Deep Mining 2024 – P Andrieux & D Cumming-Potvin (eds)

doi:10.36487/ACG_repo/2465_05

Trial of an alternative face de-stress pattern at Kanowna Belle mine

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Abstract

De-stress blasting has been used in underground mining for several decades, aiming to reduce the risk of violent ejection of rock from the development face. Typically it includes boring a number of deep boreholes reaching the rock ahead of the next face of the development heading, charging and then firing the toe sections of these boreholes. The objective is to create sufficient blast damage in the rock forward of the face so that the accumulated strain energy there is dissipated. With this technique the bulk of the rock in the new face is fractured to a various degree of severity. Generally the de-stress holes are bored in addition to the standard face profile, and are most often fired before the main development firing. This method has some practical advantages as well as some significant shortcomings. An alternative de-stress technique dubbed 'Iron Kurtain' has been developed and trialled at the Kanowna Belle mine, aiming to simplify the practical aspects of the process and address the main deficiencies of the traditional scheme. This paper describes the de-stress concept of the Iron Kurtain method, and discusses the observations made during the trial and its main results.

Keywords: *de-stress, blasting, seismicity, rockburst*

1 Introduction

Conventional face de-stress methods known to the author are based on the concept that fracturing the highly stressed rock mass ahead of the face allows for the dissipation of the strain energy in that rock and thereby reduces the risk of uncontrolled release of this stored energy when the rock in question is exposed in a drive's face. This approach has been in use since the 1950s, when first implemented in South African deep mines (Roux et al. 1957; Hill & Plewman 1958), and has proved to be reasonably practical and successful. Numerous variations of drill patterns as well as charging configurations have been developed over the years, with most of these essentially trying to achieve the same objective: to induce sufficient levels of damage in the bulk of the rock ahead of the development face, where the rock being damaged is the rock being de-stressed.

The Kanowna Belle underground mine (KB) has been using face de-stressing in deep, high-stress development to reduce the risk of facebursting. In particular, this practice has been utilised in E Block, which is the deepest current mining block at KB, extending down from approximately RL 9365 (1,000+ metres vertical depth). Main host rocks in the footwall (FW) are felsic grits and conglomerates, while the near hanging wall (HW) of E Block is dominated by porphyry with small lenses of conglomerate. The rock mass is structure-rich, particularly in the FW, according to current observations and interpretations. In situ stress levels are high at the depth of E block, with in situ principal stress, σ_1, of approximately 78 MPa at the 9115 level (1,200 m vertical depth) (Kanowna Belle 2022).

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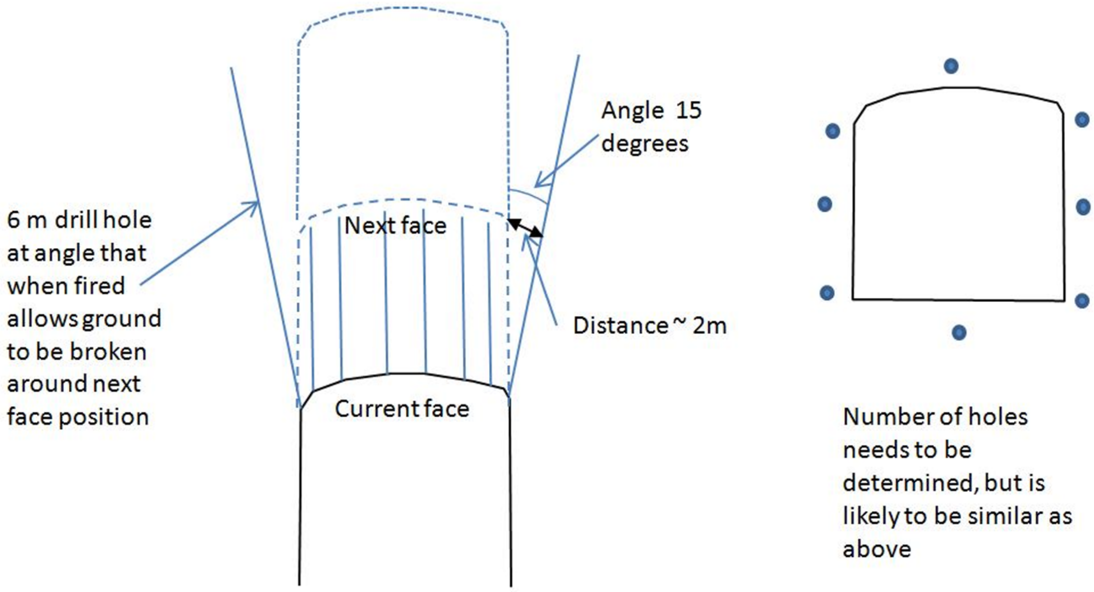
Mining in E Block started in 2010 and soon ran into significant difficulties due to the seismic response of the rock mass. Numerous large seismic events took place, many of which resulted in significant damage in E Block development, including oredrives, footwall access and some sections of the decline. Facebursting was reported on several occasions, including an incident in 9145 level (Figure 1) (Talebi 2021).

