WHITEHAVEN COAL LTD

Long-Term Geotechnical Stability of Highwalls and Endwalls at Blackwater Mine

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1. INTRODUCTION AND SCOPE

This report describes the results of a pit wall stability study for residual voids at Blackwater Mine undertaken for the purpose of informing development of the site's Progressive Rehabilitation and Closure Plan (PRCP) incorporating the final landform version LF#4.4.

The PRCP Guideline (Queensland Government, 2024) requires that the rehabilitation planning part of a PRCP include a void closure plan that in turn includes "*pit wall geotechnical and geochemical stability, considering the effects of long-term erosion and weathering of the pit wall and the effects of significant hydrological events*". This report addresses geotechnical stability of excavated pit walls (highwall and endwalls). Geochemical stability and erosional stability of spoil walls (lowwalls) are addressed as part of other specialist studies.

1.1 Limitation

This report has been prepared by Henderson Geotech Pty Ltd for Whitehaven Coal (Client) for the purpose of supporting preparation of Progressive Rehabilitation and Closure Plan for Blackwater Mine. It shall not be used or relied on for any other purpose. No parties other than the Client and the Department of Environment, Tourism, Science, and Innovation (DETSI) are authorised to rely on this report without the prior written consent of Henderson Geotech Pty Ltd.

This report is, in part, based on information provided by the Client or by other parties on behalf of the Client (Client-supplied information) in addition to data collected by Henderson Geotech Pty Ltd from the public domain. Henderson Geotech Pty Ltd has not always verified the accuracy of such information and makes no representations regarding its accuracy. Henderson Geotech Pty Ltd is not responsible for the consequences of any error or omission in Client-supplied information.

Henderson Geotech Pty Ltd has prepared this report in a manner consistent with the level of care, skill and diligence ordinarily provided by members of the same specialist field for projects of a similar nature and at the time and in the jurisdiction where the services were rendered. Henderson Geotech Pty Ltd makes no warranty, express or implied.

The outcomes described in this report are applicable only to the scenarios and inputs also described herein. A new assessment will be required if there are:

- Non-trivial changes to the location or geometry of the planned residual voids;
- Changes to proposed post-mining land uses of the voids or adjoining lands;
- Substantial changes to the understanding of stratigraphy or geotechnical properties; or
- Substantial changes to the understanding of end-of-mining and long-term groundwater levels or long-term pit lake levels.

2. BACKGROUND AND STUDY METHODOLOGY

2.1 Definition of Geotechnical Stability

The Macquarie Dictionary includes as definitions for “stability”: “firmness in position”; and “resistance to change, especially adverse change”. The Merriam Webster includes “strength to stand or endure”[1]. Note that these definitions do not require no change but do imply a threshold at which the change would be undesirable. Thresholds in turn attach to functions: for example, in the context of residual voids, what is ‘undesirable’ for water storage on a grazing property would be less onerous than that for a public recreational facility.

Practitioners take the term “geotechnical” to relate to mechanisms involving physical strength of soil and rock at an engineering scale. That is, it addresses mass movement triggered by mechanical disequilibrium between strengths and loadings. General landform erosion, which is cumulative surface transport at the particulate scale, is a different process.

In summary, for the purposes of this report, geotechnical stability is the state where mass movement related to the interaction of loadings and strength behind the wall face does not inhibit the post-mining land use of the land surrounding the void.

2.2 Mechanisms of Wall Instability

A typical highwall in the Bowen Basin comprises soil and geologically recent sediments (mainly Tertiary) overlying weathered Permian coal measure rocks, followed by fresh (unweathered) coal measure rocks down to the coal seam in the base of the wall. The characteristics of slope instability are different depending on which part of the overburden profile dictates geotechnical performance.

2.2.1 Instability in the Tertiary/Weathered Overburden

In general, the Tertiary and highly to completely weathered strata behave essentially as soil – the strength is low enough that failures will occur through the material mass, and structures such as joints and faults are rarely significant. Rockmass (or earth-mass) failures tend toward planar slip surfaces for granular soils and circular surfaces for clayey material (Figure 1). A common variant of mass failure in clayey overburden occurs when tension or shrinkage cracks open behind the wall face and subsequently fill with rainwater. The water exerts outward pressure that has to be resisted by shear strength (Figure 2). This situation is exacerbated if water also seeps into the clay and weakens it. PW Baker and Associates (2006) concluded that cracking and wetting was the predominant mechanism for instability in Tertiary and weathered overburden. However, observation in the years since then suggests that the wetting/weakening facet is not widespread and usually requires the pit to contain water higher than the base of weathering for an extended time.

[1] Stability Definition & Meaning - Merriam-Webster, accessed 16/12/2021.

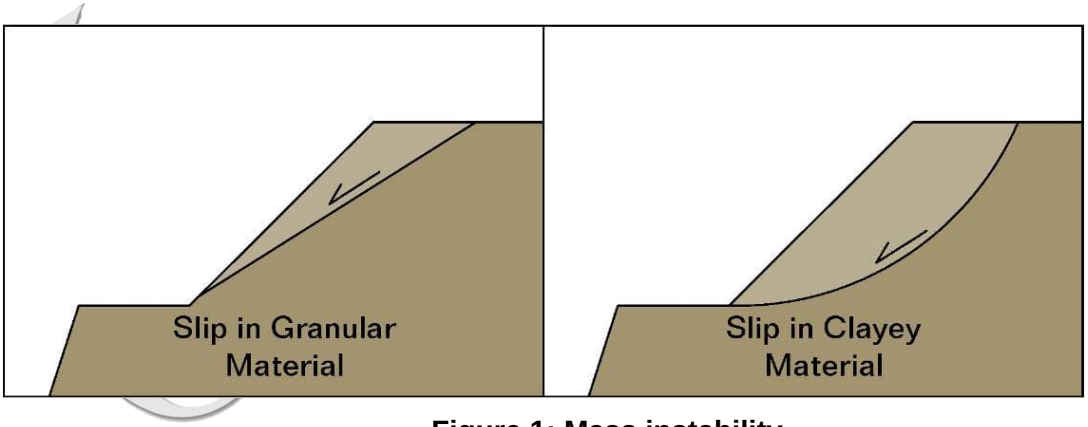


Figure 1: Mass instability

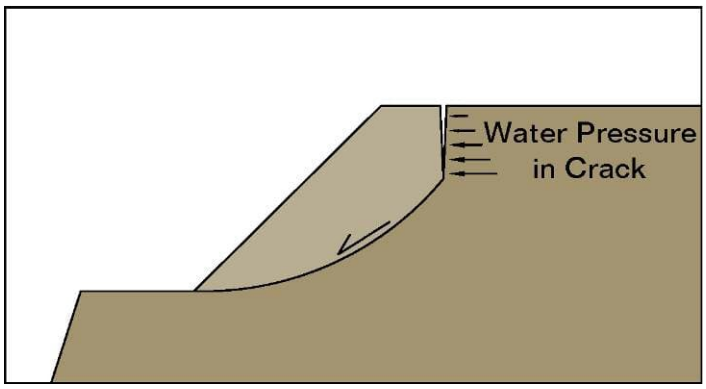


Figure 2: Mass instability with water-filled cracks

2.2.2 Instability dominated by fresh overburden

By contrast, within the fresh overburden instability generally occurs along weaker planes (defects) such as joints and faults. A common type of failure is when defects combine to define a wedge that can slide out of the wall (Figure 3). When distinct defects intersect, as is characteristic in localised 3D wedges, instability usually occurs as, or at most a few years after, the wall is excavated; hence it is addressed during mining operations and would rarely manifest after mine closure. When there are closely spaced defects such as joint sets, it may not be necessary for them to fully intersect to cause instability. Rather, they provide enough planes of weakness that the overall strength of the overburden is effectively reduced; slip surfaces can develop at least partly through the rockmass, although often in combination with distinct larger defects and weaker strata. This second type of composite wedge failure is the most common mechanism for pit wall failure and of most relevance to stability after closure, because it might take time for shears zones to develop (although observation of 20-year-old pit walls suggests that this is not a widespread occurrence). Bedding planes are another ubiquitous type of defect; however, being aligned with the coal seams, they normally dip into the highwall and so are not prone to causing instability except where local deformation has reversed the dip.

