Caving 2026 – A van As, D Cumming-Potvin & J Wesseloo (eds)

doi:10.36487/ACG_repo/2645_25

Oredrive stability in a sublevel caving project for Jwaneng mine

Catalina Álvarez [a,*], Claudio Barra [a], Loren Lorig [b], Michael Dunn [c], Lesego Queen Kebatsetse [c]

[a] *ITASCA, Chile*

[b] *ITASCA, USA*

[c] *Debswana Diamond Company, Botswana*

Abstract

The Jwaneng underground mine is progressing through a pre-feasibility study, targeting the extraction of three kimberlite pipes to an ultimate depth of approximately 1,000 m below ground surface. Open pit mining at Jwaneng is expected to conclude by 2036, with a subsequent transition to underground mining methods. The underground project involves a combination of mining methods, starting with the extraction of open pit wedges using variants of sublevel retreat, followed by deepening through sublevel caving and block caving in one of the kimberlite pipes.

Three-dimensional numerical modelling provides a robust framework for assessing the impact of mining on the surrounding rock mass. Mine-scale models developed using a hybrid methodology combining FLAC3D and gravity flow can capture slope failure progression and stress redistribution affecting underground workings. This study focuses on oredrive stability, quantified through tunnel closures and mining-induced strains. Ground support performance is implicitly evaluated based on tunnel strain thresholds.

The numerical modelling approach integrates large-scale mining geometry with localised resolution for tunnel closure assessment. Oredrive stability is evaluated for three kimberlite pipes under different spacing scenarios (15 m, 18 m and 21 m centre-to-centre). A strain-softening Hoek–Brown constitutive model is used in the analyses, with no intact rock swelling behaviour assumed for the kimberlite. Sensitivity analyses addressing uncertainty in rock mass properties, including post-peak parameters, provide a range of expected responses and serve as a numerical reference for similar underground mining operations.

Keywords: *sublevel caving, Jwaneng mine, oredrive stability*

1 Introduction

Jwaneng is progressing from a major open pit operation to an underground transition project in which three kimberlite pipes will be mined to depths on the order of 1,000 m below ground surface. Open pit mining is expected to conclude around 2036, after which underground extraction will take over through a two-phase sequence that includes blast-hole open stoping (BHOS) and sublevel retreat (SLR) in the open pit wedges, deepening through sublevel caving (SLC), and ultimately block caving (BC) in one pipe. The current indicated resource will be mined as Phase 1 and the deeper inferred resource will be mined as Phase 2. The mining layout in Figure 1 shows the distinction between the two mining phases. The underground project is a staged cave mining system in which layout geometry, cave propagation, underground mining-induced stress and inherited stress conditions from the open pit all interact with the service life of underground infrastructure.

Oredrive stability is an operationally decisive issue, involving initial ground support installation, rehabilitation frequency, support demand, and exposure of personnel and equipment to deteriorating ground conditions. The Jwaneng case is particularly demanding because the assessed oredrives are subjected to mining-induced

* Corresponding author. Email address: catalina.alvarez@OneItasca.com

loading while also being influenced by kimberlite facies contrasts, sheared kimberlite-country rock contacts, and the stress redistribution associated with deep slope mining. In Jwaneng, the contacts between the various facies are gradational rather than sheared.

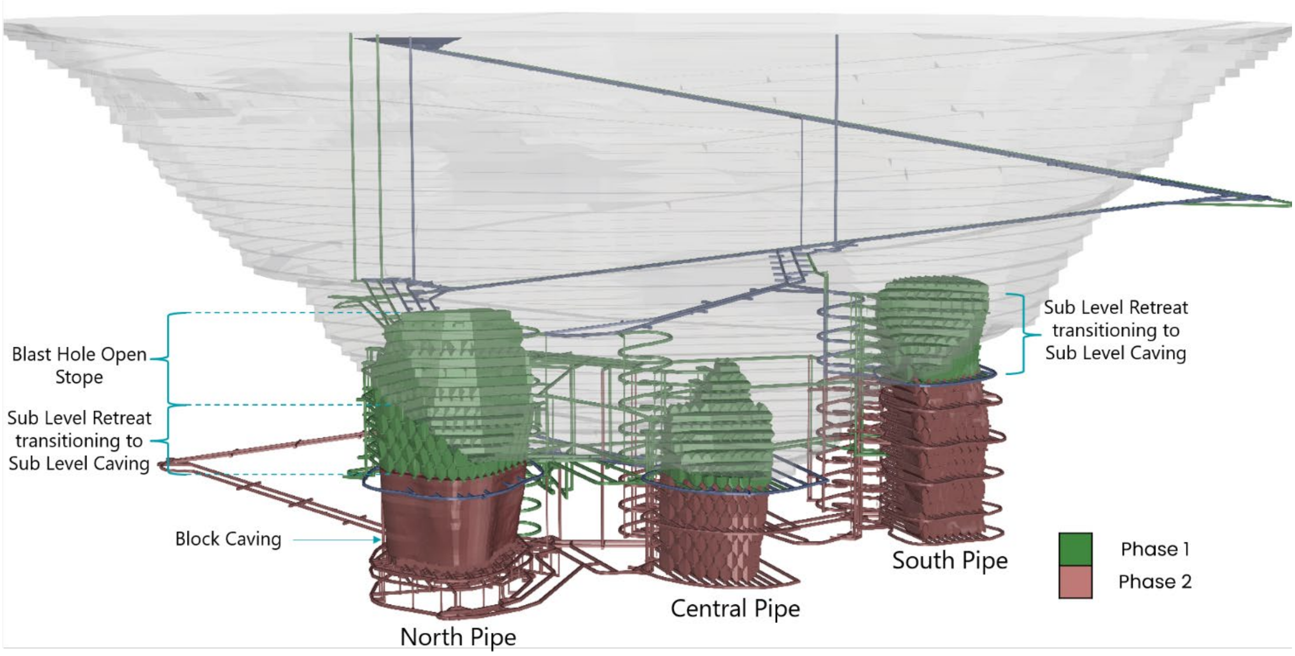

Figure 1 Mining layout for Jwaneng underground project, showing final pit shell

Mine-scale models developed using a hybrid methodology combining FLAC3D (Itasca Consulting Group 2023) and gravity flow of caved rock capture slope failure progression and stress redistribution affecting underground workings. FLAC3D™ resolves the evolving stress-deformation response and damage state of the rock mass, allowing the flowable material to be identified. MassFlow™ (Itasca Consulting Group 2025) resolves the gravity flow, rilling, cavity geometry and air-gap development associated with draw. This coupling methodology is illustrated in Figure 2.

