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Improving drawbell drill and blast performance in block caving: field-based improvements from Panel 0, Oyu Tolgoi underground

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Abstract

Drawbell establishment is a critical stage in block cave mining as it directly affects cave initiation, early material flow, and overall production reliability. At the Oyu Tolgoi underground mine, several operational challenges were observed during drawbell development in Panel 0, particularly related to single-sided drawbell configurations, brow stability, and uncertainty in undercut–drawbell connectivity.

This paper presents a series of practical design and operational improvements developed to address these challenges. The work focuses on 3 areas: improving drill and blast performance for single-sided drawbells, strengthening brow set protection, and introducing a verification approach to confirm connectivity between the undercut and drawbell.

The proposed improvements were developed based on operational observations, blast performance reviews, and drawbell trials conducted in Panel 0. Early applications indicate improvements in drawbell reliability, brow stability, and readiness for production.

Quantitative results and operational performance indicators are discussed to demonstrate the effectiveness of the revised approach.

Keywords: *block caving, drawbell design, single-sided drawbell, brow set protection, undercut connection, cave initiation, operational controls*

1 Introduction

Block caving is a widely applied underground mining method used to extract large, deep orebodies. The method relies on gravitational flow and controlled rock mass failure, initiated through undercutting, to enable continuous ore extraction at drawpoints (Hartman 1987). At the Oyu Tolgoi underground mine, Panel 0 represents the initial stage of block cave development. The panel includes 18 single-access drawpoints for drawbell construction. In the original design, drawbell length was aligned with the development drive profile, resulting in a simplified geometry intended to support efficient development. However, early operational experience highlighted several limitations with this approach. The early single-sided drawbells constructed under the original configuration exhibited early brow opening during swell mucking, where the brow opened before the target swell tonnage was achieved, material hang-ups, and limited cave flow from the overlying undercut and apex levels. These issues indicated that the drawbells were not forming as intended and that confinement within the excavation was restricting effective breakage. The Panel 0 footprint is shown in Figure 1.

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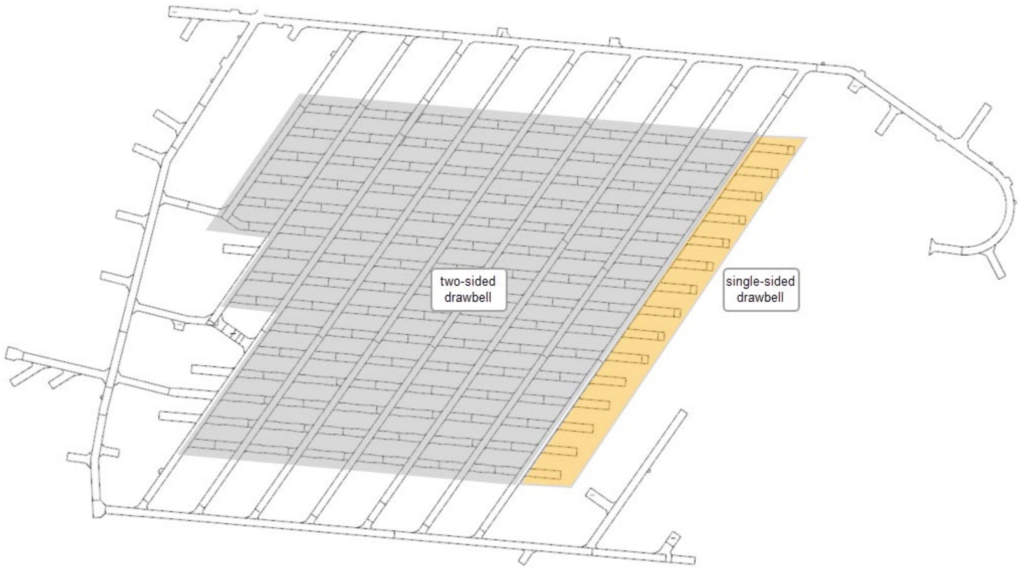


Figure 1 P0 footprint area showing two-sided drawbell and single-sided drawbell area

While conventional two-sided drawbells generally provide more favourable excavation geometry and more stable brow conditions, their implementation is not always feasible due to development constraints, infrastructure proximity, and sequencing requirements. As a result, single-sided configurations were adopted in several locations, introducing asymmetric loading conditions and increased confinement. The oblique view of single-sided drawbell relative to the development drive is shown in Figure 2.