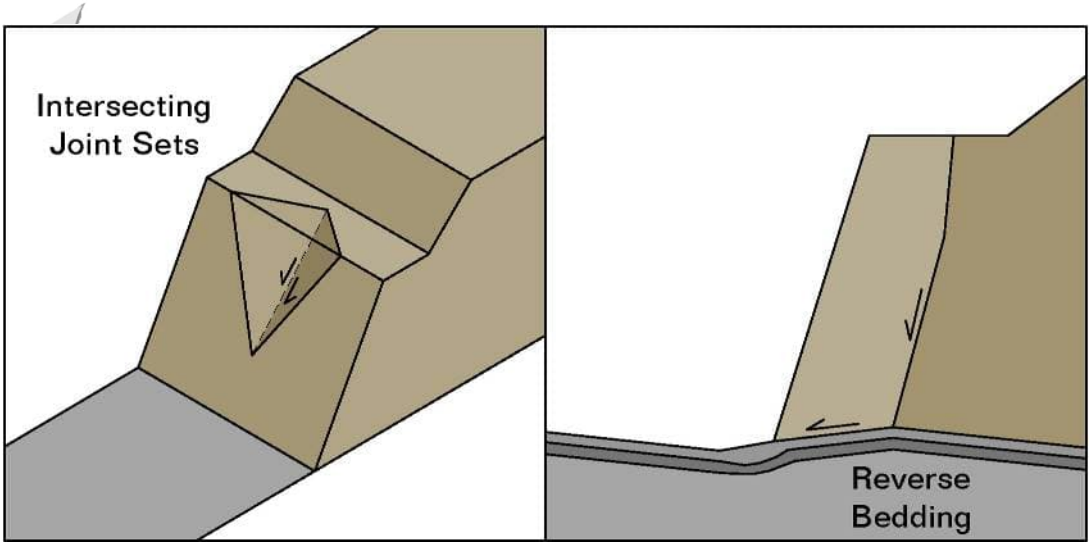


Figure 3: Defect controlled instability

Another mechanism is toppling failure, where the geometry is such that blocks can simply fall away from the defect rather than sliding along it (Figure 4). Once again, this mechanism is usually apparent, and dealt with, as mining occurs. In order for toppling failure to first occur after mining, there would need to be a set of persistent steeply dipping joints that had not been recognised and an underlying stratum that would crush or compress sometime after mining and cause that the blocks rotate outwards to the point of tipping. There is a final related mechanism – collapse - where bearing failure of a lower stratum (such as due to highwall mining or water-related weakening) initiates a slip encompassing overlying rock (Figure 5).

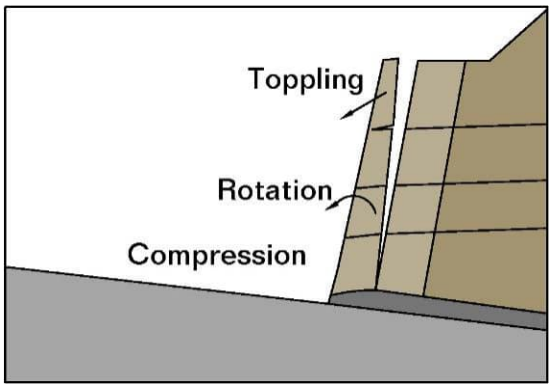


Figure 4: Toppling instability

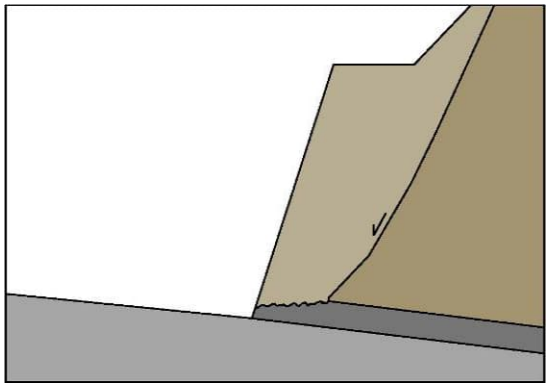


Figure 5: Collapse instability

Most types of instability in excavated walls are self-limiting in that the profile after failure is more stable than before, due to reduction in the average wall slope and to the slipped material partly supporting (buttressing) the wall. Exceptions are crack- initiated failure in clayey Tertiary and weathered overburden, and toppling failure in unweathered overburden. This is because both types of failure leave a steep new wall face behind which the same mechanism could develop, although the buttress effect of the failed material may still mitigate future instability.

2.3 Quantification

In theory, there are several broad industry accepted methods available to geotechnically assess and quantify risk of instability including:

- Limit equilibrium – compares forces on a surface with (limiting) strength if it was at the point of failing. Defects may be included explicitly as discrete strata when known, but more often are implicit within the strengths of broader material layers. Its main disadvantage is that the method assumes that all material along the surface can realise its peak strength at the same time; the significance of any consequent inaccuracy depends on the load-deformation behaviour of the particular materials.
- Kinematic assessment – the orientation (dip and strike) and distribution of various defects are plotted using stereographic projection and the result is examined to determine whether the defects can combine to 2D or 3D wedges that could slide out of the wall face. Normal geological and geotechnical drilling for open cut coal mines does not produce sufficient data for stereographic projection and hence this method is mainly used to review or refine stability assessment for pit walls once they are excavated.
- Displacement (deformation) analysis – movement of the wall face, or parts thereof, is obviously the parameter most directly related to function and safety. However, movement is caused by the interaction of force and strength on the stiffness (deformability) characteristics of the overburden materials. That is, analysis of movement requires knowledge of an extra set of geotechnical properties and more complex analyses. In addition, the correlation between load (force) and movement usually becomes very steep approaching failure so that small inaccuracy in the properties can produce large errors in predicted outcomes. Consequently, deformation analysis is rarely used for design in place of more simplistic but convenient and widely accepted limit equilibrium.
- Observation and measurement – most operational pit wall designs are at least partly based on observation of the performance of existing walls excavated in similar materials. However, at present this is largely based on undocumented experience of the particular geotechnical practitioner or team and so may be perceived as not sufficiently objective to provide quantifiable design criteria. This may change in the future, if observations by different practitioners and of different walls can be collated into a shared database.

