

Development of a Support Strategy for Cleaning Slushers Situated in Booysen's Shale at Mponeng Gold Mine

R. Carstens

^a Mponeng Gold Mine, Carletonville, South Africa.

^b AngloGold Ashanti Pty Ltd

ABSTRACT

Mponeng Mine is a deep level gold mine situated in the Carletonville district. The mine exploits the Ventersdorp Contact Reef (VCR) to depths of 3371m below surface. The mine uses the Sequential Grid (SG) mining method to extract the reef. The footwall lithologies vary across the mine with quartzite footwall to the east and Booysen's shale towards the west. Cleaning slushers are developed below the finger raises, with box holes from the slusher to the raise, to facilitate cleaning due to very long raises. Slushers situated in Booysen's shale started deteriorating during the ledging phase to the point of total collapse, which impacted significantly on mining volumes and flexibility. This paper describes the process that was followed to understand the failure mechanism using underground observations, measurements and numerical modelling. It also details the development and implementation of a successful support strategy. It highlights the initial mistakes made due to a lack of understanding

Corresponding Author

E-mail address: rcarstens@anglogoldashanti.com

1 INTRODUCTION

Mponeng Gold Mine is a deep level, seismically active, gold mine situated in the Carletonville area approximately 70km south of Johannesburg, South Africa. The mine exploits the Ventersdorp Contact Reef (VCR) using the Sequential Grid (SG) mining method. Mining depths vary from 2400m, for the shallower parts of the mine, to 3400m below surface for the deepest part of the mine. The ore body is accessed through a series of vertical shafts, haulages, x/cuts and finger raises. The upper part of the mine used the longwall mining method with follow on development. In the late eighties a decision was made to change from long wall mining to sequential grid mining. The shaft infrastructure, with inter-level spacings of 100-110m, was already established for a longwall mining method when this decision was taken. The dip of the ore body is 20° - 22° resulting in very long, 280m to 300m long, raise lines. A cleaning slusher is developed below the finger raise to alleviate the cleaning problems associated with the long raise lines.

On the eastern side of the mine these slushers are developed in relatively weak Booysen's shale and these slushers started to collapse during the ledging phase or shortly after mining commenced. This was a concern from both a safety and production perspective. Once these slushers collapsed it placed a major constraint on cleaning and production levels had to be reduced in these working places. Lost production was replaced by moving mining crews into other working places resulting in increased levels of seismicity in these areas. Slowing down in a particular area also made the overall scheduling of working places difficult to prevent the formation of remnant areas.

Initially it was understood that the failure was as a result of the water from ledging and stoping operations filtering down to the slusher, destroying the cohesion between the highly laminated shale bands.

A support strategy consisting of fibre reinforced shotcrete or Thin Sprayed Liners (TSL's) was recommended based on this understanding. Initially 50mm fibre reinforced shotcrete was applied in the slushers but this was later replaced with a TSL based on the successes at a neighbouring mine, Savuka.

This support strategy proved to be ineffective because failures continued to occur and neither shotcrete nor TSL was able to contain the rock mass deformation experienced. Questions that arose were:

- What was causing the rock mass deformation and ultimate failure of the slushers
- What type of support strategy will ensure the long-term stability of the slushers
- What alternatives were available if it proved impossible to support these slushers

Modelling was conducted in order to gain a better understanding of the failure mechanism. Results indicated that the deformation and subsequent failure was due to a significant increase in the major principal stress and a change in direction of thereof relative to the shale laminae in the hanging wall of the slushers. Based on this information both the primary and secondary support strategy was changed. Primary support was changed from splitsets to 20mm rockbolts and the support density was increased. Secondary support was changed from TSL to a system consisting of the following elements:

- Mesh and Lace with shepherd crooks
- Mechanical Anchors
- Trusses
- Sets

This support strategy proved to be successful where the support was installed prior to any ledging or stoping activities. Failures continued to occur in areas where the support was late due to operational problems.

2 GEOLOGY

The mine exploits Ventersdorp Contact Reef (VCR) to depths in excess of 3000m below surface. Hanging wall consists of strong, competent, jointed lava from the Ventersdorp Supergroup. VCR rests on strata of the Witwatersrand Supergroup.

Pre-VCR tectonics, associated with the formation of the Bank Anticline, caused uplift of the Witwatersrand sediments, centred on the region to the east of the mine. This resulted in gentle up-warping and erosion of strata. Lower Witwatersrand Shales were consequently exposed in the core of the anticline.

