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Case study: bench turnover best practice and pit wall remediation at the Newmont Boddington Gold mine

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Abstract

The Newmont Boddington Gold (NBG) mine excavates over 90 Mt of rock from its open pit operation every year. The pits are mined out in 12 m flitches to form 36 m high composite slope benches with top/middle/bottom flitch batter angles of 75/90/90°. Approximately two benches are mined out of operating pits per annum resulting in kilometres of exposed pit walls. The primary objective of pit development work is to ensure personnel are provided with safe working areas. NBG has some of the steepest pit walls in the industry; therefore, much effort is put into wall evaluation, scaling, and where required, remedial works. This case study presents and illustrates the methods and techniques used at the Boddington Gold mine during bench turnover (BTO) works, how pit walls are evaluated and approved, and what pit wall remedial works are sometimes required to ensure a safe pit. Remedial works are undertaken either during or after BTO work and can involve accessing historic areas of pit wall.

At Boddington, BTO works are guided by the geotechnical team and consist of mechanical scaling using an excavator, followed by additional scaling using a dedicated in-pit rock breaker, hydroscaling, and chaining of the crest using either a dozer or an excavator to drag the chain. Wall evaluation includes structural assessment and for the purposes of BTO completion is generally performed through visual observation by geotechnical and operations focused work groups. Documentation of completion and accountability for completing tasks is established using a multimedia based approach including in field reporting using FastField Forms™ and the workflow planning and accountability software Trello™. Remedial works are sometimes required to address particular areas of concern in the pit. Remedial works at Boddington can include additional scaling, removal of sections of pit wall, cable bolting, installation of rockfall mesh, and construction of rockfall fences. This paper discusses how works are safely planned, delivered and documented.

Keywords: *bench turnover, pit wall scaling, pit development, open pit, ground support*

1 Introduction

The Newmont Boddington Gold (NBG) mine is located approximately 130 km south of Perth in Western Australia. The mine produces gold and copper by mining bulk tonnage from a large, disseminated orebody hosted within a massive andesite/diorite rock mass criss-crossed by sub-vertical and sub-horizontal dolerite dykes. Every year NBG excavates and hauls over 90 Mt of rock from its open pit operations. Due largely to the quality and character of the rock mass, NBG is able to safely excavate steep pit walls with 36 m high benches and 15.2 m wide design berm widths. The inter-ramp angle is 60.8° and benches are blasted and excavated in three 12 m high flitches using a composite batter angle design such that top/middle/bottom flitches have batter angles of 75/90/90°, respectively.

Currently two pits are in operation, the largest of which has a current planned depth of approximately 650 m. The mining rate results in approximately two benches being exposed every year. This produces kilometres of batters that are required to be worked on and made safe prior to personnel occupying newly mined areas to perform subsequent operational tasks. Development works thus form an important function within the mining sequence crucial to the continued safe operation of the mine.

Development work at NBG consists mainly of three steps:

1. Bench turnover (BTO) work.
2. Remedial work including implementation of ground support and additional blasting.
3. Remedial work related to historic areas of pit wall.

This case study presents how these different tasks are addressed and performed at NBG in a hard rock and steep pit slope open pit environment. Although development works are often regarded as stand alone, it is noteworthy that drilling and blasting techniques have a great impact on wall conditions prior to development works commencing. Therefore, a segment of the paper also briefly addresses how drilling and blasting can impact pit wall condition.

2 Drilling and blasting

Drilling and blasting are a primary factor in determining the condition of pit walls. Poor control of drill and blast activity can have a significant impact on pit wall quality and the amount of remedial work that is required during development of the pit. The following are critical to achieving favourable outcomes and minimising the ensuing ground control effort:

1. Quality control of drilling (including related to hole deviation and over-drill).
2. Quality control of blast design (including developing standard guidelines and a review process).
3. Blast timing and angle of initiation along the wall.
4. Choice of blast direction.
5. Drill pattern design (choice of hole diameter and location relative to berm/crest/wall).
6. Understanding of rock characteristics (i.e. charge weights required to achieve fragmentation).
7. Understanding and accommodating in situ geology (i.e. sensitive areas).

At NBG, there is a continued effort to produce favourable outcomes through open dialogue between drill and blast, geotechnical and geology teams. Efforts include rigorous field and office-based QA/QC procedures and developing better techniques through trial and observation.