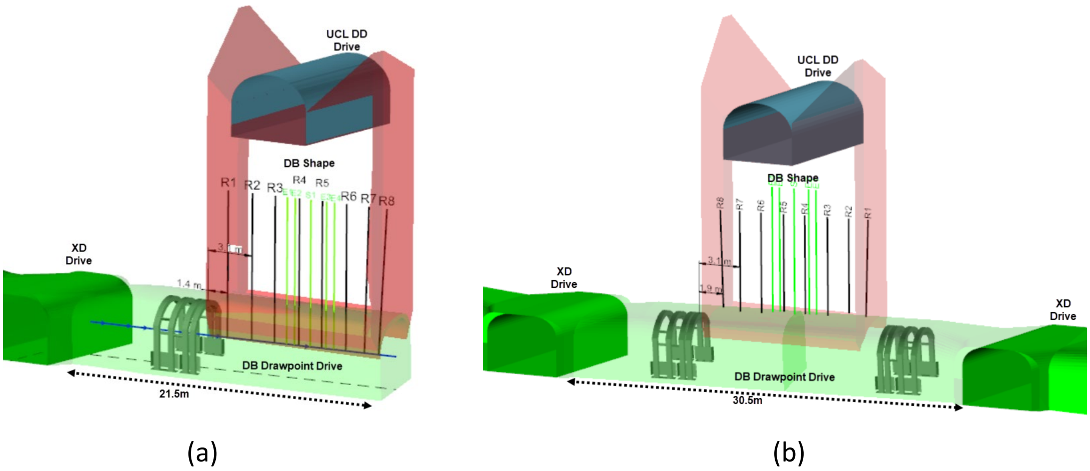


Figure 2 (a) Oblique view of P0 single-sided drawbell; (b) Oblique view of P0 two-sided drawbell

As drawbell construction progressed, key challenges were identified, including incomplete drawbell establishment, premature brow exposure, and uncertainty regarding connectivity between the drawbell and the undercut. These observations highlighted the need for improved design controls and more robust verification methods.

While drawbell design principles are well documented in literature, limited field-based studies have focused on the designed and operational challenges associated with single-sided drawbells under constrained development conditions. This study addresses that gap by presenting operationally validated improvements focused on blast performance for single-sided drawbells, strengthening browset protection, and introducing a verification approach to confirm connectivity between the undercut and drawbell.

2 Methodology

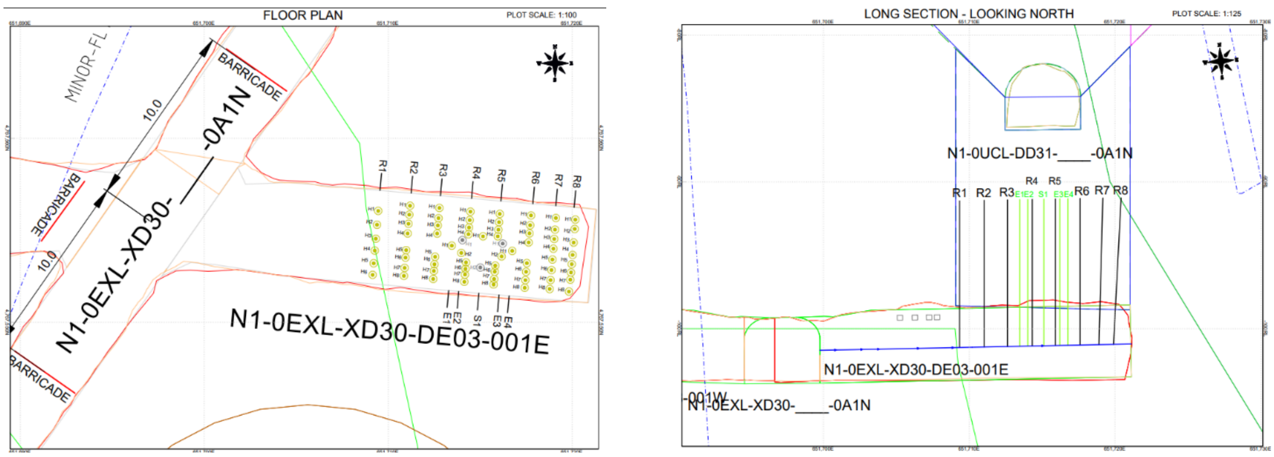
The operational review, blast performance analysis, and field observations were integrated to evaluate drawbell performance in Panel 0.