VCR was deposited on the uneven floor created by the uplift, now represented by a shallow angular unconformity. The footwall lithologies to the VCR therefore vary across Mponeng Mine as the unconformity cuts deeper in an eastward direction into older strata.

Figure 1 represents a hypothetical slice through the central part of the mine, indicating the variation in footwall topography and the relative elevation difference of the various terraces.

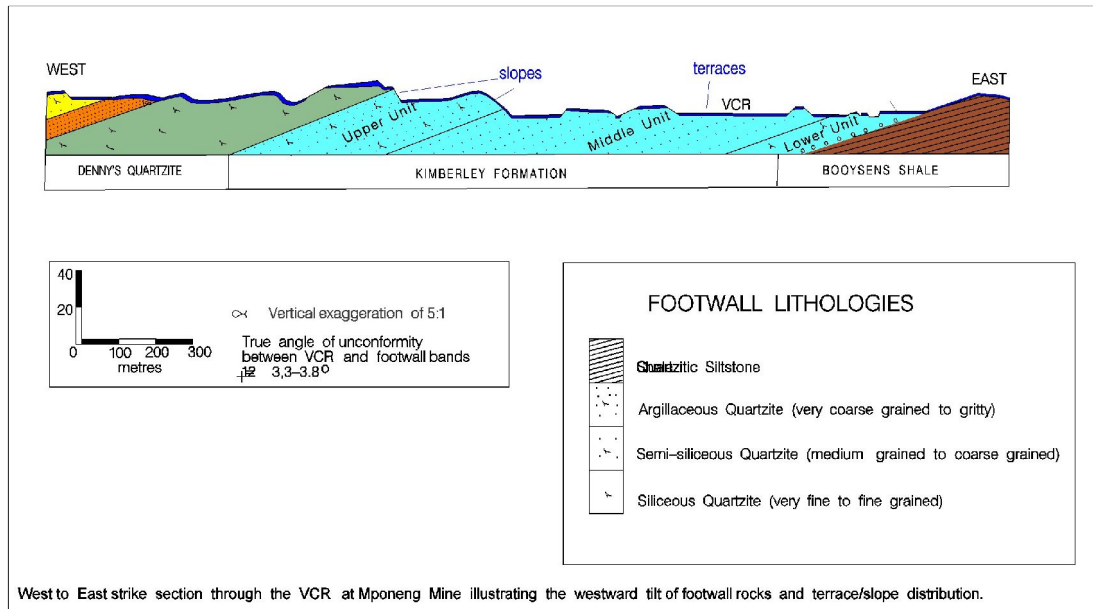


Figure 1 Section showing the footwall morphology of Mponeng Mine.

The Booysen's Shale Formation (BSF) to the eastern side of the mine comprises a sequence of interbedded argillites (true shales), and fine-grained siltstones (fine-grained quartzites). The extreme upper portion of the formation exhibits more quartzite than shale, with the shale content increasing rapidly downwards into the centre of the package. The lower half of the BSF again exhibits an increasing proportion of fine-grained quartzite.

The BSF varies in thickness from 67m in the east of the mine to over 120m in the west, as determined from borehole drilling. The westward increase is due to sedimentary thickening away from the basin margin. Figure 2 show a stratigraphic section through the Booysen's Shale Formation.