Some examples of good practice at NBG include:

- Implementing strict controls to limit unplanned sub-drill when drilling above catch berms and crest locations.
- Controlling blast timing to maintain a 70° angle of initiation as blasts progress along pit walls.
- Using pre-split blasting for all blasts in hard rock adjacent to pit walls.

- Using narrow width free face trim (FFT) blasts on all top flitch blasts to help retain crests and improve wall condition. FFTs consist of three rows of blastholes: batter, buffer, and production.
- Choosing appropriate firing directions in order to decrease the chance of opening up known or observable geological structures.

Where drill and blast techniques are successful against pit walls this helps to increase safety in the pit by reducing the chance of creating hazards and areas of pit wall that are difficult to remediate. The time, effort, and cost of ensuing development works can also be greatly reduced.

3 Bench turnover

BTO is the primary systematic approach used to improve the condition of pit walls after drilling, blasting, and excavation are complete. BTO tasks at NBG begin as the walls are exposed during excavation work in the pit. Machine operators are trained according to procedures developed to undertake the different tasks comprising the BTO. Below is a sequential list of tasks performed during the BTO process:

1. Preparation of scaling pad.
2. Assessment of pit walls.
3. Scaling loose rock from the exposed batters using a large excavator.
4. Additional detailed scaling of the pit face using a dedicated in-pit rock breaker.
5. Chaining of the crest using either a dozer or an excavator to drag the chain.
6. Removal of scaling pad by top-loading out using an excavator.
7. Hydroscaling of the face and the crest using a water cannon.
8. Additional scaling/raking of the crest by the rope access crew where/if required.
9. Removal of toe flare and final scaling performed by the rock breaker after lower section of wall is exposed.
10. Dozer cleans up debris along toe which is then loaded out.

The following sub-sections provide additional detail related to each of these tasks. Scaling is defined as the action of removing loose rock from the face of the pit wall. Scaling is used to achieve a pit wall condition that is acceptable and where the risk of rockfall has been mitigated to an ‘as low as reasonably practicable’ (ALARP) standard.

3.1 Bench turnover pad preparation

In order to create an adequate workspace for machines to be able to reach the crest/top of flitch, initial works include leaving broken stock behind against the toe of the wall as operations load and haul from the pit. NBG operates a combination of large electric (rope) and diesel (hydraulic) shovels. As the shovel excavates along batters, one of the procedural objectives is to leave enough material to form a 4 m high pad from which the excavator and other machinery used during the BTO can operate. Figure 1 provides a visual indication of intended works. The pad is formed by levelling off the top of the rill pile that is left against the wall and dozing flat to sufficient width. Large rocks are removed during levelling of the pad in order not to impede movement of machinery.

