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Ground support in open pits and operational safety

S Welideniya *Department of Mines, Industry Regulation and Safety, Australia*

N Bar *Gecko Geotechnics Pty Ltd, Australia*

J Price *MMG Limited, Australia*

Abstract

Slope stability and operational safety are important aspects of open pit mining operations which are susceptible to geotechnical hazards including rockfall planar, wedge and toppling failures, as well as large-scale slope failures. Very well planned pit designs alone cannot fully eliminate all risks (in terms of likelihood and consequence) to personnel from these geotechnical hazards as site investigations are often limited. Some manageable low risk instability is acceptable in the context of mining economics. Slope monitoring systems such as survey prisms, radar and laser scanning are used to monitor slope movements to assist in mine safety. Administrative or procedural control measures such as trigger action response plans (TARPs) and ground awareness training (GAT) are often also used to manage risks. Ground support regimes can further mitigate risks either by means of stabilisation or as a safety control where required, and include shear pins, cable bolts, rockbolts, drape mesh and catch fences. This paper provides insight into the selection of ground support in various ground conditions and their impact on operational safety.

Keywords: *active ground support, passive ground support, normal stress, asperities, kinematic stability, cable bolts, drape mesh*

1 Introduction

Open pit mining operations may need ground support from time to time to manage slope instability and to improve safety. In addition to the engineering management of slopes, there are many administrative tools used in the industry for the management of risks associated with open pit high walls. Trigger actions response plans (TARP), ground awareness training (GAT) and various forms of hazard reporting systems are a few such administrative tools. A robust design can seldom be achieved across the entire pit design due to localised instabilities caused by the varying ground conditions, which change during the mining cycle. Ground support and real-time monitoring systems such as prisms, radars and scanners are useful tools to mitigate risks and improve operational safety (Bar et al. 2016; Baczynski & Bar 2017). Currently, there are many ground support types available for a variety of applications. Therefore, selection of suitable ground support for corresponding ground conditions is critical for their best outputs. Ground support installation is considered a specialised task requiring a high level of professional expertise. Quality assurance and quality control (QA/QC) of ground support during and post installation, as well as at predefined intervals, are also important to ensure that expected performance is achieved.

Stable slopes with a Factor of Safety (FoS) exceeding the design acceptance criteria (Department of Mines, Industry Regulation and Safety 2019) is an essential requirement under Western Australia's Acts and regulations (e.g. Government of Western Australia 1994, 1995).

2 Ground support types

Ground support can be divided into two categories based on their practical applications. They are:

1. Active ground support.
2. Passive ground support.

2.1 Active ground support

This support type is preferred due to its inherent risk mitigation properties. Active ground support enhances the rock mass strength by increasing confinement which helps the rock mass to support itself and prevent block sliding. This category includes:

- Rockbolts, including friction bolts and point anchor bolts, as well as a variety of grouted bolts.
- Cable bolts.
- Shear pins.
- Shotcrete and fibrecrete.

2.2 Passive ground support

Passive ground support does not enhance rock mass strength, its aim is to mitigate any risks associated with unstable ground. It is not designed to impart any additional strength to rock/soil or to improve its stress/strain behaviour or FoS. Instead, passive ground support is designed to minimise the impact of slope failures or rockfall on their surroundings by acting as barriers to prevent the progression or runout of failures to areas of concern (Saroglou & Bar 2017).

Passive ground support includes catch fences and drape mesh. Catch fences catch rolling or bouncing rock blocks that may have considerable momentum and energy falling from height. Drape mesh imparts a controlled fall trajectory (Coates et al. 2004) along the slope face, restricting the horizontal trajectory. Therefore, both act in minimising the impact on the surroundings, but do not improve wall stability.

3 Ground support design

The ground support design can be divided into a few stages. The most important prerequisite for any ground support design is understanding the geological, structural, rock mass and hydrogeological properties and, above all, potential failure modes. Without having a good understanding of these factors, the ground support design may not perform to its full capacity to provide the expected outcome. Well planned and executed field studies give a better understanding of potential failure modes for the design of ground support (Bar et al. 2018). The ground support design must focus and collate all these factors in order to improve the shear strength of the rock mass, joints, fault zones, etc. through applied active support theory. Therefore, the role of ground support in improving safety will be dependent on the following:

- Geotechnical field mapping.
- Kinematic and numerical modelling for the development of pit wall geometry.
- Selection of the most suitable ground support.
- Expertise in their installation.
- Ground support installation and post-installation QA/QC procedures.

