^0. This variation is shown in Figure 4 below.

Figure 4: Mavis Pit Highwall Design



The photo below shows a typical highwall representation.

E Pit Highwall

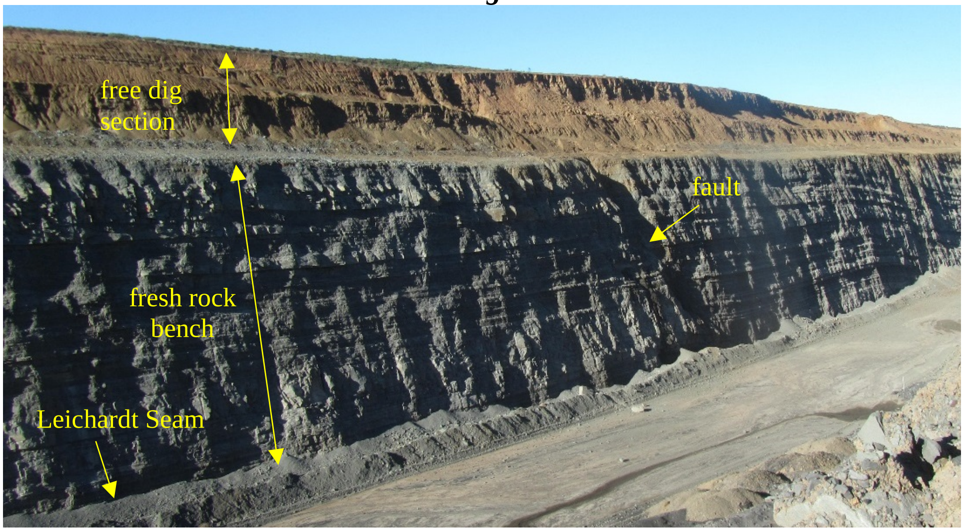


Photo taken 28/06/2016, looking ENE

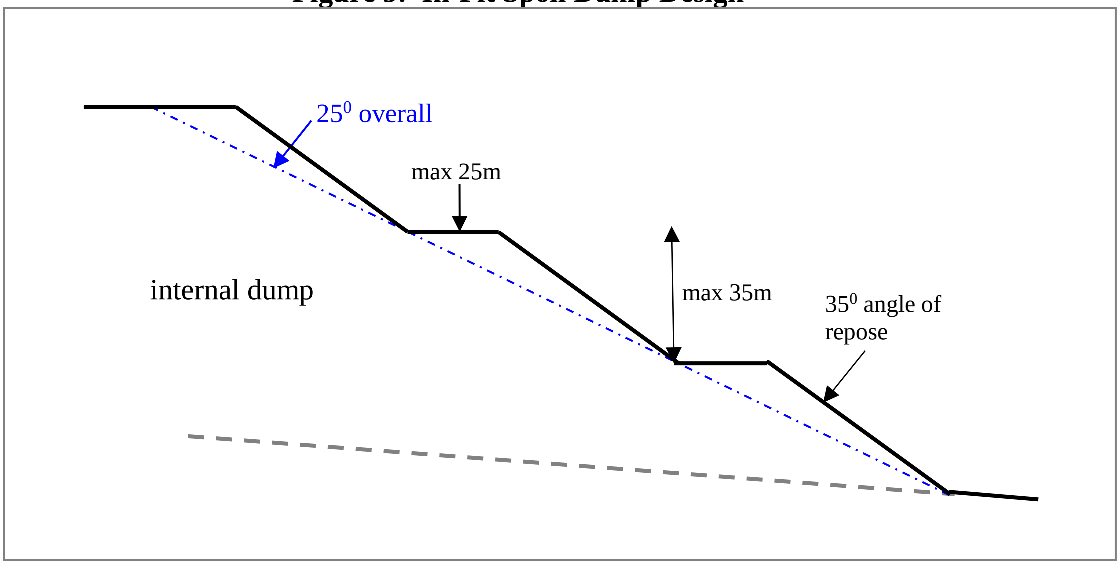
4.2 Spoil Dumps

In-pit spoil dumps are built up in lifts at angle of repose batters with berms. Angle of repose is 35^0 on average. The final profile may depend on operational factors but is within the following constraints:

- Maximum dump bench height 35m;
- Maximum berm width 25m;
- Maximum overall slope angle (toe to toe) not to exceed 25^0 (46%).

The design profile is illustrated in Figure 5 below.

Figure 5: In-Pit Spoil Dump Design



The general aspect of the in-pit dump is illustrated in the photo below, which shows the face of the advancing dump in B Pit.

B Pit in-pit dump

Photo taken 9/05/2017, looking SW

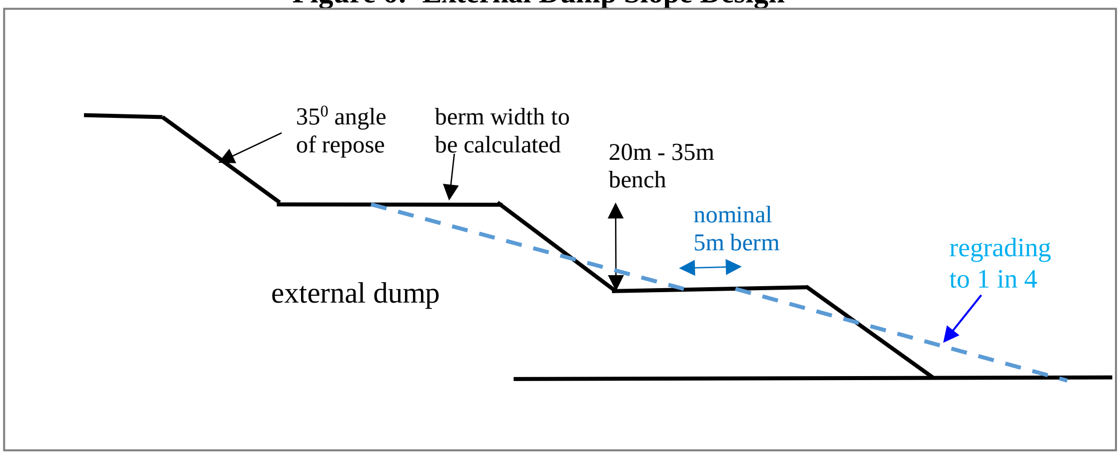
Floor treatment is used to disrupt bedding or slip planes prior to dumping or casting spoil on steeper floor dips to ensure the in-pit dump remains stable. This is only applicable to parts of Mavis Pit where the dip exceeds 12½^0.

External dump faces are formed to facilitate re-grading to 1 in 4 slopes for rehabilitation. The final dump profile will be depend on the circumstances and will be calculated to give a cut-and-fill balance for the re-grading push-down. Berm width varies according to the bench height and is designed to leave a nominal 5m residual berm after pushing down the batter. The overall guide is:

- Maximum bench height 35m;
- Nominal bench height 20m;
- Residual berm width nominally 5m;
- Final re-graded batter 1 in 4 (14^0).

The design profile is illustrated in Figure 6 below. For a 20m bench height, which is the usual design, the berm width would be 56m.

Figure 6: External Dump Slope Design



The photos below show as-constructed external slopes of the low wall spoil dump at D Pit and re-graded rehabilitated external slopes at E Pit.

Pit external low wall spoil dump face

Site photo 143458861 taken 18/07/2017, looking ENE

E Pit external low wall rehabilitated spoil dump face

Photo taken 9/05/2017, looking NE

4.3 Compliance

The Environmental Authority (EA) specifies that highwall slopes in competent rock can remain as constructed if they are geotechnically stable or otherwise benched with 15m berms at 20m intervals. This would be equivalent to a maximum overall slope angle of 63^0 for benched slopes. Low wall spoil dumps are to be benched or reshaped accordingly to ensure geotechnical stability. External spoil slopes (landform) must not exceed 1 vertical to 3 horizontal (18^0). The specified and as-formed slope angles are tabulated below.

Slope Type	EA requirement	As constructed
Highwall – competent rock	geotechnically stable	70^0 benches; 15m berms
Low wall – void side	geotechnically stable	benched, 25^0 overall
Landform – external dump side	max 1 v : 3 h	re-graded to 1 in 4 (14^0)

The EA requirements for pit slopes are not specific in terms of design parameters, the criterion being that they should be geotechnically stable. The as constructed highwall slope profiles are typical opencut coal industry designs that have proven adequate for general application.

Normal coal measures rock is too strong to undergo shear failure under gravitational loading and requires the presence of pre-existing separation planes, such as pervasive joint planes, faults or dykes to create conditions of potential instability. So that in the absence of adverse structure, 70^0

or vertical highwalls can be expected to stand indefinitely without risk of major collapse. The Millennium Mine design is thus compliant in providing geotechnically stable highwalls.

Instances of where faults intercept or occur close to pit walls are treated on an individual basis with the standard design modified as necessary to ensure any instability can be managed.

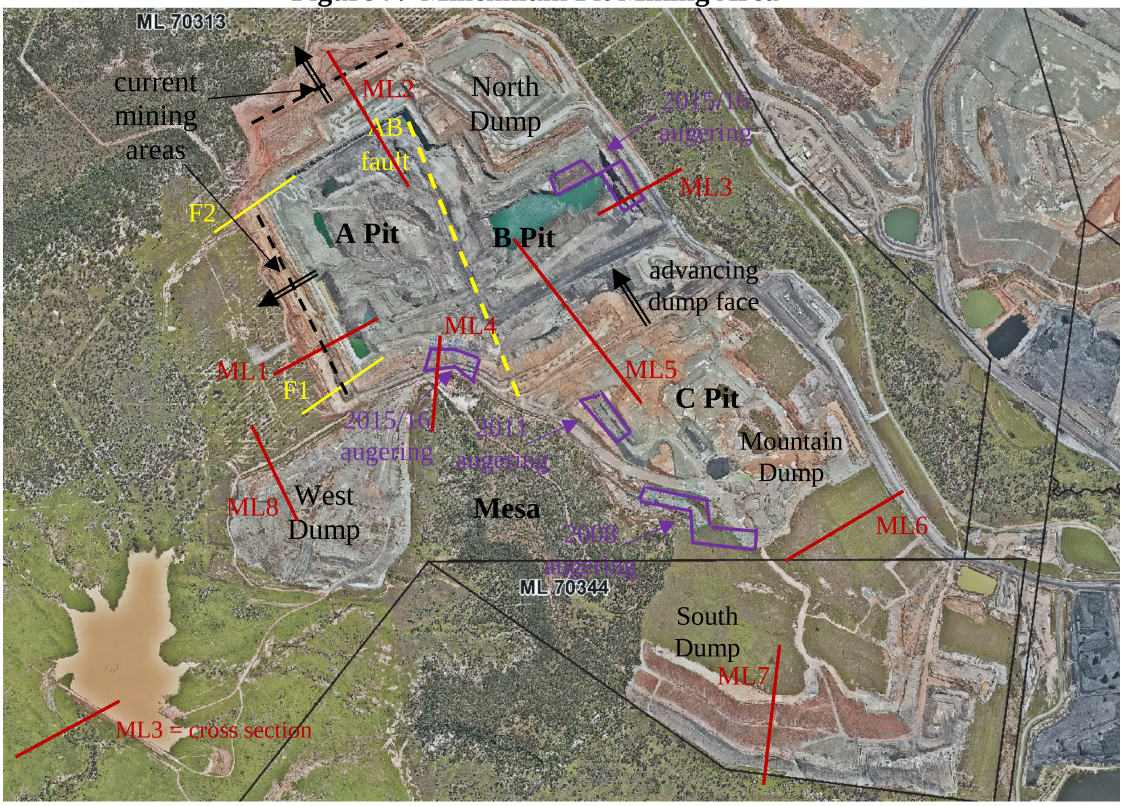
Low wall dumps are built up in benches at angle of repose to a maximum lift height of 35m between berms, which is a typical well-proven industry design for rockfill dumps on flat or gently dipping ground, and thus complies with the EA requirement for geotechnical stability. In-pit dumps are generally susceptible to mass failure if the floor is sloping, particularly if there are weaknesses in the floor. Steeper dips are a feature of some parts of Mavis Pit but there are design variations involving floor treatment or re-assessment of the design if the dip exceeds a threshold value of 12½^0.

External dumps have been re-graded to 1 in 4 which is flatter than the EA requirement.