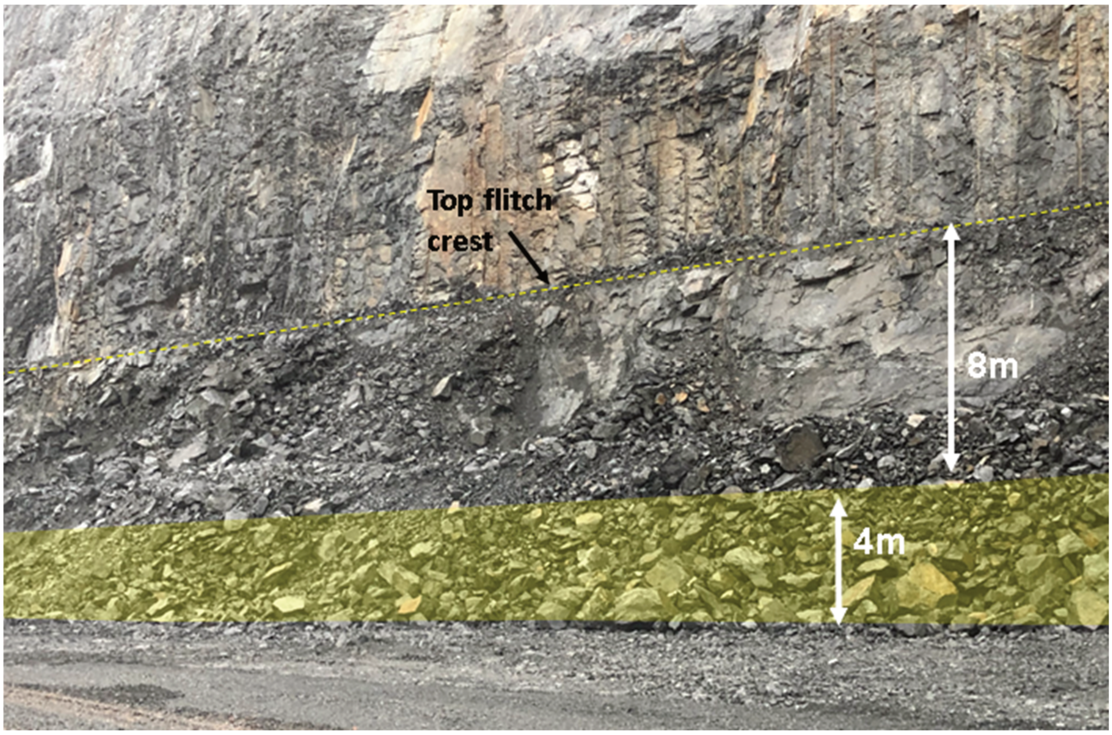

Figure 1 Operations leave sufficient material to form 4 m high scaling pad when mining through area

If insufficient material is left by the shovel, this creates problems with reach including affecting the quality of scaling that can be achieved in the crest area. In this case, truck haulage and additional work may be required to bring material in and level up the pad.

3.2 Pit wall assessment

Different levels of assessment are performed during the BTO process. Various personnel are involved in assessing the walls depending on the stage of the BTO, the amount of blast damage, and the geological structures present. Personnel regularly involved include mine operations personnel, geotechnical personnel and the structural geologist. Where required, assessment and further work may also involve various other personnel in the geotechnical and survey teams.

Initial assessment is performed by the geotechnical engineer and work groups involved in undertaking the BTO. Preliminary assessment involves evaluating loose material on the wall. This is often done by trained operators familiar with conditions that present on the walls and who can recognise what material is loose and requires removal.

Subsequent assessment by the geotechnical engineer highlights any areas where additional material is required to be removed. This may involve judgement of the extent of blast damage near the crest or along a particular section of wall and also in areas where machine operators have contacted the geotechnical engineer for guidance in determining the required extent of scaling work. Often, additional interpretation is required of the potential for certain sections of rock to loosen during future mining/blasting activity in the pit. Where this is determined to be the case, additional scaling is planned and undertaken.

Where significant geological structures form features of concern such as potential wedge formation and where these structures are either damaged by blasting or naturally weak, additional assessment is undertaken by the structural geologist. In this case, initial visual assessments are followed by high resolution point cloud laser scanning of affected areas. The resulting geo-referenced digital terrain model is then interrogated using 3D software including GEM4D™ (Basson 2021) and Leapfrog™ to interpret the extent and orientation of geological structural planes. Once this work has been done, potential interaction of intersecting planes is assessed and decisions on how best to address geotechnical concerns are made.

Figure 2 presents an example of structural modelling undertaken at NBG. High resolution scans are collected, and geological mapping of pit walls is undertaken for all pit walls. The time frame of this work is accelerated according to the requirements of the BTO process.