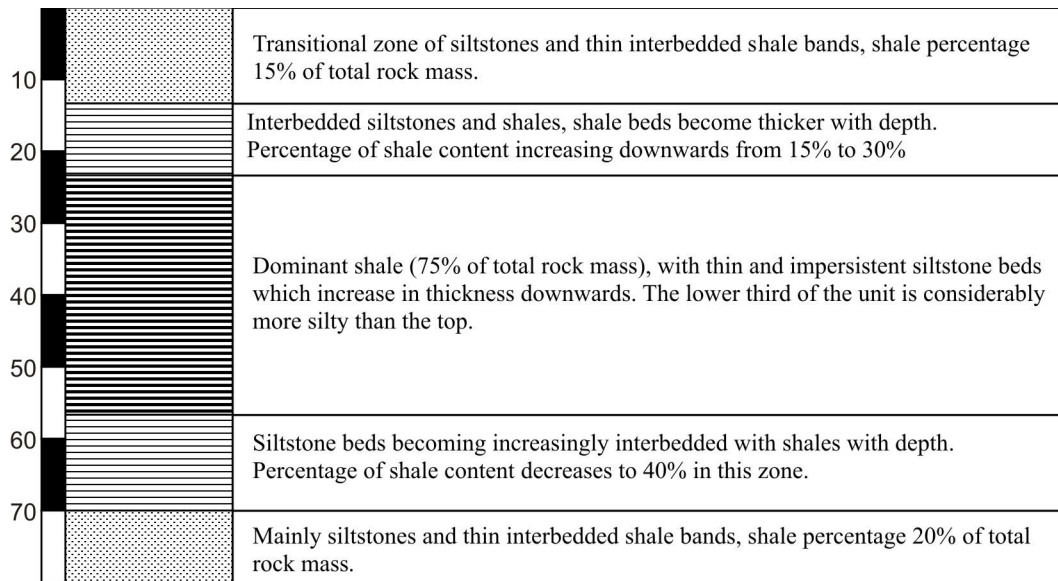


Figure 2 Stratigraphical section through shale package.

The uniaxial compressive strength (UCS) of the shale varies both within the relative position in the package and is highly anisotropic due to the highly laminated nature thereof. The UCS perpendicular to the laminae varies between 120 – 140 MPa. No shear strength tests have been conducted to date.

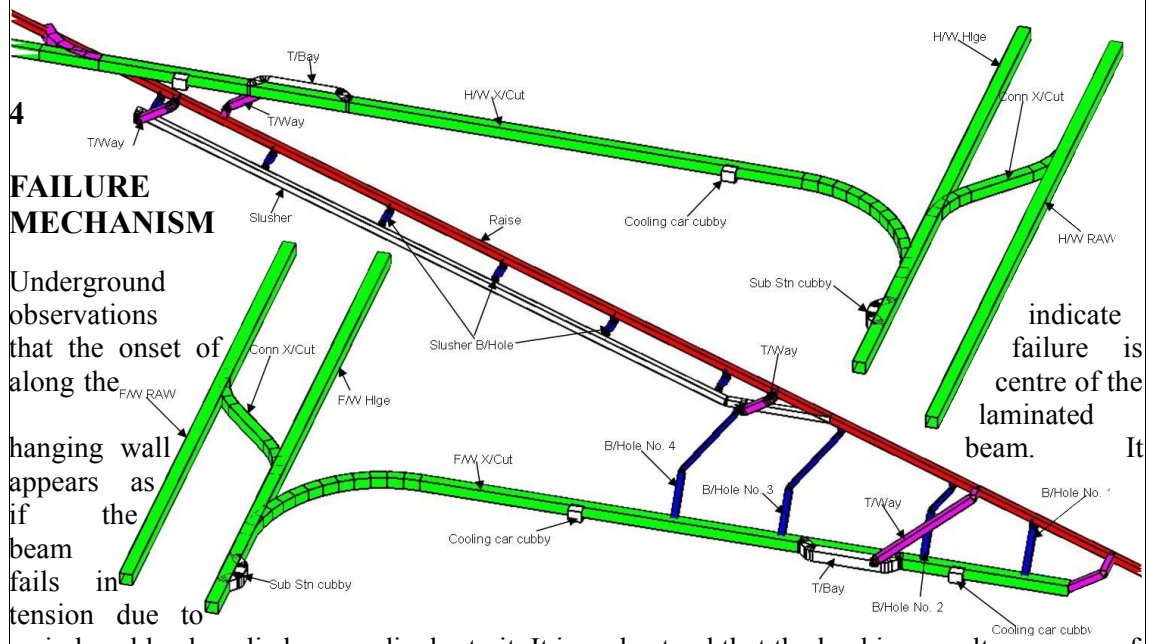
3 MINING LAYOUT

Reef is exploited using a sequential grid mining method with 30m wide dip stability pillars spaced 180m apart. Both hanging wall and foot wall development is used to access the reef and is placed either high in the hanging wall or deep in the footwall to limit damage associated with high stresses and subsequent stress changes (Figure 3). From the x/cut a travelling way is developed to the reef horizon and a finger raise developed on-reef to the upper level. A 2,4m high x 1,8m wide slusher is developed below the finger raise to facilitate removal of the ore when ledging and stoping starts. Box holes are developed from the slusher to the raise for every stope panel.

Slushers on the eastern side of the mine are developed in Booysen's shale due to the change in footwall morphology from west to east. Hanging wall failure was observed in these slushers during the ledging phase and subsequent stoping phase. Unravelling of the hanging wall continued once the hanging wall beam failed up to the stage where these excavations had to be abandoned. This meant that cleaning had to be done through the original finger raise. Stopping volume had to be reduced in these raise lines due to cleaning constraints.