5. MILLENNIUM PITS

The aerial photo below (Figure 7) shows the salient features of the Millennium Pit mining area. These include the designated pit areas A Pit, B Pit and C Pit and the out-of-pit dumps which are built above ground level. Also shown are the highwall augering blocks, the lease boundaries and the locations of cross sections (ML1 etc) referred to in the text.

Figure 7: Millennium Pit Mining Area



Mining commenced in C Pit which is now mined out and completely infilled with spoil and built up to RL305, some 50m above ground level. This referred to as Mountain Dump. The initial boxcut spoil for C Pit was dumped to the south as the South Dump; this old dump has been regraded and largely rehabilitated. Other out-of-pit spoil was placed in the North and West Dumps. The main in-pit dump is advancing north across B Pit and a new dump is being established in A Pit.

A mesa forms high ground between the south and west dumps which constrained mining on the south side. This feature contains cultural heritage sites. As the insitu low wall was exposed along the mesa on the south side, successive periods of auger mining were undertaken, extending under the low wall. The east highwall and north wall of B Pit was also subject to highwall augering after they had been established as final wall locations.

Current opencut mining is restricted to the north and west walls of A Pit, where one or two strips are planned. The eastern half of the north highwall was not visible at the time of the inspection as it had been blasted and was obscured by cast blast material. There could be a potential for highwall mining in the final north and west highwalls.

The final plan will leave a void against the north and west walls in the current mining areas in A Pit. It is intended to infill B Pit to ground level, at least for the most part, with a possible spoil-bounded void in the middle. B Pit is currently occupied by a pond that can be seen in Figure 7. Preliminary modelling results of maximum long term void inundation levels by Hatch indicates the water level in Millennium Pit would rise to a maximum of RL164 after 10 years and would fluctuate around RL160 thereafter.

5.1 Highwall Stability

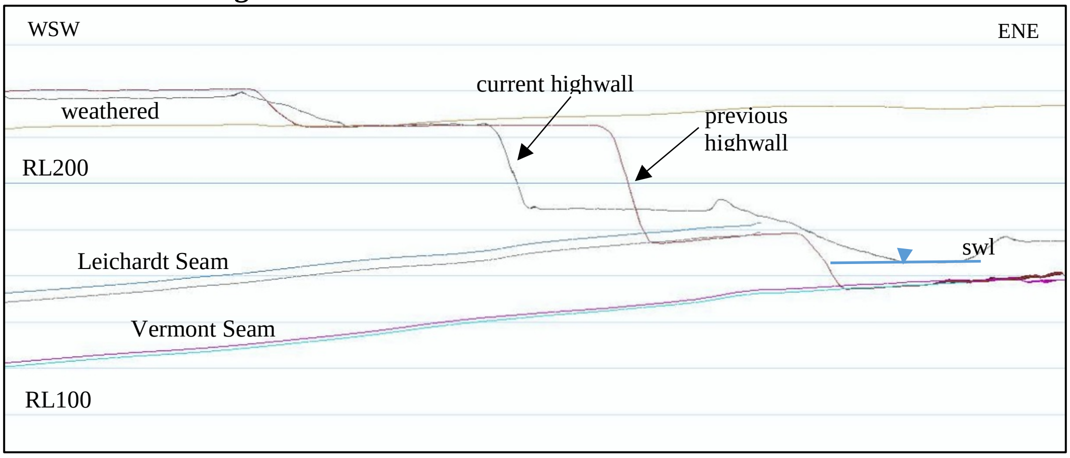
In normal conditions the pre-split rock benches are clean and stable. In some cases the walls have not been pre-split but have been scaled to present a reasonably clean face. In either case there will always be a background risk of small blocks becoming detached through weathering and falling out. The Rangal Coal Measures, particularly the finer grained rock, are susceptible to slaking and this allows the softer material to weather out and undercut the harder sandstone blocks. This has no impact on the overall geotechnical stability of the slope but represents a long term weathering effect. The photo below shows a typical scaled highwall bench with undercutting of the harder sandstone bands.

A Pit south highwall

Photo taken 4/12/2016, looking NE

Full height final highwall faces will be left along the west and north sides of A Pit. Cross Section ML1 in Figure 8 below shows the current configuration for the west wall, with the partially exposed highwall for the next strip. More strips may be mined but the final configuration should be the same, comprising a 45^0 upper bench up to 30m high through the weathered zone and a 70^0 pre-split main overburden bench up to 55m high. Also shown is the predicted long term void water level at RL164.

Figure 8: Cross Section ML1 - A Pit west wall



The highwalls are cut through material that is too strong to permit material failure by shearing and hence will stand indefinitely subject only to weathering degradation. The systematic risk of massive block slippage can also be discounted since the bedding dips back into the wall. However, rock failure conditions can be created by adverse pervasive discontinuities such as fault planes, joint planes or combinations of planes producing block or wedge configurations.

The main structural disturbance at Millennium Pit is the A/B Fault which runs NNW-SSE and separates A Pit from B Pit. This fault dips at between 25^0 and 35^0 to the west and has a vertical displacement of about 80m. Localised instability has occurred as a result of slippage down the fault plane but this was an interim mining issue that could be managed by judicious location of the temporary faces within the pit. No instability has been noted where this fault system intersects the north highwall, as the fault system is perpendicular to the wall, which tends to neutralise any potential instability from adversely dipping planes.

Several large steep reverse faults occur within the mining areas, but most of these are also more or less perpendicular to the wall and do not usually result in any significant instability. Where these faults are parallel to and just behind a face they can create a risk of large scale wall collapse. One of these was in the north wall of B Pit; this was remedied by cutting back the upper part and buttressing the affected part of the wall with spoil after mining the coal.

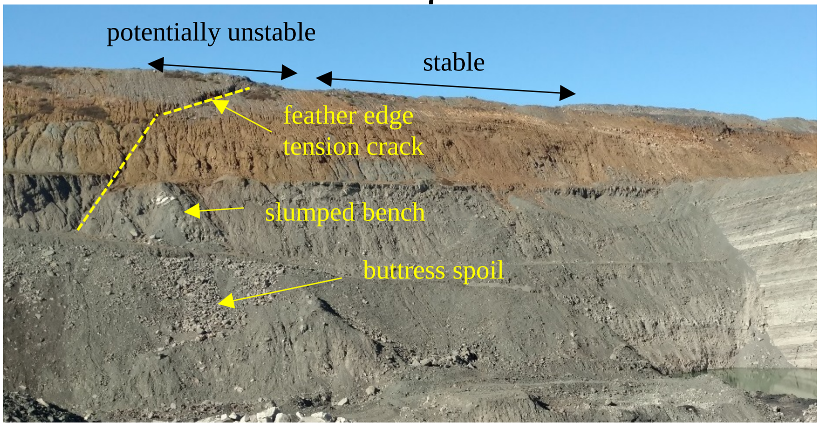
Two other instances of potential fault-induced instability occur at each end of the west wall, marked as F1 and F2 on Figure 7. F1 appears to be a high angle fault running behind and sub-parallel to the south wall, dipping out of the wall. It has incurred some movement, manifest as a tension crack along the edge of the haul road and slumping of the lower bench. The tension crack enlarged significantly following inflow from cyclone Debbie in March 2017 as shown in the photo below.

F1 tension crack

Site Photo taken 9/05/2017, looking NE

Inspection of the face reveals that the movement is due to a slumping collapse of the feather-edging fault intersection with the wall – too much weight on too narrow a base – and that the main section of wall in front of the crack appears to be intact. The feather-edging tension crack is shown in the photo below cutting down across the upper weathered benches. The lower rock batter has incurred slumping collapse.

South wall fault F1



Site Photo IMG_20170524_ 091625948 taken 24/05/2017, looking NE

A spoil buttress has been placed against the wall and this has effectively buttressed the lower bench against any further slumping. The residual risk would be shallow slip failure through the top of the weathered material and haul road spoil at the top.

In terms of remedial action for final void, because the failure is fault controlled it will not extend any further back than the fault itself marked by the tension crack, the recommended action would be to leave as is with a rock bund along the haul road 15m from the tension crack. As the fault trend is moving further away from the wall the potential for mass failure should be reduced and it is unlikely to have any impact on the stability of the next strip endwall.

The other fault (F2) is also projected to run almost parallel to the northern endwall of the next strip. This fault can be seen daylighting in the current north wall but with no indication of instability. The fault plane appears to be dipping back into the wall which would negate the potential to induce a similar collapse of strata off the fault plane. As the fault trend is also slightly oblique to the wall, it will be further back from the face on the next strip which would minimise the risk of fault-induced endwall failure in the next west wall strip.

In either case the consequences of wall failure would be material movement into the residual void, with a failure extend defined by the fault line, hence the recommendation to bund off behind the line of the fault or tension crack to prevent access into a potentially failing edge area. The alternative would be to buttress the wall to ground level with the in-pit spoil dump.

The top bench is cut through weathered rock for the most part. Circular slip type failure is theoretically possible but can be discounted given the absence of lower strength Tertiary clay or completely weathered mudstone (clay type material) in the batter and the inherently higher shear strength of weathered rock which tends to include some stronger sandstone bands.

Rockfall is more prevalent from the top bench however due to softer soil-like material eroding out from around the more resistant blocks, particularly if a steeper batter has been formed. The upper bench of B Pit north wall shown in the photo below is an example of a steep rough-cut batter.

B Pit north wall

Photo taken 9/05/2017, looking NW

In this instance a band of strong sandstone has prevented the formation of the normal 45^0 batter and although there is no risk of mass failure, there is a likelihood of large blocks weathering out. Any rockfall will report to the void and will in any case be contained on the wide rock berm.

B Pit north wall bund

It is planned to leave an access road along the wall behind this bench as part of the final works. There should not be an issue with that provided the substantial rock bund already in place some 15m back from the crest to protect the current haul road, is left as a permanent exclusion against the edge area.

Photo taken 9/05/2017, looking E

The upper bench east wall of A Pit is also likely to be left as a final wall off the void. This is shown in the photo below. In this instance the standard 45^0 batter has been cut through the weathered rock creating an intrinsically stable bench but still subject to minor rockfall from weathering effects. There is a 25m catch berm below for rockfall.

B Pit east wall

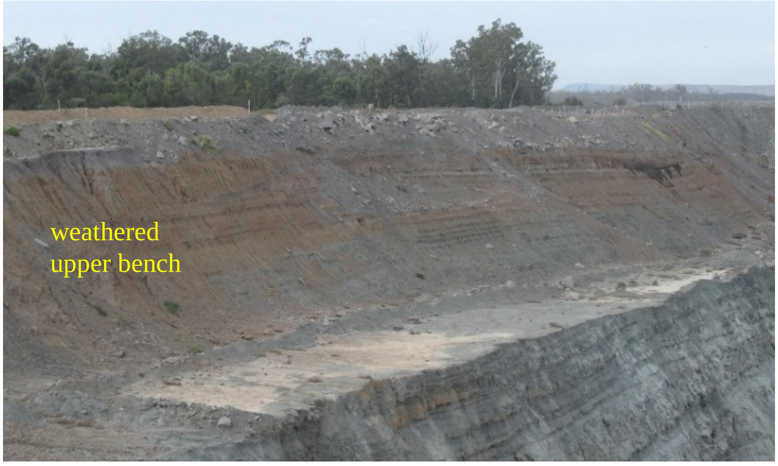


Photo taken 9/05/2017, looking SE

From experience to date and the current condition of the walls, it can be concluded that the highwall design is appropriate for producing a stable final wall, except for those areas where faults are present behind and parallel to the face as discussed above.

In terms of long term void water level, the predicted RL164 mark would result in inundation of the lower rock bench to a height of about 5m and 10m above the pit floor respectively for the north and west final highwalls. Submergence of fresh rock benches does not normally change the stability condition and hence would not be expected to trigger any failure.

Slopes in weathered rock would be susceptible to slaking and erosion and the batter could degrade due to slumping if the water level reached higher than the base of weathering. As the base of weathering is between RL225 to RL240, the top bench in weathered material would be well above the maximum predicted void inundation levels and this situation would not arise.

5.2 Dump Stability

There is no apparent history of low wall failures in Millennium Pit, other than localised slippage on steep dips associated with the AB Fault. Both the in-pit dump and the external dumps are clearly stable, nevertheless slope stability analyses were carried out to confirm the Factor of Stability (FoS). Shear strength parameters used for analyses, based on the foregoing, were as follows.