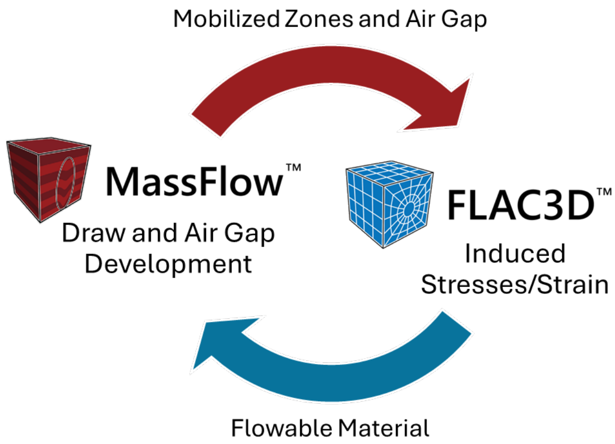

Figure 2 Schematic description of the numerical coupling

The mine-scale model implemented in the hybrid approach does not consider explicit representation of the underground infrastructure but provides the evolution of the mining advance and the emerging slope conditions. The model results from the mine-scale model are then used in a detailed model adequate to evaluate tunnel closures and induced strains. The detailed model is also at mine-scale level but considers a finer mesh around the tunnels in FLAC3D. This represents a multi-scale model approach aimed at optimising running times, since the hybrid approach is computationally intensive. This approach facilitates the implementation of parameter sensitivities affecting mainly tunnel stability at local scale, which becomes much faster if decoupled from the mining advance and material flow computations.

A strain-softening Hoek–Brown constitutive model is used in the analyses, with no swelling behaviour assumed for the intact kimberlite. Note that the support system considers a thin skin layer (TSL), which acts as a membrane to protect the rock from weathering. Sensitivity analyses addressing uncertainty in rock mass properties, including post-peak parameters, provide a range of expected responses and serve as a numerical reference for comparison with similar underground mining operations.

2 Kimberlite parameters

The kimberlite units are the main components for the oredrive stability analyses, which are defined in terms of volcaniclastic and pyroclastic facies as shown in Figure 3. The Centre Pipe breccias shown in the same figure are not considered in the mining program. The properties are summarised in Table 1, showing similar geological strength index (GSI) values among the facies, but higher intact strength for the pyroclastic kimberlite (PK) than for the volcaniclastic kimberlite (VK).

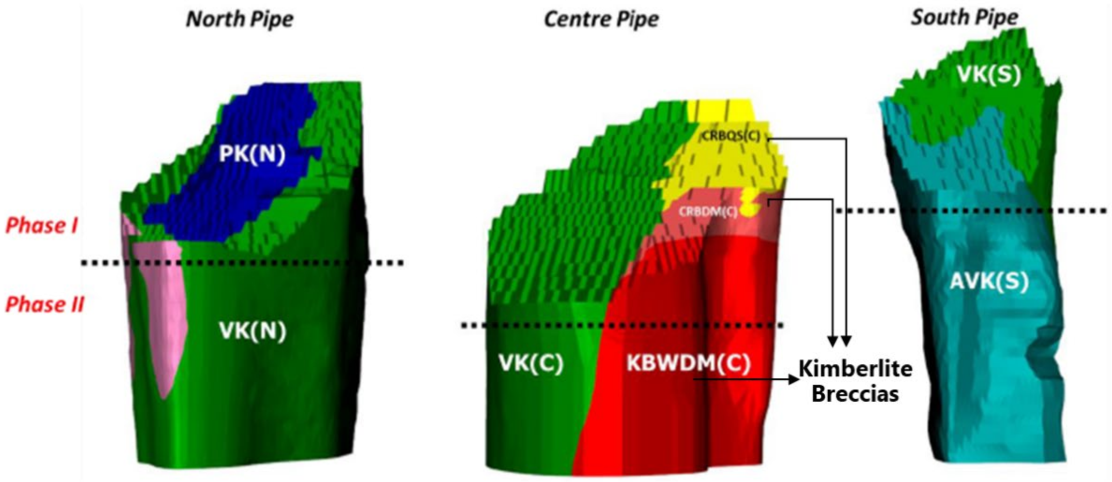

Figure 3 Main kimberlite facies in the underground horizon

Table 1 Rock mass properties for kimberlite (Dunn & Kebatsetse 2024)

Unit	Label	σ_{ci} (MPa) mean	m_i	GSI mean	E_i (GPa)
Centre volcaniclastic kimberlite	VKC	32	7	74	8
North volcaniclastic kimberlite	VKN	42	7	73	11
North pyroclastic kimberlite	PKN	61	15	74	18
South autolytic volcaniclastic kimberlite	AVKS	24	9	75	7
South volcaniclastic kimberlite	VKS	27	9	74	6

The kimberlite pipes are surrounded mostly by highly competent dolomite (UCS ~230 MPa and GSI ~70), which limits interaction between pipes during underground mining. The FLAC3D model explicitly implemented faults and the sheared contact around the kimberlite pipes. Figure 4 shows the model at the end of open pit mining.

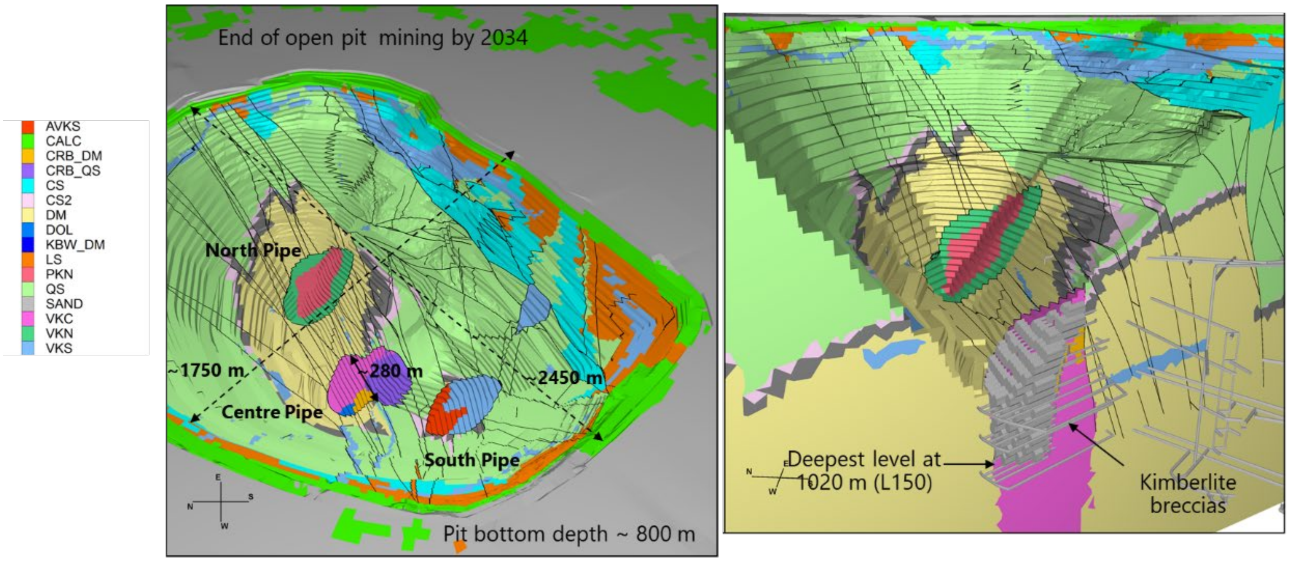

Figure 4 FLAC3D model showing the rock units, faults and kimberlite contacts by end of open pit mining

The mining layout for SLR/SLC considers different tunnel spacing scenarios (15 m, 18 m and 21 m centre-to-centre), with the base case at 18 m spacing. Details for the Centre Pipe mining layout are given in Figure 5, listing the mining levels in terms of reference elevations. The deepest level (150) is located at around 1,000 m below ground surface for the Centre Pipe and South Pipe. The deepest SLC level in North Pipe is at a depth of 800 m below ground surface.

