Problem Statement

The response of a shear zone to mining an ore body following pyramid sequence is studied in this example using Map3D software (BEM stress analysis). The analysis is carried out in 3D and suppose the geometry of the shear zone is properly identified based on a series of exploration and geotechnical diamond drill holes (DDH). The shear zone is characterized by local variation of dip angles ranging between 5 to 20° and has an overall north-south dip direction.

The underground method used in this example is a longitudinal long hole with a bottom-up sequence (Figure 1-a). The accesses are placed in the HW of the ore body as shown in Figure 1 (b). The average height of stopes is 30m with a HW dip angle of 68°. The ore body is located approx. 850m below surface.

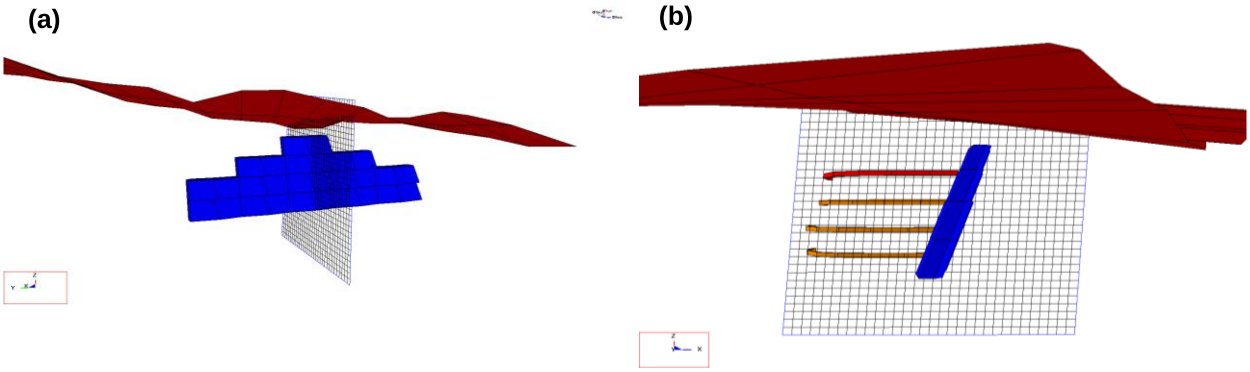


Figure 1: (a) North-South Longitudinal view showing the shear zone above mining. (b) East-West section across the mining area showing the output grid orientation

The host rock is modeled as linear elastic and its properties are listed in Table 1 (a). The fault is modeled as elasto-plastic and its properties are listed in Table 1(b):

Table 1 : Host Rock Properties

Material Type	Linear-Elastic
Young's Modulus (E)	25 GPa
Poisson's Ratio (v)	0.2
UCS (rock mass)	120 MPa

Table 2 : Fault Properties

Material Type	Heterogeneous
Friction Angle* (ϕ)	15° ≤ ϕ ≤ 30°
Cohesion (c)	0
Normal Modulus	100 MPa
Shear Modulus	100 MPa

* Varies along the geometry to reach critical state equilibrium

The pre-mining stress state is characterized by a major principal stress direction of 90° (East-West) and a plunge of -20°. Stresses of the major principal stress ($\sigma_{H\ max}$) increase linearly with depth by 25 kPa/m with a constant stress of 20 MPa. The vertical stress component also increase linearly with depth by 20 kPa/m with a constant stress of 7 MPa.