4 Geotechnical field mapping

Geotechnical mapping of the focus area would help in understanding geotechnical properties of soil/rock and geology providing a firm basis for the design of ground support. Field mapping needs to capture structural features, lithology and groundwater regimes. Furthermore, a detailed kinematic assessment using suitable kinematic modelling software (i.e. SWedge, RocPlane, Topple, etc.) will provide an indication of the size of the potential instability which will guide to define the required minimum berm widths. Figure 1 shows a ramp wall where structural mapping was carried out for the design of ground support. The stereonet presented in Figure 2 shows all major joint sets on this wall and their potential failure directions. The foliation planes mapped on this wall section are dipping at 40–50° north. The foliations were found to be daylighting due to their lesser dip on a 60° batter face angle. Hence, there is a high probability of planar sliding instabilities on this batter face angle. Therefore, any ground support capable of increasing their shear strength across the sliding planes would act positively, increasing FoS.

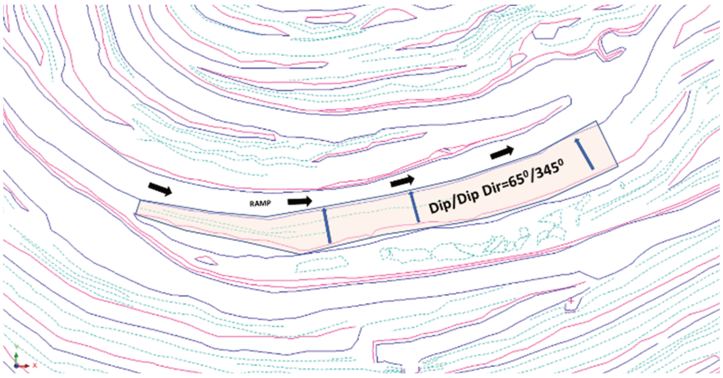

Figure 1 Ramp wall with potential sliding and toppling instabilities

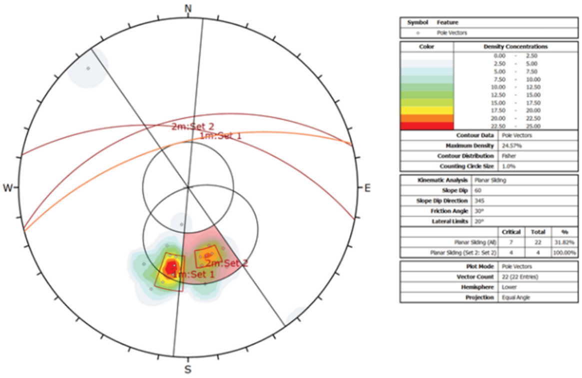

Figure 2 Kinematic analysis of joints and foliations

5 Selection of ground support

As described previously, ground support selection for a particular slope will be based on multiple factors. If the failures are at an acceptable level, that is, they do not incur any significant impact on overall stability and operational safety, then passive ground support may be acceptable (smaller blocks separating from the wall due to water, heat, foliations, Figure 3). If the potential failure (wedge and planar failures, Figure 4) could have a significant impact on wall stability and safety, then active ground support, or a combined approach which includes both active and passive ground supports, would be required.