Initially it was understood that the failure was as a result of the water from the reef horizon filtering down to the slusher and destroying the cohesion between shale layers.

Figure 3 Hanging wall and foot wall development layout showing position of the slusher relative to the finger raise.



FAILURE MECHANISM

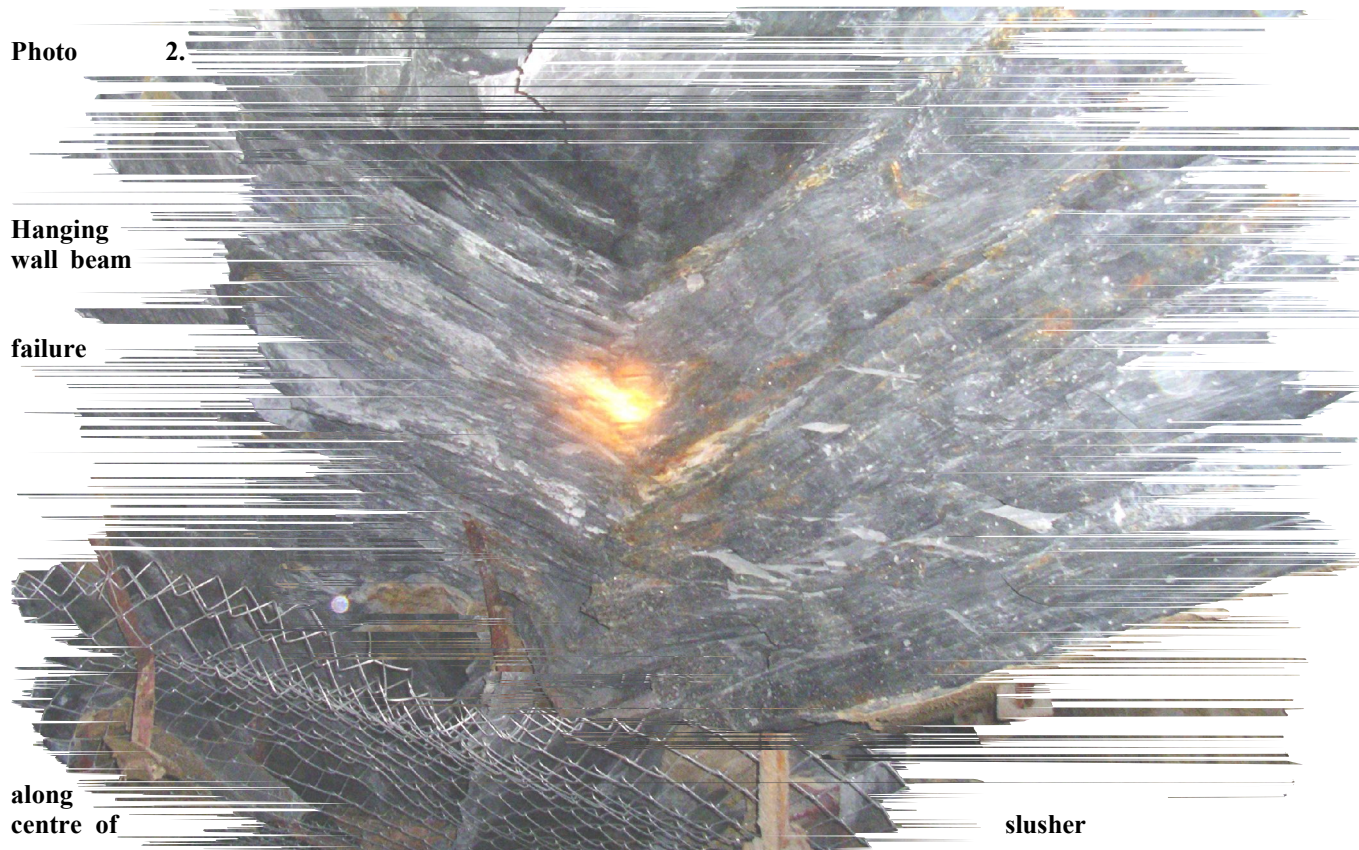
Underground observations that the onset of failure is along the

hanging wall appears as if the beam fails in tension due to

an induced load applied perpendicular to it. It is understood that the load is a result of dilation caused by relative movement between individual shale laminae. The relative movement between individual laminae is caused by an increase in the principal stress due to the ledging operations. This will be discussed in more detail in the modelling section. Once sag/failure occurred, the individual laminae had already slid over one another and reduced the frictional resistance. In some cases it was observed that a certain amount of subduction occurs between opposite sides of a failed hanging wall beam. It is assumed that this is a result of side wall dilation/closure.