In conclusion, although limit equilibrium is not the most rigorous or direct means of assessing geotechnical stability, it is currently generally accepted by industry as the most practical method available and so has been adopted for the PRCP for Blackwater Mine.

Factor of Safety computed by limit equilibrium is essentially a ratio of the strength available to hold a slope in place divided by the loads tending to move, or destabilise, material behind the slope face. Thus, a factor of safety less than 1 indicates instability, and a value greater than 1 implies that the slope is stable because the capacity to resist slipping is greater than the forces promoting slipping. Factor of safety is a relatively coarse and simplified measure of stability that was devised to use as a design methodology. In this context, a minimum value somewhat greater than 1 is specified to allow for inaccuracies and uncertainties in both the method and the input data. When a slope is actually constructed, much of the uncertainty disappears – if a slope exists and is not moving then it is obviously stable under current conditions, regardless of any computed measure. The important consideration should then be whether there is potential for those current conditions to change in a way that would then adversely affect stability.

2.4 Application

As a design or performance criterion, the selected minimum factor of safety should be appropriate to the consequences if instability did occur, which in the closure context in turn relates to land use (Martin and Stacey, 2018 p125 & PW Baker and Associates, 2006 p30). A minimum factor of safety of 1.5 is often adopted for long-term stability of civil engineering features such as road cuttings and dam walls, that is, features with broad public access. By contrast, factors of safety of 1.2 and 1.3 are typically applied to operational design for coal mine pit walls, where stability is required for a shorter time and with limited human exposure. Because the selected factor of safety encompasses more than just variability in material properties, it does not map uniquely to probability of failure; however accumulated experience suggests that a minimum of 1.5 typically provides much less than 1% likelihood of failure while coal open pit mining operates at around 10% likelihood of failure.

Pending industry research to develop observational methods and consequence assessment for long-term pit wall stability, for closure planning Whitehaven has adopted a minimum factor of safety of 1.5 for highwalls and endwalls. However, a too-conservative approach could lead to an unnecessary increase in void area at the expense of adjoining higher value land uses. If all void walls were flattened back to where the factor of safety is 1.5, in more than 99% of the cases that would have been unnecessary additional land disturbance. Hence, Whitehaven is applying the minimum factor of safety not to the physical crest of the pit wall but to a distance set back behind the crest, such that there are no environmental or third-party assets of significant value within that set-back. Reasoning from the other direction, final pit walls have been located such that their computed set-back does not include any valuable assets. This is a no-regret approach for the purposes of closure planning that allows the flexibility to apply improvements in stability practice in the future.

2.5 Design tool

A common engineering approach, when it is anticipated that designs will be required for a large number of similar scenarios, is to undertake upfront a large number of analyses to cover the range of expected scenarios and collate the results into a design tool, for example design charts or empirical formulae or lookup tables. It is important to appreciate that such tools do not omit design analyses, it is simply that all the analyses are carried out first so that when a particular scenario is considered, the result is already available. Set-backs for long term pit wall stability at coal mines clearly lends themselves to this approach – regional geology is broadly consistent; mining methods constrain the range of efficient wall geometries; and given the number of pits and different planning horizons, there will be a large number of specific scenarios to address over time.

BHP, the previous operator of Blackwater Mine, developed a pit wall stability design tool, as detailed in Section 4.1, and the key features are summarised below. As discussed in Section 4, the tool was not applicable to Bonnie Doon, Laleham-R74 and Comet Downs East voids. Consequently, bespoke geotechnical stability analyses were undertaken for those voids using the same general approach and material properties as the design tool.

3. INPUTS TO ASSESSMENT - REGIONAL

3.1 Regional geology and geotechnical (strength) properties

In the Bowen Basin, predominantly Permian age coal measure sedimentary rocks are unconformably overlain by younger, mainly Tertiary age, sediments. At some locations, the latter contain laterally confined basalt that was deposited in the early Tertiary.

In the context of wall stability, the important geological boundaries are Base of Tertiary and Base of Weathering; however, for simplicity in the design tool, Tertiary and weathered Permian rocks were treated as one material. This is a conservative assumption for slightly weathered rock but as noted in PW Baker and Associates (2006, p7), differences between Tertiary and weathered Permian sediments are more a matter of degree than character.

Stability analyses forming the basis of the design tool used the wall geometry summarised in Table 1 which was based on consultation with the BHP Geotechnical Team and examination of preliminary final landforms for all BHP coal mines in Queensland. Assumed strength properties, presented in Table 2, were the default values suggested in the Geotech Design, Operating and Monitoring Manual (BHP, September 2020).

Table 1: Wall geometry covered by stability design tool

Aspect	Value range
Average wall angle in Tertiary overburden	35° (constant)
Depth of Tertiary/weathered overburden	1m to 100m
Bench width at base of Tertiary overburden	30m (constant)
Average wall angle in Permian overburden	40° to 70°
Depth of Permian overburden incl. 10m coal	50m to 400m

Table 2: Strength properties applied in stability design tool

	Cohesion (kPa)	Friction Angle (°)	Unit Weight (kN/m^3)
Tertiary/weathered	50	30	22
Fresh Permian	450	42	24
Coal	30	35	15

3.2 Effect of weathering

It is obvious that weathering affects the character and strength of rocks. However, weathering that has occurred over geologic time before the pit wall is excavated is automatically accounted for in the strength properties adopted for operational wall design and so has no additional geomechanical impact on rehabilitation and post-mining landforms. Hence, additional effects of weathering on long-term stability would only relate to weathering that might occur after cessation of mining.

There are two phases to weathering, physical degradation and chemical decomposition. Degradation starts almost as soon as the rock face is exposed and is essentially larger fragments or rock breaking down into smaller fragments. This breakdown, or 'slaking', is mainly caused by salt crystals adsorbing moisture and swelling, by clay minerals adsorbing moisture and swelling (although salts are usually involved as well) and less commonly by cementing minerals being dissolved in water. Rainfall and in-pit storage cause immediate slaking in susceptible materials but humidity can produce the same result over a couple of years. Because degradation depends so heavily on water ingress, it is largely restricted to the surface of pit walls and does not penetrate far enough to cause geotechnical instability. An exception may be when particularly moisture-sensitive rock is below the long-term void water level, but this is addressed by adopting saturated strength properties and therefore does not need to be considered separately.

Chemical decomposition involves reactions of the actual rock minerals to form different minerals (ultimately, clay minerals). Because it occurs at the crystalline/molecular level and only where water and other reactants can reach, chemical weathering occurs mainly at the rock surface and along joints and bedding planes, but even there, it progresses at a very slow rate relative to other processes. For example, reported rates of soil formation throughout the world range from 0.01 to 7.7 mm/yr, with an average of about 0.1mm/yr (Morgan, 2005). As weathering is what causes soil formation, this implies that weathering penetrates less than 1m depth in a hundred years.

Both forms of weathering occur fastest in hot wet climates – rainfall providing the necessary moisture, and high temperature promoting chemical reactions. The climate at Blackwater Mine is hot but not wet and as shown on the Peltier diagram in Figure 6, only "very slight" ongoing weathering is expected.