A total of 44 drawbells constructed between June 2022 and May 2023 were reviewed, including 5 single-sided configurations located at panel boundaries. Performance comparisons were made between early drawbells developed under the initial design and subsequent drawbells implemented with revised design controls. Operational data included blast performance records, mucking observations, cavity monitoring system (CMS) surveys, and hang-ups. These data were used to identify recurring performance issues and underlying contributing factors.

Based on this assessment, targeted design and operational modifications were implemented in selected drawbells. Performance was evaluated through post-blast observations and key operational indicators, including brow condition, material flow behaviour, and requirement for secondary blasting.

3 P0 single-sided drawbell

As mentioned above, 5 drawbells were developed as single-sided configurations: XD15-DB11, XD31-DB03, XD31-DB04, XD31-DB05, and XD31-DB06. The single-sided drawbell configuration is shown in Figure 3.



(a) (b)

Figure 3 (a) Floor plan of P0 single-sided drawbell; (b) Long section view of P0 single-sided drawbell

The single-sided drilling parameters were as follows:

- box hole diameter: 750 mm
- drillhole diameter: 89 mm
- total rings: 13 rings
- total number of holes: 70 holes
- total drilling: 957 m
- R8 dumped at 3°
- three central holes next to the box hole.

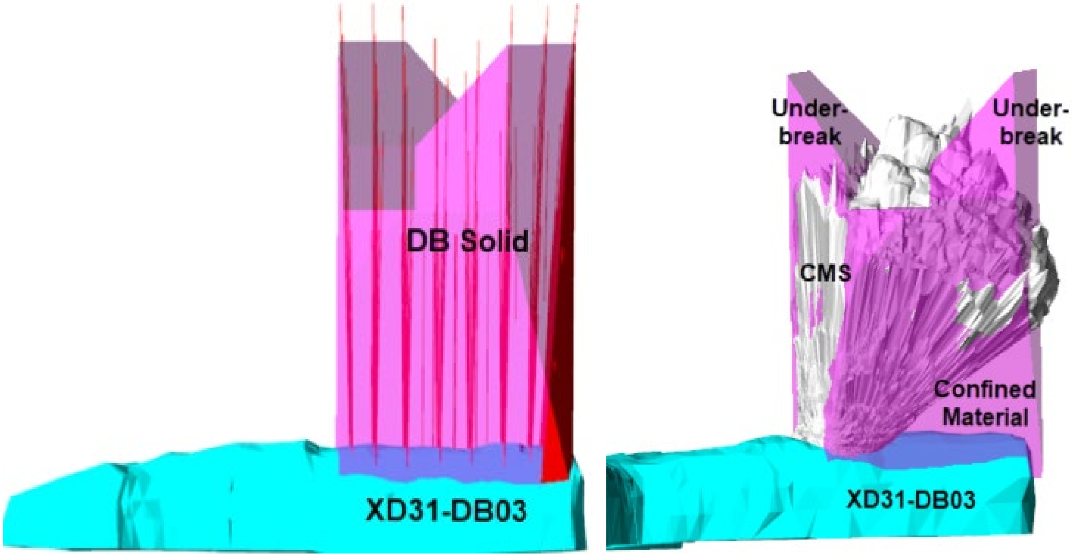
The charging parameters were as follows:

- emulsion density: 1.0 g/cc
- total explosive: 4,821 kg
- drawbell tonnage: 5,797
- powder factor: 0.83 kg/t
- total detonators: 142
- void ratio: 23%
- delay in a spiral pattern
- electronic detonators.

Although the post-blast inspection showed relatively uniform muck distribution and acceptable fragmentation, operational issues became evident during swell mucking of the first 2 single-sided drawbells, XD31DB03 and XD31DB04. The post-blast inspection photos are shown in Figure 4.

Figure 4 Post-blast inspection at single-sided drawbell in P0

After removal of swell material, both drawbells exhibited premature brow opening, localised hang-ups, and limited cave flow from the undercut levels. CMS surveys confirmed that the drawbells had not developed to the intended mining shape. The CMS of XD31-DB03 and its photo can be seen in Figure 5.



(a) (b)

Figure 5 (a) The XD31-DB03 DB firing shape; (b) The XD31-DB03 CMS result

Underbreak and confined material were observed in the upper crown and blind side of the excavation, indicating that confinement within the excavation had restricted effective blast breakage. These observations highlight a key limitation of single-sided drawbells, where asymmetric geometry and limited available void restrict blast expansion and lead to incomplete fragmentation.