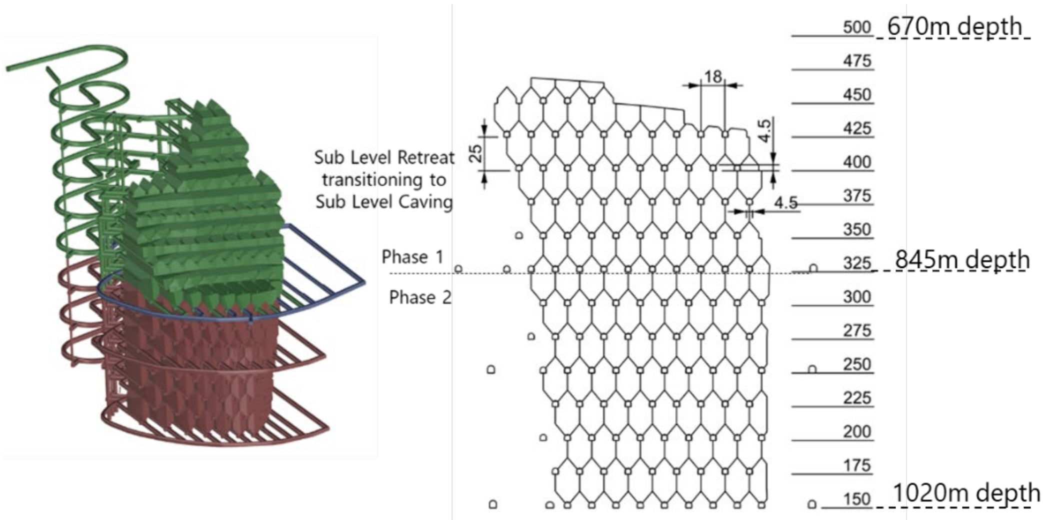

Figure 5 SLR/SLC layout for Centre Pipe listing the mining levels

3 Modelling methodology

3.1 Multiscale models

The numerical approach is multi-scale by design. A mine-scale parent model couples FLAC3D with gravity flow simulation so that cave geometry, mobilised zones and air-gap development are generated in a single integrated framework. An example showing the resulting cave geometry (bulked material) and the emerging crater is shown in Figure 6. The same figure shows the resultant fracturing sector (in red) corresponding to the area undergoing significant yielding.

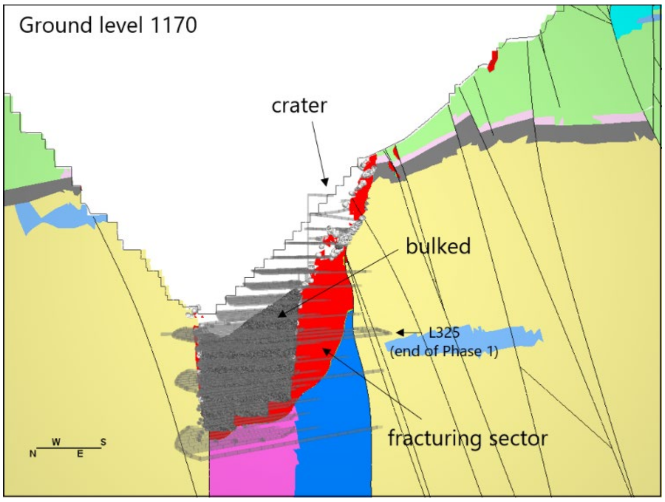

Figure 6 Example of caving advance in the FLAC3D–MassFlow model

The parent model is then used to populate detailed tunnel models with the local cave shape and bulked material distribution representing the underground mining advance. For the tunnel-scale models, zoning (mesh size) is refined to approximately 0.25 m in the vicinity of the excavations so that closures can be estimated with sufficient spatial resolution. Figure 7 shows an example for the Centre Pipe kimberlite. Note-that the detailed models are also at mine-scale level.

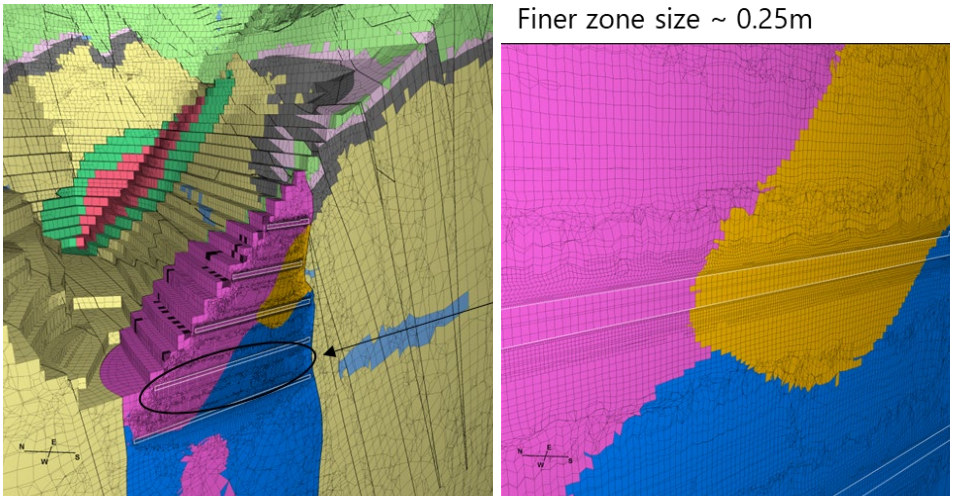

Figure 7 Detailed tunnel model for the Centre Pipe

The detailed models were initialised by importing the induced stresses from the parent model at the end of open pit mining. Tunnel closures were then evaluated as underground mining advanced. Tunnel excavation was simulated under drained conditions, and mining advance inside the caved region was represented by initially zeroing stresses within the caved material while assigning caved kimberlite properties. The analysis therefore captures the stress-transfer effects of cave advance and broken-rock loading.

3.2 Strain-softening constitutive model

The Itasca Constitutive Model for Advanced Strain Softening (IMASS) was developed to represent the rock mass response to stress changes (i.e. rock mass yield, modulus softening, density adjustment, dilation, dilation shutoff, scaling of properties to zone size, cohesion weakening, tension weakening and frictional strengthening). This constitutive model was developed using strain-dependent properties that are adjusted to reflect the impacts of dilation and bulking as a rock mass undergoes plastic deformation. Further details about the model are given in Ghazvinian et al. (2020). The rock mass stress-strain behaviour is illustrated in Figure 8, showing the post-peak response, which is driven by the critical plastic shear strain, denoted $\epsilon^{p}_{\mathrm{crit}}$ and defined by default by Equation 1 (Lorig & Pierce 2000), where 'd' is zone size in metres. The ultimate strength is driven by volumetric deformation (bulking).