There may be very specific situations where even a very small amount of additional weathering might affect pit wall stability, most notably where weak degradable strata underlie more resistant strata. As the degradable material ravels and falls away, the harder layer loses support and may subsequently fall. This is generally a localised scenario that may only be apparent when the pit wall is excavated. Hence it cannot generally be planned for but will be assessed and managed at the end of coal extraction.

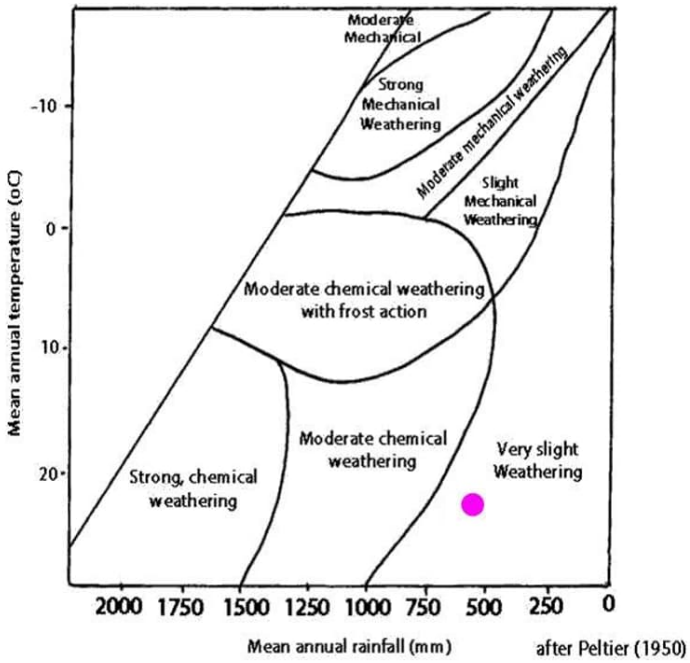


Figure 6: Weathering conditions at Blackwater Mine

3.3 Effect of long-term erosion

Erosion is the detachment of solid particles from the soil or rock mass and the subsequent transport of those particles away from their initial location. Most commonly, detachment occurs due to mechanical means – the impact of raindrops and the energy of flowing water – and the transport is also provided by flowing water. In this scenario, the severity of erosion depends on the character of the material – how easily particles are detached – and increases with catchment size and surface slope, both of which increase the volume and velocity of runoff flow.

In dispersive material, detachment can also occur by chemical means. In this case, the bonds and ionic charges within the material are such that clay particles will "disperse" into even static water that is not applying mechanical energy. However, flowing water is still required for the transport phase of erosion.

On highwalls and endwalls in the Bowen Basin, erosion in fresh rock is mainly limited to material that has already slaked because the intact rock is too strongly bound for particles to be readily detached. Above the base of weathering, particles are more easily detached. As particles are transported in water flow, erosion develops and progresses over time along flow lines and these are mainly perpendicular to the line of the wall. By contrast, slip failures involve surfaces that are at least sub-parallel to the line of the wall. Consequently, erosion rarely causes geomechanical instability. Even if an unusual arrangement of intersecting erosion gullies created the potential for a wedge-type failure, it would be addressed through surface water and erosion control measures rather than by slope stability design.

This prediction that weathering and long-term erosion will generally have little impact is supported by a study comprising visual assessment of 39 pit walls that were more than five years old which found that significant geotechnical instability was not correlated to wall age (Encompass Mining, 2018 and BHP, 2021). This is not to say that erosion is not a rehabilitation issue in its own right, but it is generally not a significant factor in pit wall geotechnical stability. Consequently, it has not been considered further in this study.

3.4 Effect of significant hydrological events

In Bowen Basin coal mines, weathered overburden is generally susceptible to softening when saturated, especially materials containing significant clay. Unweathered (fresh) coal measure rocks generally do not show significant strength loss on wetting, as evidenced by the large number of inactive pits that contain water without any noticeable change in wall stability. Some particular claystones/mudstones may be more sensitive to moisture but these tend to start slaking soon after exposure to humid air, and so are apparent during mining when wall designs can be amended to mitigate any impact on wall stability.

Water balance modelling for the proposed voids at Blackwater Mine predicts average and long-term void water levels many metres below the base of weathering. The long time series rainfall record used for water balance modelling included "significant hydrological events". Consequently, void water will only contact fresh rock and so will not affect geotechnical stability of excavated pit walls. The one exception was Comet Downs East Void, which was analysed separately.

The most serious potential impact of severe rainfall events would be inrush of floodwaters to the void. In theory, an initial inflow could scour a new channel through the ground between the

void and the watercourse, thus directing more water into the void at a greater flow rate. In practice however, this scenario will be prevented by including appropriate drainage diversions and landforms to protect the voids from inundation.

There is one other mode of instability related to water storage, namely draw-down failure. This can occur when pore water pressures in the containing earth and rock have equilibrated with the water level in the storage and that water level is then lowered quicker than the containing materials can drain, so that the pore pressures are no longer balanced out. This will not be an issue for voids to contain water passively or for normal stock water supply because evaporation and small capacity pumps will not lower the water level quickly enough to establish this imbalance. Stability under draw-down would be a consideration for PMLUs involving movement of large volumes of water, such as large-scale irrigation and pumped hydro energy storage, but such uses are not proposed for Blackwater Mine.

4. INPUTS TO ASSESSMENT - LOCAL

Long sections extracted from the current Blackwater Mine geological model provided void wall profile data as summarised in Table 3.

Bonnie Doon and Laleham-R74 voids have depths of fresh Permian overburden outside the limits for the design tool (refer Table 1), because both voids will be partly filled with tailings and covering much of the fresh Permian strata. In addition, auger mining had been carried out along part of the base of the Laleham R74 highwall. The predicted long-term pit lake for Comet Downs East void is above the base of weathering on the highwall, which is also inconsistent with the design tool. Consequently, bespoke stability analyses were undertaken for these voids.

For these analyses, one typical cross-section was considered for each void. More precise geotechnical profiles were used, in particular with Tertiary overburden and weathered Permian overburden differentiated. Pit lake levels were taken from SLR (2026 b) and hydraulic properties were broadly consistent with those in the calibrated hydrogeological model (SLR (2026 a). Strength properties for the additional materials required for these refinements are presented in Table 4.

Table 3: Geotechnical profiles for the residual void walls at Blackwater Mine

Geotechnical profile parameters		R08	Bonnie Doon	Mimose / Besgrove	Deep Creek	R30
Depth of Tertiary/ weathered overburden (m)	Average Range 90% less than	16 14 – 18	15 10 – 21 21	18 7 – 27 25	12 11 – 12 12	11 11 - 12
Depth of fresh overburden (m)	Average Range 90% less than	60 53 - 68	13 0 – 40 33	138 68- 175 169	118 90 – 147 145	72 70 - 72
Total Wall depth (m)	Average Range 90% less than	76 67 - 87	29 10 – 50 45	156 91 – 196 190	130 101 – 159 157	75 62 - 83

Geotechnical profile parameters		Stewarton North	Stewarton South	Tannyfoil	South Ballamoo	Kenmare
Depth of Tertiary/ weathered overburden (m)	Average Range 90% less than	15 11 – 24 21	20 15 – 24 24	16 12 – 23 21	61 45 – 81 77	47 38 – 53 52
Depth of fresh overburden (m)	Average Range 90% less than	152 68 – 202 197	104 59 – 126 123	114 79 – 135 132	192 148 – 224 222	106 82 – 124 120
Total Wall depth (m)	Average Range 90% less than	167 82 – 213 213	124 83 – 141 139	130 101 – 151 149	253 215 – 290 286	153 131 – 163 163