Shear Strength Parameters

Material	Density (kN/m^3)	c (kPa)	ø	Reference
Fresh spoil	20.0	50	30^0	Category 3 dry
Aged spoil	20.0	30	28^0	Category 2 dry
Basal spoil (submerged)	20.0	15	23^0	Category 2 saturated
Weathered rock	22.0	25	35^0	estimate

Rock spoil is blocky when fresh and appears to be mostly BMA Category 3[1] (blocky spoil with fines) with a reasonably high shear strength. Over time the spoil will undergo slaking with breakdown of the lumps so that the spoil has more fines than blocks. Testing of spoil from the nearby Moorvale Mine[2] shows predominantly low plasticity for the fines which would tend towards a Category 2 spoil type (fines with blocks). Spoil from the weathered zone already can be assumed to be similar to the same material at Moorvale Mine, which testing showed to be low to intermediate plasticity with high dispersivity, that is equivalent to Category 2.

Analyses were made for specific as constructed profiles represented by the selected cross sections, together with the standard design in the case of the in-pit dump profile. The analyses were made using the Galena code for circular failure for external dumps and bi-planar slippage for the in-pit dump. The results are summarised below. The inundated case is for the void flooded to the maximum 10 year level at RL164.

[1] Simmons J V & McManus D A 'Shear Strength Framework for Design of Dumped Spoil Slopes for Opencut Mines' Advances in Geo Engineering, The Skempton Conference, Thomas Telford, London, pp981-991

[2] Ward B 'Moorvale Mine Residual Void Slope Stability Study' Geotechnical Consulting Services Pty Ltd, Report No.158 November 2014

Analysis Results (FoS)

Section	Dip	Current	Inundated
West Dump (Section ML8)	flat	2.44	-
In-pit standard	6^0	1.61	1.40
West wall void (Section ML1)	6^0	1.68	1.58
North wall void (Section ML2)	1.5^0	1.72	1.67

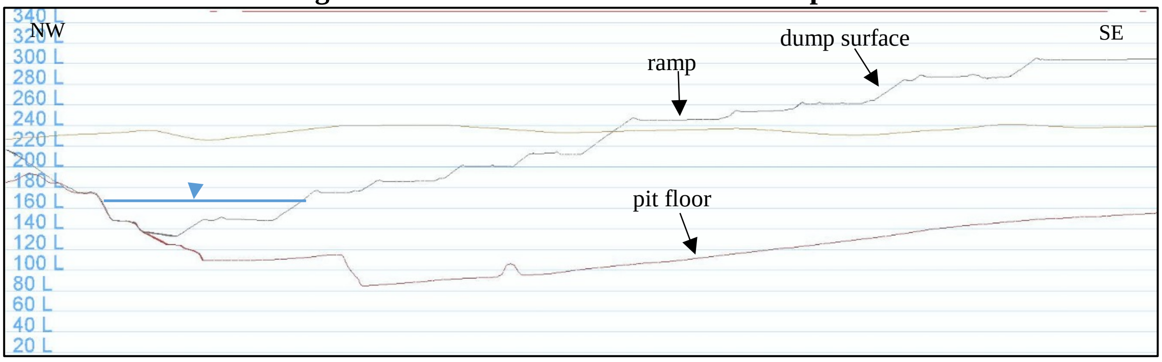
The FoS criteria in common use in the coal mining industry are:

FoS $\geq$ 1.2 short term run-of-mine slopes
FoS $\geq$ 1.5 long term slopes or where slope failure could impact on infrastructure etc

Figure 9 shows the profile along Cross Section ML5 through the advancing in-pit dump face from pit bottom to the top of the Mountain Dump. This is as per the standard design although the overall slope is flatter due to the insertion of ramps at various levels across the dump face.

The in-pit standard analysis was based on this cross section from pit bottom to the elevated top height at RL305 on the 6^0 dipping floor but without the ramps. In practice there are ramps crossing the face of the dump which would reduce the overall slope angle so that the profile without ramps represents the worst case. The results indicate stable conditions for this hypothetical case with the inundated condition having a slightly less than desirable FoS for long term stability, noting however that the FoS for the as-constructed low wall would be higher with the inclusion of the ramps in the profile.

Figure 9: Cross Section ML5 - B Pit dump

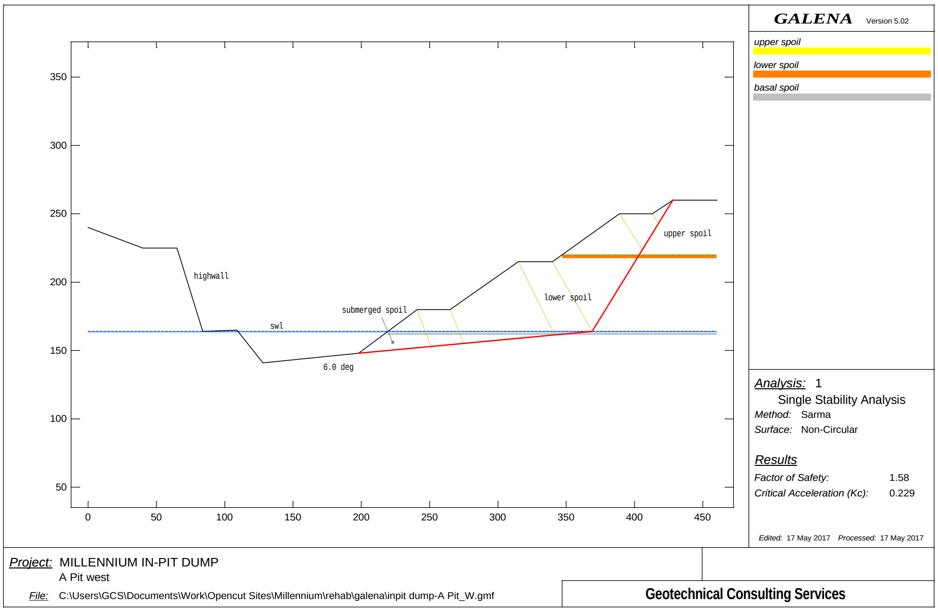


Irrespective of the analysis results however, Cross Section ML5 shows that the spoil dump extends to the opposite highwall and is buttressed against that and the Vermont Seam bench. This would preclude the possibility of mass failure for the current in-pit dump.

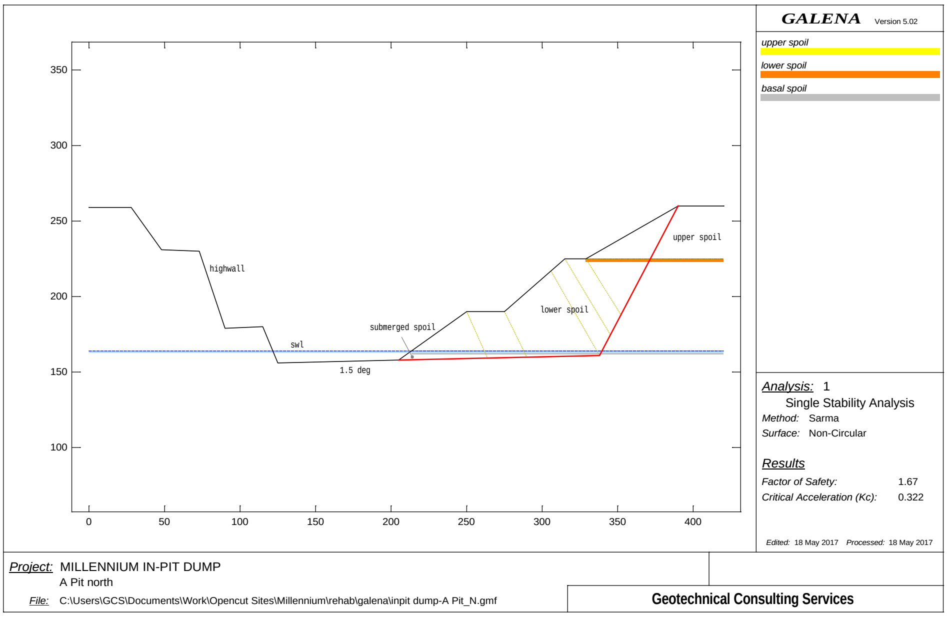
Unbuttressed in-pit dump faces would be formed at the completion of mining in A Pit opposite the west and north walls. For these cases the standard dump design was applied to Cross Sections ML1 and ML2, assuming the A Pit dump is raised to ground level at RL260. Analyses were made for a presumed final void profile, allowing for inundation to RL164. The upper spoil forming the top bench may include some weathered material and has thus been treated as Category 2, with submerged spoil as Category 2 saturated. Failure mode is bi-planar with slippage on the pit floor and shearing back up through the spoil dump.

The results tabulated above show FoS in excess of the long term design value for both as constructed (drained) and inundated conditions. This would indicate that internal dump failure would be highly unlikely. Note that displaced material from failing slopes would in any case be contained within the pit void. The outputs from the Galena program are presented below. The FoS for the north facing dump are higher because of the shallower dip in that direction.

A Pit west wall void



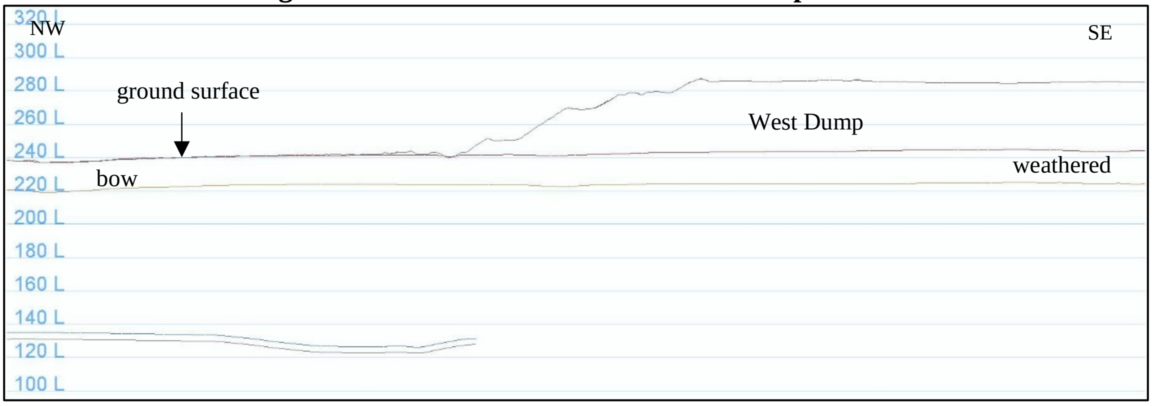
A Pit north wall void



External dump profiles are currently determined from a calculator designed to balance the cut and fill to allow for pushing down the batters to an overall 1 in 4 rehabilitation slope. In theory they would normally be 20m benches at angle of repose with 56m wide berms. With a wide-bermed profile like this the possibility of mass failure is eliminated. Slumping of individual benches is possible under extreme conditions of saturation but is highly unlikely.

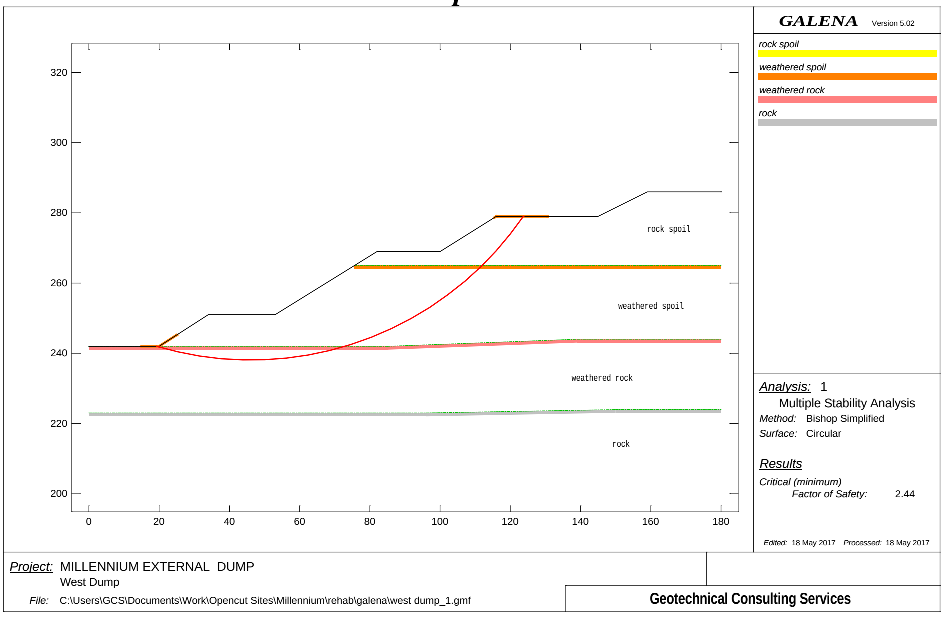
Earlier out-of-pit dumps were steeper with narrower berms and this includes the North and West Dumps. Both of these have an as-constructed profile as they have not yet been re-graded, although technically they are in compliance with the EA requirements. Figure 10 below shows the profile for Cross Section ML8 through the northern side of the West Dump.