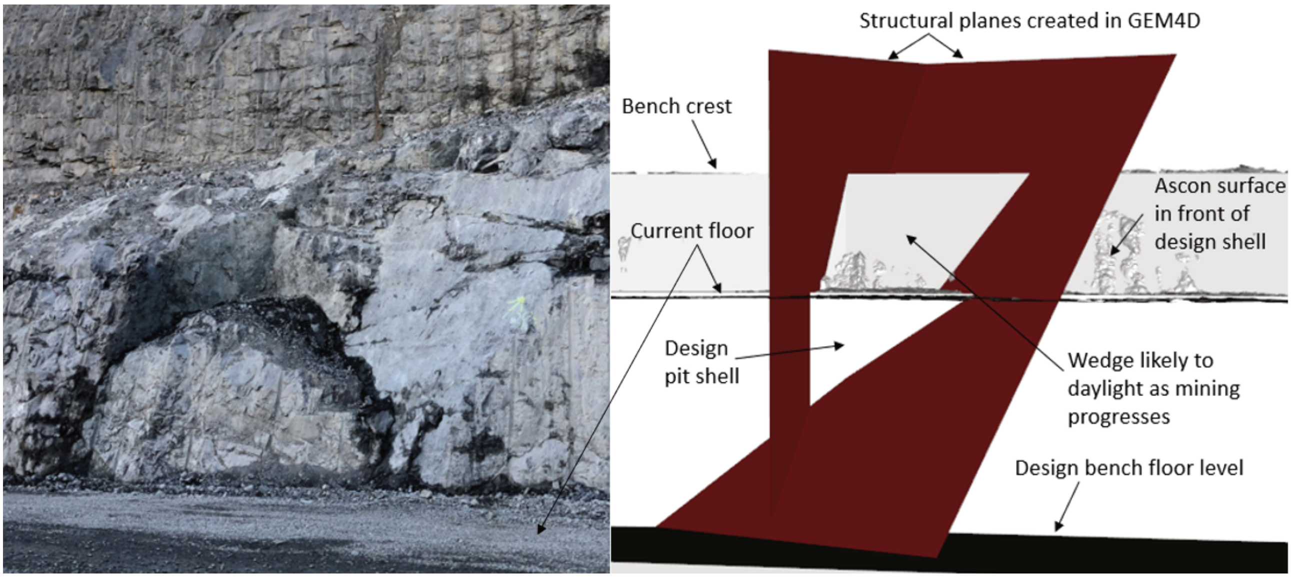

Figure 2 Example of geological structural mapping and interpretation

3.3 Scaling using the excavator

Scaling using an excavator is the primary means of removing the bulk of loose rock from the pit face to expose the surface created by pre-split blasting. At NBG, a large excavator is used to scale the batter face and crest. The power and reach of the large machine can help to safely remove loose rock and rock cling that can be present in front of the pre-split boundary. Objectives of scaling with the excavator include the following:

- Pull loose material off the crest.
- Where unfavourable structures exist along the crest dipping into the pit, scale to hard and consult geotechnical engineer to confirm any further work.
- Expose half barrels from pre-split blasting and remove all loose rocks and cling.
- Create a narrow trench along the bottom of the pit wall to catch debris during scaling with the rock breaker.

Figure 3 shows examples of what top flitch walls can look like before and after scaling by the excavator. It is the intention for scaling using the excavator to perform the lion’s share of scaling work since this can help to accelerate the BTO process.