Once the immediate hanging wall failed it continues to unravel to the point where the slusher collapses completely and has to be abandoned.

Photo 1. Hanging wall beam failure along centre of slusher.



5 MODELLING

Modelling was done using both Map 3D and FLAC modelling packages in an attempt to gain a better understanding of the observed rock mass deformation and failure. Initial modelling was elastic using Map3D. The results from this modelling were used as input into the inelastic FLAC model. The 109/62 raise line was used as a case study and the actual ledging sequence and face shapes were modelled. In-plane stresses were calculated on grid planes placed perpendicular to the slusher and raise line for the different mining steps. In total, fourteen mining steps were modelled. Results from modelling show the following:

- The maximum in-plane stress (σ_{1i}) increases from 40 MPa to 70 MPa in the immediate hanging wall of the slusher. (Figure 4 & 5)
- The direction of the maximum in-plane stress, measured anti-clockwise from horizontal, changes from near vertical (68°) to almost parallel (26°) to the shale laminae in the hanging wall.

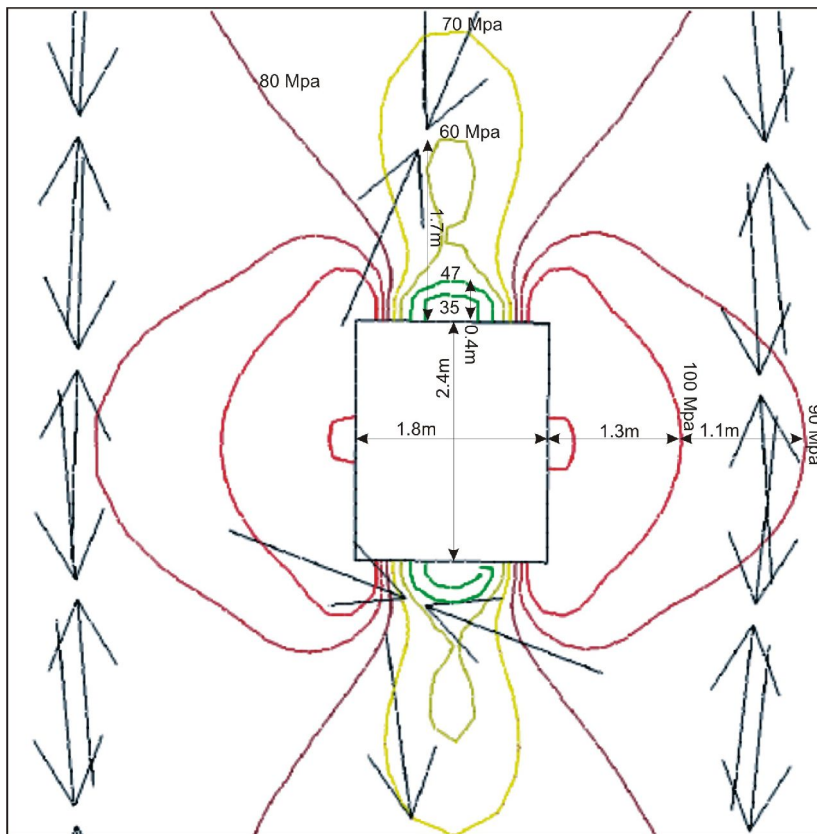


Figure 4 Stress distribution around slusher excavation during development phase

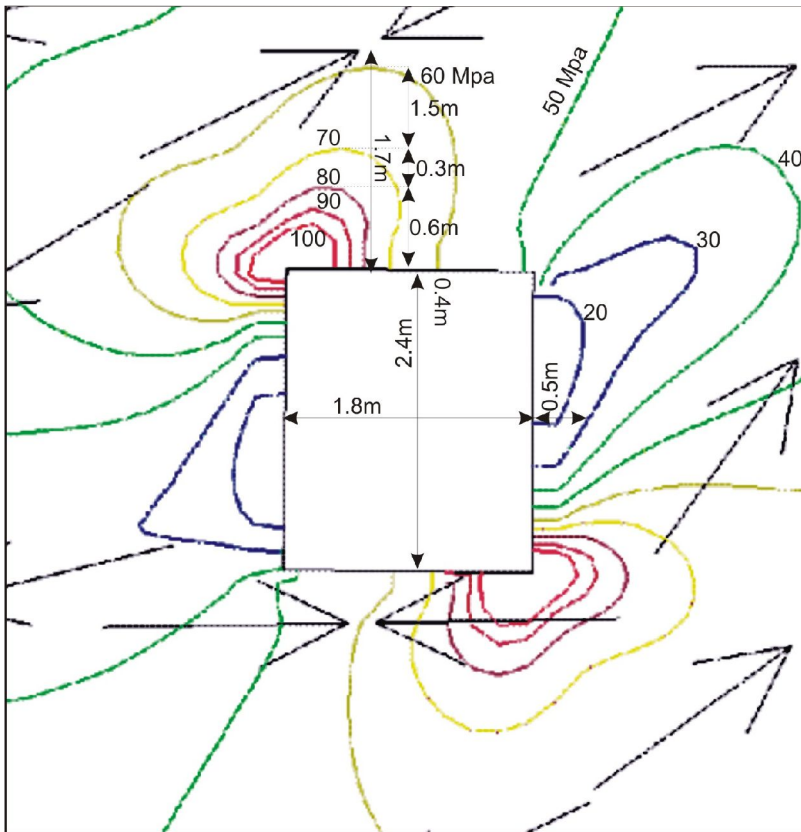


Figure 5 Stress distribution around slusher excavation once ledging is complete

The asymmetric distribution of stresses around the excavation in Figure 5 is due to unequal ledging distances. It is understood that the increase in σ_{li} from 40 MPa to 70 MPa together with the change in direction result in relative movement between shale laminae as the shear strength between these layers is exceeded. The associated cumulative dilation from movement between multiple layers results in buckling failure of the thin shale laminae.