Geotechnical profile parameters		Laleham-R74	North Marshmead	South Marshmead	Kennedy West	Comet Downs East
Depth of Tertiary/ weathered overburden (m)	Average Range 90% less than	20 14 – 28 23	71 24 – 97 89	67 54 – 82 79	34 28 – 43 41	36 35 - 37
Depth of fresh overburden (m)	Average Range 90% less than	6 0 – 11 9	156 125 – 199 187	118 104 – 125 125	84 57 – 126 114	97 96 - 97
Total Wall depth (m)	Average Range 90% less than	26 22 – 30 30	227 169 – 270 260	185 157 – 206 204	118 90 – 167 148	134 133 - 135

Table 4: Additional strength properties used in bespoke analyses

	Cohesion (kPa)	Friction Angle (°)	Unit Weight (kN/m^3)
Unsaturated Spoil	40	30	18
Saturated Spoil	23	25	20
Unsaturated Tertiary	50	30	20
Unsaturated weathered Permian	75	30	24
Subsided Fresh Permian[@]	275	36.5	23
Tailings[#]	15	0	14

From BHP, 2020, except:
* cohesion assumed 40% value for unsaturated
[@] adopted properties mid-way between intact and blasted fresh Permian
[#] typical for normally consolidated saturated coal tailings with undrained load response

For the walls that were within the design tool limits, computations were made with two assumed wall angles, namely, 50° and 60°. Computed set-back from wall toe is not very sensitive to that parameter but steeper angles are slightly more conservative because they impose greater overburden weight on the potential slip surface.

4.1 Stability analyses

The procedure for estimation of set-back developed in the design tool is:

1. If D_{TW} =<47m, FoS_{TW} >=1.5 and $S_{TW} = D_{TW}/\tan(35°)$
2. Otherwise $S_{TW} = 2.58\ D_{TW} – 41.5$
3. $S_1 = S_{TW} + 30 + D_P/\tan(A_P)$
4. $FoS_P = 1.208 + 0.0655/\sqrt{D_{TW}} + 13.87/\sqrt{D_P} - 0.0168A_P$;
   if FoS_P >=1.5 then $S_P = D_P/\tan(A_P) + 30 + D_{TW}/\tan(35°)$
5. Otherwise, $S_P = 0.856D_{TW}^{1.15} + 3.727D_P^{0.94} + 39.35\tan(A_P)^{1.09} + 35.01FoS_P^{2.49} -389$
6. Required set-back from the wall toe = $\max(S_1, S_P)$

Where:

D_{TW} = depth of Tertiary/weathered overburden (m)

D_P = depth of fresh Permian overburden (m)

A_P = average wall angle in fresh Permian overburden (degrees)

S_{TW} = set-back for stability in Tertiary/weathered overburden (m), measured from the toe of the weathered overburden batter

FoS_{TW} = factor of safety for instability confined to the Tertiary/Weathered overburden

S_1 = set-back for whole operational wall design (m), measured from the toe of the whole wall

S_P = set-back for stability of whole wall (m), at FoS = 1.5

FoS_P = factor of safety for instability affecting the whole wall

The results for the pit set-backs computed using the design tool are tabulated in Appendix A and summarised in Table 5. The values in red show voids where the average factor of safety without set-back was less than 1.5, and therefore any adjoining PMLU must be set-back behind the wall. Note that when the factor of safety at the crest of the wall is greater than 1.5, the reported set-back from the toe of the wall is simply the distance from the toe to that crest.

Set-backs for endwalls will range from the value at the end of each highwall down to the value coinciding with the excavated wall crest as the exposed wall height reduces.

Table 5: Set-backs for long-term wall stability at Blackwater Mine (for pits using the design tool)

Geotechnical stability parameters		R08	Mimose / Besgrove	Deep Creek	R30	Stewarton North	Stewarton South	Tannyfoil
A_P (°)				**50**				
S_1 (m)	Average Range 90% less than	64 63 – 73 71	130 76 – 164 159	109 85 – 134 132	63 52 – 70	140 69 – 179 178	104 69 – 118 117	109 85 – 127 123
FoS_P	Average Range 90% more than	2.18 2.06 – 2.28 2.09	1.59 1.43 - 2.07 1.45	1.69 1.53 - 1.85 1.54	2.14 2.02 - 2.35	1.54 1.36 - 2.07 1.37	1.77 1.62 - 2.18 1.64	1.70 1.58 - 1.95 1.59
S_p (m)	Average Range 90% less than	104 95 – 113 111	180 20 – 248 236	146 121 – 171 169	100 89 – 107	207 107 - 295 290	146 113 – 157 157	148 122 – 166 163
Set-back from toe of wall (m)	Average Range 90% less than	104 95 – 113 111	180 120 – 248 236	146 121 – 171 169	100 89 – 107	207 107 – 295 290	146 113 – 157 157	148 122 – 166 163
A_P (°)				60				
S_1 (m)	Average Range 90% less than	44 39 – 50 49	90 52 – 113 110	75 58 – 92 91	44 36 – 48	96 47 – 123 122	72 48 – 81 81	75 58 – 87 85
FoS_P	Average Range 90% more than	2.01 1.89 – 2.12 1.92	1.42 1.27 - 1.90 1.28	1.52 1.36 - 1.68 1.37	1.97 1.85 - 2.18	1.38 1.20- 1.90 1.20	1.60 1.45 - 2.02 1.47	1.53 1.41 - 1.78 1.42
S_p (m)	Average Range 90% less than	88 81 – 96 94	176 102 – 249 236	136 98 – 180 175	83 76 – 88	201 89 – 298 293	124 98 – 142 138	129 99 – 161 153
Set-back from toe of wall (m)	Average Range 90% less than	99 91 – 96 94	176 102 – 249 236	136 98 – 180 175	83 76 – 88	201 89 – 298 293	124 98 – 142 138	129 99 – 161 153

Geotechnical stability parameters		South Ballamoo	Kenmare	North Marshmead	South Marshmead	Kennedy West
A_P (°)				**50**		
S_1 (m)	Average Range 90% less than	275 209 – 325 314	163 136 – 187 183	271 142 – 336 321	230 184-273 267	99 76 – 140 124
FoS_P	Average Range 90% more than	1.38 1.30-1.51 1.31	1.74 1.62 – 1.91 1.65	1.50 1.36 – 1.62 1.39	1.66 1.61 – 1.74 1.62	1.93 1.61 – 2.22 1.68
S_p (m)	Average Range 90% less than	355 263 – 434 423	186 169 – 198 195	291 186 – 389 367	225 194 – 251 247	149 125 – 195 173
Set-back from toe of wall (m)	Average Range 90% less than	356 277 – 434 423	186 169 – 198 195	298 186-389 367	232 194 – 273 267	149 125 – 195 173
A_P (°)				60		
S_1 (m)	Average Range 90% less than	224 143 – 271 263	132 94 – 158 155	229 98 – 296 279	200 157 – 241 234	68 52 – 97 85
FoS_P	Average Range 90% more than	1.22 1.14 – 1.35 1.14	1.57 1.46 – 1.74 1.48	1.33 1.19 – 1.45 1.22	1.49 1.45 – 1.57 1.45	1.76 1.45 – 2.06 1.51
S_p (m)	Average Range 90% less than	359 277 – 438 427	163 147 – 175 173	299 193 – 392 369	213 167 – 253 249	129 110 – 183 144
Set-back from toe of wall (m)	Average Range 90% less than	359 277 – 438 427	163 147 – 175 173	299 193 – 392 369	213 167 – 253 249	129 110 – 183 144

The relevant geometric parameters and results for bespoke analyses of Bonnie Doon TSF, Laleham-R74 TSF and Comet Downs East void are summarized in Table 6 and the graphic output for each section is included in Appendix B. For Laleham R74, a zone of subsided fresh Permian overburden was placed in the area affected by auger mining; however, this was not significant because the lower factors of safety occurred above the base of weathering. For both voids, the minimum factor of safety at representative cross-sections was greater than 1.5.