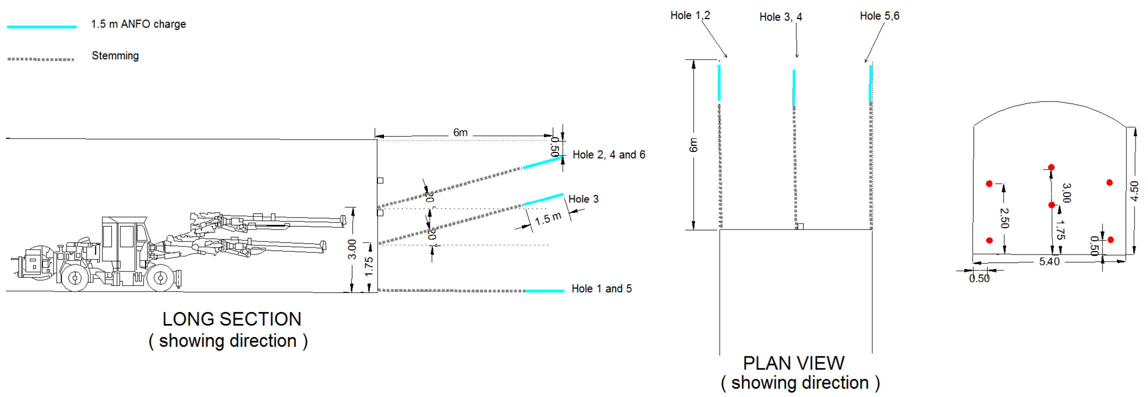
Figure 1 Faceburst in 9145 level

2 Past and current approaches at Kanowna Belle

In the past, numerous de-stress or preconditioning patterns have been in use at KB (Morkel 2013; Varden 2011). Some examples are shown in Figure 2.



(a)



(b)

Figure 2 Face preconditioning patterns: (a) Kanowna Belle 2011; (b) Kanowna Belle 2013

The current face de-stress method used at KB was designed by the Western Australian School of Mines (WASM). This conventional method requires boring 10 de-stress holes (64 mm diameter) and charging a section of each at the toe (Figure 3). These holes are fired before the main face charge (Drover et.al. 2018). The length of the charged section was reduced (originally 1.5 m long but reduced to 0.6 m long in the latest version of the method) to lower the risk of cross-initiation between de-stress holes and standard cut holes, which could disrupt the main firing sequence and thus potentially lead to unsatisfactory performance of the cut. Feedback from operators also included complaints about excessive damage to the rock in the face of the next development cut. It was reported that this excessive rock damage resulted in additional time being required for scaling and created issues in boring the burn cut away from the butts of the previously fired de-stress holes.