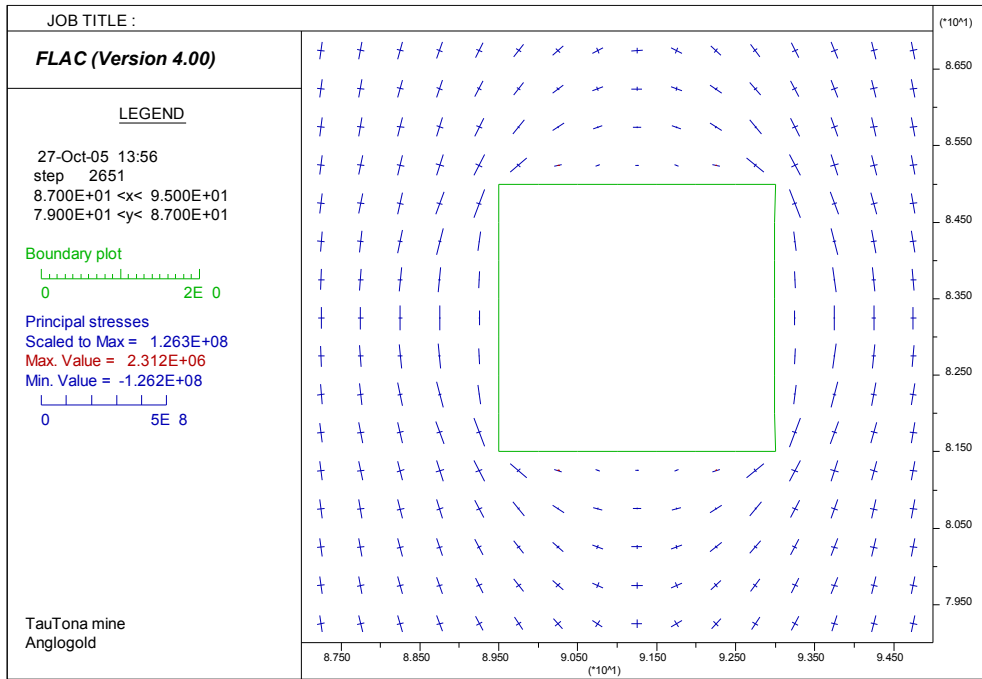


Figure 6 Stress distribution around slusher excavation once ledging is complete

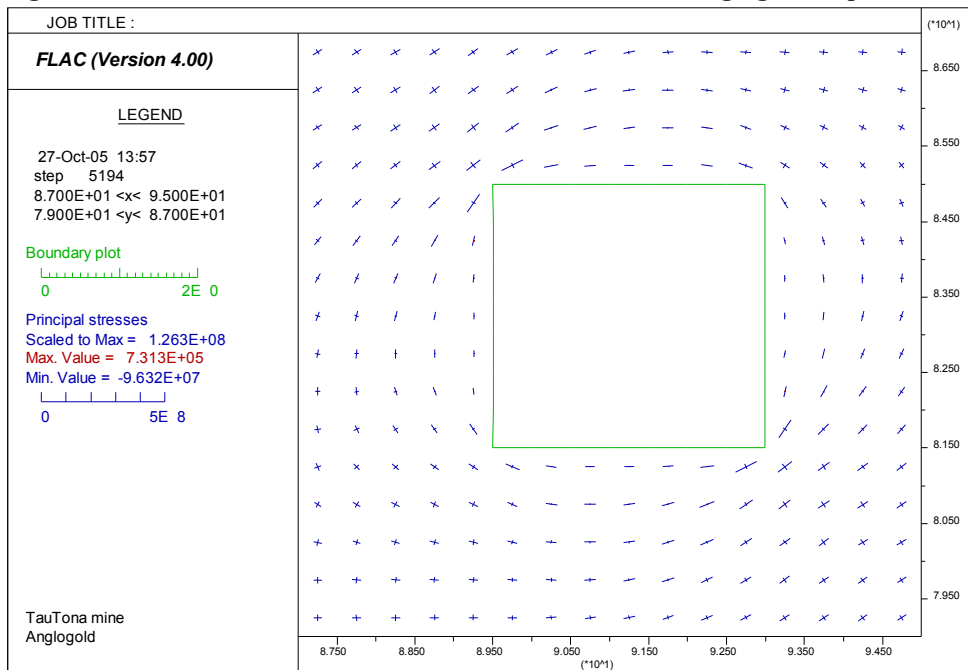


Figure 7 Stress distribution around slusher excavation once ledging is complete

The FLAC modelling results confirm a significant increase in the stress parallel to the shale laminae, in the immediate hanging wall of the slusher, as indicated in Figures 6 & 7.

6 SUPPORT STRATEGY