4 Remedial action

Initial remediation involved water cannon and slash blasting between adjacent drawbells to release confined material (Figure 6). While this approach successfully recovered some material, brow opening was again observed during mucking. This indicated that the issue was not limited to residual material but was instead related to drawbell establishment and confinement conditions, which may also result in excessive rock mass damage due to confined blast concussion and shock wave propagation. As a result, further changes were required to address the underlying mechanism. The slashing rings can be seen in Figure 6.

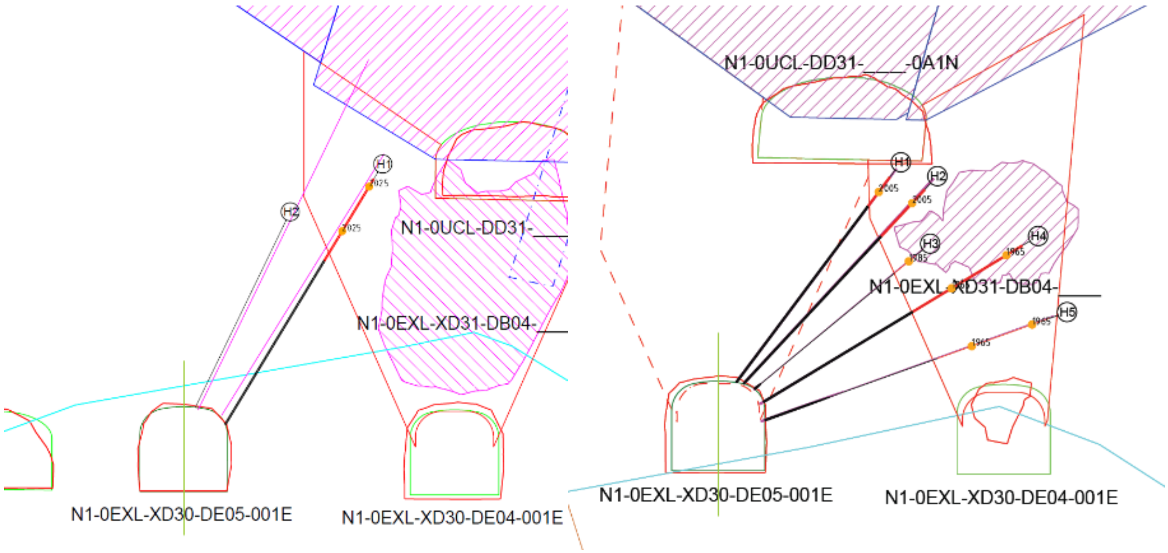


Figure 6 Slashing ring design at P0 single-sided drawbell

5 Contributing factors

The investigation was completed and identified several factors that may have contributed to the drawbell hang-up. These include:

- Void ratio: limited void static ratio available for single-sided drawbell compared to the standard two-sided drawbell.
- Confinement: the single-sided drawbell was confined and did not have a free face to fire into and therefore relied entirely on the dynamic void created by the preceding blast to relieve blast gases, compressive energy, and blast concussion effect.
- Drilling constraints: the drawbell development drive was aligned with the eastern extent of the drawbell shape and terminated at the drawbell boundary. As a result, the drill boom could not be positioned directly beneath the ring collars, requiring dump rings to be designed instead of vertical rings to achieve the required drawbell profile.

6 Design improvements

To address confinement in early single-sided drawbells, development drives at the cave boundary were extended by one additional drill round prior to drawbell drilling. The development drill length was approximately 4 m, with an advance of around 3.5 m achieved in practice. The long section view showing the additional development is shown in Figure 7.