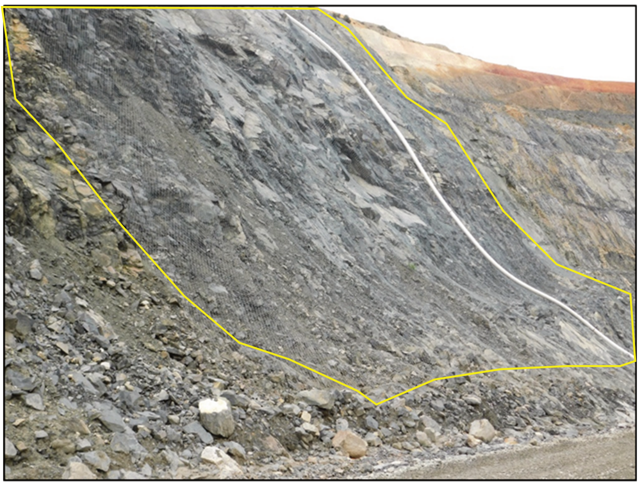

Figure 3 Pit wall with a drape mesh controlling rockfall trajectory

Figure 4 Unstable blocks on pit wall supported with grouted cable bolts (shown by yellow circles)

The application of drape mesh and catch fences will require a clear assessment of the falling debris and estimation of maximum block size and consequent impact energy respectively. Rockfall impact energy measured in kilojoules (kJ) could be estimated using suitable software (SWedge, etc.) once block size is estimated.

Technical specifications of some passive and active ground support types widely used in Western Australia and supplied by many ground support service providers (i.e. Geobrugg, Jennmar, SRG Global, etc.) are shown in Tables 1 and 2.

Table 1 Passive ground support technical specifications

Type	Wire diameter (mm)	Width/height (m)	Length (m)	Capacity
Catch fence	Varies	2–9 m height	No limit	100–8,000 kJ rockfall energy
Drape mesh	3 mm	3.5 m width	No limit	1,770 N/mm^2 wire tensile strength

Table 2 Active ground support technical specifications

Type	Diameter (mm)	Hole diameter (mm)	Yield	Elongation
Thread bars (resin or grout)	22–37	35–45	15–44 MT	20%
Shear/crest pins (high tensile rebar – grouted)	25–40	40–76	500–1,030 MPa (tensile)	10%
Mining Split Sets	33–47	29–45	8.5–15.8 MT	16–20%
Cable bolts plain (grouted)	21.8	35	27 MT	5–7%
Bulbed cable – single	15.2 (strand)	45–50	245 kN (25 MT)	5%
Bulbed cable – twin	15.2 (strand)	52–55	490 kN (50 MT)	5%
Bulbed cable – triple	15.2 (strand)	55–65	735 kN (75 MT)	5%
Pumps used for grouting range from 500–1,000 kPa pumping pressure				

6 Ground support effect on rock mass strength

The effect of ground support for the improvement of rock mass shear strength works in different ways. This mainly depends on how effectively the ground support acts on improving the shear strength of structures which could cause instability in the rock mass. The kinematic instability depends on the orientation of structural elements. As described previously, active ground support (different types of rockbolts) improves rock mass behaviour in many ways, as listed below (Indraratna et.al. 2005):

- Increasing normal load on the joint plane constrains dilation.
- Increasing contact area of the joint surface.
- Improving connectivity among adjoining blocks of rock mass and restricting their independent movements.

If there is any infill, depending on the load applied across the joint plane, there is a possibility for infill to squeeze out and further improve the direct contact between joint walls increasing friction against shearing (Indraratna et al. 2005). The action of rockbolt/cable bolt will bring joint behaviour near to the constant normal stiffness (CNS) condition by restricting its dilation (Figure 5). Restricted dilation during shearing will activate the asperity effect on joint shear strength as described in the joint shear strength formula (Patton 1966).

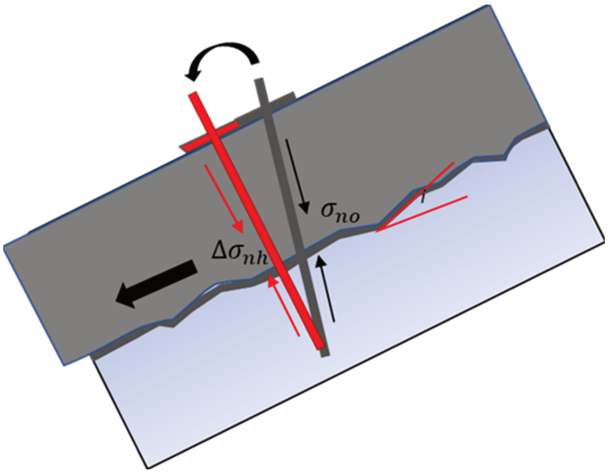

Figure 5 Rock joint and the role of tensioned bolt

Patton (1966) described the shear strength (τ) of rough joints with regular asperities as:

$$\tau = \sigma_n \tan(\phi_b + i) \tag{1}$$

where:

σ_n = normal stress.