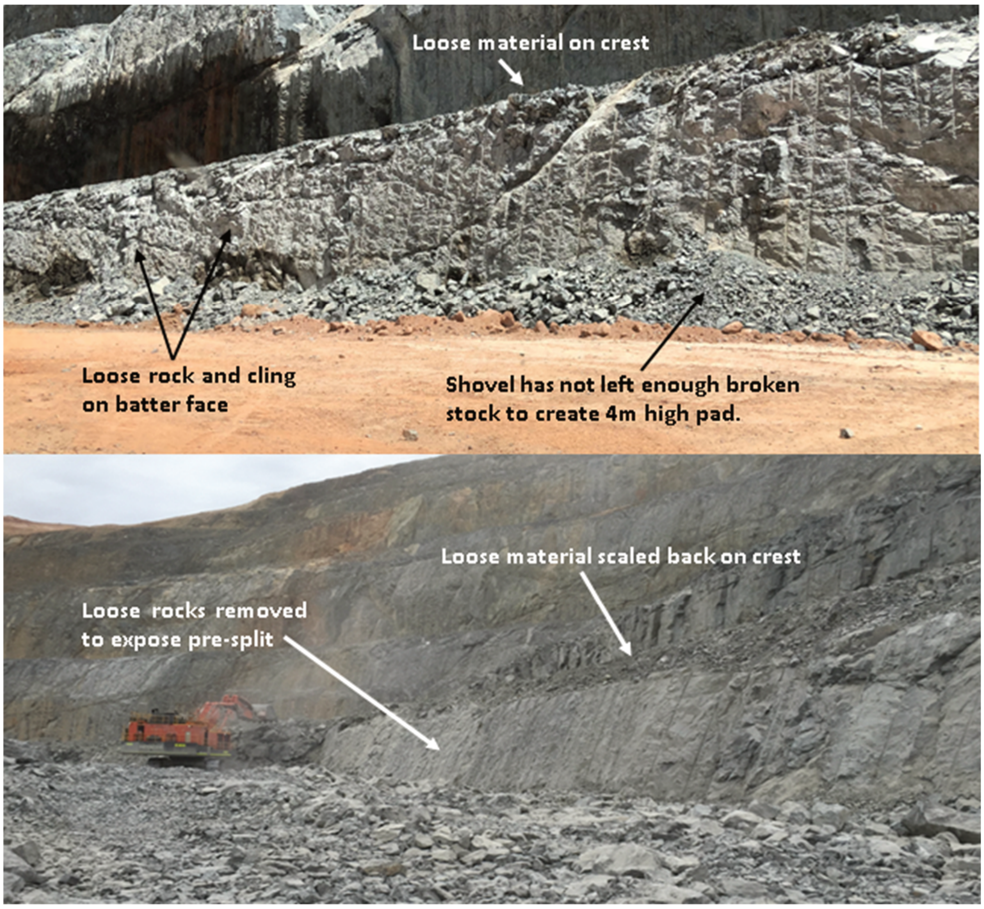

Figure 3 Examples of top flitch walls before and after scaling with an excavator

3.4 Scaling using the rock breaker

After scaling has been completed by the excavator, a rock breaker is used for detailed scaling. The rock breaker removes any cling or loose rock that the excavator was not able to reach or address effectively. When scaling the crest and majority of the wall, firing the moil is kept to minimum depending on circumstance. The rock breaker is also used to remove toe flare in the final steps of the BTO process after the scaling pad is removed. At this time, firing of the moil may be required more frequently to remove hard sections of rock that can jut out from the toe of the batter. Figure 4 shows the rock breaker removing wall flare.

Figure 4 Rock breaker removing wall flare

3.5 Chaining of the crest

After scaling with an excavator and the rock breaker, the next step in the BTO process is to chain the crest. At NBG, this is performed by attaching a heavy chain with a large weight attached to the end to either a D11 dozer or an excavator. The dozer then accesses the berm and drags the chain across the length of the crest being worked on. This helps to get rid of some of the remaining loose rocks along the crest. Chaining can only be done where sufficient berm width exists. The dozer will also not be able to access any section of berm beyond pinch points in the berm that reduce the berm width to less than approximately 10 m. In certain circumstances, for example when chaining is required over a windrow for sections of wall directly below a ramp, chaining is performed using an excavator instead of a dozer. Figure 5 below shows an image of a dozer undertaking chaining of the crest.

Figure 5 Dozer chaining the crest on the top flitch

3.6 Hydroscaling

One of the final steps used to render to the crest and pit wall into an acceptable condition is to use the water cannons attached to the water cart to hydroscale remaining debris and smaller rocks. This is done for targeted sections of wall/crest when required. An important aspect to this task is to ensure that water cannons have suitable strength so that the water jets can reach target areas while the cart maintains a safe distance from the wall. Hydroscaling can be very effective at reducing the amount of small size debris is a controlled manner. Figure 6 shows the water cart in action hydroscaling the crest area.

Figure 6 Water cart hydroscaling the crest area

3.7 Manual scaling

Where loose debris is required to be cleared from the crest or pit wall and neither machinery nor hydroscaling can reach or address the area, manual scaling techniques are relied on. This involves utilising the skills of the rope access team NBG has onsite at all times. Rope access personnel are trained to be able to safely scale crest and wall areas using a top-down methodology, ensuring areas are secure prior to moving to lower portions of the wall. In the crest area, this type of work varies from raking loose small-scale debris off the wall to using either steel bars or air bags to pry, loosen, and dislodge medium to large boulders off the wall. Steel bars and airbags are used further down the wall face where necessary. Figure 7 below shows the NBG rope access team on a scaling job above an in-pit ramp.

Figure 7 Rope access crew performing manual scaling on high wall

4 Bench turnover assessment and tracking

Final BTO assessment and tracking are important QA/QC and efficiency tools used to ensure the quality of the final wall and to help progress the BTO process. NBG uses a combined site inspection format and a formal sign-off document to involve teams that will be working near and under pit walls. In order to build in accountability and sequential task initiation, NBG uses a software tool called Trello™ (Atlassian 2021).

4.1 Bench turnover sign-off procedure

After the BTO has been completed by the operations team, and the operations crew supervisor is satisfied with the work, the geotechnical engineer performs a final inspection and a formal sign-off process begins where no further works are required. The formal sign-off involves responsible members of work groups whose crews will undertake future work under the walls being signed-off. Signatories include representatives of the following work groups:

- Geotechnical.
- Drilling.
- Blasting.