Table 6: Long-term wall stability for pits analysed by bespoke analysis)

		Bonnie Doon CH500	Laleham R74 CH1900	Comet Downs East
Tertiary overburden	m	12	10	24
Weathered Permian overburden	m	29	10	11
Water cover below base of weathering	m	24	4	-11
Water depth	m	5	7	107
Tailings depth	m	32	18	n/a
Assumed angle of draw	deg	n/a	60	n/a
Minimum FoS		2.02	2.22	1.08
Set-back from wall toe to FoS>1.5		crest	crest	165

5. IMPLICATIONS FOR RESIDUAL VOIDS

A computed factor of safety >1.5 implies that the required set-back from the wall toe is in front of the crest (that is, contained within the wall). Consequently, the crest itself may be taken as defining the boundary of the void NUMA. Where the factor of safety <1.5, the set-back approach to long-term geotechnical stability offers several options to meet the requirements for mine closure including:

1. Where the distance from the wall toe to crest equals the set-back distance, the wall has a Factor of Safety not less than 1.5 and no further action is necessary; otherwise
2. Stop the mining pit with the toe of each pit wall at least the set-back distance away from significant permanent assets including: lease boundaries, third-party infrastructure, and Matters of State Environmental Significance (MSES); or
3. Move the asset in question, for example to relocate a public road; or
4. Undertake more detailed geotechnical investigation and wall stability analysis to remove some of the conservatism imposed by the design tool; or
5. Investigate partially backfilling the residual void. In simple terms, this would reduce the (exposed) wall depth and depth of fresh Permian overburden, which would in turn reduce the set-back. However, partial backfill might result in a perched pit lake that acts as a source to groundwater.

It is expected that these options, and combinations thereof, will be considered on a case-by-case basis for highwalls and endwalls as each pit approaches its final location.

6. REFERENCES

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APPENDIX A COMPUTED SET-BACKS BEHIND HIGHWALLS

R08 Void

ID	D_{TW}	D_P	A_p=50°				A_p=60°			
			S_1	FoS_P	S_P	Set-back from toe (m)	S_1	FoS_P	S_P	Set-back from toe (m)
CH250	14	53	56	2.28	95	95	39	2.12	81	81
CH500	16	59	63	2.19	103	103	43	2.03	87	87
CH650	18	68	73	2.06	113	113	50	1.89	96	96

Deep Creek Void

ID	D_{TW}	D_P	A_p=50°				A_p=60°			
			S_1	FoS_P	S_P	Set-back from toe (m)	S_1	FoS_P	S_P	Set-back from toe (m)
CH500	12	95	90	1.81	127	127	62	1.64	102	102
CH750	12	147	134	1.53	171	171	92	1.36	180	180
CH1000	12	139	127	1.56	164	164	87	1.39	163	163
CH1250	11	90	85	1.85	121	121	58	1.68	98	98

R30 Void

ID	D_{TW}	D_P	A_p=50°				A_p=60°			
			S_1	FoS_P	S_P	Set-back from toe (m)	S_1	FoS_P	S_P	Set-back from toe (m)
CH500	11	72	70	2.02	107	107	48	1.85	88	88
CH750	11	70	68	2.05	104	104	47	1.88	86	86
CH1000	12	50	52	2.35	89	89	36	2.18	76	76

Mimosa-Besgrove Void

ID	D_{TW}	D_P	A_p=50°				A_p=60°			
			S_1	FoS_P	S_P	Set-back from toe (m)	S_1	FoS_P	S_P	Set-back from toe (m)
CH250	23	68	76	2.07	120	120	52	1.90	102	102
CH500	23	88	92	1.86	136	136	64	1.70	113	113
CH750	17	94	93	1.81	133	133	64	1.64	109	109
CH1000	22	97	99	1.79	142	142	68	1.63	117	117
CH1250	22	107	108	1.72	151	151	74	1.55	123	123
CH1500	26	111	114	1.70	160	160	79	1.53	131	131
CH1750	25	119	120	1.66	165	165	83	1.49	143	143
CH2000	25	127	128	1.61	173	173	88	1.44	159	159
CH2250	23	132	131	1.59	174	174	90	1.42	166	166
CH2500	21	75	80	1.99	122	122	55	1.82	103	103
CH2750	18	88	89	1.86	130	130	61	1.69	106	106
CH3000	17	165	152	1.46	223	223	105	1.30	223	223
CH3250	15	175	159	1.43	242	242	110	1.27	243	243
CH3500	19	163	153	1.47	222	222	105	1.30	222	222
CH3750	17	169	155	1.45	231	231	107	1.28	231	231
CH4000	18	169	157	1.45	233	233	108	1.28	234	234
CH4250	23	170	161	1.45	242	242	111	1.28	243	243
CH4500	25	170	164	1.44	248	248	113	1.28	249	249
CH4750	26	168	162	1.45	243	243	112	1.28	243	243
CH5000	27	163	160	1.47	235	235	110	1.30	235	235
CH5250	26	159	155	1.48	225	225	107	1.31	225	225
CH5500	21	155	148	1.50	210	210	102	1.33	210	210
CH5750	13	152	139	1.51	177	177	95	1.34	191	191
CH6000	9	147	131	1.53	166	166	90	1.37	176	176
CH6250	17	142	133	1.55	172	172	91	1.38	174	174
CH6500	17	139	131	1.56	171	171	90	1.39	170	170
CH6750	15	138	128	1.57	167	167	88	1.40	165	165
CH7000	16	135	127	1.58	166	166	87	1.41	161	161
CH7250	14	135	125	1.58	163	163	86	1.41	157	157
CH7500	13	132	121	1.59	159	159	84	1.43	150	150
CH7750	13	135	124	1.58	161	161	85	1.41	155	155
CH8000	10	138	124	1.57	160	160	85	1.40	159	159
CH8250	8	142	126	1.56	160	160	86	1.39	164	164
CH8500	7	147	129	1.54	163	163	89	1.37	172	172
CH8750	10	148	133	1.53	169	169	91	1.36	179	179
CH9000	14	148	136	1.52	174	174	94	1.36	184	184
CH9250	14	150	138	1.52	176	176	95	1.35	188	188
CH9500	13	146	133	1.53	171	171	92	1.37	178	178
CH9750	12	151	136	1.52	173	173	94	1.35	187	187
CH10000	13	148	136	1.52	174	174	93	1.36	184	184