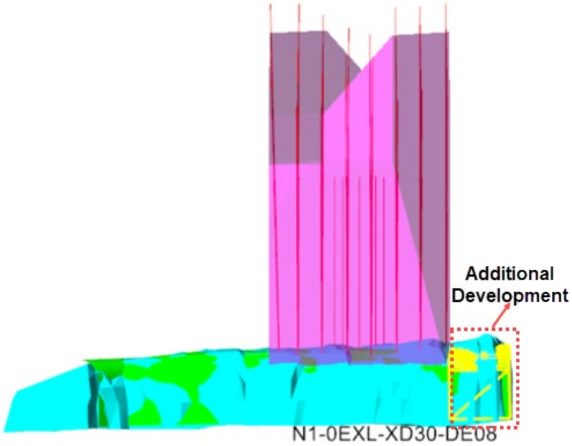


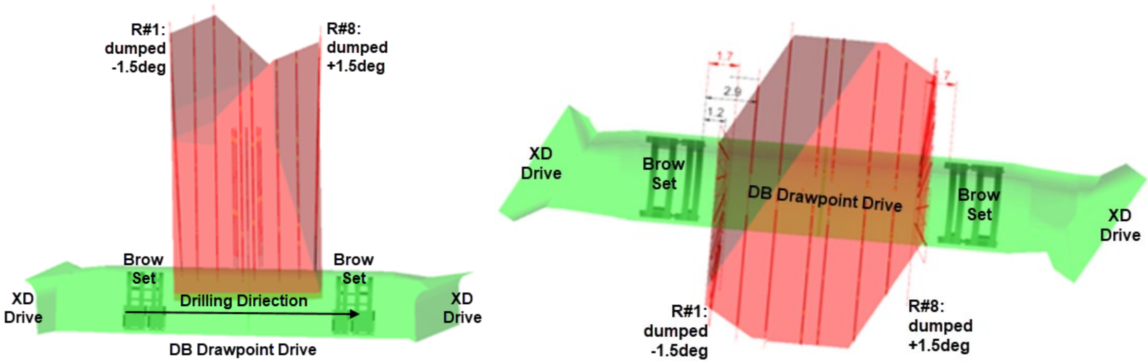
Figure 7 The long section view showing the additional development at single-sided drawbell

This modification increased available void for blast expansion and reduced confinement on the blind side of the drawbell. The additional void provided sufficient space for blast-induced rock movement, allowing improved energy utilisation and more complete fragmentation. Subsequent drawbells constructed under this approach demonstrated more consistent establishment, reduced evidence of underbreak and eliminated hang-ups.

7 Brow set protection

Brow exposure was identified as being strongly influenced by local energy distribution during blasting. Early designs resulted in excessive energy concentration near the collar region, contributing to premature brow opening during mucking.

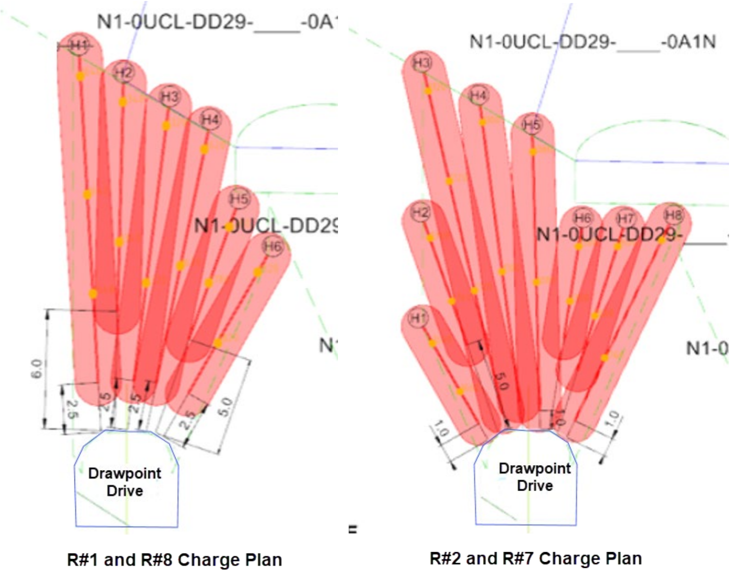
To address this, adjustments were made to increase in situ brow thickness by shifting perimeter rings, reducing powder factor at collars adjacent to the brow to reduce the overbreak, and improving blast orientation by dumping the ring angle by 1.5° to promote a funnel-shaped breakout and avoid concentrating blast energy on the installed brow set. The plan and long section view of the dump’s drawbell rings can be seen in Figure 8.



(a) (b)

Figure 8 (a) The long section view of ring dump adjustment at P0 drawbell; (b) The plan view of ring dump adjustment at P0 drawbell

The charge plan adjustment to reduce the overbreak is shown in Figure 9.