The sign-off inspection of the area is performed together by responsible parties and any concerns are raised and addressed accordingly. The results of the inspection are captured using the multimedia software FastFieldForms™. The software allows quick manufacture of forms that are accessible using a tablet and can be easily shared digitally. For BTO sign-off, the NBG template identifies the area of wall being addressed, the date, and lists several binary and open-ended questions to ensure that various tasks have been completed to the required level. The tablet is brought into the field during the inspection and details, comments, and photos are recorded providing evidence of the inspection and noting requirements for further work, or satisfaction with existing conditions. On-screen signatures are collected and the form can be sent out by email in PDF format to relevant parties and filed for QA/QC purposes.

4.2 Productivity using Trello

Trello is accountability and productivity software that is available as an online tool to help track workflows. Using the software Trello, a task list is constructed comprising the various steps required in the BTO process. The Trello application can be installed onto tablets and mobile phones and acts as an interactive project dashboard that different parties can access remotely. Tasks are assigned to specific work groups. Task completion is recorded through a tick box within the app with an option to provide additional commentary. Once a prerequisite task is complete, notification to the owner of subsequent tasks can be either through the app or via means outside the app interface.

Notes related to particular tasks can be added such as start and end times of partial completion of work being performed and time taken to fully complete the task. Photos can also be added to provide evidence of the quality of work or inform others of how the job is progressing. Figure 8 provides an example of the Trello application interface.

The data collected within Trello is used to better understand work progression through the BTO process and inform on any areas of greater interest where there may be room for productivity to be streamlined.