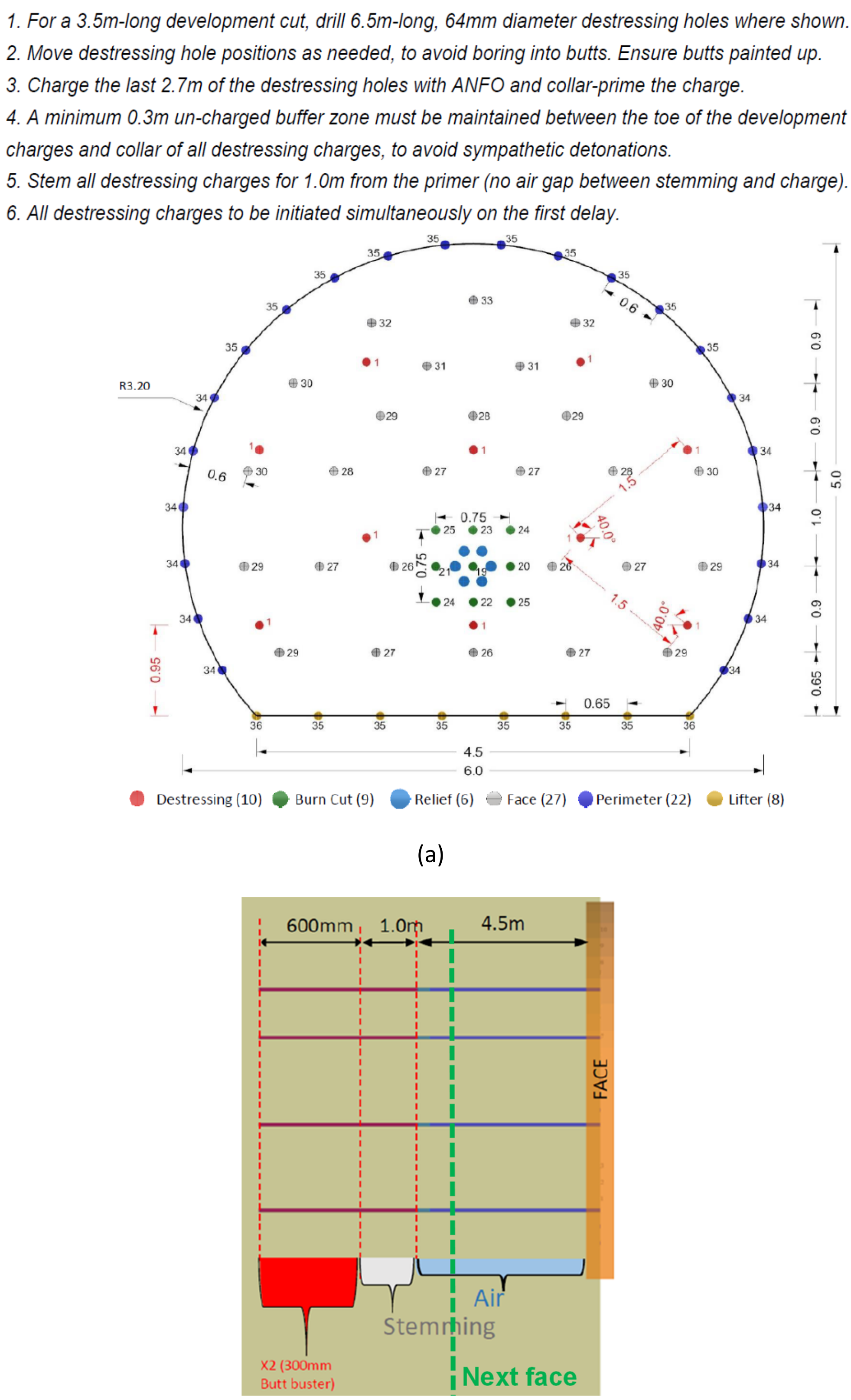


Figure 3 Western Australian School of Mines de-stress holes (a) drill pattern and (b) charge plan

However, the main disadvantage of the method (similar to other de-stress patterns used in the last several decades which are known to author) is an inherent risk of boring into unreacted detonator/primer in the case of a misfire in de-stress holes. This can happen while boring the next face or during the installation of ground support (for the de-stress patterns where charges are placed outside the drive's perimeter). Inspection of the de-stress holes for unreacted explosives is impractical due to reasons including the locations of boreholes, possible collapse of the boreholes and the potential presence of the stemming material (blocking the hole). In addition, firing the ground outside the drive's design profile introduces a lot of unnecessary damage to the drive's perimeter, making effective ground control even more challenging.

Finally, there is concern that when only the toe section of the de-stress holes is fired it creates a de-stressed rock zone deep in the face, leaving a zone immediately next to the new face unaffected by blast damage and therefore still able to carry significant accumulated strain energy. For the example of a cut length of 3.7 m, with de-stress charges starting at a depth of 5.5 m (Figure 3), the thickness of this non-de-stressed section can be estimated as 1.8 m. This method has the unintended potential, once fired, of forming a relatively thin zone (1.8 m) of non-damaged rock in the exposed face of the next development cut, followed by the preconditioned zone. In this configuration the stress and accumulated strain energy levels in the new face may even be increased, particularly if σ_1 is acting perpendicular/sub-perpendicular to the strike of the drive (Figure 4).

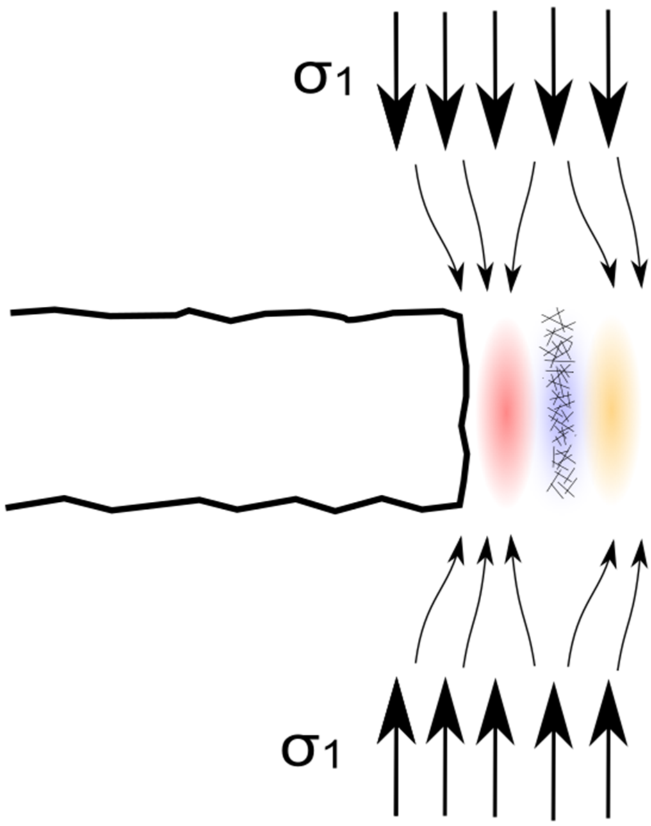


Figure 4 Mechanism of possible unintended stress concentration in the face (red) despite the presence of a highly damaged de-stressed zone (blue)

Existence of this mechanism was substantiated using the analysis of the seismic response during the trial in 9215 level (Drover & Villaescusa 2020). Figures 5, 6 and 7 have been adopted from the above report. Zone C (shown in Figure 5) was identified as the most seismically active, with its strike sub-perpendicular to the direction of σ_1.