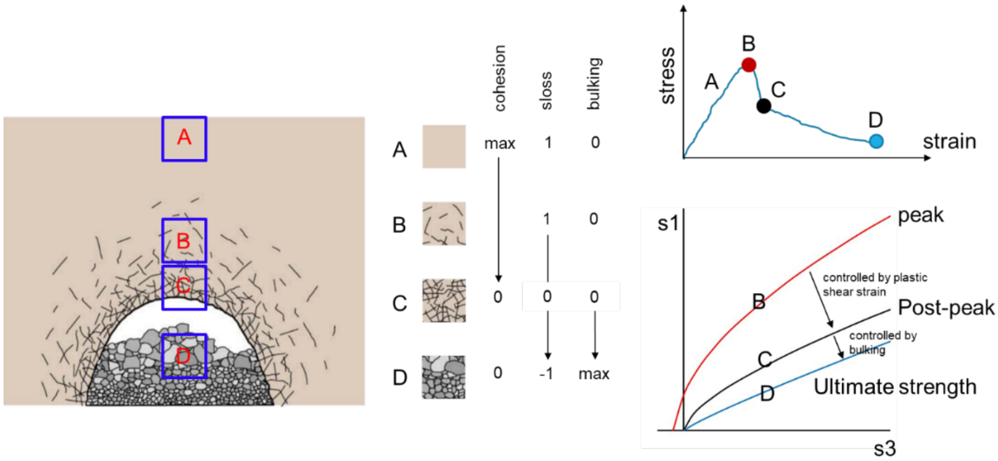

Figure 8 Schematic representation correlating various degrees of damage in a rock mass with the post-peak behaviour (points B, C and D) (Ghazvinian et al. 2020)

$$\epsilon^{p}_{\mathrm{crit}} = (12.5 - 0.125 \times \mathrm{GSI})/100d \qquad (1)$$

The critical strain is a key parameter for post-peak behaviour. The greater this factor, the more ductile the rock mass behaves. The base analyses assume a comparatively ductile reduction from peak to post-peak strength, with critical plastic shear strains of approximately 5% for the volcaniclastic kimberlite and 2.5% for the pyroclastic kimberlite. A dedicated sensitivity case then halves these values to test a more brittle rock mass response. This is a necessary uncertainty approach because the exact post-peak response is rarely known with confidence.

3.3 Modelling considerations

Support was represented implicitly rather than with explicit structural elements. An equivalent pressure of 140 kPa was applied above the invert to mimic tunnel support, representing a 1.2 × 1.2 m rock bolt design. Importantly, a no-support sensitivity for the deepest Centre Pipe level produced closures within 1% of the supported case, indicating that the predicted deformation is controlled primarily by rock mass response and cave-induced loading rather than by the simplified support proxy. The support categories used later in the paper should therefore be interpreted as design implications derived from deformation demand, not as final support specifications.

Tunnel stability was evaluated for three different spacings as described in Table 2. The sensitivity cases relate to changes in kimberlite for intact rock properties (m_i and E_i), post-peak properties (eps_crit) and an overall shear strength reduction (SSR) of 1.3. The shear strengths of selected discontinuities (faults and kimberlite-country rock contact) were also varied.

Table 2 Key modelling assumptions and sensitivity case definitions

Item	Assessed range	Comment
SLC layouts	15, 18, and 21 m centre-to-centre spacing (pipe dependent)	North Pipe was studied at 18 m; South Pipe at 15 and 18 m; Centre Pipe at 15, 18 and 21 m.
Sensitivity cases	m_i values, fault strength, kimberlite-contact strength, 30% E_i reduction, SSR = 1.3, halved eps_crit	Applied primarily to Centre Pipe, 18 m spacing.

3.4 Performance metrics and damage interpretation

Oredrive performance was assessed using tunnel closure, computed from wall displacements around the excavation and maximum principal strain (or radial strain) in the surrounding rock mass. The maximum principal strain correlates well with closure and was therefore used as the primary metric for damage assessment.

The project interpretation scheme maps deformation demand into five categories: A (0–1%, negligible), B (1–2.5%, minor), C (2.5–5%, severe), D (5–10%, very severe), and E (>10%, extreme) as summarised in Table 3. These thresholds are not merely descriptive; they are tied to expected support and rehabilitation consequence This normalisation is consistent with the squeezing-ground framework discussed by Hoek (2001) and by Potvin & Hadjigeorgiou (2008). In practice, Category A and B conditions are generally manageable using fully encapsulated bolts and fibre-reinforced shotcrete (FRS) or mesh, whereas Category C and D conditions imply increasing reliance on cables, engineered sets or repeated rehabilitation. Category-E indicates that conventional extraction-level support may become inadequate unless the layout or mining conditions are changed (Hadjigeorgiou & Potvin 2023).

Table 3 Tunnel damage categories used to translate model strain/closure response into support implications

Category	Descriptor	Strain/closure (%)	Indicative support implication
A	Negligible	0–1	2.4 m fully encapsulated bolts plus FRS or mesh. Very little or no damage to the surface support layer.
B	Minor	1–2.5	Base support system still applicable but cracking in the FRS is expected to initiate and maintenance becomes more likely.
C	Severe	2.5–5	Bolts, FRS and cables are likely required. Substantial damage to the surface support is expected and rehabilitation is highly likely.
D	Very severe	5–10	Bolts, FRS, cables and/or engineered sets may be required. Multiple rehabilitation cycles are likely to be needed and excavations may become operationally marginal if support is inadequate.
E	Extreme	>10	Steel sets, concrete segmented lining or other engineered systems would need to be considered. Excavations may become unviable if the driving conditions are not changed.

4 Results and discussion

4.1 Base case SLC response by pipe

The North Pipe, evaluated through the BHOS-SLR-SLC transition, is distinctly less deformation-prone than the other sectors during the reported stage. Tunnel assessment was carried out when SLC advance had reached approximately halfway across the level, and both closures and strains remained below 1%. According to the tunnel damage categories defined in Table 3, the North Pipe drifts are in Category A, indicating that they are unlikely to require major rehabilitation during the mining.

The Centre Pipe behaves very differently because the kimberlite properties are weaker and the deepest SLC level is 200 m deeper than in the North Pipe. For the 18 m spacing case at Level 150 (deepest level at 1,020 m below ground surface), the response reaches approximately 5% closure and contains a mix of D, C and B damage categories (Table 3), with the most severe damage concentrated in the drifts closest to the kimberlite breccias. The result summaries for the different tunnel spacing scenarios are given in Figure 9 to Figure 11. Figure 11 provides a summary of tunnel damage evaluation for selected levels, indicating mainly a damage increase as the levels deepens, apart from levels being affected by the stress concentration below the pit bottom (800 m depth).

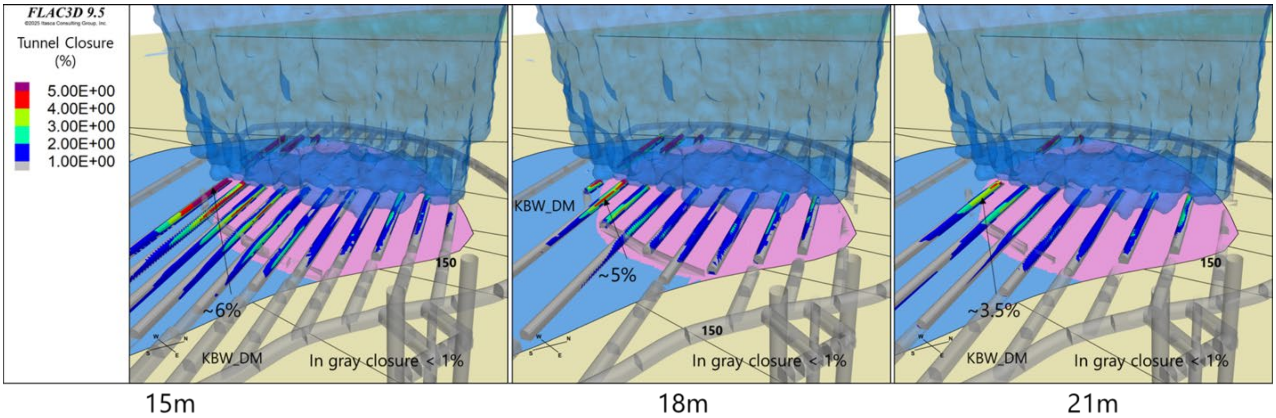

Figure 9 Deepest SLC level performance for Centre Pipe in terms of tunnel closure