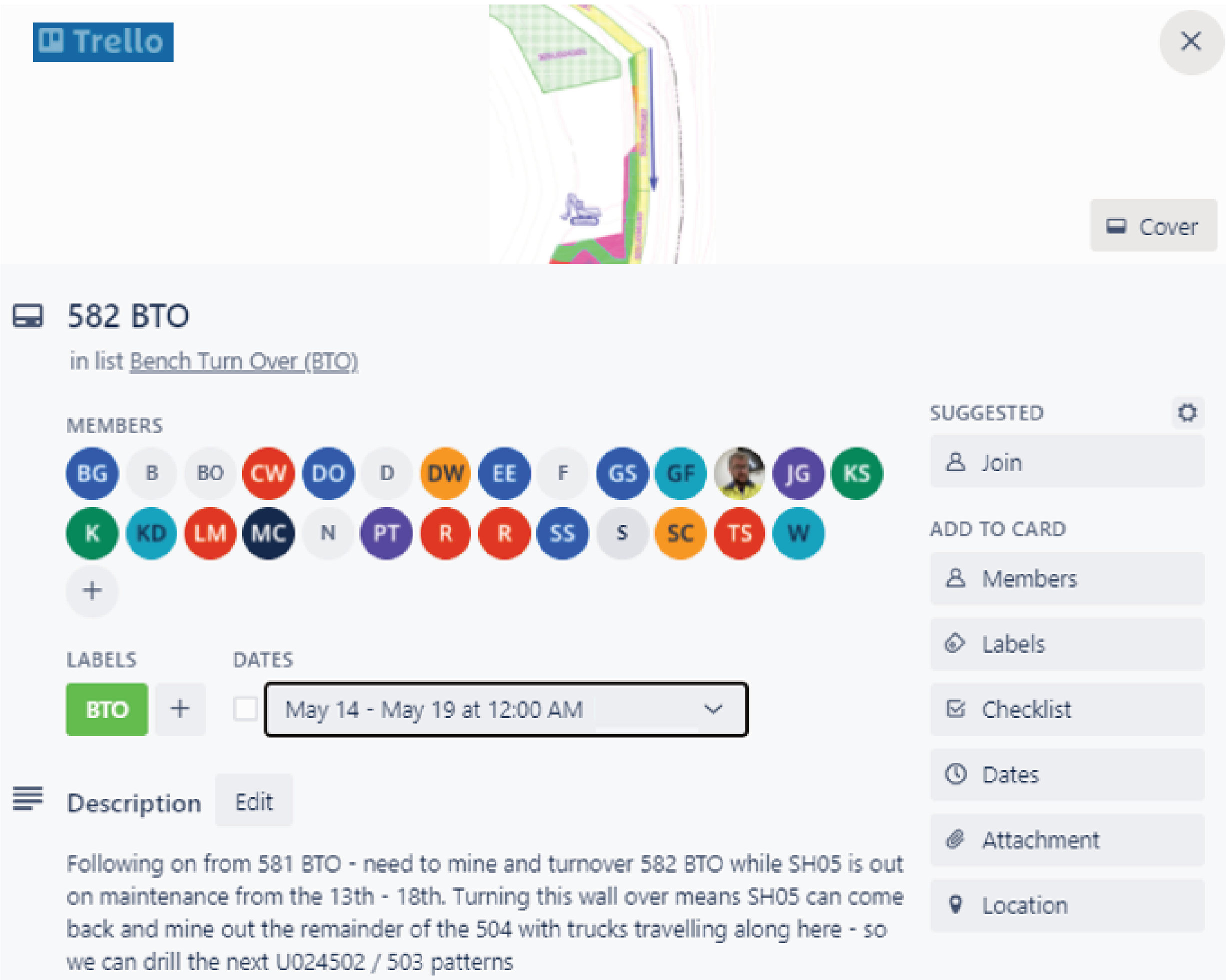

Figure 8 Example of Trello application user interface

5 Remedial measures over and above basic bench turnover tasks

Excessive blast damage, adverse geology or structural orientations, or a combination of these can result in sections of pit wall requiring additional attention over and above basic BTO development work. Sometimes pit wall conditions can change due to nearby blasting and areas need to be revisited. For example, blasting can cause dislocation or dilation along a structure in a section of wall where the BTO process has been completed and signed-off.

Additional remedial work can include the following:

- Correction cuts.
- Implementation of ground support.
- Additional scaling and pre-emptive hazard removal.

5.1 Correction cuts

Where adverse conditions manifest on pit walls such as significant undercutting or blast results that open up geological features, there are times when interpreted severity results in a decision to undertake additional blasting to remove hazards. This is done by various means which may include the following:

- Inspection.
- High definition survey using LiDAR point cloud scanner.
- Office-based interpretation of extent of desired correction cut.
- Design of blast.
- Implementation of drilling and blasting.
- Remedial BTO related work.

Correction cut blasting usually requires a ramp to be constructed to regain access to the berm above the hazard area. Drilling is normally done top-down after a ramp has been constructed, however, in certain cases it is possible to drill and fire a blast using horizontal drill holes.

Due to the time and cost associated with correction cuts, efforts are made to avoid situations where this type of work is required. For example, where known geological conditions such as adverse structures are present, additional care is taken during blast design. This can often include modifications to drillhole diameter, spacing, burden, blast direction, and powder factor. This is also a driver in choosing to use methods such as pre-split and FFT blasting to better control outcomes along pit walls.

5.2 Ground support

Ground support is used at NBG to support the rock mass within pit walls where potential hazards may exist due to unfavourable conditions. It is used, for example, where conditions are either not interpreted to require a correction cut or where this is not feasible. The main forms of ground support used at NBG are grouted and tensioned cable bolts. The process involves interpretation of geological characteristics and structures, design of reinforcement, drilling and implementation in the field.

Although NBG has the capacity to drill and install ground support up to 18 m high on the pit wall, the preference is to drill closer to floor level. Drilling near floor level can be done using more efficient drilling techniques that take less time and reduce risk. This enables the use of relatively quick production rigs normally used to drill pre-split holes. A high reach drill (HRD) is used to access elevated areas on the pit wall where necessary. The HRD can be operated remotely, however, it does not have as high productivity compared to the production pre-split drill rigs. The HRD has a quick hitch that allows the drill extension to be removed and replaced by a working platform in order to facilitate post-drilling installation and grouting of cable bolts. Figure 9 shows a photo of cable bolts being installed into holes previously drilled by production rigs.

Figure 9 Installation of cable bolts using elevated platform

5.3 Additional scaling and pre-emptive hazard removal

Experience with the local rock mass and ongoing operations at NBG is relied on to make judgement calls to remove additional material where certain conditions manifest on pit walls. There are situations, for example, where geological structures may intersect to form wedges that may not cause a hazard at the current level of mining, however, may cause significant issues when fully exposed at lower levels. Another example is where leading edges can form near the inflection point of the first and second flitch when structures with similar orientations to the pit face dip sharply into the pit. In similar cases, additional time and effort are expended to pre-emptively remove sections of rock while access allows. This helps to promote greater versatility and efficiency. Often this type of work involves using the rock breaker and/or additional effort with the excavator to dislodge the rock.

