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Face destressing blast design for hard rock tunnelling at great depth

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ABSTRACT

Destress blasting of development headings is a construction technique in deep tunnels, whereby explosives are used to fracture the rock in such a way that strain energy is dissipated from the rock mass, with minimal deformation. This is intended to reduce the frequency and severity of violent stress-driven face or floor instability. Effective destressing relies on shear mechanisms of rock mass failure. For this to occur, the length and directionality of blast-induced radial fractures must be sufficient to generate fracture continuity between adjacent explosive charges. Natural rock structure must also be weakened by blasting. The blast-induced fracture network characteristics are largely dependent upon the explosive properties, rock mass strength, natural structural characteristics, as well as the magnitude, orientation and anisotropy of the principal stresses. This paper presents a destress blasting design concept consisting of a series of symmetrical rows of destressing charges which are sub-parallel, yet almost oblique to the major principal stress. When detonated, these rows of charges are intended to create a series of continuous fracture planes which may deform in shear, transitioning the rock face to a post-peak loading condition. The blast design and related damage zones have been examined numerically using the Hybrid Stress Blasting Model. The modelling results guide the blast design parameters, such as borehole diameter, burden, spacing, explosive charge properties and alignment of the borehole rows relative to the major principal stress. It is suggested that the optimal destressing charge consists of a collar primed, fully confined and coupled explosive.

1. Introduction

Destress blasting involves the controlled detonation of explosives ahead of an advancing tunnel, with the intent of reducing the frequency and severity of violent rock mass failure. Such failures can pose a serious safety hazard to the underground workforce due to the unpredictable and often violent ejection of rock from the tunnel boundaries. The specific intent of destress blasting is to create a zone of fractured rock ahead of a largely unsupported face. This fractured zone has reduced strain energy density with respect to the adjacent rock mass. Conceptually, this fractured zone is formed via blast-induced intact rock fracture and dilation of pre-existing discontinuities. Fracturing is accompanied by small deformations which are sufficient to release stored strain energy in the rock mass and temporarily prevent it re-accumulating (Toper et al., 1997). This technique has been suggested to have the effect of pushing the highly stressed seismogenic zone further away from the excavation (Fig. 1) (Roux et al., 1957; Toper et al., 1999).

Destress blasting has been used throughout the global mining industry for many decades (Roux et al., 1957). However, there is still considerable uncertainty surrounding the effectiveness of the technique. Destress blasting is often implemented reactively in response to the visible onset of face instability. This can be attributed to the difficulty in anticipating spalling conditions at the advancing development front. Furthermore, no definitive design process is available to guide either the necessity for implementing destressing of a particular excavation or the specific blasting design geometry required to successfully limit instability. Instead, blast designs frequently follow a conventional geometry (Carr et al., 1999), as shown in Fig. 2.

2. Rock fracture

The effectiveness of destress blasting is dependent upon the explosive charge properties, rock mass strength and natural joint structure, as well as the magnitude, orientation and anisotropy of the principal stresses (Fleetwood, 2011). The often very high confining stresses at the face act to limit blast-induced radial fracturing and confine pre-existing natural fractures, inhibiting dilation of these fractures due to

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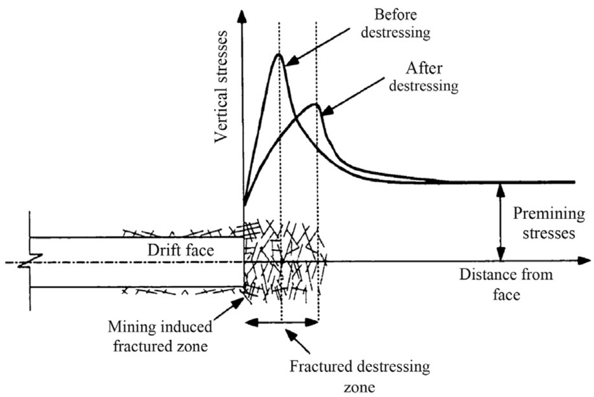

Fig. 1. The theoretical effect of destress blasting on stress concentrations ahead of the face (Roux et al., 1957).

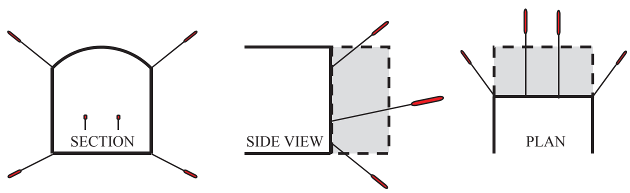

Fig. 2. Typical convention for development face destress blast design in hard-rock (Carr et al., 1999).

gas penetration. Laboratory experiments by Jung et al., 2001 have shown that the limits of radial fracturing are highly dependent upon the orientation and magnitude of the major principal stress acting on the rock mass. Specifically, radial fracturing propagates in all directions in the absence of an applied stress (Fig. 3a), whereas radial fracture propagation is restricted to orientations sub parallel to the major principal stress when one is applied (Fig. 3b).