Figure 10: Cross Section ML8 - West Dump



Analysis of this profile shows a high FoS of 2.44 for circular slip failure, with the most critical failure surface through to the third bench as illustrated on the Galena model below.

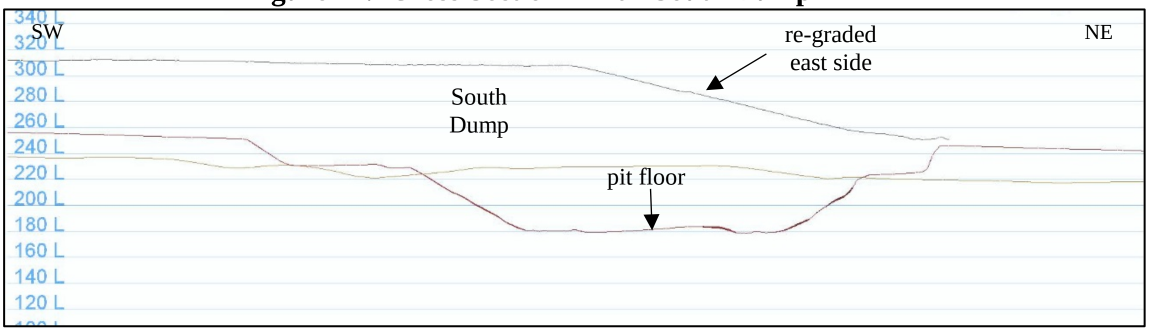
West Dump



It can be concluded that the external dump faces with as-constructed profiles are geotechnically stable.

Final external dump faces are re-graded to 1 in 4, covered in rock mulch and grassed for rehabilitation status (see Section 4.2). Cross Section ML6 below shows the profile through the east side of the old south dump. This is an example of early re-grading without any berms.

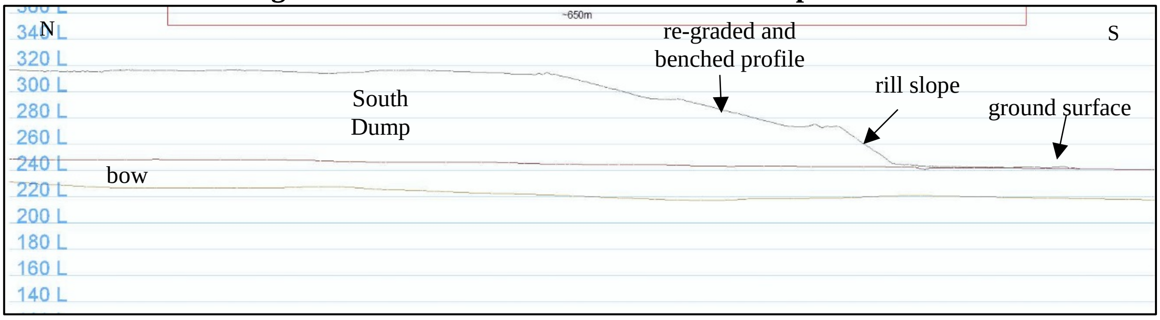
Figure 11: Cross Section ML6 - South Dump



The top of the dump is flat to reduce run-off as per the requirements of the EA. In this respect it has been the practice to bury tailings in cells in the spoil – this causes differential compaction which tends to create temporary ponding on the surface over the cells.

The south side of the South Dump has also been re-graded as shown in Cross Section ML7 below. In this case however, final works have not been completed pending agreement to push material over onto the adjacent lease. As a consequence the bottom batter is still as-dumped at angle of repose.

Figure 12: Cross Section ML7 - South Dump



Due to the shallow slope profile created by the re-grading, there is no risk of mass slope failure and rehabilitated slopes can be considered geotechnically stable over the long term.

5.3 Highwall Augering

Highwall augering has been undertaken at Millennium on three occasions in 2008, 2011 and 2015/6. The locations of the auger mining are shown on Figure 7. The 2008 augering was in C Pit low wall at the southern end of the mine area, with single row panels in both the Leichardt and Vermont Upper Seams. Subsequent augering was in the Leichardt Seam only with a double row of holes wherever possible.

The next section of B Pit low wall was mined in 2011, together with an internal panel along a north wall in B Pit. These entries, and the earlier ones, have all been buried under the in-pit dump.

B Pit Highwall Augering

In 2015/16 augering was undertaken in the next section of low wall in A Pit together with east and north walls in B Pit. The photo shows auger holes in the north wall of B Pit.

Photo taken 12/04/2016, looking E

Auger designs are based on a Factor of Stability (FoS) of not less than 1.2 for the coal pillars under maximum overburden loading and not less than 1.5 at the portal under the highwall face[3].

[3] Ward B 'Millennium Mine Highwall Augering' Geotechnical Consulting Services Pty Ltd, Report No.165, September 2015

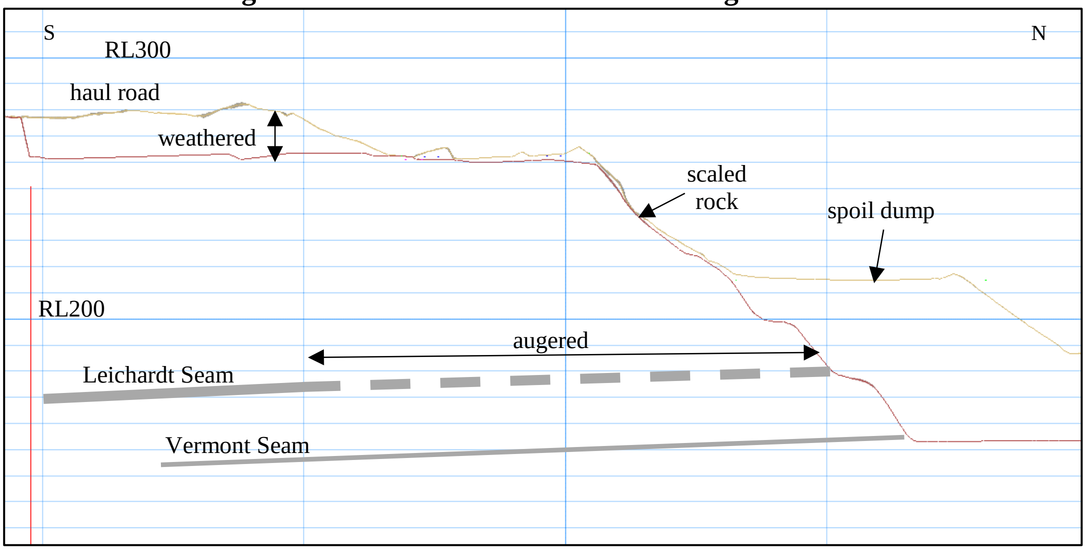
These general design FoS values are for run-of-mine extraction and are not adequate for ensuring long term stability, and although there has not been any indication of distress in any of the auger entries or pillars to date at Millennium, there will be a possibility of long term deterioration (creep) of the coal pillars over time, allowing the pillars to eventually fail and crush down. The consequences of a long term deterioration and collapse would be subsidence at the surface but this would not be expected to exceed about 0.75m.

Pillar failure at the portal would undermine the highwall and could result in a collapse of the highwall face. Slope failures from this cause tend to be relatively shallow, more of a collapse type slump than a deep seated slope failure, and do not extend far behind the highwall. The use of the higher long term stability FoS value under the highwall should reduce the risk of highwall collapse in isolation, although a widespread collapse of pillars inbye could run forward under the highwall.

The 2008 and 2011 auger blocks are now buried under spoil such that highwall instability is now irrelevant and any subsidence reporting to ground level through the spoil would not be of any consequence.

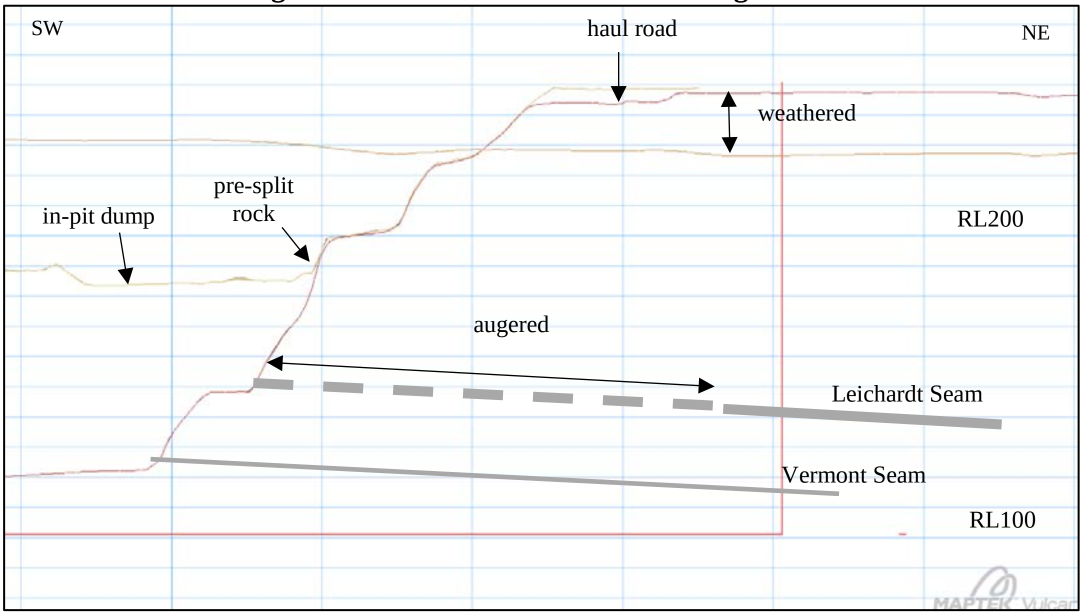
A cross section through the south wall is shown in Figure 13 below. The auger holes generally penetrated between 80m and 160m, with a maximum of 200m in places, so did not penetrate further in than the haul road, which would not therefore be affected by any long term subsidence. The stability of the scaled 50^0 upper batters would not be affected by any subsequent pillar crushing and only the bottom rock bench would be at risk of face collapse. However the holes are now buried under a buttressing spoil dump which would offer greater confinement to the pillars under the face and reduce the opportunity for pillar failure.

Figure 13: Cross Section ML4 - south highwall



A similar case applies to the east wall auger holes, as illustrated in Figure 14 below. The auger holes penetrated some 140m to 155m and passed beneath the haul road but were stopped well short of the New Chum Creek levee. As the pit is already partially backfilled there is no residual risk of face collapse from long term pillar deterioration but a possibility of some small amount of easily remedied subsidence under the haul road if this is to be left as an access road.

Figure 14: Cross Section ML3 - east highwall



The other 2016 holes in the internal north wall are limited to the lower rock bench which will be buried beneath the in-pit spoil dump.

Consideration is being given to post opencut scavenging of the current highwalls (north and west) using highwall mining. Unlike augering which produces round holes, mining is carried by a continuous mining machine which cuts a rectangular section typically 3.5m wide. Nevertheless the same comments in regard to long term stability and the possibility of pillar creep apply. Full penetration is 300m, geological structure permitting, which may result in undermining a greater area of the crest.

6. MAVIS PITS

The aerial photo overleaf (Figure 15) shows the salient features of the Mavis Pit mining area. These include the designated pit areas D Pit, E Pit and S Pit together with dump areas and the highwall augering block. Also shown are the locations of cross sections (MV1 etc) supplied for analytical purposes.