6 Remedial work related to historic areas of the pit

As mining progresses and the pit gets deeper, the condition of previously exposed walls can deteriorate depending on geology, vibrations due to ongoing blasting and weathering. This can result in new hazard areas and rockfall. The risk of rockfall is also increased where sections of berm crest have been lost and the berm loses width and capacity to arrest falling rocks. At NBG areas where crest loss is known to be significant are scheduled for rockfall mitigation works. Depending on the assessed severity of rockfall risk, remedial works may consist of the following:

- Scheduled inspections and rope access scaling.
- Application of interlinked steel rockfall mesh.
- Construction of rock catch fences and attenuation systems.

Where necessary, rockfall assessment and modelling is used to better understand the risk of rockfall associated with any particular section of pit wall. At NBG, this is done using various software tools including GEM4D and the 3D rockfall assessment software Trajec3D™ (Basson 2020).

6.1 Scheduled inspections and rope access scaling

Scheduled inspections and rope access scaling are used in hard-to-reach areas and where additional controls are deemed to not be warranted. This work also often forms the preliminary stages of next level mitigation measures in advance of mesh application or installation of rock catch fences. Rope access scaling utilises similar techniques to those described in Section 3.7 related to manual scaling.

Inspection work is either undertaken by unmanned aerial vehicles or in-person using rope access methods. The use of aerial drone flights and video footage has become standard practice and reduces risks related to safety while significantly increasing productivity and the capacity to share knowledge through video imagery. When in-person inspections are undertaken, this is usually combined with undertaking rope access scaling. For designated areas of elevated risk, inspections are scheduled to occur on a suitable timescale. Information collected during inspections is used to determine the need for rope access scaling and the amount of additional scaling that is likely required to remove loose rocks.

6.2 Application of interlinked steel rockfall mesh

Rockfall mesh is used in different areas at NBG to reduce risk to personnel working on the pit floor by containing falling rocks close to the pit face and guiding them onto catch berms. Rockfall assessment and modelling is performed prior to determining the need or extent of treatment. Different grades of mesh exist and are chosen according to interpreted requirements at specific locations. NBG uses steel interlinked mesh produced by Geobrugg. Mesh is attached and anchored above the berm crest by drilling and grouting in steel GEWI bars and tightened steel head plates. The mesh rolls are then lowered down the face and clipped together to form blanket coverage over the designated area.

Mesh is deployed as mining progresses away from the areas that require meshing since ongoing blasting and fly rock near the bottom of the pit has the capacity to damage or destroy it as it hangs along the wall. As such, where areas require treatment, rolls of mesh can sometimes be placed at strategic locations on berms in advance of deployment. This can be done either by high reach machine, by crane or other methods. Drilling related to anchor installation is often performed using a lightweight mobile drill rig that can be placed onto the designated berm or using smaller-scale hand drilling techniques that can drill to sufficient depth and diameter.

6.3 Construction of rock catch fences and attenuation systems

Where the risk of rockfall cannot be adequately mitigated using other techniques, NBG uses rock catch fences or attenuation systems to help reduce risk. In order to determine the extent, effectiveness and required fence or attenuation system rating, Trajec3D is used to model likely scenarios. This is done by gaining an understanding of likely block sizes that may release and assessing likely release locations. Trajec3D can then be used to import a section of the as-constructed pit shell in order to enable the evaluation. Engineering judgement is also applied as appropriate during any assessment.

Rock catch fences are available in many different sizes and ratings. Catch fences are installed along berms and can be vertical or angled and have various anchoring systems including for fence post base plates and upslope/downslope anchors. Similar to mesh, rock fences are installed at appropriate times in mining to limit damage from fly rock. It is sometimes possible and advantageous to pre-drill and install post foundations and anchor holes along berms before losing access.

7 Conclusion

Development works related to the conditioning of pit walls to mitigate geotechnical risks are essential to providing a safe working environment for mining personnel as mining progresses deeper in the pit. At NBG, significant effort, time, and cost are expended to ensure best practice is maintained. Immediate risks are addressed at the flitch and bench scale during the BTO workflow, while risks that manifest in historic areas of the pit are addressed as appropriate during the mining phase. In the mining industry, a common motto is 'If we can't mine safely, we will not mine'. This paper addresses an important part of what this looks like from an operations and geotechnical perspective at the NBG mine site. Where possible, tools and methodologies are used and developed to help NBG achieve greater efficiency in ensuring safe working areas. It is a continual effort to determine and progress more effective means of work including evaluating and incorporating new technologies.

Acknowledgement

The primary author thanks all team members who have continuously contributed to improving the BTO process at NBG and offers a vote of support to all pit wall panel beaters across the industry.

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