Modeling Procedure

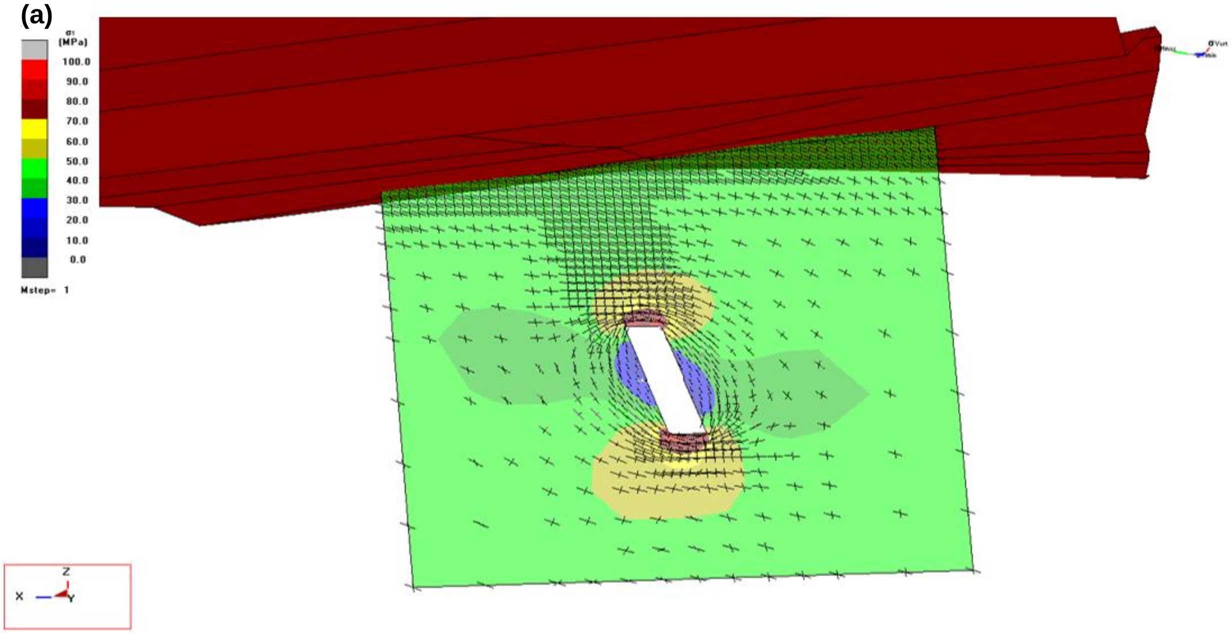
The first step of the simulation corresponds to the situation where the bottom two levels are already mined-out. At this point, a fault slip is not expected as mining is still relatively distant from the structure (at this stage, seismicity is considered low in the location of the shear zone). The second and third steps model the progression of mining towards the shear zone.

In this example, the fault is assigned a heterogeneous strength distribution (functionality in Map3D) in such way that the structure is marginally stable (at the point of failure) (wiles, 2014). This assumption could be conservative as the fault becomes sensitive to adjacent mining. However, it could be a realistic assumption in cases where seismicity starts occurring on the shear zone following a certain level of mining adjacent to it (seismicity could be a cluster of micro-seismicity or macro-seismic events in the vicinity of the fault).

Results and Discussion

Contours of the major principal stress are presented in Figure 2. It is clearly shown that the major principal stresses are increased towards the shear zone as mining progresses. Depending on the local orientation of the shear zone and the trajectory of σ1, some areas of the shear zone will be subject to more shear stress than others. Figure 3 presents the excess shear stress occurring on the shear zone. It is interesting to note that most of the ESS occurs on the HW of the ore and has relatively large footprint. Figure 4 presents the shear displacement (i.e. fault ride) at different mining steps. There is little induced displacement in step 1 and step 2 as the influence of mine induced stress changes haven't reached the shear zone yet. On the other hand, step 3 indicates that a shear displacement around 15 mm on the fault could occur in this example.

(a)