Following the initial failures all slushers were supported with either 50mm steel-fibre reinforced shotcrete or 5mm Thin Sprayed Liner (TSL). This strategy proved to be unsuccessful and failures continued to occur once ledging commenced. Neither shotcrete nor TSL were able to contain the observed deformation in the hanging wall of slushers. (Photo 4 & 5)

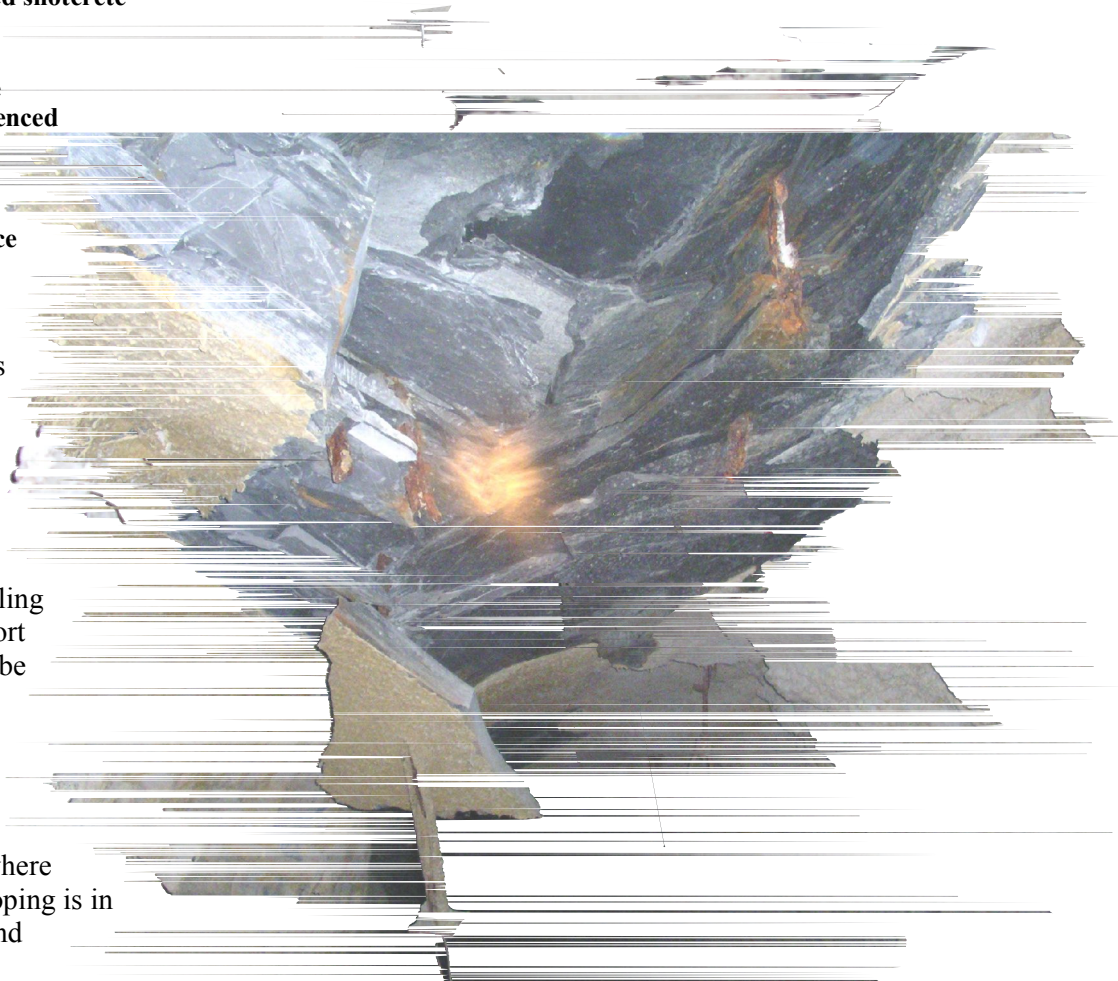
Photo 3. Condition of slusher prior to ledging supported with 50mm steel-fibre reinforced shotcrete