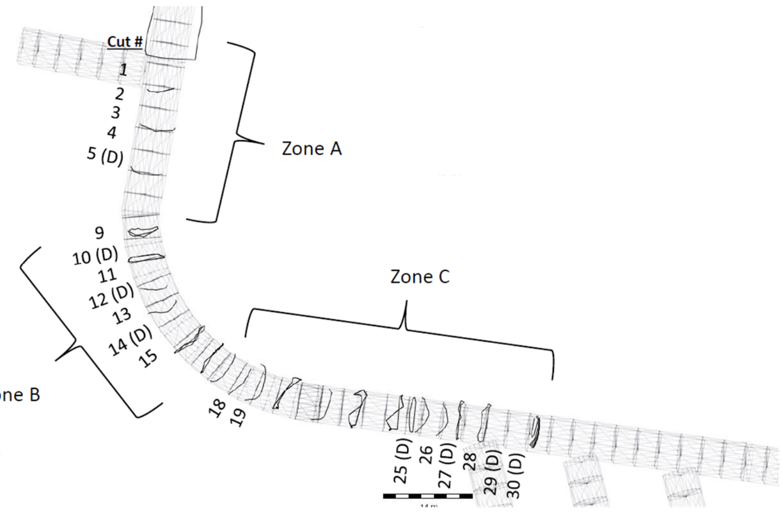


Figure 5 Zones of development and cuts analysed in 9215 level

Figures 6 and 7 demonstrate that de-stressed cuts in Zone C had a distinct spike of seismic energy released within 0.5 m of the new face, indicated by red circle in Figure 6. Average energy radiated in this zone in de-stressed cuts exceeded the peak value in conventional cuts (yellow circle) almost by an order of magnitude.

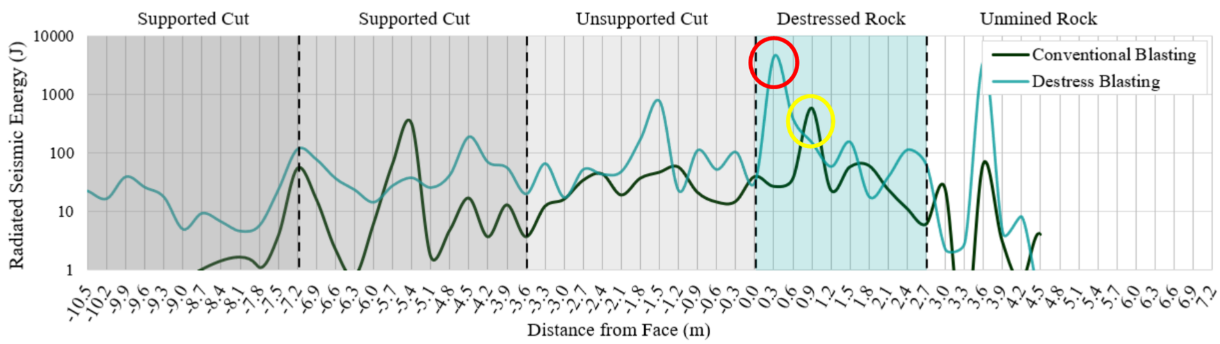


Figure 6 Typical (average) seismic energy release for both conventional and face de-stress blasting techniques through Zone C

Figure 7 Typical (average) seismic potency (volume of inelastic, co-seismic rock mass damage) for both conventional and face de-stress blasting techniques through Zone C

It must be noted that this mechanism became evident only in locations where σ_1 was acting perpendicular to the drive's direction or close to that. Otherwise, the preconditioned zone in front of the face effectively shields the stress and no significant seismic activity in the non-damaged zone is noted (Zones A and B). When σ_1 is perpendicular to the drive's strike, which is typically considered the most adverse condition it terms of faceburst risk (Figure 4), it creates a loading scheme that can result in buckling failure of the face, which may have quite high ejection velocities. Therefore a preconditioning (de-stress) method where the blast-damaged zone extends right to the face would be advantageous, as long as the risk of cross-initiation is eliminated. This is one of the additional objectives that the alternative de-stress method is designed to achieve.

3 The Iron Kurtain method concept

A trial of an alternative face de-stress method known as Iron Kurtain, or IK, has been conducted at KB in 9190 level. This method aims to address the major observed drawbacks of other approaches relying on pre-fracturing the rock mass ahead of the face, in particular:

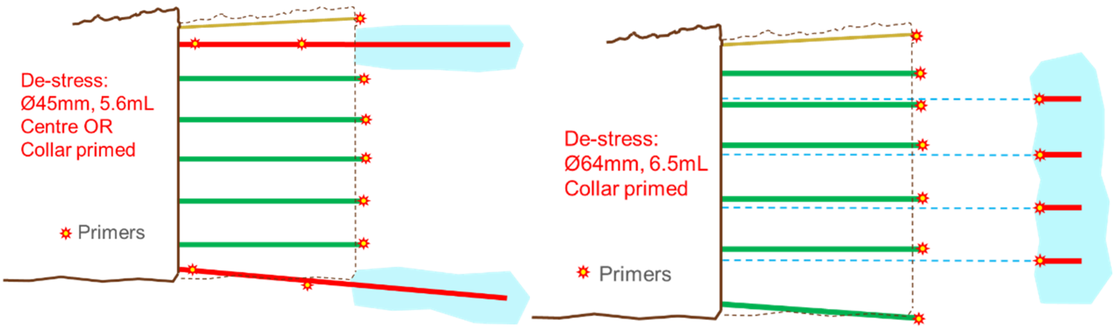
- eliminating the risk of leaving an unreacted primer/detonator unidentified in the face
- ensuring that the rock in the face is fully de-stressed, without leaving an intact section which can remain seismically active
- eliminating the extra holes in the boring pattern and difficulties in placing the burn
- reducing the total amount of boring metres.

In addition, IK can provide deep preconditioning of the floor, which can be helpful in the case of floor heave (Figure 8).