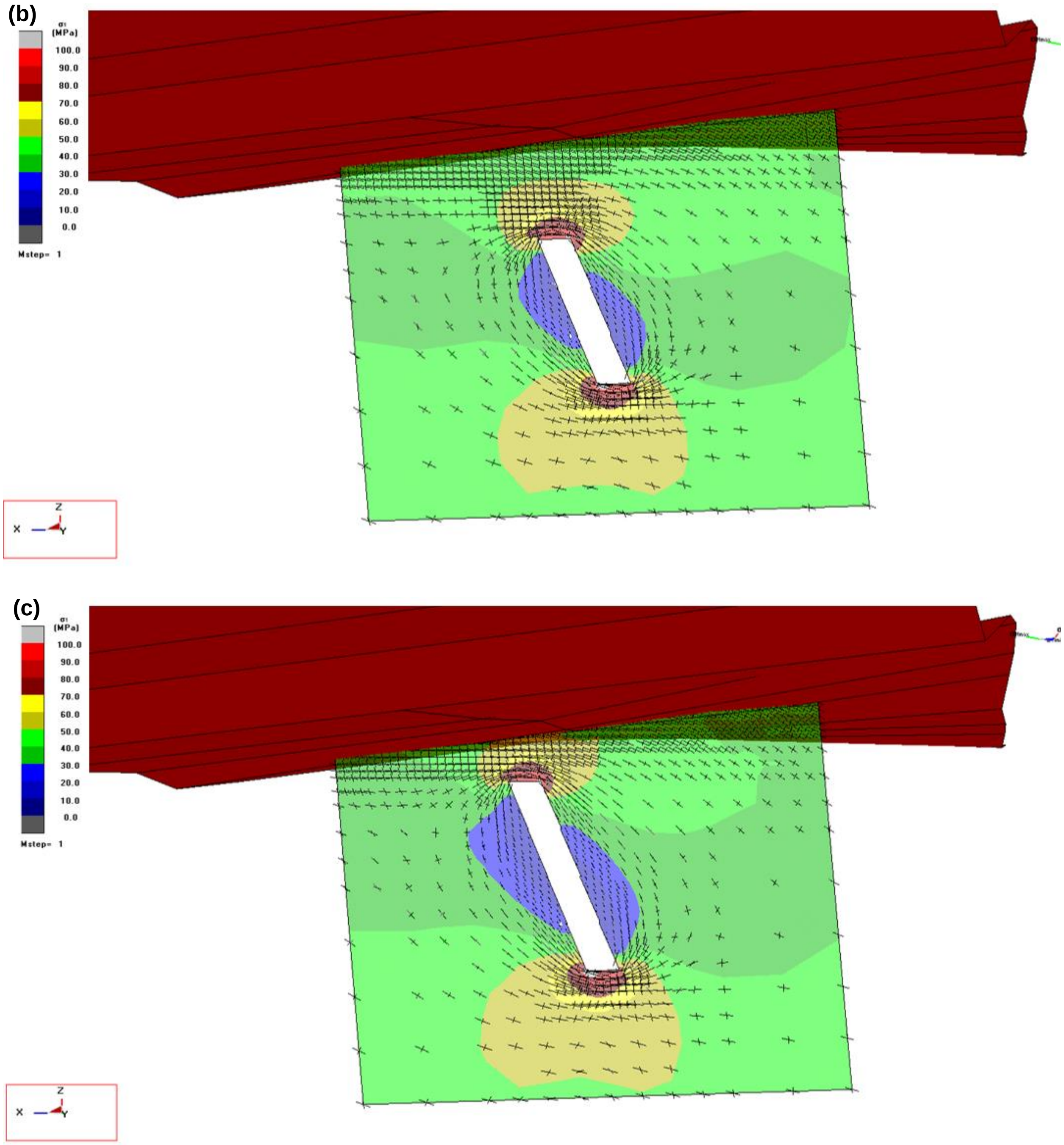


Figure 2: (a) Iso-contours and stress trajectory vectors of the major principal stress and at (a) step 1 (bottom two levels mined out), (b) step 2 (three levels mined out) and (c) step 3 with all stopes mined-out.

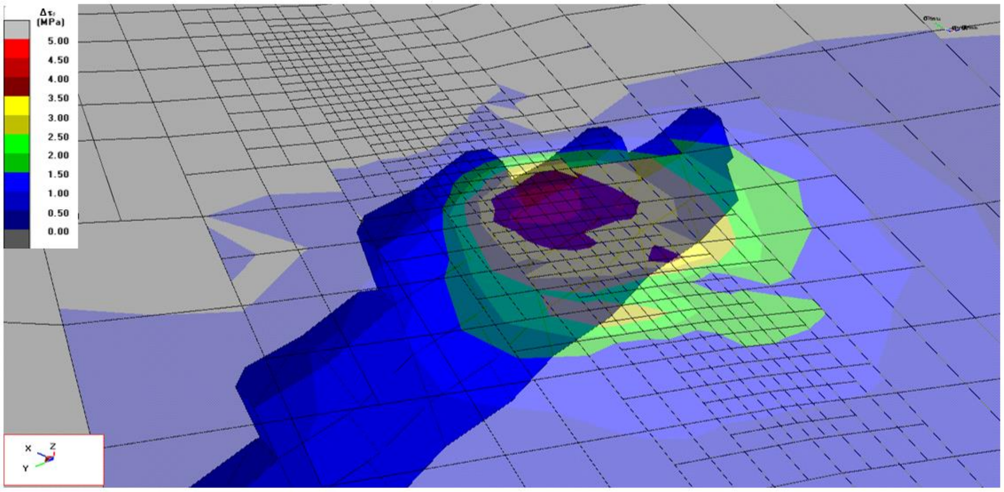


Figure 3: iso-contours of excess shear stress (ESS) on the surface of the shear zone post mining (step 3).

