Reply to the Comments made by

F.S.A. de Frey

on the paper 'Design of Merensky Reef crush pillar'

by B.P. Watson, J.S. Kuijpers, and T.R. Stacey

The discussion written by Dr de Frey suggests that mine design should be based on closely spaced stability pillars. However, this concept leads to low extraction ratios at depth. The concept of 'crush' pillars in conjunction with more widely, appropriately spaced stability pillars allows for significantly larger extraction ratios, particularly at depth. It should be noted that the rock conditions in many areas of South African platinum and gold mines are good, allowing significant spans to be mined safely between stability pillars.

'Crush' pillars are cut small enough to fail stably near the face under stiff loading conditions, and their residual strength is intended to support about 10 m rock height between stability pillars. While this support resistance cannot be achieved by conventional support, crush pillars have been proven to have the required capacity for this purpose. The concept of leaving smaller crush pillars with appropriately positioned stability pillars has been used successfully for more than 30 years in areas of South African platinum and gold mines.

Crush pillars were inadvertently designed by Korf[1] in 1978. In his paper Korf describes how serious problems were experienced where stoping advanced to a point 30 m to 40 m on both sides on the centre gully. Sudden failure of the hangingwall beam frequently occurred at this stage. Korf[1] maintains that the introduction of the crush pillars stopped the 'backbreak' problem. Crush pillar residual strength was subsequently estimated by Ozbay *et al.*[2] to be at least 5% to 10% of the peak pillar strength. Back analysis performed by Roberts *et al.*[3] showed that normal sized crush pillars have a residual strength in excess of 10 MPa. Watson *et al*[1] describes underground measurements of residual strength.

It should also be noted that a system of 'small', closely spaced stable pillars has problems of its own. For instance, these pillars are susceptible to 'pillar runs' (large-scale pillar failure) if one or two pillars are inadvertently overloaded due to unforeseen weaknesses. Such failures have been observed at Everest Mine in South Africa (Lombard[4]). In addition, overloaded stability pillars can be a source of seismicity.

Dr de Frey, in an unsubstantiated argument, claims that crush pillars have negligible cohesion, suggesting a limited residual strength. Several other opinions are also presented in his discussion. His arguments are shown below in blue with a joint response from the authors of the paper: 'Design of Merensky Reef crush pillars' in red.

The crush pillar

A crushed pillar will have the following characteristics:

- Fragmented material with limited resistance to closure
- Negligible vertical or lateral cohesion in the pillar as well as its surrounding region
- No shock absorbtion ability to transfer shockwaves vertically or laterally
- Increased vertical and lateral stresses in the hangingwall and footwall
- Diminished ability to form stable beams between crushed pillars
- Failure to assist in maintaining equilibrium by the inability to distribute strains and stresses, especially tensile stresses, equally amongst the pillars and their host rock
- Weak clamping affect between pillars, especially where geological disturbances are present in the pillars as well as the bords.

In theory, failed/fractured rock may be expected to have negligible cohesive strength and consequently limited (residual) strength. However, crush pillars have been proven to be effective in stabilizing large spans (Korf[1]). In addition, underground stress measurements demonstrated substantial residual strength of such crush pillars. Although it is not immediately clear what is causing this residual strength, it is clear that the theoretical assumption of negligible cohesive strength is incorrect. This was addressed in the paper by Watson *et al.*[5]. It is empirically accepted within the platinum mining industry that crush pillars with width-to-length ratios of about 3 have a residual strength in excess of 10 MPa (Roberts *et al.*[3]). However, we (the authors of the paper Watson *et al.*[5]) agree that further investigations are necessary to understand the mechanism of the non-zero residual cohesion.

The squat pillar

The failure of realistic pillar systems, with the probable exception of very slender pillars in hard rock, is to large extent controlled by fracture and failure processes in the foundation. The author would like to add failure in the hangingwall.

The foundation of a pillar in mining includes both hanging- and footwall.

Increasing pillar strength and pillar load results in increasing damage and failure in the hanging and or footwall. The author is of the opinion this can be alleviated by smaller pillars carrying smaller loads as a result of smaller spans. Stable pillar design and behaviour cannot be considered in isolation.

The determination of stable spans was not directly addressed in the paper, which deals with pillar behaviour.

Reply to the Comments: Design of Merensky Reef crush pillar

Span stability is dependent on several factors such as: geology, depth, and stress ratios. The crush pillars provide local support and (squat) stability pillars provide regional support.

In their paper 'Design of Merensky Reef Crush pillars' Watson *et al.*[5] state that pillar size should be designed with residual strength in mind, and also the need to consider peak strength and loading environment. It is the author's considered opinion that no crush pillar design will achieve this.

Refer to our initial comment on empirical and measured residual strength.

Watson *et al.*[5] again concentrate on assessing pillar strength but come to the conclusion that, and the author quotes: 'The calculations should include panel spans between pillars rather than a pure extraction ratio.' It is the author's opinion that this should not allow any probability of failure by loading pillars in excess of their peak pillar strength.

Stability pillars are designed not to fail and to provide regional support. However, crush pillars are designed to provide local support and maintain a considerable residual strength.

Wagner[5] states that the most important parameters that control the magnitude of induced stresses, decrease with increasing pillar size and decreasing bord width.

Ultimately a zero extraction ratio will provide the safest conditions!

References

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