Photo 4. Onset of shotcrete failure once ledging commenced

Photo 5. Onset of TSL failure once ledging commenced

The support strategy was modified based on the understanding gained from underground observations and numerical modelling results. The support strategy can be divided into two categories:

- Slushers where ledging/stoping is in progress and failure has already occurred



- Slushers where no failure has occurred prior to any ledging or stoping operations

The objective of the modified support strategy is beam creation using some of the rock properties (i.e. cohesion and friction between layers) to create a stable beam. A prerequisite for beam building is that the bolts have to be installed before the shale laminae starts to sag or separate. Once this occurs it implies that relative movement between layers have already occurred reducing the frictional resistance and destroying the cohesion. In areas where failure already started the objective was suspension and containment.

The support strategy for slushers where failure already occurred consisted of the following:

- Welded mesh covering the complete hanging wall and 0,5m of the sidewalls.
- Sets consisting of 4m long, 20 ton, cable anchors and 2m long wooden slab laggings.

The cable anchors/trusses were installed 1,5m apart along the length of the slusher and joined with a double locking barrel. These were tensioned to 10 tons once the laggings were inserted. This support strategy is only partially successful and continued rehabilitation is required to keep these slushers open.

The support strategy in slushers where support can be installed prior to ledging and stoping was changed to the following:

- Wire mesh and lace using welded mesh together with heavy duty plastic mesh against the hanging wall and 1m of the side walls. The purpose of the plastic netting is to provide long term areal coverage when the steel mesh starts to rust. The tendons used are 2,3m long, ripple bar, shepherd crooks.
- 3,5m long mechanical anchors on a 2:1 pattern spaced 1,5m apart along the length of the slusher. These anchors are pre-tensioned to 10 tons in an attempt to clamp the shale layers together thereby increasing the shear strength between individual shale layers.
- Sets consisting of trusses and wooden laggings.

Primary support was changed from 1,5m long splitsets to 1,5m long, 20mm, fully grouted bolts to limit horizontal movement between shale layers. Additional cable trusses are installed at the slusher-boxhole intersections to ensure the long-term stability thereof.



Photo 6.

**Photo
showing**

**construction of the cable
trusses spaced 1,5m apart along length of slusher, cable anchors and mesh.**



Photo

7. Photo showing the complete set installation with wooden laggings.

It was decided to establish additional dip gullies on either side of the raise to serve as a backup should the support strategy prove to be ineffective.

6 CONCLUSIONS

- The hanging wall failure observed in slushers situated in Booysen's shale is caused by an increase in the horizontal stress in the immediate hanging wall of the slusher.
- The support strategy is only partially successful if installed after the onset of failure.
- The support strategy appears to be successful to date where support could be installed prior to ledging operations. This however needs to be monitored to determine the longer term effectiveness thereof given that limited mining has taken place where the strategy has been implemented.

7 ACKNOWLEDGEMENTS

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