The key underlying concept in this alternative technique is that the de-stressing effect is achieved by allowing some expansion of the interior portion of the next face, as well as some convergence of the surrounding rock mass. To fulfil this, a series of relatively closely spaced voids (boreholes) are drilled around the target zone, just inside the perimeter of the next face (Figure 9). These boreholes are then charged and fired with the development round. This firing results in a relatively narrow continuous zone of highly damaged rock around the boreholes. This crushed rock envelopes the central core of the next development face (Figure 10), which remains unaffected by blast damage. The flow of the damaged rock into the boreholes, as well as towards the new face, also allows for the expansion of the central zone, thus reducing the level of accumulated strain energy and therefore the risk of rockburst. At the same time, the rock just outside the de-stress perimeter is significantly damaged and therefore strain energy there is also dissipated, similarly to the conventional de-stress approach. As the outside rock mass is allowed some convergence towards the drive, the available deflection and, in turn, energy in the loading system, are reduced as well.

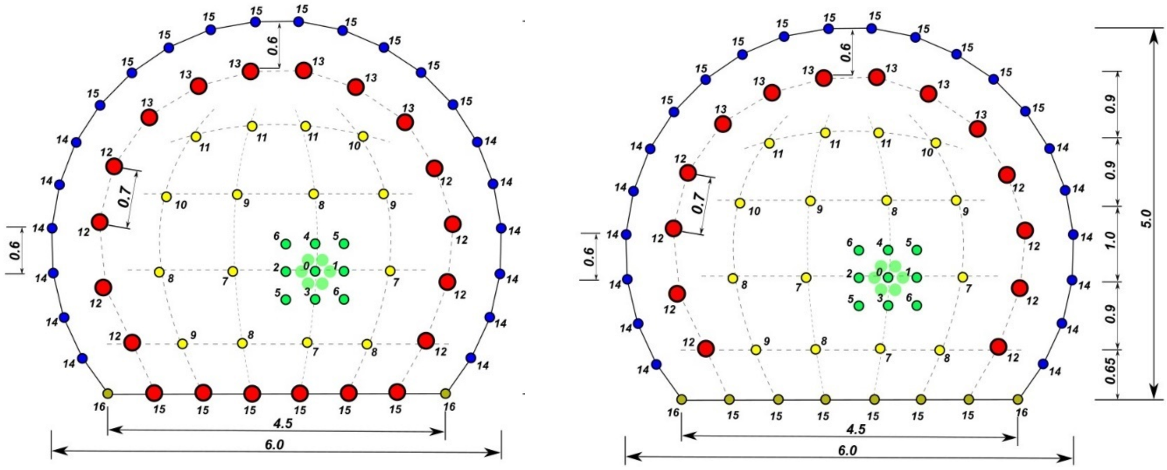
In the IK method the drill pattern is the same as is standard for the heading, but the buffer holes are extended to a 5.6 m depth, using a single long drill steel (no couplings) with the same standard diameter bit as for the rest of the face, and charged with standard explosive in full length (Figure 8). These holes must be either centre primed (primer placed at 2–3 m from the collar) or collar-primed, thus eliminating the chance of leaving an unreacted detonator/primer in the next face. The face can be fired using a standard sequence, however, it is recommended that the de-stress holes be fired on the same delay if practicable (they can be split into two to three groups). If the risk of floor heave is considered negligible, de-stress holes may be omitted in the floor, as shown in Figure 9b (i.e. IK standard).

The extent of rock mass preconditioning from the blastholes can be evaluated based on R_d – practical damage radius (PDR) concept. 'By "practical", it is meant that if the rock mass lying outside of this ring were removed, the rock remaining within the ring would easily break apart.' (Iverson et al. 2013). Using Equations 1 and 2 (Hustrulid 1999), estimations of R_d have been obtained (Table 1).



(a) (b)

Figure 8 Long section view of (a) Kanowna Belle Iron Kurtain full pattern and (b) Western Australian School of Mines pattern. The zones of preconditioned rock are shown in light blue



(a) (b)

Figure 9 De-stress pattern variations: (a) Iron Kurtain full; (b) Iron Kurtain standard. De-stress extended buffer holes are shown in red

$$\frac{R_d}{r_h} = 25\sqrt{\frac{\rho_e \, s_{ANFO}}{\rho_{ANFO}}}\sqrt{\frac{2.65}{\rho_r}} \tag{1}$$

$$\frac{\rho_e \, s_{ANFO}}{\rho_{ANFO}} = RBS \tag{2}$$

where:

r_h = blasthole diameter (mm)

ρ_e = density of explosive used (g/cm^3)

ρ_{ANFO} = density of ANFO = 0.85 g/cm^3

ρ_r = density of the rock mass (g/cm^3)