Stewarton North Void

ID	D_{TW}	D_P	A_p=50°				A_p=60°			
			S_1	FoS_P	S_P	Set-back from toe (m)	S_1	FoS_P	S_P	Set-back from toe (m)
CH250	24	113	115	1.69	159	159	79	1.52	129	129
CH500	23	180	170	1.41	265	265	117	1.25	266	266
CH750	18	189	174	1.39	277	277	120	1.22	279	279
CH1000	18	193	178	1.38	286	286	122	1.21	289	289
CH1250	13	200	178	1.37	293	293	123	1.20	296	296
CH1500	11	202	179	1.36	295	295	123	1.20	298	298
CH1750	14	170	154	1.45	229	229	106	1.28	230	230
CH2000	14	127	118	1.62	157	157	81	1.45	142	142
CH2250	15	122	115	1.64	154	154	79	1.47	134	134
CH2500	14	125	116	1.63	155	155	80	1.46	138	138
CH2750	11	125	114	1.63	150	150	78	1.46	134	134
CH3000	12	133	122	1.59	159	159	84	1.42	151	151
CH3250	12	148	134	1.53	171	171	92	1.36	182	182
CH3500	13	182	164	1.41	254	254	113	1.25	256	256
CH3750	14	68	69	2.07	107	107	47	1.90	89	89

Stewarton South Void

ID	D_{TW}	D_P	A_p=50°				A_p=60°			
			S_1	FoS_P	S_P	Set-back from toe (m)	S_1	FoS_P	S_P	Set-back from toe (m)
CH250	24	59	69	2.18	113	113	48	2.02	98	98
CH500	15	126	118	1.62	157	157	81	1.45	142	142
CH750	18	120	116	1.65	156	156	80	1.48	135	135
CH1000	21	114	113	1.68	155	155	77	1.52	125	125
CH1250	19	106	105	1.73	146	146	72	1.56	118	118
CH1500	24	102	106	1.76	150	150	73	1.59	123	123

Tannyfoil Void

ID	D_{TW}	D_P	A_p=50°				A_p=60°			
			S_1	FoS_P	S_P	Set-back from toe (m)	S_1	FoS_P	S_P	Set-back from toe (m)
CH500	22	78	84	1.95	127	127	58	1.78	106	106
CH750	14	87	84	1.88	122	122	58	1.71	99	99
CH1000	12	89	85	1.86	122	122	58	1.69	98	98
CH1250	25	83	91	1.90	136	136	63	1.73	114	114
CH1500	24	107	109	1.72	153	153	75	1.56	125	125
CH1750	19	102	102	1.76	143	143	70	1.59	116	116
CH2000	14	109	104	1.71	142	142	71	1.54	114	114
CH2250	18	99	98	1.78	139	139	68	1.61	113	113
CH2500	15	107	102	1.73	141	141	70	1.56	113	113
CH2750	15	111	106	1.70	145	145	73	1.53	116	116
CH3000	15	119	112	1.66	151	151	77	1.49	129	129
CH3250	18	116	112	1.67	153	153	77	1.50	122	122
CH3500	15	121	114	1.65	153	153	79	1.48	133	133
CH3750	14	117	110	1.67	148	148	75	1.50	124	124
CH4000	14	122	114	1.64	153	153	79	1.47	134	134
CH4250	14	124	115	1.63	153	153	79	1.47	135	135
CH4500	14	125	116	1.63	155	155	80	1.46	138	138
CH4750	18	131	125	1.59	165	165	86	1.43	156	156
CH5000	17	129	122	1.61	162	162	84	1.44	150	150
CH5250	15	135	126	1.58	165	165	87	1.41	160	160
CH5500	15	134	125	1.58	164	164	86	1.42	157	157
CH5750	14	131	121	1.60	159	159	84	1.43	150	150

South Ballamoo Void

ID	D_{TW}	D_P	A_p=50°				A_p=60°			
			S_1	FoS_P	S_P	Set-back from toe (m)	S_1	FoS_P	S_P	Set-back from toe (m)
CH750	81	180	318	1.41	365	365	271	1.24	367	367
CH1000	74	190	309	1.38	375	375	260	1.21	378	378
CH1250	53	199	263	1.36	357	357	211	1.19	360	360
CH1500	56	214	282	1.32	395	395	226	1.16	399	399
CH1750	59	224	299	1.30	422	422	241	1.14	427	427
CH2000	71	220	325	1.31	434	434	267	1.14	438	438
CH2250	63	221	306	1.31	423	423	249	1.14	427	427
CH2500	58	219	291	1.31	409	409	233	1.15	413	413
CH2750	52	200	261	1.36	357	357	208	1.19	360	360
CH3000	59	185	267	1.40	338	338	219	1.23	340	340
CH3250	45	203	209	1.35	352	352	143	1.18	355	355
CH3500	66	173	273	1.43	322	322	228	1.26	323	323
CH3750	58	174	255	1.43	310	310	209	1.26	312	312
CH4000	50	165	226	1.46	278	278	183	1.29	279	279
CH4250	76	148	279	1.51	263	279	240	1.35	290	290
CH4500	60	156	245	1.49	277	277	204	1.32	277	277

Kenmare Void

ID	D_{TW}	D_P	A_p=50°				A_p=60°			
			S_1	FoS_P	S_P	Set-back from toe (m)	S_1	FoS_P	S_P	Set-back from toe (m)
CH500	49	82	153	1.91	169	169	132	1.74	147	147
CH750	49	106	174	1.73	189	189	146	1.56	161	161
CH1000	53	110	187	1.70	198	198	158	1.53	169	169
CH1250	38	124	136	1.62	189	189	94	1.46	175	175

North Marshmead Void

ID	D_{TW}	D_P	A_p=50°				A_p=60°			
			S_1	FoS_P	S_P	Set-back from toe (m)	S_1	FoS_P	S_P	Set-back from toe (m)
CH750	24	145	142	1.53	186	186	98	1.36	193	193
CH1000	26	150	148	1.51	194	194	102	1.34	207	207
CH1250	41	146	156	1.53	210	210	108	1.36	221	221
CH1500	58	139	224	1.55	229	229	188	1.38	238	238
CH1750	66	125	234	1.62	229	234	201	1.45	225	225
CH2000	70	129	246	1.60	238	246	213	1.43	239	239
CH2250	79	135	276	1.57	256	276	240	1.40	269	269
CH2500	88	134	297	1.57	268	297	262	1.40	284	284
CH2750	88	140	303	1.55	273	303	267	1.38	295	295
CH3000	74	163	285	1.46	317	317	243	1.29	318	318
CH3250	84	156	307	1.49	323	323	266	1.32	322	322
CH3500	95	151	329	1.50	292	329	290	1.34	331	331
CH3750	97	152	336	1.50	339	339	296	1.33	338	338
CH4000	87	163	319	1.46	341	341	277	1.29	342	342
CH4250	83	173	317	1.43	354	354	271	1.26	355	355
CH4500	78	176	309	1.42	353	353	262	1.25	355	355
CH4750	74	185	305	1.40	364	364	256	1.23	366	366
CH5000	70	196	304	1.37	380	380	253	1.20	383	383
CH5250	72	199	311	1.36	389	389	259	1.19	392	392