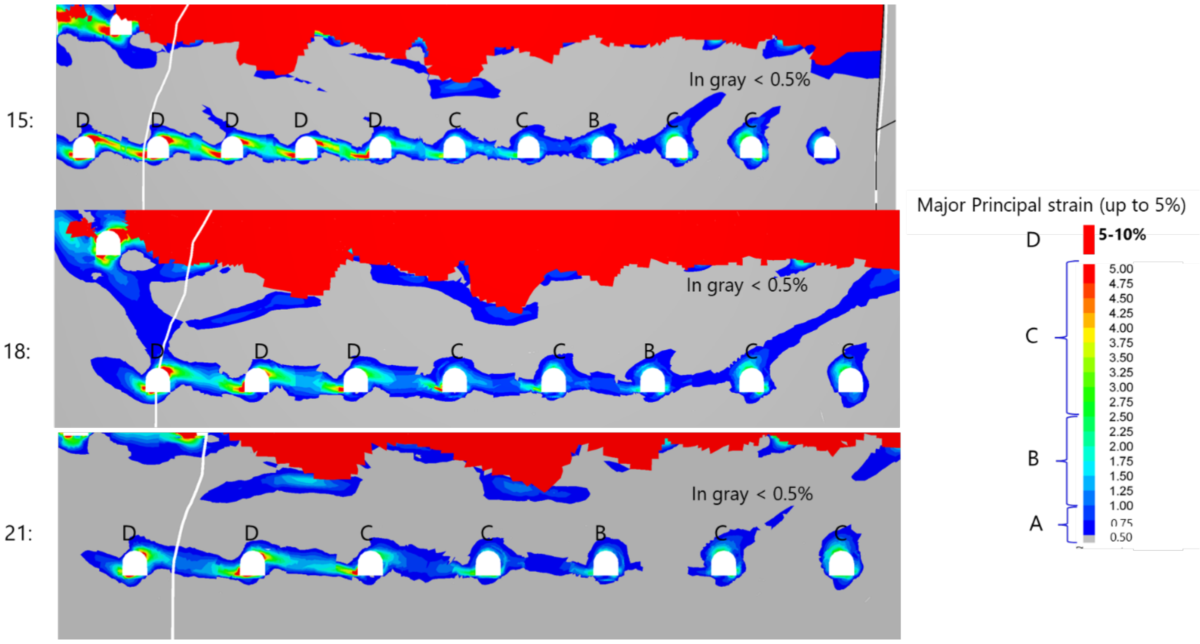

Figure 10 Deepest SLC level performance for Centre Pipe in terms of maximum principal strain shown in cross-section view (used to define tunnel damage categories according to Table 3)

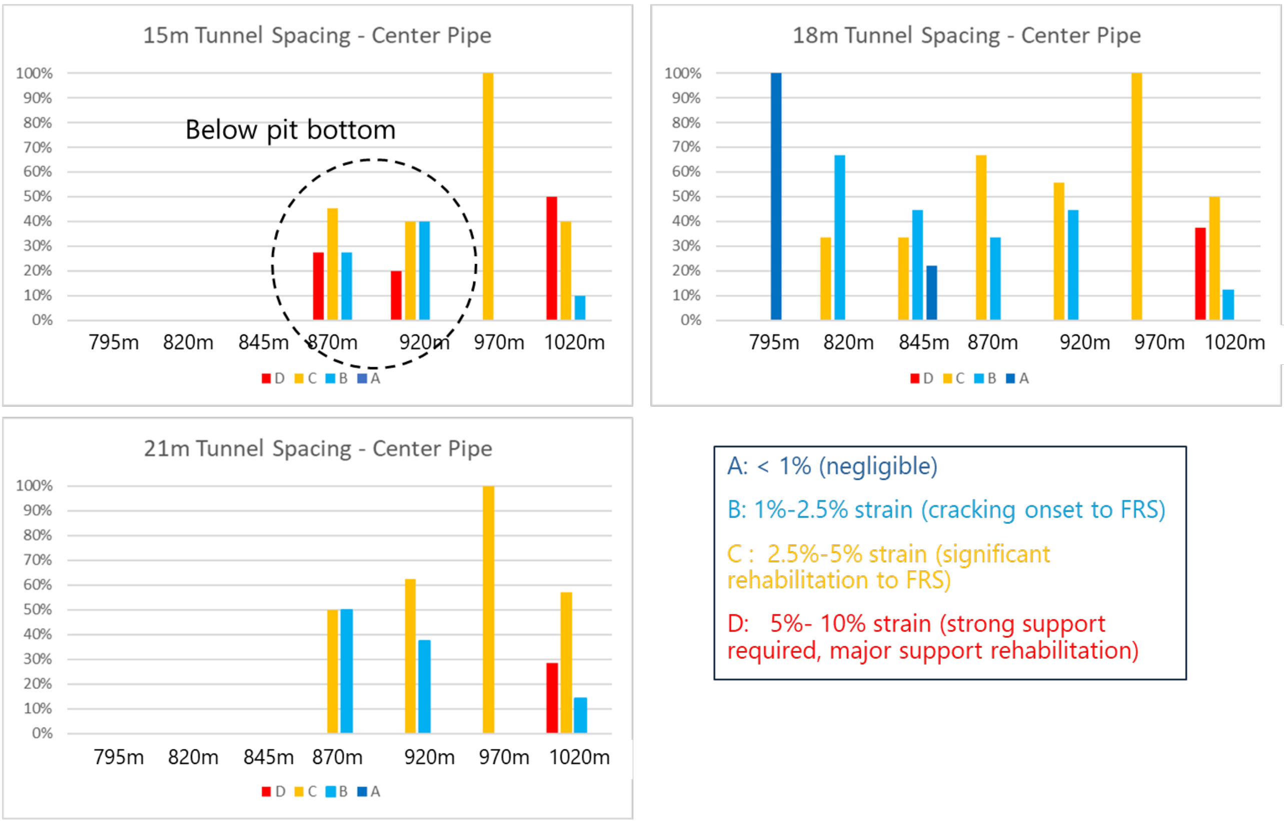

Figure 11 Tunnel damage evaluation for selected levels (defined in terms of depth) in Centre Pipe

The South Pipe is intermediate in terms of intact strength between the North Pipe and Centre Pipe. For the 18 m spacing case, the controlling Level 150 closure is approximately 3.6%, and the deepest drifts are dominated by C-class behaviour with localised D-class response (Table 3). The South Pipe response is therefore less severe than the Centre Pipe but still falls within the range where systematic rehabilitation planning and support upgrades are likely to be required. The results for the 15 m and 18 m tunnel spacing scenarios are summarised in Figure 12 to Figure 14.