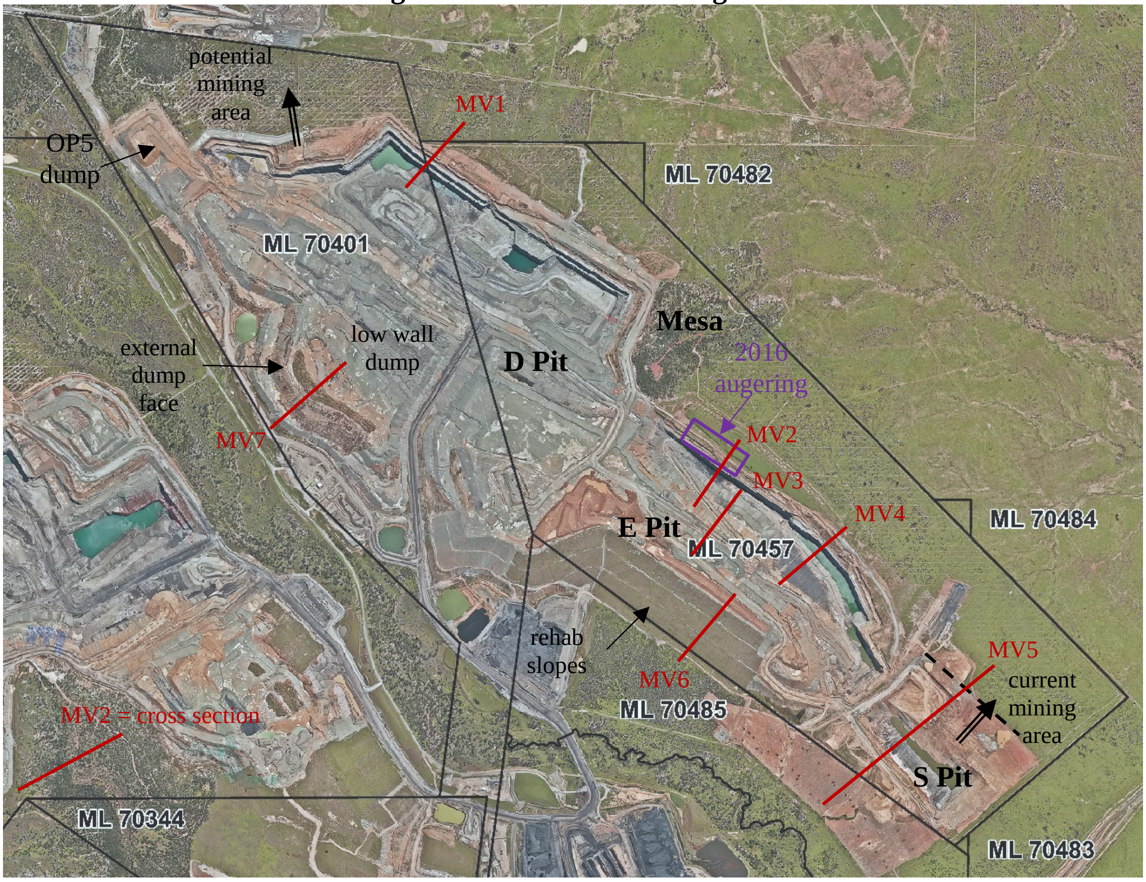
Mavis Pit is a strip mine, with successive strips being mined down-dip against an advancing highwall on the north-east side and spoil dumped behind each strip on the south-west side. The initial boxcut spoil was dumped west of the low wall on natural ground and the dump raised and advanced by spoil from subsequent strips. A small out-of-pit dump (OP5) was formed at the northern end of the strip.

S Pit was developed as a boxcut with spoil dumped externally on the low wall side. It was then used for water storage but is now currently being mined with one or more strips towards the north-east where it will terminate against a major fault.

Spoil is dumped in lifts on the up-dip side to form an advancing low wall dump leaving an external face on the south-west side. Re-grading and rehabilitation has been undertaken on the E Pit external face.

Current opencut mining operations are restricted to D Pit and S Pit, with a potential to extend the pit to the north (D Pit North) towards the lease boundary. A small mesa forms high ground behind the D Pit southern endwall. Highwall augering is underway in the final E Pit highwall, as indicated in Figure 15 below, with plans to extend over the rest of the northern half of the pit. The seam dip in the southern half is too steep for auger mining.

Figure 15: Mavis Pit Mining Area



Current final void planning is for partial infilling of the northern end of E Pit with open voids against the remainder of the highwall and extending into S Pit and an open void against the whole of D Pit highwall, including the north wall where there is a potential extension into D North Pit. Preliminary modelling results of maximum long term void inundation levels by Hatch indicates the water level in D Pit would rise to a maximum of RL182 after 10 years and would fluctuate around RL180 thereafter, whilst in E Pit it would be at RL174 and vary between RL170 and RL175 over the longer term.

6.1 Highwall Stability

The highwall slopes are formed in moderately strong back-dipping bedded rock and are inherently stable for the most part. The walls are intersected by a number of large high angle faults but these have tended to be perpendicular to the face and thus do not create a potential for mass failure. In some cases there has been some spalling or shallow slumping to create a vee-shaped notch down the wall but this is a very local feature confined to the fault intersection and does not prejudice the stability of the rest of the face.

The photo below shows a typical highwall face, together with a fault intersection.

E Pit north highwall

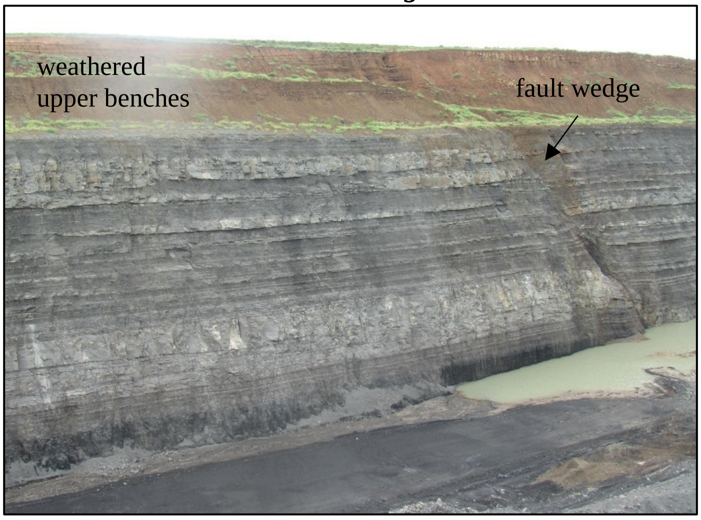


Photo taken 5/01/2017, looking E

A more substantial wedge failure has occurred in D Pit highwall due to a major joint plane intersecting a fault in the face. Material within the wedge has slipped down or been scaled back to the intersecting sliding planes. In terms of long term effect, the zone of instability is confined to within the triangle on the berm formed by the intersecting discontinuities. The failure cannot extend any further back into the highwall in the absence of any other contributing planes and any residual material left suspended will slide down into the void.

D Pit wedge failure

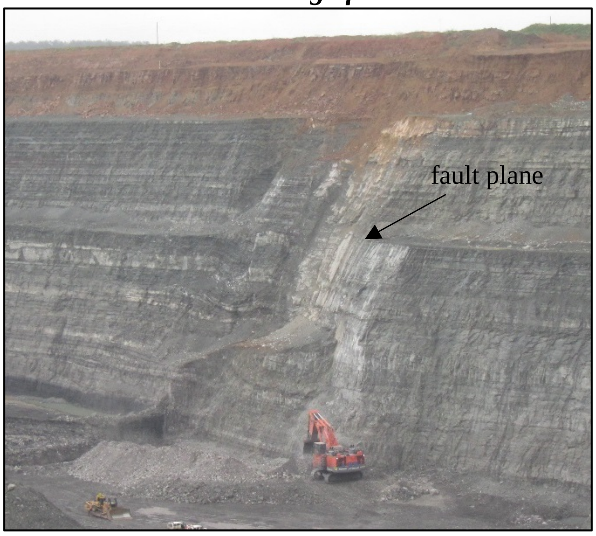
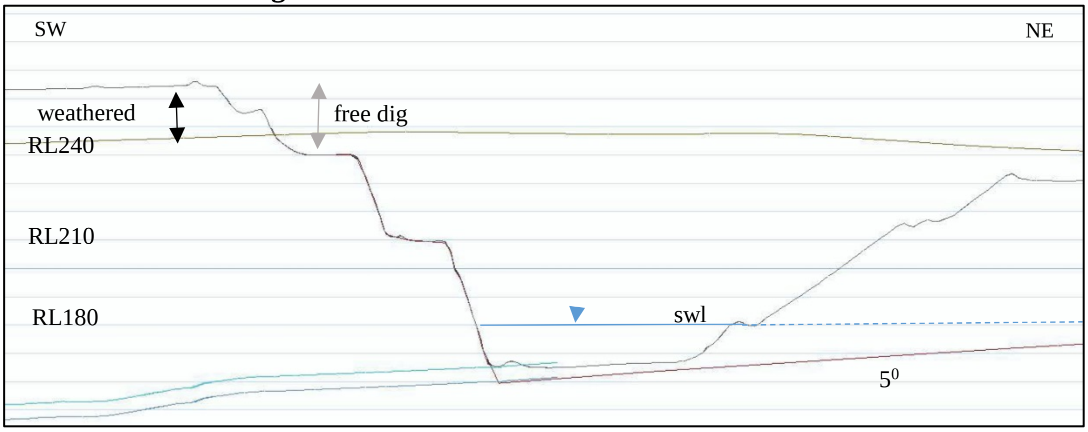


Photo taken 11/05/2017, looking N

The failure has cut back to and slightly undercut the weathered rock bench. This may cause some shallow slumping or erosion in the softer material but would not prejudice the geotechnical stability of the upper benches. No further action would be needed for residual void protection other than the standard exclusion bund at the crest.

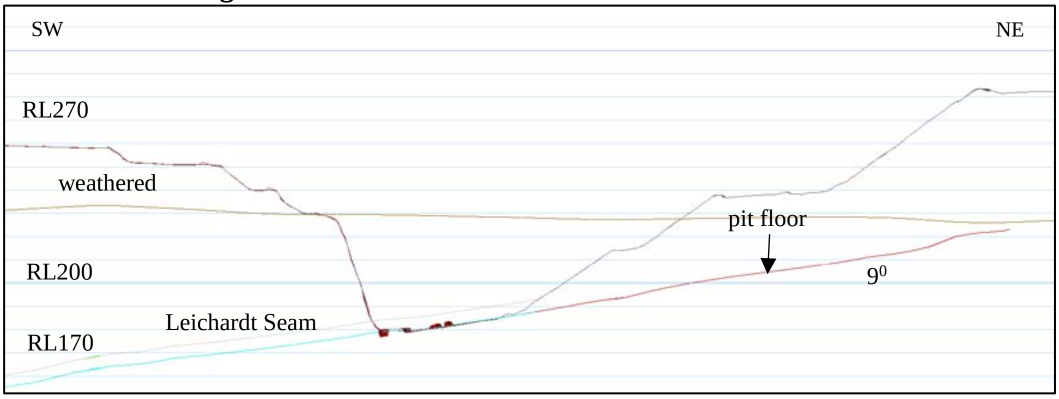
Cross Section MV1 at the northern end of D Pit is presented below. This shows the general configuration for an 80m high double bench highwall, with 70^0 pre-split benches and 15m berms at RL210 and RL240. It also illustrates the shape of the 'rough-cut' free-dig benches through the weathered material. The benched in-pit spoil dump is constructed on the pit floor up-dip of the mining void at angle of repose. The predicted long term water level is shown at RL180.

Figure 16: Cross Section MV1 - D Pit North



In E Pit the rock highwall is 50m to 60m high and has been cut as a single bench, as illustrated in Figure 17 below (Cross Section MV2). The pit floor in the northern part of E Pit is at RL180 or so and would be above the predicted long term water level.

Figure 17: Cross Section MV2 - E Pit North



In terms of long term void water level, the predicted RL180 mark in D Pit would result in inundation of the lower rock benches to a height of about 20m above the Leichardt Seam. In E Pit only the southern part would accumulate water for a predicted long term level of RL175, again indicating a maximum submergence depth of 20m at the highwall. In each case only the lower part of the fresh rock bench would be impacted, and this would not be expected to induce any instability in the rock face.

The northern limit of mining in S Pit is apparently a fault running parallel to the pit. Faults parallel to the highwall present a significant risk to wall stability, as discussed in Section 5.1, however it is understood that the current plan is mine out to the other side of the fault plane such that the fault would not be left behind the highwall thus removing the risk of instability.