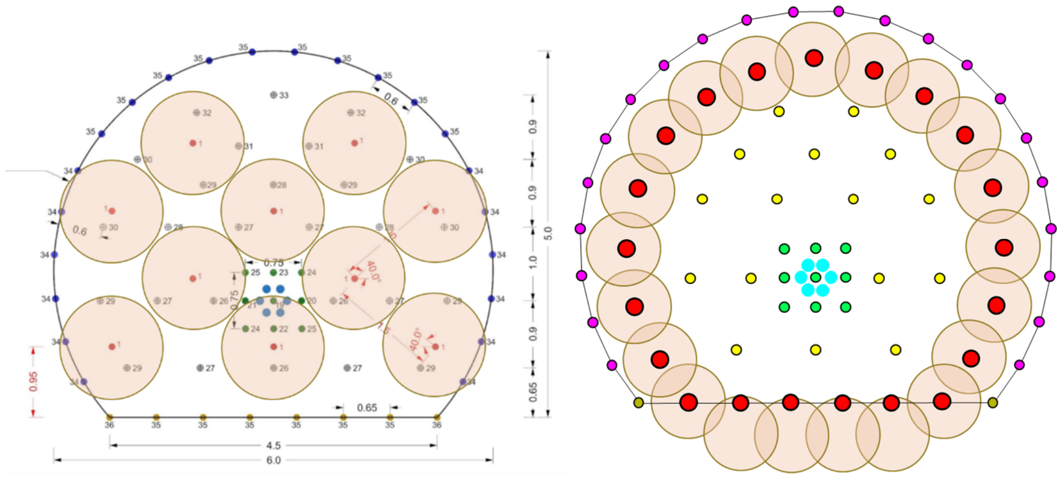
s_{ANFO} = weight strength of the explosive relative to ANFO

RBS = bulk strength relative to ANFO.

Table 1 Practical damage radius values

Hole diameter (mm)	Explosive type	Explosive density (g/cm^3)	PDR (mm)
64	ANFO	0.8	750
45	ANFO	0.8	525

Accordingly, estimated zones of practical damage can be produced for both de-stressing methods as shown in Figure 10. It has to be noted that radial cracks extend further than individual PDR zones from the blastholes and may form an additional network of discontinuities, promoting de-stressing further into surrounding the rock mass.



(a) (b)

Figure 10 Estimated practical damage zones in (a) Western Australian School of Mines method and (b) Iron Kurtain full method

The 9190 access drive was selected to trial the IK method due to high levels of in situ stress and its proximity to the same array of seismic sensors that were utilised in the previous trial of a conventional de-stress method. The main criteria to assess the performance of the IK were underground observations, feedback from the operators and analysis of seismic response in the rock mass, particularly ahead of development within 5 m of the face, as seismic activity in this area is thought to correlate most with the risk of a faceburst.

It must be noted that both conventional and IK de-stress methods can only reduce the risk of a stress-driven rockburst from the face. Neither method is likely to be effective in preventing a shakedown of a wedge/slab if there is a significant seismic event nearby, such as a slip on a major structure, etc.

4 Analysis of seismic activity during Iron Kurtain trial

Eight conventional development cuts were taken in the 9190 access and the 9190 sump 34. These cuts were followed by eight de-stressed cuts which used the IK pattern. The post-firing seismic activity that followed both the conventional and IK cuts was analysed and compared.

The seismic events registered in the 3 m directly ahead of the corresponding cut's face in the 72 hours after each firing are displayed in Figures 11 and 12. Out of all these events, only those that largely fall within the development cross-section, or in very close proximity to that zone, are considered relevant for potential facebursting. These events are circled in green.

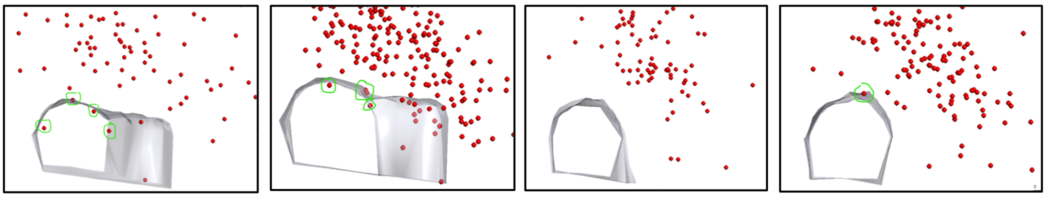


Figure 11 Seismic activity ahead of the face, cuts 1 ACC, 2 ACC, 3 ACC, 4 ACC (left to right). Standard development, no de-stress, looking west

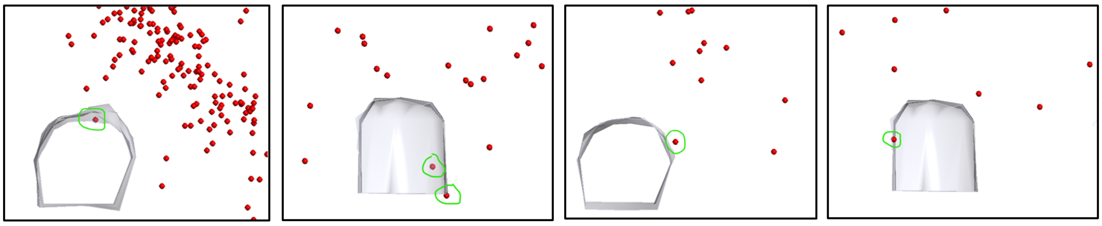


Figure 12 Seismic activity ahead of the face, cuts 5 ACC, 6 SMP, 7 ACC, 7 SMP (left to right). Standard development, no de-stress, looking west

A total of 14 seismic events were registered in the eight conventional cuts' faces, and this number can be used as an indicator of the expected seismic activity within a conventional face in that drive. This activity is associated with a higher risk of face instability and changes to the rock mass in the immediate volume of the fresh cut.

In the same way, de-stressed cuts were analysed with only a single event detected in the area of interest (Figures 13 and 14).