(a) (b)

Figure 9 (a) R#1 and R#8 charge plan adjustment to protect the brow set at P0 drawbell; (b) R#2 and R#7 charge plan adjustment to protect the brow set at P0 drawbell

To better understand brow stability during single-sided drawbell blasting, near-field vibration assessments were reviewed as part of the blast performance evaluation. Previous internal assessments indicated that brow conditions were sensitive to loaded and uncharged collar lengths, particularly within perimeter and end rings located near the brow set. To minimise potential brow damage, adjustments to collar lengths and stand-off distances were incorporated into the revised blasting approach.

Peak particle velocity (PPV) monitoring from nearby drawbells recorded values between 375 and 478 mm/s at monitoring distances ranging from approximately 16 to 22 m from the production holes (Oyu Tolgoi 2023). These values remained below the recommended brow damage threshold of approximately 650 mm/s from previous internal assessments.

PPV monitoring near the brow region was conducted using an Instantel vibration monitor during production blasting. Representative monitoring results are presented in Figure 10.

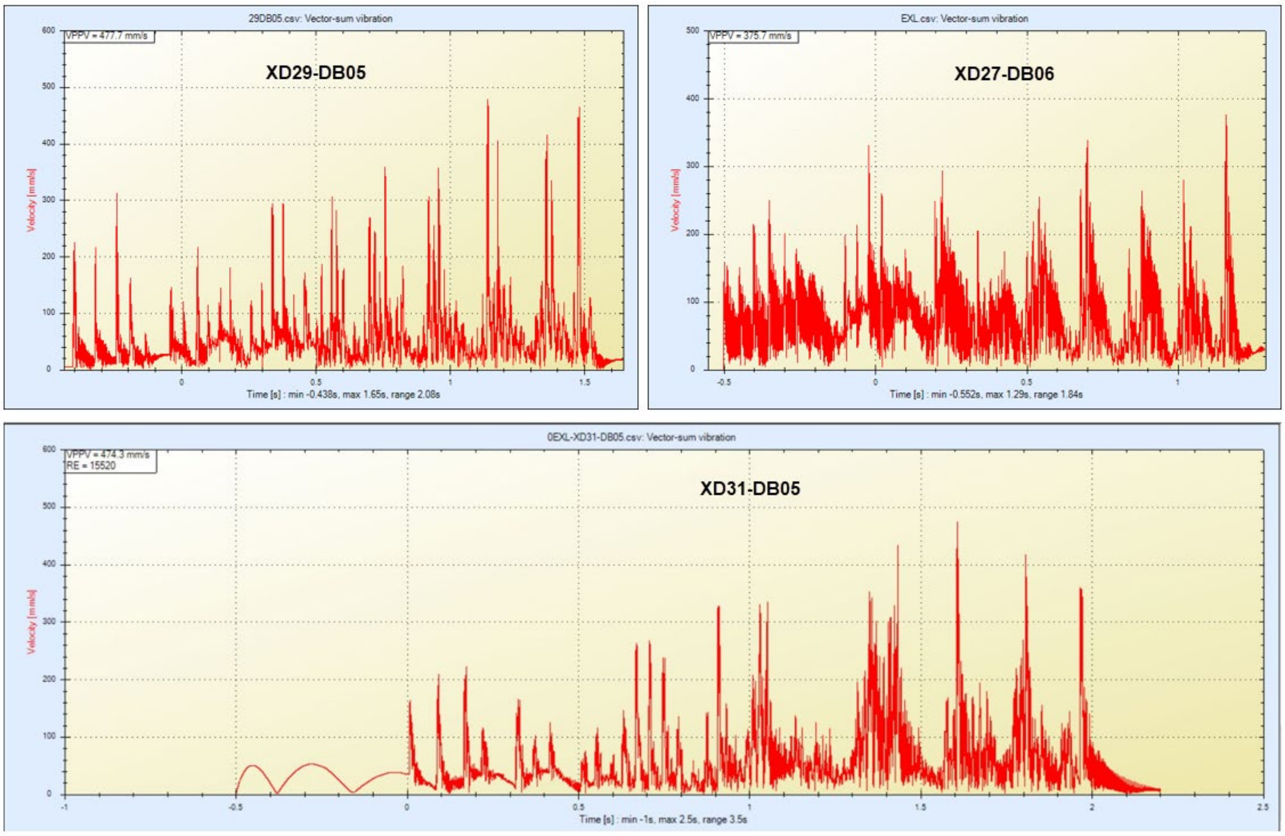


Figure 10 Vibration monitoring result near the brow region

Table 1 summarises representative Instantel monitoring results, including recorded PPV values, maximum instantaneous charge (MIC), and monitoring distance from selected drawbell blast.