South Marshmead Void

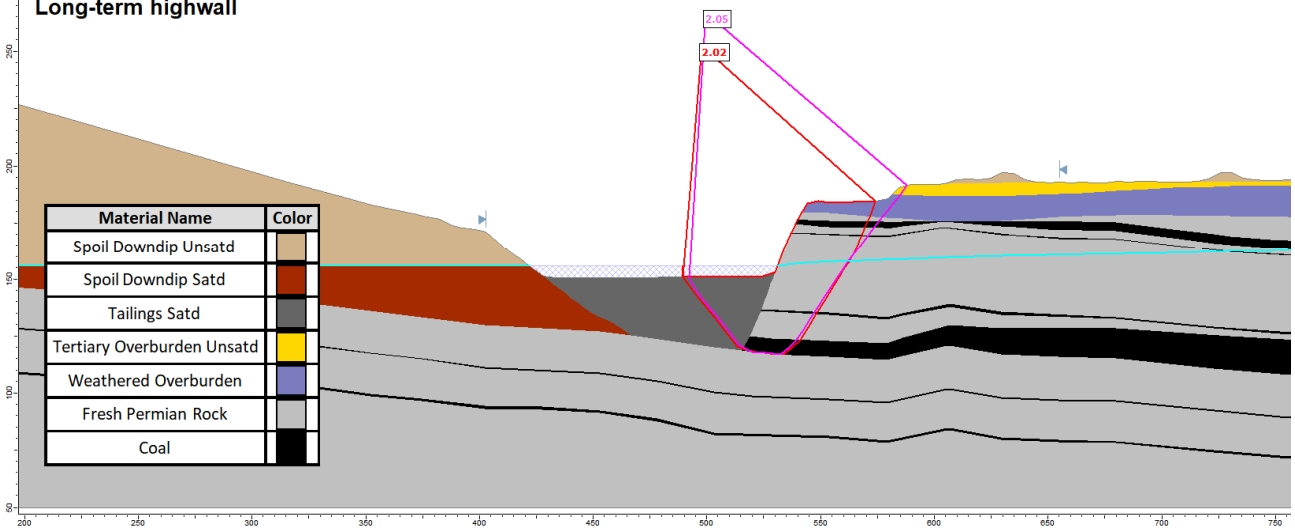
ID	D_{TW}	D_P	A_p=50°				A_p=60°			
			S_1	FoS_P	S_P	Set-back from toe (m)	S_1	FoS_P	S_P	Set-back from toe (m)
CH500	54	104	184	1.74	194	194	157	1.57	167	167
CH750	61	111	209	1.69	210	210	180	1.52	181	181
CH1000	63	118	221	1.65	220	221	190	1.48	208	208
CH1250	66	125	235	1.61	230	235	202	1.45	227	227
CH1500	76	125	260	1.62	244	260	227	1.45	244	244
CH1750	82	124	273	1.62	251	273	241	1.45	253	253

Kennedy West Void

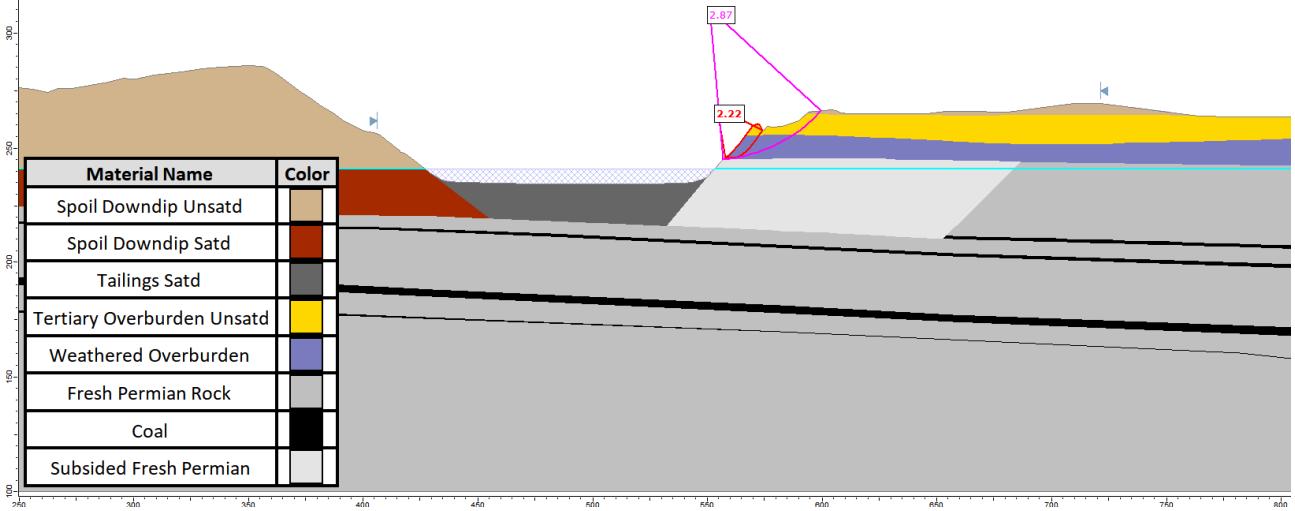
ID	D_{TW}	D_P	A_p=50°				A_p=60°			
			S_1	FoS_P	S_P	Set-back from toe (m)	S_1	FoS_P	S_P	Set-back from toe (m)
CH250	41	126	140	1.61	195	195	97	1.45	183	183
CH500	37	121	132	1.64	184	184	91	1.47	166	166
CH750	34	115	124	1.67	174	174	86	1.51	144	144
CH1000	31	111	119	1.70	168	168	82	1.53	139	139
CH1250	29	106	113	1.73	160	160	78	1.56	132	132
CH1500	28	99	106	1.77	153	153	73	1.60	127	127
CH1750	28	86	95	1.87	142	142	66	1.71	119	119
CH2000	28	79	89	1.94	135	135	61	1.78	115	115
CH2250	29	74	87	1.99	134	134	60	1.82	114	114
CH2500	31	64	79	2.11	127	127	55	1.94	111	111
CH2750	31	68	83	2.06	132	132	57	1.90	114	114
CH3000	31	63	78	2.13	126	126	54	1.96	110	110
CH3250	34	60	78	2.18	128	128	54	2.01	112	112
CH3500	33	57	76	2.21	125	125	52	2.05	110	110
CH3750	38	57	79	2.22	132	132	55	2.06	117	117
CH4000	41	65	89	2.10	143	143	61	1.93	126	126
CH4250	41	69	92	2.05	147	147	64	1.88	129	129
CH4500	43	79	103	1.93	158	158	71	1.77	137	137
CH4750	43	84	106	1.89	162	162	73	1.72	140	140
CH5000	35	88	103	1.86	154	154	71	1.69	131	131
CH5250	32	87	100	1.87	149	149	69	1.70	126	126
CH5500	31	89	101	1.85	149	149	69	1.68	126	126

APPENDIX B RESULTS FROM BESPOKE STABILITY ANALYSES

Bonnie Doon CH500
Long-term highwall



Laleham R74 CH1900
Long-term highwall



Comet Downs East Highwall
Long-term pit lake