As per Millennium Pit, the walls slake readily, leading to undercutting of the harder sandstone blocks and a creating a background risk of small blocks becoming detached through weathering and falling out.

Upper spoil benches are cut through weathered rock, which has a variable nature depending on the presence of more durable sandstone beds. In Mavis Pits the weathered zone appears to be more soil-like with less harder bands but still has a high enough strength to form stable batters. However, the silty and clayey fractions are dispersive and prone to erosion which can effect environmental stability without impacting on the geotechnical stability.

The condition of the upper batters is illustrated in the photo below. The batters were 'rough-cut' design and are individually too steep for long term environmental stability and, as a consequence, are gullying from run-off and eroding into lower angle rill slopes.

E Pit upper highwall benches

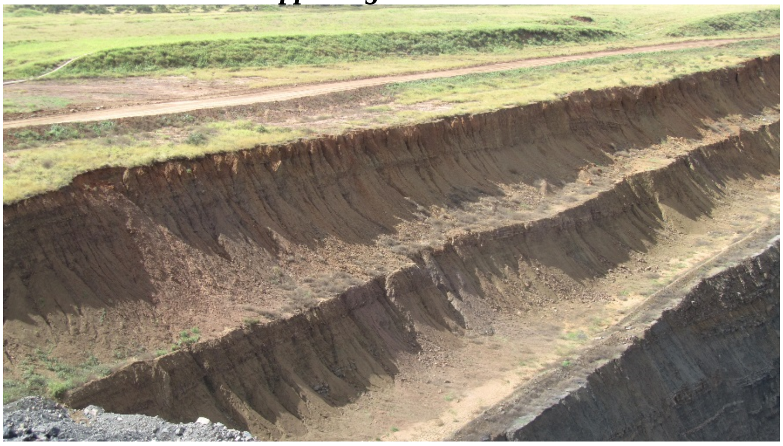


Photo taken 11/05/2017, looking ESE

There is no risk of mass failure but the degradation will continue to eventually create a 35^0 or so slope. There is adequate room on the rock berm to accommodate rilled material.

The upper benches at the northern end of D Pit are steeper with a greater proportion of harder material. This is resulting in a different weathering profile whereby the top section is failing by toppling collapse which thus creates and maintains a near-vertical top part, with a smaller rill slope.

D North Pit upper highwall benches

Photo taken 11/05/2017, looking E

The long term implication of this is that the toppling collapse could cause the shape to be retained and allow the crest to be eaten back further over time rather than degrading to a continuous rill slope. One option for remediating this would be to push down the batters to say 28^0 (typical angle for dozer-push) which would remove the toppling type degradation.

The overall conclusion is that the highwall design is appropriate for producing a stable final wall but with the likelihood of ongoing long term degradation of the over-steep 'rough-cut' batters through the weathered zone.

6.2 Dump Stability

Low wall dumps on a dipping floor are at risk of mass failure due to basal slippage, particularly if the floor contains weak or sheared horizons. In Mavis Pit the experience has been that dumps are stable on dips up to 8^0 in general, or $12½^0$ on sound floor. No dump instability was apparent from the site inspection. The photo below shows the stable low wall configuration with good quality spoil forming the base.

E Pit low wall spoil

Photo taken 11/05/2017, looking SE

The dip on the floor varies along Mavis Pit, increasing from north to south with the change commonly occurring across faults. The general situation is summarised in the following table.

Floor dip

Area	D pit	E North Pit	E South Pit	S Pit
Dip	4^0 to 5^0	9^0	16^0	20^0

In-pit spoil dumps have only been formed on the shallower dip areas of D Pit and E Pit North. The stability of the dumps in these two cases was examined by carrying out slope stability analyses for bi-planar slippage along the pit floor using the Galena code for Sarma's method. The shear strengths used were as per the Millennium Pit analyses (see table on page 13).

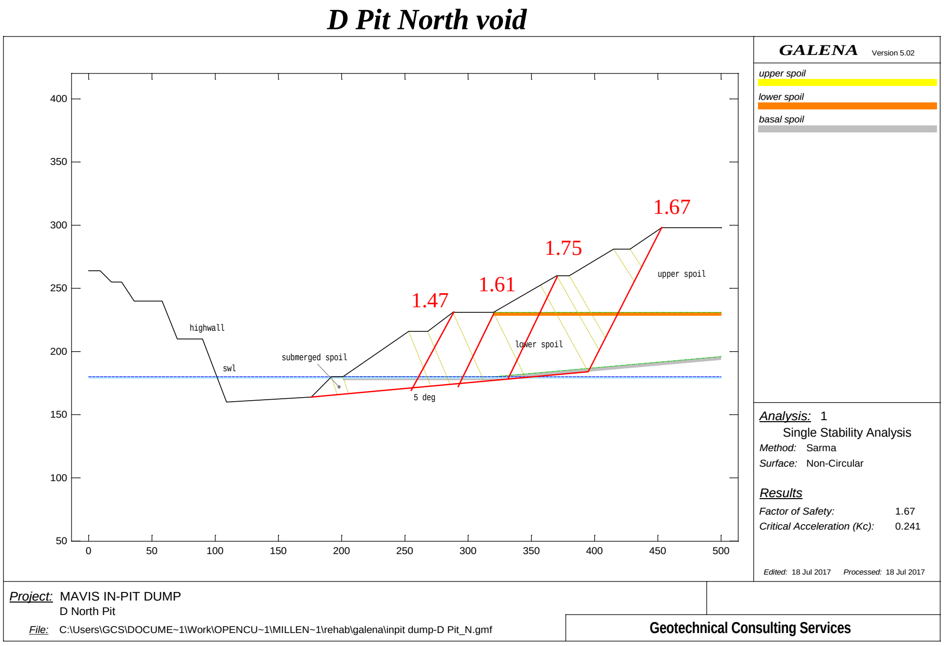
The results are summarised below. The inundated case is for the void flooded to the maximum 10 year level at RL180 in D Pit and RL175 in E Pit.

Analysis Results (FoS)

Section	**Dip**	**Current**	**Inundated**
D Pit (Section MV1)	5^0	1.73	1.47
E North Pit (Section MV2)	9^0	1.71	1.71

The analyses for D Pit North were based on Cross Section MV1 in Figure 16 **(**p.22), extended up to the full height of the dump at about RL300. The Galena analysis model showing the full profile is presented below.

Analyses were made failure configurations ranging from the RL230 crest up to the top of the dump at the RL300 crest as shown above. The results show FoS from 1.73 to 1.90 for the as-constructed dry conditions, well in excess of the long term design value. The FoS for the inundated condition are shown on the model section; these are lower but still more than adequate for the most part.



The influence of the submerged spoil becomes more apparent towards the toe of the dump causing a reduction in the FoS. A minimum FoS of 1.47 was noted at the RL230 crest as indicated on the plot above.

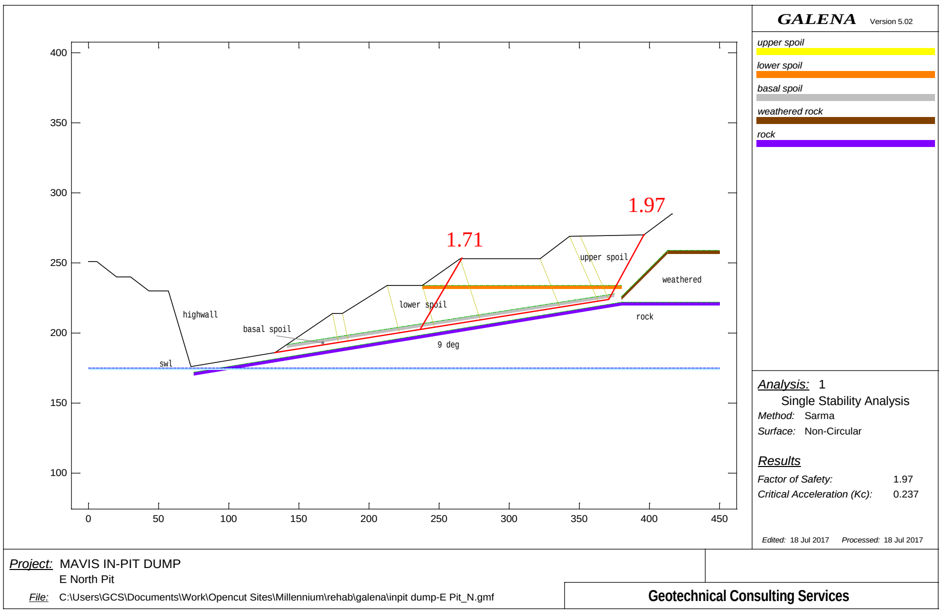
These results would indicate that mass failure of the internal dump would be highly unlikely, with the worst case FoS of partial failure under inundation still more or less acceptable for long term stability. Although inundation to the predicted level would not prejudice the dump in terms of mass instability, it could possibly cause some shallow slumping if the slope was undercut by notching at the water line. The spoil is not dispersive but has a high potential for slaking from wetting and drying.

The analyses for E Pit North were based on the profile in Cross Section MV3, as illustrated in Figure 18 below, which extends to the full dump height but using the floor profile from Figure 17 (p.22).

Figure 18: Cross Section MV3 - E Pit North

The floor level in the void in this part of E Pit is generally above the predicted flood level so that inundation is not a factor in stability analysis. The other issue is the geometric constraint on failure due to the upper part of the dump being situated on insitu ground. This would preclude full height failure as bi-planar slippage would be limited to the front part only, where the spoil has been dumped on the pit floor. The farthest back for failure is thus on the RL270 bench. The Galena analysis model is presented below.

E Pit North void

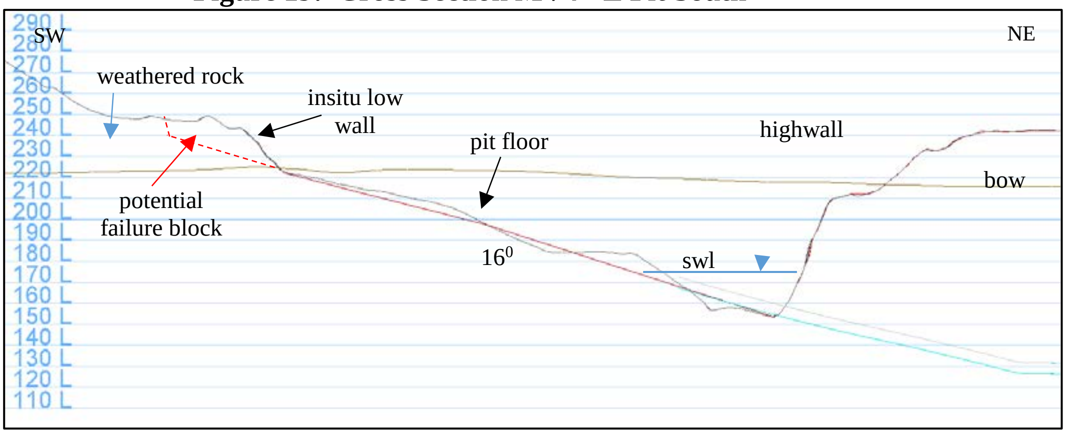


The FoS are high, despite the steeper dip, because of the lower dump height and the lack of submergence of the spoil. Mass failure of the in-pit spoil dump can be discounted in this instance. Notwithstanding the foregoing, the long term plan is to continue to infill E Pit North with spoil, which will mean that the low wall will be buttressed against the highwall. This will remove any possible risk of mass movement of the low wall.

In both D Pit and E Pit North there will be a residual risk of downwash and scouring of fines but any displaced material would be contained within the pit void.

Steep dips are a feature of E Pit South and S Pit and no spoil has been dumped on the pit floor in these areas because of the risk of slumping. Cross Section MV4 in Figure 19 below shows the configuration for E Pit South.