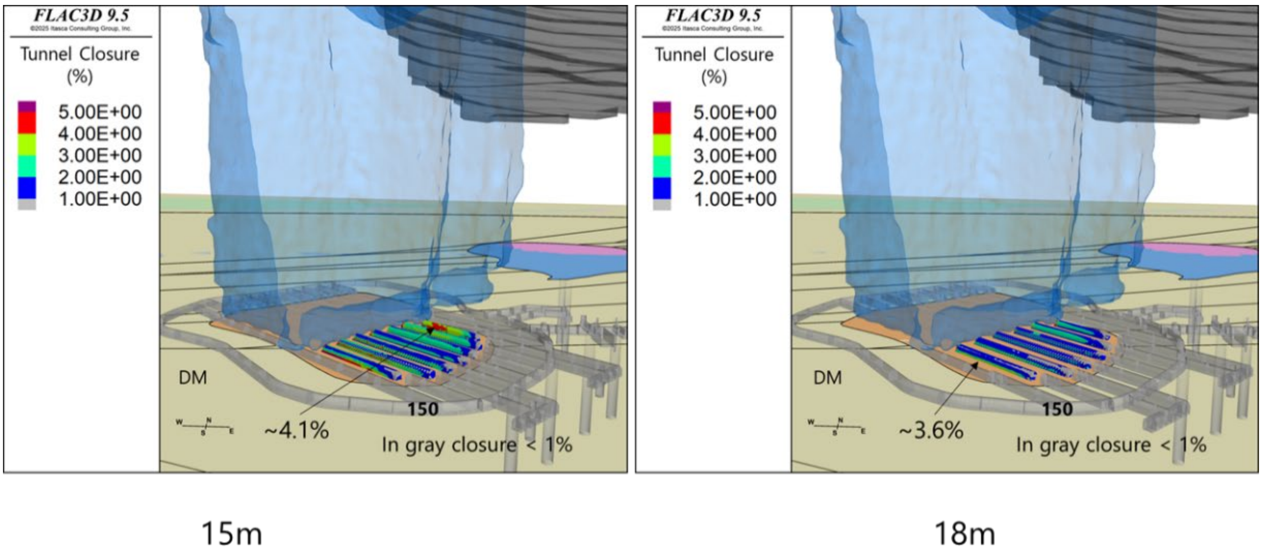

Figure 12 Deepest SLC level performance for South Pipe in terms of tunnel closure

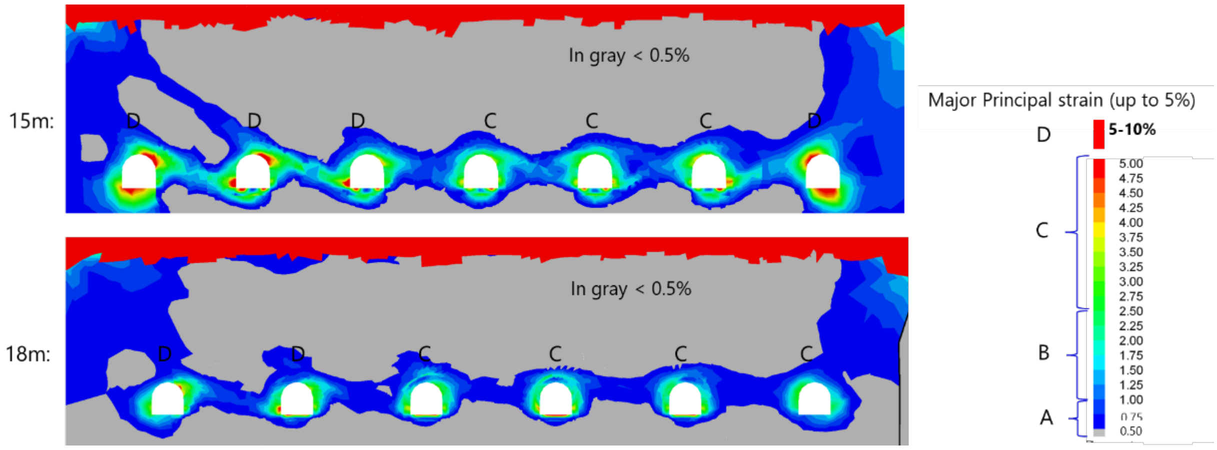

Figure 13 Deepest SLC level performance for South Pipe in terms of maximum strain shown in cross-section view (used to define tunnel damage categories according to Table 3)

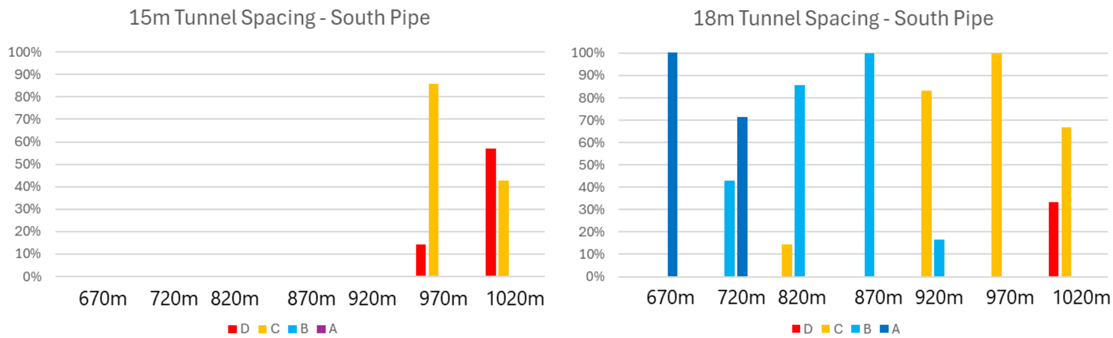

Figure 14 Tunnel damage evaluation for selected levels (defined in terms of depth) in South Pipe

4.2 Effect of oredrive spacing

The spacing comparison demonstrates that farther away oredrive spacing does not automatically improve excavation performance. In the Centre Pipe, 15 m spacing is the most adverse case, with approximately 6% closure at Level 150 and 50% D-class drifts. By contrast, the 18 m and 21 m configurations are more similar to one another than either is to 15 m. The 21 m layout reduces the number of D-class drifts and lowers the representative closure to roughly 3.5%, but the difference relative to 18 m is less significant.

This finding is operationally important because it points to a diminishing-return threshold. From a geotechnical perspective, moving from 15 m to 18 m provides a clear stability benefit in the Centre Pipe. Moving from 18 m to 21 m yields additional improvement, but the improvement is incremental rather than step-changing. At pre-feasibility, that is precisely the kind of result required for integrated mine design: it suggests that the final spacing decision should not be made on geomechanics alone, but on the combined basis of infrastructure stability, ore recovery/dilution, extraction geometry and production flexibility.

In the South Pipe, the wider spacing is preferable, although the gain is moderate in terms of closure, the damage pattern shifts from almost 60% D-class drifts to around 30% D-class drifts. The geotechnical implication is that South Pipe remains support-intensive even at 18 m spacing, but the wider geometry reduces the concentration of very severe sectors and should therefore reduce both rehabilitation intensity and localised exposure to unstable conditions.

Taken together, the spacing results imply that the project should avoid assuming a universal spacing rule across the three pipes. North Pipe appears robust in the assessed stage, Centre Pipe is the primary layout-control concern, and South Pipe requires a moderate-risk support strategy rather than a wholesale layout redesign. This pipe-specific conclusion is one of the stronger practical outputs of the study because it allows the project team to target design effort where it matters most.