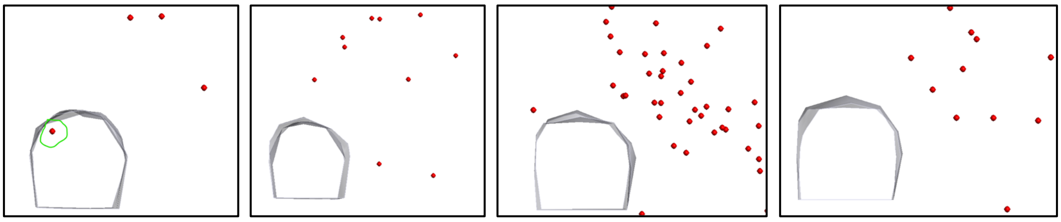


Figure 13 Seismic activity ahead of the face, cuts 8 ACC, 9 ACC, 10 ACC, 11 ACC (left to right). Iron Kurtain face de-stress method, looking west

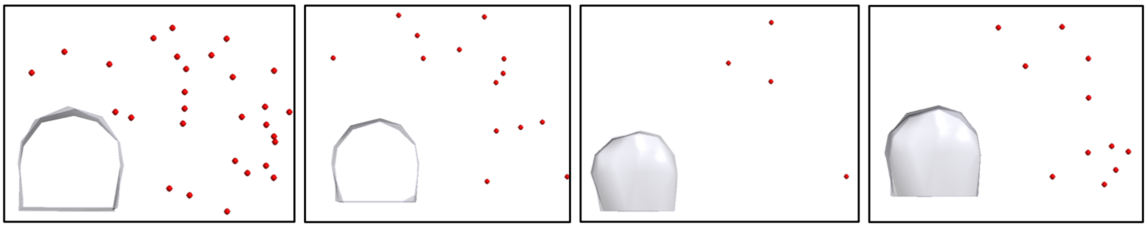
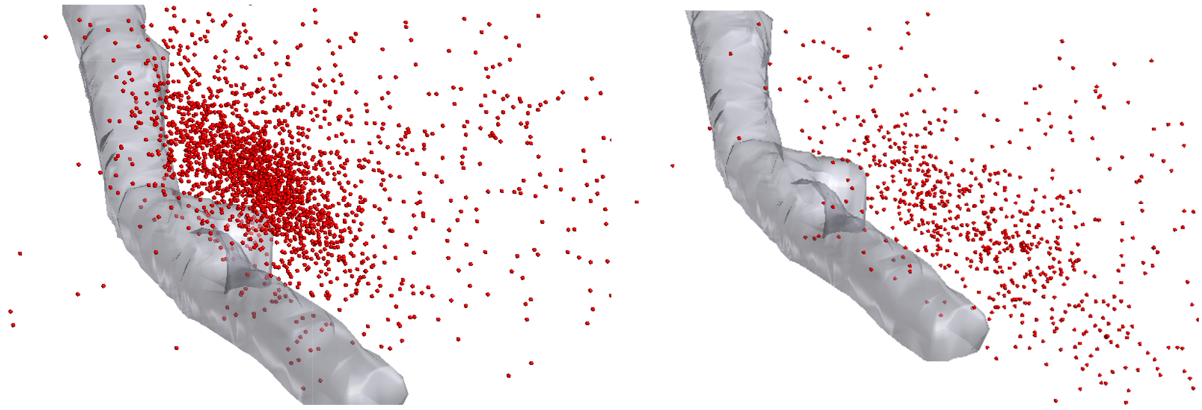


Figure 14 Seismic activity ahead of the face, cuts 12 ACC, 13 ACC, 14 ACC, 15 ACC (left to right). Iron Kurtain face de-stress method, looking west

The total seismic response to the eight cuts taken using a standard drill and blast pattern (no de-stress) versus the IK de-stress method is shown in Figure 15. Summarily, 2,395 events were registered after conventional cuts and 850 events after IK de-stressed cuts. In all cases, only the events in the 72-hour window after firing were included in the analysis.



(a) (b)

Figure 15 Total registered seismic events from (a) eight standard development cuts and (b) eight Iron Kurtain de-stressed cuts in 9190, looking west

Based on the available data it can be stated that the use of the IK de-stress method resulted in significantly lower seismic reaction in the rock mass than the conventional development, both in terms of overall count (850 versus 2,395 events) and directly in the development face (one versus 14). This finding takes into account the seismic system's sensitivity and location accuracy, discussed below, as these parameters were very similar for both standard development and IK cuts during this trial.

Generally the character of seismic activity around the development was very similar to the one noticed earlier in the eastern E-block and modelled (Koupriantchik & Talebi 2021) as a disseminated reaction of surrounding rock mass to firings, where most of the response is a large number of small events (the bulk of registered events in this trial varied between ML-3.0 and ML-1.0), located to the northwest of the firing and at slightly higher RL (Figure 15). The locations of these events correlate very well with modelled change in excess shear stress on ubiquitous joints–dominant bedding/joint set in the area.

A significant number of small events were detected during the IK trial. Out of the total 850 events recorded, 570 had a magnitude lower than ML-2.0 and 21 events were smaller than ML-3.0. Only one of these events, a ML-2.2, was in the vicinity of the development face. This event occurred in the shoulder, approximately 1.5 m in from the face (Figure 13, cut 8) and thus outside of the central de-stressed zone. Conversely, the conventional development resulted in 14 events within close proximity to the face and with a maximum magnitude of ML-2.1. Of these 14 events, four occurred within 1.5 m of the face position. This is considered a strong indication that that the use of the IK method resulted in a significant reduction of the risk of dynamic instability at the development face.