Figure 19: Cross Section MV4 - E Pit South

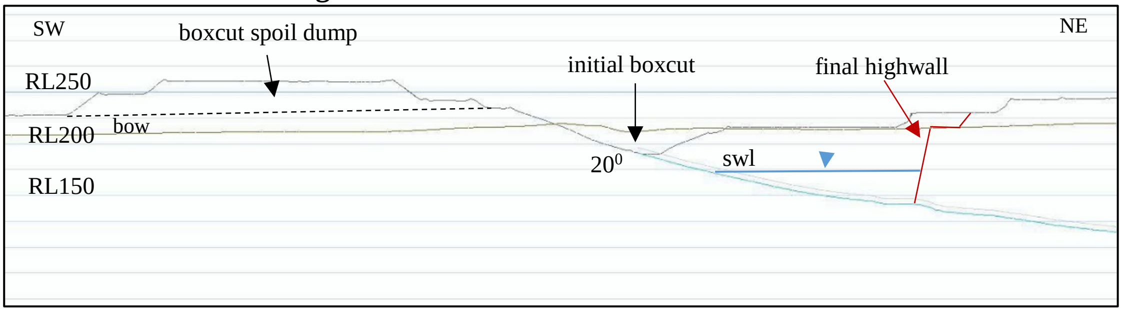


In this case however an insitu low wall has been cut down to the base of weathering, which leaves a residual risk of low wall failure due to slippage along the relict coal horizon extending up through the weathered zone. The potential failure configuration is shown above. The FoS is obviously more than 1.00 but as the dip angle is at least as much as the expected friction angle on the relict slip plane, the FoS can be presumed to be close to 1.00. This means there will be a high probability of failure in the insitu low wall at some stage, as consequence of softening of the shear strength and increased pore pressure from ingress of water, particularly during storm events.

In terms of long term exposure, the low wall would not have an acceptable margin of stability and failure can be expected. This condition could be alleviated by pushing down the low wall bench in front of the out-of-pit dump to match the pit floor. Alternatively it could be left to fail as any displaced material would migrate down the pit floor towards the highwall and would be contained within the void.

S Pit was developed as a boxcut with all the spoil being dumped out-of-pit away from the low wall because of the high dip. After being used for water storage, mining has now been resumed. The cross section through S Pit and the boxcut spoil dump is shown below.

Figure 20: Cross Section MV5 - S Pit

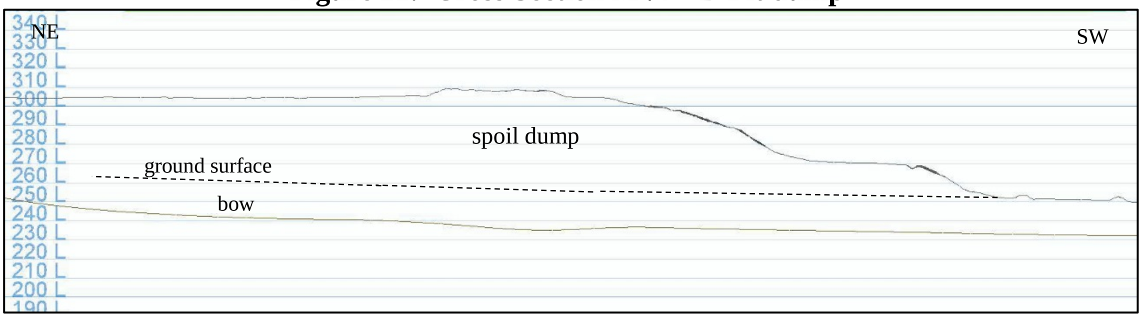


The initial insitu low wall was cut down at the dip angle so there is no material resting on the potential relict coal slip plane and the pit floor, which is effectively a footwall, is not steep enough to present any risk of slab failure. As a result the pit configuration is stable with no kinematic condition conducive to failure.

The outer face of the D Pit spoil, the small out-of-pit OP5 dump and the S Pit dump are as-constructed following the standard design. These slopes are clearly stable having been there for some time. Out-of-pit dump stability was discussed in Section 5.2 with analysis of the standard profile showing FoS of over 2.40 for circular slip failure.

Figure 21 below shows a cross section through the outer part of the D Pit dump, illustrating the shape of the benches and the flat top.

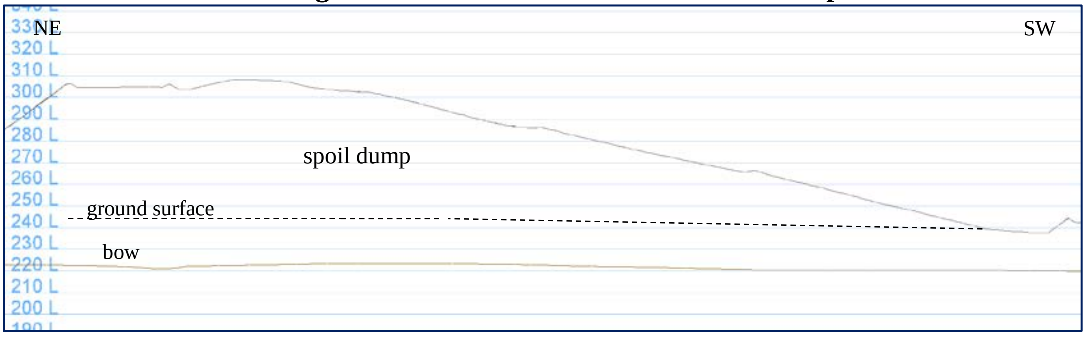
Figure 21: Cross Section MV7 - D Pit dump



These slopes formed as per the standard design can be considered to be inherently stable for the long term in regard to potential mass failure. In terms of environmental stability they will be subject to ongoing surface erosion which will gradually over millennia flatten the batter angle of the faces.

The outer face of the E Pit dump has been re-graded and rehabilitated; Figure 22 below shows the final profile at 1 in 4 slopes with nominal 5m berm, giving an overall slope angle of 13^0. There is no risk of mass failure with re-graded slopes at this angle.

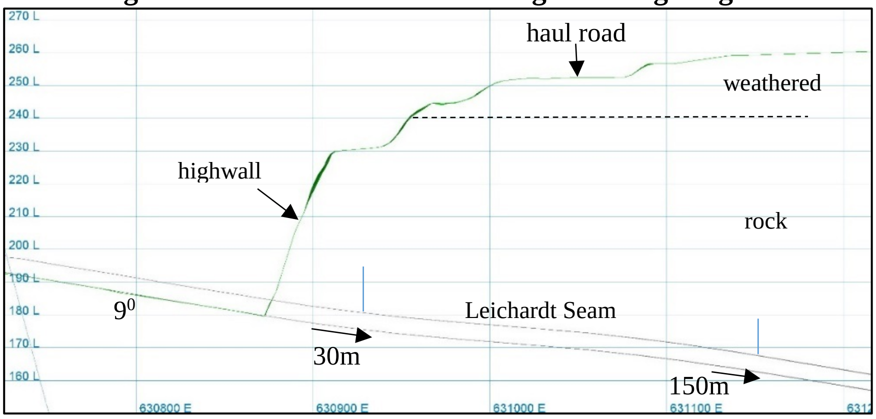
Figure 22: Cross Section MV6 - E Pit dump



6.3 Highwall Augering

Highwall augering has been carried in the northern half of E Pit North with a double row of holes in the Leichardt Seam. The location of the mined block, along a section of highwall between two faults, is shown in Figure 15. A cross section through the highwall is shown in Figure 23 below.

Figure 23: Cross Section MV2 - highwall augering



Full penetration of 200m was not achieved due to the presence of an unknown fault running at an angle behind the highwall, penetration depths being between 30m and 150m. Many of the holes would have extended under the haul road along the crest, but stopping a long way short of the perimeter drain and levee, which is approximately 200m back from the crest.

Augering is planned at other locations in D Pit highwall but these are of very limited lateral extent, being confined between faults, and would not be wide enough to present a risk of long term extensive pillar creep or subsidence.

The implications of augering with respect to the long term stability of Millennium Pit highwalls is discussed in Section 5.3 and the same comments apply to E Pit although the FoS are probably higher in E Pit since the web widths would have been conservative, being designed for full penetration.

Consideration is also being given to possible highwall mining in D Pit. There are no structures behind the highwall, other than access roads, that would be affected by any long term subsidence of pillars. Any pillar collapse at the portal should not result in deep-seated failure of the highwall, any slumping or collapse being most likely confined to the lower rock bench.

7. ENVIRONMENTAL STABILITY

The preceding section on geotechnical stability refers to the possibility of mass failure of the slope. However, regardless of the overall stability, there will be a residual effect of slope degradation due to weathering and erosion, referred to as environmental stability.

Differential weathering – E Pit

The Permian Rangal coal measures are prone to slaking, in particular the siltstone, which slakes and falls as fines continuously from the highwall. This action undercuts the harder more durable sandstone beds and leads to ongoing rockfall. Observations of highwalls at Burton Mine suggest a degradation rate of 40mm to 50mm per year on the highwall, equivalent to 1m after 20 years.

Photo taken 10/05/2017

In the long term the entire highwall face will move back, however it should still maintain its profile as the harder bands act as reinforcement within the slope. This process has no impact on the geotechnical stability of the highwall and as there are 25m berms at rockhead there is no risk of undercutting the upper weathered benches. The ongoing rockfall hazard means that people should not enter final voids.

The weathered rock and the thin cover of superficial deposits in the upper benches is likely to be slake susceptible and dispersive, and will gradually degrade to a flatter slope angle. There is ample room on the rockhead berm to allow this process without significant displacement of material into the void. The only exception is where fault wedge failures have occurred, for example D Pit South, where the wedge has cut back through the rock berm and is undercutting the weathered material above. In these cases rilling of weathered rock will run down the wedge into the void.

As the softer weathered rock and superficial deposits at the crest will degrade, especially if there is surface or concentrated run-off over the edge, allowance should be made with the placement of bunds or fences (see Section 9). Run-off over the rock edge is unlikely to have any detrimental impact of the rock face.

Fresh rock spoil is blocky with little fines but the rock slakes and breaks down so after 12 months or more the blocks are less apparent and there is a significant amount of fines. Aging spoil dump surfaces will be susceptible to erosion from surface run-off with a possibility of 10% loss of fines. This would apply to untreated low wall dump faces or other in-pit dumps. In these instances this would result in fines reporting to the enclosed void, which is inconsequential. Outer dump faces are to be re-graded and rehabilitated with rock mulch and grassed which will reduce the potential for downward migration of fines.

8. WATER MANAGEMENT

There is higher ground to the north of Millennium Pit with run-off mainly going into New Chum Creek which flows to the south between the Millennium Pit and Mavis Pit opencut areas. A levee runs along the B Pit eastern highwall to protect the opencut operations from flooding in New Chum Creek. This will not be needed for that purpose at the end of mining, however it may be advisable to retain it to prevent direct run-off over the highwall.

Run-off over the highwall should have no impact on the stability of the rock benches – no areas of potential mass instability have been identified – but concentrated run-off will erode and gully the upper free-dig benches in weathered rock. This should not result in slope failure but gullying will tend to eat back from the crest over time.

As discussed in Section 5.3 the highwall augering in the east wall stopped well short of the New Chum Creek levee and hence would not create any potential for subsidence issues.

Run-off towards the A Pit north wall is intercepted by a catch drain and directed round the pit towards the south-west. A permanent drain and bund will be needed to prevent uncontrolled erosive discharge over the highwall, or alternatively, a rock-lined discharge point could be cut into the crest to direct run-off into the pit at a given location. The potential for subsidence damage may need to be taken into account in the event that highwall mining of the north and west walls penetrates far enough to undermine any flood protection drains and bunds.

A drain runs along the south highwall at the base of the Mesa, directing run-off to the west via a vee-drain. As the top benches of the south highwall are to be left exposed, this drain will form part of long term water management.

The ground behind D Pit highwall slopes to the north-east or east-northeast, away from the highwall such that long term run-off would be limited to the immediate crest area and haul road. At the northern end of D Pit there is drainage towards the highwall and a discharge point would need to be considered to control the flow into the pit.

Water draining south off the small mesa is by a drain that runs south along E Pit highwall but well back from the edge. The E Pit highwall augering did not penetrate as far as this drain. The drain will eventually discharge into S Pit void, together with general run-off from behind the highwall. S Pit is a current mining area and the highwall was not exposed at the time of the slope assessment inspection. A review of the final highwall condition should be undertaken to check that there are no major instability issues with respect to discharging run-off over the highwall, given that there is a predicted major fault close to the proposed highwall location.

In general terms, water management is not seen as presenting a risk to geotechnical stability as run-off scouring would have only a limited impact on the stability of the highwall due to the lack of easily eroded unconsolidated material and the presence of hard rock layers in the weathered zone. No action would be needed with respect to the overall stability of the final void, other than a small bund, minimum height 1m (or 0.5m above the predicted 1 in 100 flood level if this is applicable) around the highwalls in order to limit the run-off area behind the crest. Exclusion bunds, as discussed in Section 9, may be used for this purpose.