ϕ_b = basic friction angle of the joint surface.

i = asperity angle on the direction of applied shear force.

Rock joints found in nature are usually not planar and instead they could have rough and undulating surfaces. Clearly, shearing a rough, undulating surface must overcome total sliding resistance. Equation 1 holds true for low values of normal stress (σ_n) where dilation is not restricted. If the normal stress rises above a certain value at which dilation is inhibited, then degradation of asperities may occur during continuous shearing. Rockbolts are installed by drilling holes in the wall to a depth that reaches the stable zone beyond the potential unstable zone. The installed rockbolts/cable bolts (grouted and tensioned) will increase normal stress across the structure/joint restricting dilation and mobilising the asperity effect on joint shear strength.

In this case, the shear strength criterion must be modified to account for a new dilation angle that will be less than the original asperity angle (*i*). Under CNS conditions, there will be an inevitable increase in the applied normal stress as dilation is constrained by the rockbolt/cable bolt. Therefore, under these circumstances, CNS conditions become more relevant to model shear strength. Hence, neglecting any asperity breakage, the shear stress developed by a joint will be a function of the current normal stress at a given horizontal displacement (σ_{nh}), the asperity angle (dilation angle) and the basic friction angle of the joint surface (φ_b) as given by Equation 2:

$$\tau_{(h,CNS)} = \sigma_{nh} \tan(\phi_b + i) \tag{2}$$

Under the effect of the cable bolt/rockbolt, the displacement of rough discontinuities can cause an increase in normal stress which may promote asperity degradation with continuous shearing. The dilation under such conditions is expected to be less than the initial asperity angle. This effect is presented by Equation 3 developed by Seidel & Haberfield (1995).

$$\tau_{(h,CNS)} = (\sigma_{no} + \Delta\sigma_{nh}) \left[\frac{tan(\varphi_b)+tan(i)}{1-tan(\varphi_b)\,tan(i_\mathrm{h})}\right] \tag{3}$$

where:

$\tau_{(h.CNS)}$ = joint shear stress at a horizontal displacement of h.

σ_{nh} = corresponding normal stress.

i = initial asperity angle.

i_h = tangent to the dilation curve at a horizontal displacement of h under CNS conditions.

σ_{no} = initial normal stress.

7 Conclusion

Active ground support acts to increase joint shear strength, thus improving overall rock mass strength and preventing potential instabilities. It is important to support ground before any shearing takes place to maximise the positive effect of asperities on shear strength. Asperity shearing will reduce joint roughness, negatively affecting joint shear strength.

Passive ground support, such as drape mesh and catch fences, will minimise hazardous conditions by limiting the rolling distance of the failed mass and any human/machine interaction with falling debris. Catch fences should be designed to meet the impact force of the rolling debris. This may vary from a few hundred to thousands of kilojoules. However, passive ground support will not improve the wall/face conditions or their overall stability.

Ground support could be considered as a useful design element in open pit mining and slope management. Therefore, careful selection of suitable ground support to manage constantly changing ground conditions with clear objectives should always be considered for efficient slope management, preventing any hazards, minimising risks and improving operational safety.

It is also important to put in place other administrative risk mitigation procedures such as GAT and TARPs for effective slope management and improved safety. GAT will improve workforce knowledge of hazards and ground conditions. This will promote hazard reporting and follow up remedial actions in mitigating risks. TARPs will also lay down fundamental action and response plans to face any evolving hazard and take appropriate steps for its risk reduction (Welideniya 2016). This can be further improved with ground support and other technical procedures such as real-time monitoring. Therefore, a combined approach with active and passive ground support, technical and administrative tools, and pit wall monitoring will immensely contribute to the safe management of open pit slopes.

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