In conditions of significant stress anisotropy, it is suggested that conventional destressing designs (Fig. 2) may simply generate isolated pockets of broken ground, with radial fracturing aligned sub parallel to the major principal stress. Fracture interaction between adjacent boreholes would be unlikely to occur for such designs, given the large spacing between charges and the fact that the alignment of blast holes does not form rows of consistent spacing aligned with conditions of reduced confining stress. Conventional destressing patterns may not necessarily form continuous fracture zones or, therefore, effect the necessary rock mass damage needed to cause a broad shear mode of rock mass failure at the face.

3. Application of destressing

The desired benefit of a destress blasting program is a reduction in the frequency and energy of violent stress-driven spalling of the rock

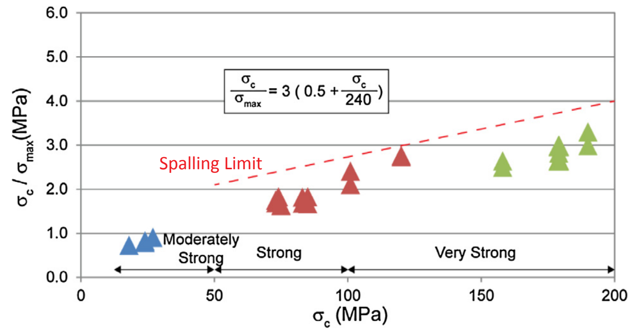

Fig. 4. Unsupported tunnel spalling as a function of rock mass UCS and maximum tangential stress (Kusui, 2015).

mass surrounding a development heading. Recent work by Kusui (2015) showed that the onset of spalling of an excavation can be reliably estimated if the rock mass UCS and maximum induced stress tangential to the excavation surface are known. Specifically, an excavation surface is likely to spall violently wherever the ratio of the intact rock UCS (σ_c) to maximum induced stress (σ_{max}) tangential to the surface falls below the spalling limit, as shown by the red dashed line in Fig. 4. Destress blasting may be required in such conditions, in order to reduce potentially hazardous instability. This is particularly true where the σ_c/σ_{max} ratio falls significantly below the spalling limit, which is indicative of more violent instability with potentially greater release of strain energy.

Identifying the potential for instability in advance of construction requires definition of the stress orientation and its maximum magnitude tangential to an excavation. These parameters may be defined by first conducting in-situ stress measurements within the vicinity of the planned excavations. Numerical stress modelling and/or the use of simple stress concentration factors (Obert & Duvall, 1967), may then be used to refine the estimated stress conditions at the tunnel boundary. The maximum stress concentrations acting at an excavation boundary should be estimated considering the orientation of the excavation with respect to the major principal stress. In typical Australian deep mining conditions, the major principal stress is often sub horizontal. Consequently, face spalling (or floor heave) conditions most frequently present where the longitudinal axis of the excavation is sub-perpendicular to the azimuth of the major principal stress. This process of assessing stress-driven instability at the face may be applied well in advance of tunnel construction, in order to estimate which excavations may require face or floor destressing. In this way, the potential risk of violent instability may be anticipated and proactive risk control measures implemented before the construction workforce are exposed to hazardous conditions.

4. Blast design concept

Conventional destress blast designs place charges in a symmetrical

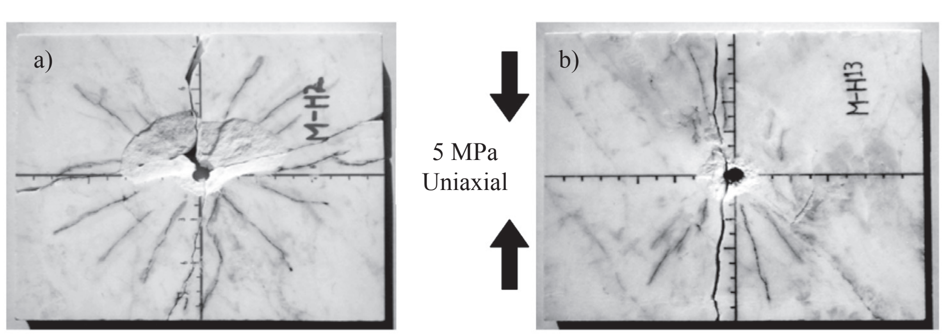

Fig. 3. Effect of stress magnitude and orientation on radial fracture propagation in rock (Jung et al., 2001).