5 Practical implementation aspects, learnings and operators' feedback

5.1 Reduction of drill metres and other operational benefits

One of the practical advantages of the IK method is that it requires less total drill metres to de-stress the face (compared to conventional de-stress methods, where numerous long de-stress holes are bored separately and in addition to the face pattern), as seen in the example in Table 2. In this example, only the lengths of the buffer and de-stress holes were taken into account as all other holes were the same for all patterns. Also, the length of de-stress holes was assumed at 5.9 m in all cases to make a like-for-like evaluation. Compared with the standard pattern (no de-stress of any kind), IK standard requires an extra 36.4 m to be bored whereas the conventional 10-hole de-stress method (WASM) requires an extra 59 m. Thus use of IK Standard pattern allowed for a 22.6 m reduction in drill metres per face compared to the conventional 10-hole de-stress method.

Table 2 Comparison of drill metres, circular profile

	Standard holes (buffers + lifters only)		Long holes (de-stress)		Total drill metres	Difference (m)
	Number	Length (m)	Number	Length (m)		
Standard pattern	17	4.2	0	5.9	71.4	
WASM pattern	17	4.2	10	5.9	130.4	59
Iron Kurtain standard	6	4.2	14	5.9	107.8	36.4
Iron Kurtain full (with lifters)	0	4.2	20	5.9	118	46.6

In addition to the time saved by drilling 22.6 m less, jumbo time was further reduced due to the de-stress holes in the IK pattern having a standard 45 mm diameter which allows for higher penetration rates than the 64 mm de-stress holes used in a conventional 10-hole pattern. However, a detailed time and motion study has not been conducted so this benefit is difficult to quantify more precisely.

Another possible advantage of the IK method is its potential to reduce ‘dishing’ of the face due to the buffer holes having a strong impact around the perimeter. Data collection to prove whether this potential benefit can be realised will be in the scope of future work.

Also, inspecting de-stress drillholes for unreacted explosives in the IK method was relatively straightforward compared to conventional de-stress techniques, as was remediation (washing out) if such an issue was discovered.

5.2 Operators’ compliance

On the operators’ level execution was initially inconsistent, possibly due to IK’s trial status as opposed to a standard procedure. In an earlier instance where some technical elements of IK method were tested before the IK trial commenced in earnest, an operator only bored the de-stress holes in the back and shoulders to full length, which predictably resulted in de-stressing the top portion of the face but increasing stress levels in the bottom section. As a result a higher level of seismic activity was reported from the bottom section of the face, including minor spalling of the rock. At the time of writing, compliance issues are still a problem, with some of the cuts occasionally having some of the de-stress holes missing or not bored to full length. This becomes evident only after firing. Similar operators’ compliance issues had been noted as part of the conventional de-stress method, including poor stemming (or none at all), the incorrect number of bored de-stress holes, etc.

5.3 Problems associated with the use of a coupling on drill steel

Initially two drill steels with a coupling were used to bore the long holes, which required a larger bit diameter (64 mm). This proved to be problematic due to poor flushing of the hole if the cut was taken in a decline. Also, coupling/uncoupling of the steels required significant jumbo time, likely due to the holes being close to the perimeter. Both of these issues were resolved by using a single 5.9 m-long steel for de-stress holes. In addition to solving flushing and coupling issues, this allowed the use of a standard 45 mm bit for all boreholes, which improved drilling time and allowed the use of the same explosive in all holes except the perimeter.

5.4 Charge performance

The need for a centre or collar priming technique caused some issues as occasionally the toe part of the de-stress hole failed to initiate due to habitual use of a priming system for the toe of the hole. This matter was raised with the mining contractor and has been addressed by the use of bidirectional priming for centrally primed holes.

5.5 Learnings and general feedback

Generally, after issues with coupling and flushing were resolved, the feedback from experienced operators was positive, particularly as the number of drill metres required in the IK method is lower than that in the conventional method and the need for coupling/uncoupling of rods is eliminated. Interestingly, however, there has also been a reported lack of understanding among operators as to the purpose of the application, given that a de-stress system has been in place for some time. An education system is therefore likely to generate a more consistent execution and performance of the method.

Further work will be conducted on optimisation of the charging technique, as well as drill pattern, with the aim of further reducing drill metres required while eliminating the chance of de-stress holes not being bored to full length (or misfiring). Also, a detailed comparison of seismic activity associated with conventional de-stress techniques versus the IK method is to be conducted at a later stage.

6 Conclusion

Based on the analysis above the alternative IK face de-stress method has been implemented at KB mine as the standard procedure in high-stress headings where the risk of faceburst is considered significant. The main reasons for the change were:

- eliminating the risk of drilling into an unidentified unreacted detonator/primer left in the rock mass
- lowering requirements for jumbo time
- using the standard bore pattern for the face so moving the burn is not impeded
- ease of inspection of de-stress holes performance
- demonstrated reduction in seismic activity after firing compared to conventional cuts
- risk of cross-initiation remaining the same as for the standard face pattern
- reduced risk of rifling, excessive blast damage to the face and scaling requirements.

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