4.3 Sensitivity ranking: what actually controls deep SLC deformation?

The sensitivity assessment was focused on the most critical SLC case – Centre Pipe with 18 m spacing – and is arguably the most valuable part of the study because it identifies which uncertainties matter and which do not. Six classes of uncertainty were tested independently: reduction of the Hoek–Brown constant m_i from 7 to 5 in the VKC domain, alternative fault strengths, stronger kimberlite-country rock contact properties, a 30% reduction in elastic modulus E_i, a weakened kimberlite-contact case represented by SSR = 1.3, and a more brittle post-peak response produced by halving the critical strain (eps_crit). The resulting patterns are far from equivalent.

The fault strength and kimberlite-contact cases behave very similarly to the base case. Both cases considered stronger properties. Note that there are no faults within kimberlite. Weaker properties may therefore represent a less conservative case than stronger properties as fault/contact sliding may shed stress transfer inside the kimberlite pipe. The stronger fault assignment does not significantly inhibit fault movement under the inherited underground stress field, which already includes the influence of approximately 800 m of slope mining.

The m_i and E_i sensitivities are more consequential. Lowering m_i increases the Level 150 closure from approximately 5% to about 6%. Reducing E_i by 30% generates a similar categorical shift but a stronger closure increase in the selected deepest tunnels. These two cases show that both strength nonlinearity and deformability uncertainty matter, but stiffness degradation appears to have the larger impact on closure demand for the same layout. The results for E_i sensitivity are shown from Figures 15–17, along with other significant sensitivities described next.

More severe still are the post-peak and SSR sensitivities. When the post-peak critical strain is halved, the entire Level 150 becomes D-class. This indicates that the assumed ductility of the kimberlite is not a minor constitutive detail, it is a first-order consideration. The SSR = 1.3 case is the governing lower-bound scenario. In that case Level 150 is 75% D-class drifts and 25% E-class drifts, and the selected-tunnel closure trend reaches approximately 11% (boundary with kimberlite breccias). In practical terms, E class is the threshold at which conventional extraction-level support assumptions are no longer sufficient as the sole control measure. Either the layout, the mining sequence or the design ground support philosophy must change.

The overall sensitivity ranking can therefore be stated clearly: SSR = 1.3 is the controlling lower-bound case, more brittle post-peak behaviour is the next most important factor, and reduced stiffness produces a moderately adverse impact. By contrast, increased fault strength and a stronger kimberlite-country rock contact are close to base case outcomes. At deep SLC horizons, investment in better characterisation of kimberlite strength, deformability and post-peak response is likely to return much more design value than further refinement of (already secondary) structural strength assumptions.

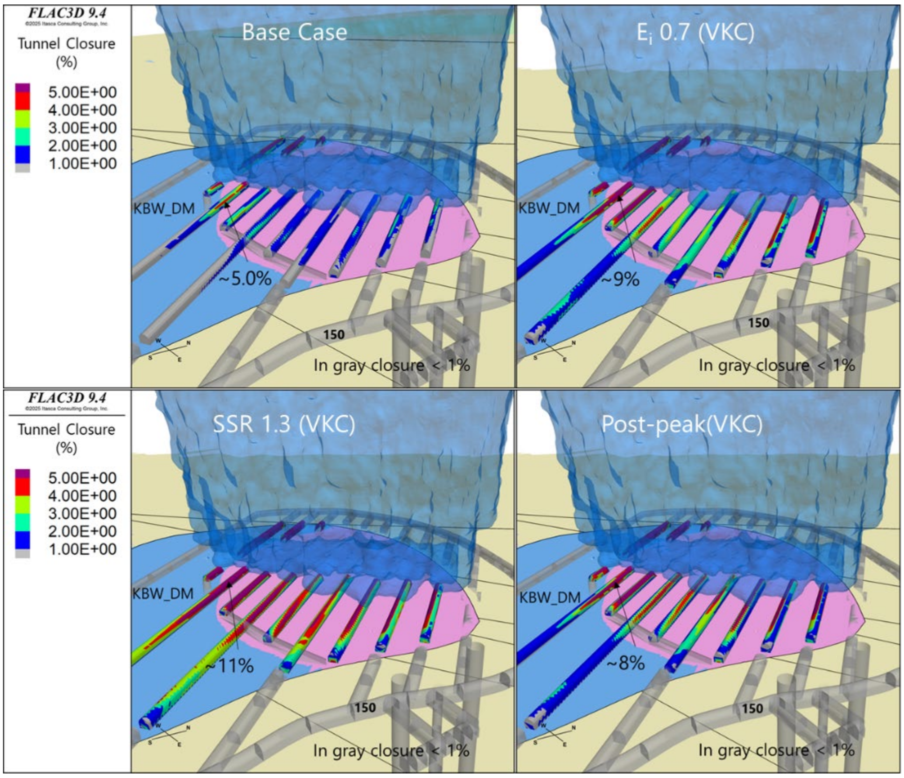

Figure 15 Deepest SLC level performance comparison for Centre Pipe in terms of tunnel closures – sensitivity cases