Table 1 Near-field vibration monitoring data

Drawbell name	R# H#	MIC (kg)	3D distance (m)	PPV (mm/s)
XD27-DB06	R#1H#2	130.0	17.3	375.7
XD29-DB05	R#1H#1	123.5	16.1	477.7
XD31-DB05	R#1H#3	138.0	21.6	474.3

MIC = maximum instantaneous charge; PPV = peak particle velocity.

8 Undercut–drawbell connectivity validation

Uncertainty in connectivity between the drawbell crown and the undercut was identified as a key operational risk. In early cases, connectivity was assumed rather than verified. A validation approach was introduced in which selected drill holes were extended into the undercut zone to confirm breakthrough conditions and identify potential bridging or remnant material.

This approach provided direct confirmation of connectivity and enabled refinement of blast design parameters. It also reduced uncertainty in cave initiation behaviour and improved confidence in drawbell readiness. Figure 11 shows the holes that were extended in the drawbell.

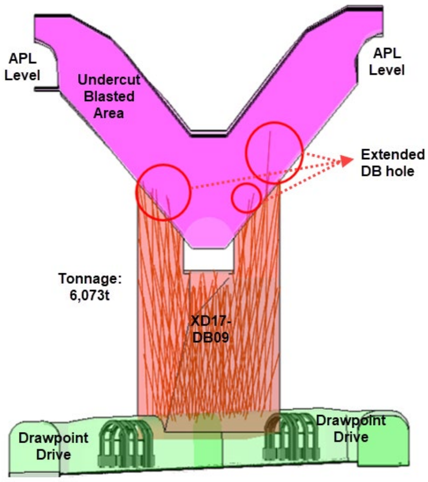


Figure 11 The plan and long section view of ring dump adjustment at P0 drawbell

The extended drilling into the undercut was conducted under controlled condition. The breakthrough area, located within the undercut rings, was confirmed to be free from misfires, ensuring there was no risk of unintended detonation during drilling.

The extended holes were used to assess whether the undercut had developed in line with the undercut ring design profile and to identify any remaining area of solid rock. As shown in Figure 10, one of the drawbell holes extended a substantial distance into the undercut, indicating the presence of retained solid rock in a localised area, while the remaining holes generally broke through close to the expected design shape. Based on the overall results of the extended hole drilling, the interpreted condition was considered acceptable to proceed without modifying the final blast design. The information obtained from the extended hole drilling was therefore used as part of the blast readiness verification and risk assessment process prior to firing.

9 Conclusion

Operational experience in Panel 0 at Oyu Tolgoi demonstrates that drawbell performance can be significantly improved through targeted adjustments to design and execution. Key improvements, including increased void availability, improved energy distribution, and connectivity verification, resulted in more reliable drawbell establishment, reduced hang-ups, and improved brow stability.

Implementation of the revised approach resulted in a clear improvement in drawbell performance across subsequent single-sided configurations. Brow exposure, which was frequently observed in early drawbells, was reduced to isolated occurrences following the introduction of improved perimeter control and energy distribution. Similarly, hang-ups during swell mucking were significantly reduced, with more consistent material flow observed across later drawbells. The requirement for trim blasting also decreased, indicating improved initial blast effectiveness.

These improvements were directly linked to changes in confinement conditions and blast energy utilisation. In the initial design, limited void on the blind side restricted blast expansion, resulting in energy dissipation within a confined rock mass. This led to incomplete breakage, retained confinement in the crown, increased damage to the apex and pillar due to confined blast concussion and increased likelihood of hang-ups. The introduction of an additional development cut at the drawbell development drive increased available void, allowing blast-induced rock movement to occur more freely. This improved fragmentation and enabled the drawbell to develop closer to its intended geometry.

Brow performance was also strongly influenced by energy distribution. By reducing localised over-energisation near the collar and increasing in situ brow thickness, more stable excavation conditions were achieved.

The introduction of connectivity verification further improved operational reliability. Confirming breakthrough conditions ensured that drawbells were fully connected to the undercut prior to production, reducing uncertainty in cave initiation and early material flow behaviour.

Overall, the implemented changes resulted in more consistent drawbell establishment, reduced rework, and improved operational confidence during early production stages. These findings highlight the importance of addressing confinement and energy distribution in single-sided drawbell configurations and provide practical guidance for similar operations operating under development constraints.

Acknowledgment

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