Notwithstanding the low geotechnical risk, there is nevertheless a potential for concentrated run-off over highwalls in some places which is likely to cause erosion damage in the top benches in softer material without having any significant impact on the stability of the rock benches. Training run-off around the affected areas with bunds and drains is an option for limiting this but for long term effectiveness it is preferable to run with the flow as water will eventuate find the direct gravitational pathway.

In these cases where the general flow direction is towards the highwall, run-off could be directed into rock-lined discharge points over the highwall, or alternatively be allowed to drain freely over a wider area through gaps in a boulder-size rock exclusion bunds, as mentioned in Section 9.

Run-off pathways may develop over time in the internal spoil dump faces as water drains towards the pit and these would result in minor scouring of fines, as the spoil appears to be liable to dispersion, but would not prejudice the stability of the dump.

9. EXCLUSION

All abandoned pit walls contain some residual risk to people standing beneath or climbing on them. There is an obvious risk of rockfall with steep rock slopes as the faces weather and joint-bounded blocks can be released but there is also a risk of boulders on flatter or re-graded slopes weathering out or being washed out and rolling down the slope.

It is not practicable to treat slopes to entirely eliminate such hazards. The approach taken is minimize the likelihood of such hazards by re-grading slopes that present a significant risk, as described in the preceding sections, and then restrict access to the pit itself. This is achieved by bunding off the access ramps and placing exclusion bunds along final void highwalls.

It is understood that the entire mining area is fenced off to restrict access, however a more durable physical barrier is advisable around the voids to restrict access to the crest of pit walls as the edges will become eroded, crumbly and ill-defined over time. Limits of access should be marked by a bund wall and signs. Bund walls for this purpose should have a minimum height of 2m and should be constructed of non-dispersive material, or alternatively by placing large rocks which would prevent vehicular access without constricting run-off if water is being directed into the void.

Exclusion bunds need to be located at adequate distances from the highwall edge to avoid damage from slope failures or degradation, but from a psychological perspective should be close enough to allow the hazard to be seen or identified from the bund. There are no official guidelines in Queensland pertaining to the appropriate location of exclusion bunds, however the following generic guidelines have been developed, based on unpublished comprehensive studies of opencut voids at German Creek by Ward[4] and at Oaky Creek by Klenowski[5].

1. Highwalls that are geotechnically stable:

Inside edge of bund to be offset 10m from projected lines as illustrated below:

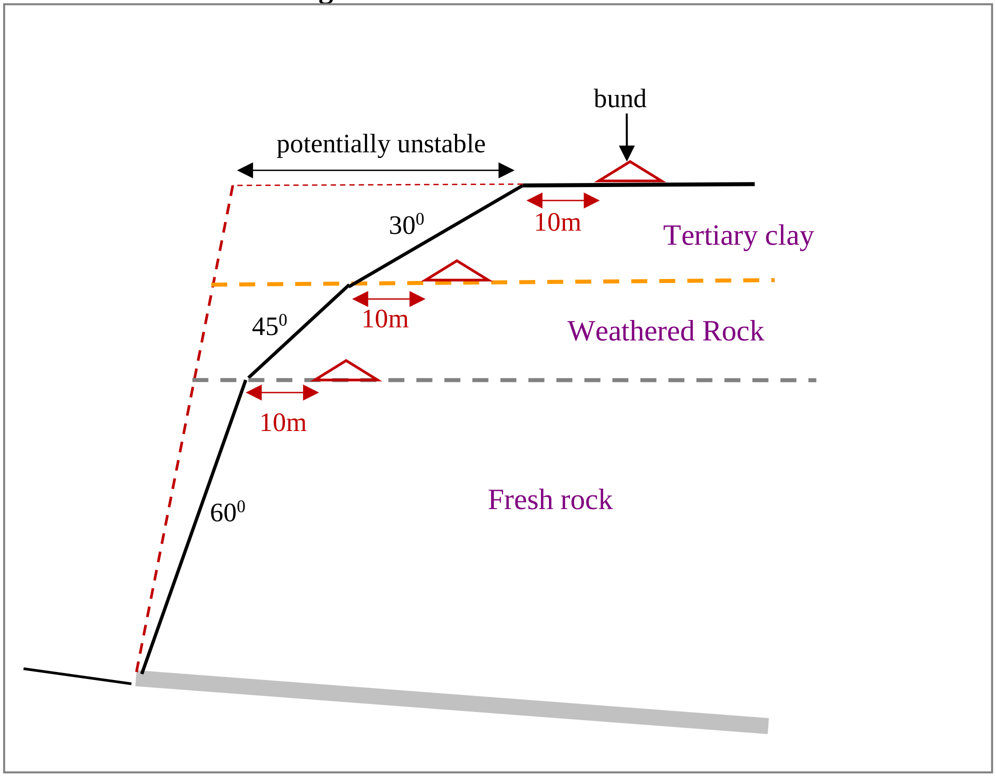
- 60^0 from toe for fresh rock;
- 45^0 from base of weathering through weathered rock;
- 30^0 from base of Tertiary to surface.

This is illustrated diagrammatically in Figure 24 below. Any part of the highwall profile steeper than the projected lines is deemed potentially unstable with regard to the possibility of failures cutting back into the crest and the bund is to be located 10m back as shown.

[4] Ward B 'Slope Design for Long Term Stability at German Creek Mine' Geotechnical Consulting Services Pty Ltd, Report No.109, Feb 1999 (Report for Capricorn Coal Management)

[5] Klenowski G 'Report on Highwall Safety Bunds for Final Voids at Oaky Creek Mines' Australian Mining Engineering Consultants, Mar 2017 (Report for Glencore Coal Queensland)

Figure 24: Bund Location Guide



The bund location relative to the actual crest is thus determined according to the thickness of the three material types present in the highwall, and the projected angles.

2. Highwalls with a history of slope failure or with a potential for slip failure:

Inside edge of bund to be offset as follows:

- existing failures - 5m back from the farthest tension crack;
- potential failures - 5m back from the location of the backscarp for the most critical slope failure path;
- rock slopes subject to structural disturbance with closely spaced discontinuities - at the point defined by where a line drawn at 50^0 from the toe of the slope meets the ground surface (that is 50^0 line instead of the 60^0 line in Figure 24).

These cases need to be assessed on an individual basis to check the failure geometry. Slopes where the dip is towards the face such that block slippage is possible have the potential to fail a long way back from the crest. Where failure is a result of movement on major discontinuities such as fault planes or combinations of faults and major joint planes, the distance back into the crest may be determined by the failure geometry.

There is very little if any Tertiary in the highwalls at the Millennium Mine complex, the only significant Tertiary thickness occurring under the mesas. The bund location will therefore be governed by the weathered rock profile. At Millennium Pit the standard design is for a 45^0 top bench so the bund would normally be located 10m back from the crest. In some cases, however the batter has been undercut to a steeper angle, for example B Pit north wall (see p.12) in which case the bund should be 10m back from a projected 45^0 line, or to make it simple 15m back from the crest.

In the case of Mavis Pit with a double undercut bench, the bund should be 10m back from a projected 45^0 line from the toe of the upper bench, again 15m back from the edge would provide a general approximation.

The only case of major instability is at the fault intersection in the south wall of A Pit (see **p.10**), where a large tension crack is visible in the access road. The criterion here would be 5m back from the tension crack or 10m back from a projected line from the base of weathering in the highwall face, whichever is the furthest back.

The foregoing is primarily directed at reducing the risk to people. At the Millennium opencut consideration is being given to post-operational use for agricultural purposes, specifically for running cattle. In this situation cattle could have free access to partially filled voids where grass is growing, and in particular, to within close proximity of abandoned highwall faces. Although over time it is likely that small scree slopes will form at the toe of exposed rock walls from weathering which will inhibit growth and thus discourage cows from foraging close to the wall.

Protection of personnel from rockfall hazards during mining operations is by means of a 10m wide exclusion zone at the toe of the wall which is normally marked by a small bund; cognisance of risk is obviously not an appropriate control for animals. Protection for animals (and landowners) could be addressed by a physical barrier along the exclusion zone such as an agricultural type wire fence. However, given the very low likelihood of occurrence and the low level of consequence, protective measures may not be justified and the decision to install fencing may be left to the landowner.

10. CONCLUSIONS

- The standard slope designs meet the EA requirements for as-constructed pit slopes to be geotechnically stable with regard to the ground conditions at the Millennium Mine complex;

- The highwalls are inherently stable against mass failure but local instability can occur where fault planes daylight in the wall and any new exposed final highwalls should be subject to geotechnical inspection to check for geological structure that could give rise to instability;

- Major wall failures due to faulted ground are present in the final south highwall in A Pit and at the wedge in D Pit but these failures are localised and fault-constrained and do not prejudice the overall long term stability of the highwall;

- The ‘rough-cut’ upper benches in Mavis pits are individually too steep for long term environmental stability and will degrade through gullying and erosion into lower angle rill slopes or in the case of the northern end of D Pit with the harder bands causing toppling failure,, could continue to eat back randomly into the crest;

- Pushing down the ‘rough-cut’ upper benches would be a means of preventing the continuous toppling cut-back effect on the crest;

- In-pit low wall dumps are stable with a more than adequate long term Factor of Stability, including a condition of partial submergence to the predicted 10 year water level;

- Historical instability in the low wall has been counter-acted by floor treatment and by avoiding dumping on the steeper floors, or by buttressing the spoil against the highwall;

- The external dump slope for E Pit and most of the south dump over the former C Pit have been regraded and rehabilitated in accordance with the EA specifications but the external slopes of other out-of-pit dumps are as-constructed with angle of repose batters and are not compliant with the final void requirements;

- The dump faces that require re-grading are the bottom bench of the south dump along the lease boundary, the West Dump, the small OP5 Dump and the whole of the external slopes at D Pit;

- There are no issues relating to potential risk of geotechnical instability due to run-off entering the void;

- The spoil has a susceptibility to slaking resulting in low plasticity fines which have a strong dispersive reaction which will wash down into the void;

- Highwall augering (and highwall mining if undertaken) has the potential to cause subsidence or collapse the highwall if the pillars fail due to long term creep;

- The highwall augering has not penetrated far enough back from the highwall to undermine any significant structures such as levees, so that any potential long term surface subsidence should not present any significant concern;

- Any subsidence induced face failure is only likely to impact on the lower rock bench, with material collapsing into the void, and should not extend back far enough to prejudice the upper benches through the weathered part or the crest.

11. RECOMMENDATIONS

The general findings of this study are that there are no significant issues in regard to mass slope instability and as a consequence there are no specific recommendations for remedial treatment. However mining is still underway in a number of places. A further review of highwall and ground stability is recommended for the following cases.

- The final A Pit north and A Pit west highwalls, and any new section of D Pit highwall, to be inspected and checked for any structural instability.

- Sections of highwall subject to highwall mining to be checked for potential damage from undermining and monitored (see below) with photographic recording immediately after mining and 12 months later.

The softer upper benches in weathered material will be subject to environmental instability with erosion from weathering and run-off. Consideration should be given to options for treatment of the following situations.

- Run-off management where the natural flow is towards the highwall at the northern end of D Pit and also A Pit north wall and A Pit south wall at the base of the Mesa where there are permanent drains. There may be a case for long term management by directing water flow over the highwall into the void by means of a rock-rubble drain or by diffusive flow through a permeable bund.

- Erosion of free-dig upper benches from weathering of over-steep batters. The slope will degrade over time to become self-stabilising or in the case of D Pit north, the crest may migrate back through toppling type degradation. There may be a case for pushing down the batters to a flatter angle which would reduce the potential for uncontrolled eating back into the crest. This would be recommended in any case if there was any a risk of animals or people using the surface area in front of the exclusion bund as otherwise the edges could be crumbly and unstable.

One means of monitoring the performance of the residual slopes over time is through photographic records. The recommendation would be to undertake drone surveys at say 5 year intervals (plus a survey after 12 months of completion of any highwall mining to check for pillar creep damage), with oblique shots of highwalls to show the overall aspect and condition. This would provide a means of monitoring areas of ongoing environmental degradation. Oblique shots of the dump faces and upper surfaces could be used to monitor the performance of rehabilitation practices and identify any unplanned areas of erosion.

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