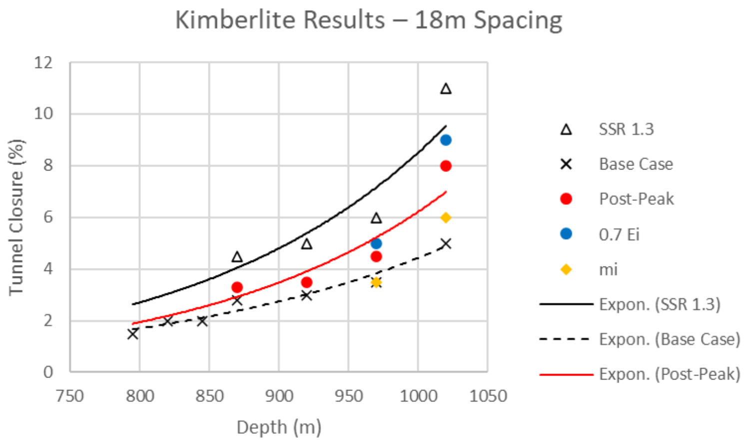

Figure 16 Tunnel closure summary – sensitivity cases

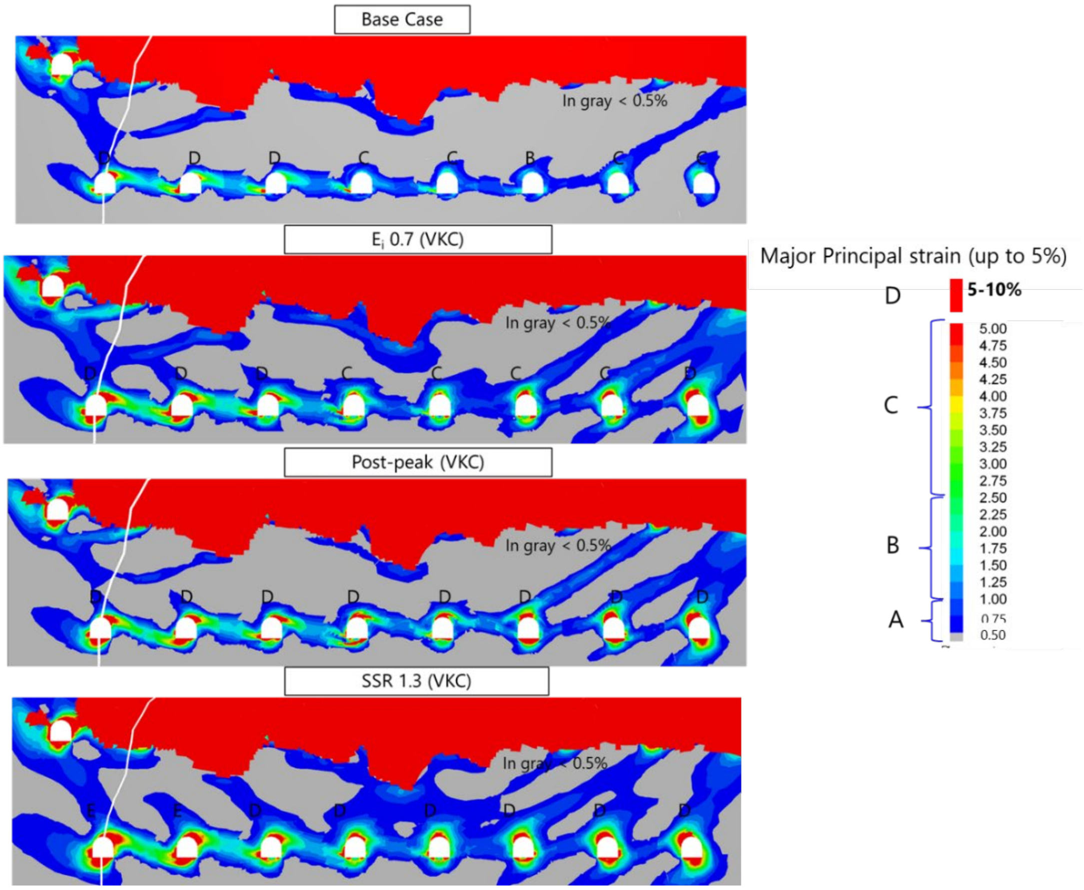

Figure 17 Deepest SLC level performance comparison for Centre Pipe in terms of maximum principal strain – sensitivity cases

4.4 Design and operational implications

The North Pipe results show that some sectors can remain comfortably within negligible or minor deformation limits, while the Centre Pipe demonstrates that a few deep drifts can dominate the overall geotechnical risk and rehabilitation burden. That contrast argues strongly for pipe-specific infrastructure criteria, not a generic extraction-level standard carried across the whole underground project.

A second implication concerns support philosophy. Because support was evaluated implicitly through deformation demand and because the no-support check only had a marginal impact on closures, the results should not be interpreted as final bolt-and-cable designs. Rather, they define the demand envelope that support must tolerate. Under that interpretation, the Centre Pipe base case already requires a yielding and rehabilitation-tolerant support philosophy at the deepest level, while the SSR and brittle post-peak sensitivities indicate that even engineered yielding systems may be insufficient without layout or sequencing changes.

A third implication is that geotechnical uncertainty should be ranked, not merely listed. The Jwaneng study shows that fault strength and kimberlite-contact strength are not the dominant controls on deep SLC tunnel behaviour, because there are no faults within kimberlite and the contact shields the kimberlite inside. Instead, bulk kimberlite strength, stiffness and post-peak degradation dominate the severe response scenarios. For the broader caving community, this is a useful methodological lesson: uncertainty studies should be designed to identify the parameters that change design outcomes materially so that site characterisation can focus on the highest-value tests and back-analyses.

Finally, the study demonstrates the practical value of a multi-scale workflow that couples cave progression with infrastructure response. Mine-scale caving models are often used to answer questions about breakthrough, flow or surface impact, while detailed excavation models are used separately for support design. The Jwaneng workflow links those two scales directly. As a result, the project obtains something more useful than a static stability map: it obtains a decision framework that can compare layouts, identify the controlling sectors, rank uncertainty and translate deformation demand into likely operational consequences. This is a meaningful contribution to risk mitigation, production planning and design optimisation at the pre-feasibility level in modern cave mines.

5 Conclusions

A model that couples mine-scale behaviour to tunnel-scale behaviour provides a practical and technically defensible way to assess oredrive stability in a cave mine project. The method captures cave-scale stress redistribution while preserving the local resolution needed to interpret closures and support demand.

The North Pipe SLC is geotechnically benign in the assessed stage, with predicted closures and strains below 1%. The Centre and South pipes are materially more prone to deformation, demonstrating that a single project-wide SLC stability assumption would be misleading.

For the Centre Pipe, 15 m spacing is clearly less stable than the wider alternatives. The 18 m and 21 m layouts behave similarly below pit bottom, implying that the main geotechnical benefit is achieved by moving away from 15 m, while the additional improvement beyond 18 m is incremental.

The sensitivity ranking is unambiguous: weakened kimberlite strength (SSR = 1.3) is the governing lower-bound case, more brittle post-peak behaviour is the next most adverse mechanism, and reductions in stiffness or m_i are moderately adverse. By contrast, stronger faults or kimberlite-contact properties produce outcomes that approach the base case. Note that there are no faults within kimberlite. Thus, weaker properties may represent a less conservative case than stronger properties as fault/contact sliding may shield stress transfer inside the kimberlite pipe.

The principal value of the study to the caving community is the explicit linkage between geotechnical uncertainty and operational consequence. The workflow does not simply identify whether deformation occurs, it identifies which parameters most strongly affect layout acceptability, support demand and rehabilitation risk.

Acknowledgement

The authors thank Debswana for allowing publication of this paper.

Use of artificial intelligence disclosure statement

In the preparation of this work, the authors used ChatGPT 5.4 for general assistance in writing and editing. The authors have reviewed the content and edited it where required and take full responsibility for said content.

References

Dunn, MJ & Kebatsetse, LQ 2024, 'Development of the geotechnical model for the Jwaneng underground project', in D Johansson & H Schunnesson (eds), *MassMin 2024: Proceedings of the International Conference & Exhibition on Mass Mining*, Luleå University of Technology, Luleå, pp. 213–233, https://doi.org/10.36487/ACG_repo/2435_B-03.

Ghazvinian, E, Garza-Cruz, T, Bouzeran, L, Fuenzalida, M, Cheng, Z, Cancino, C & Pierce, M 2020, 'Theory and Implementation of the Itasca Constitutive Model for Advanced Strain Softening (IMASS)', *Proceeding MassMin 2020 Conference*.

Hadjigeorgiou, J & Potvin, Y 2023, 'Ground support guidelines for squeezing ground conditions', *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 123, no. 7, pp. 371–380.

Hoek, E 2001, 'Big tunnels in bad rock', *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 127, no. 9, pp. 726–740.

Itasca Consulting Group, Inc 2023, *Fast Lagrangian Analysis of Continua in 3D (FLAC3D),* version 9.0, computer software, ITASCA, Minneapolis.

Itasca Consulting Group, Inc 2025, *MASSFLOW – Analysis of Material Flow to Drawpoints*, ITASCA, Minneapolis.

Lorig, L & Pierce, M 2000, *Methodology and Guidelines for Numerical Modelling of Undercut and Extraction Level Behaviour in Caving Mines*, ITASCA.

Potvin, Y & Hadjigeorgiou, J 2008, 'Ground support strategies to control large deformations in mining excavations', *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 108, no. 7, pp. 397–404.