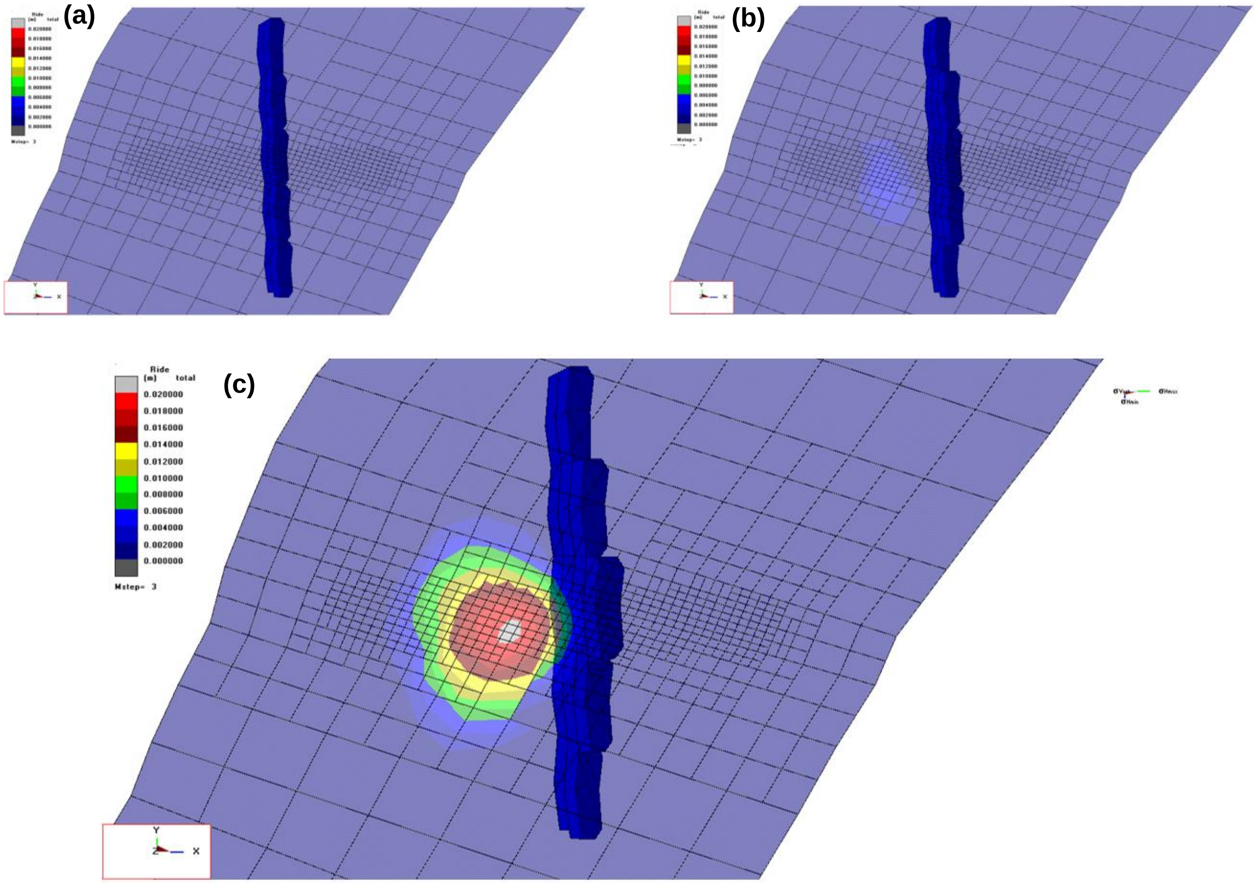


Figure 4: (a) Iso-contours of shear-displacement (fault ride) at (a) step 1 (bottom two levels mined out), (b) step 2 (three levels mined out) and (c) step 3 with all stopes mined-out.

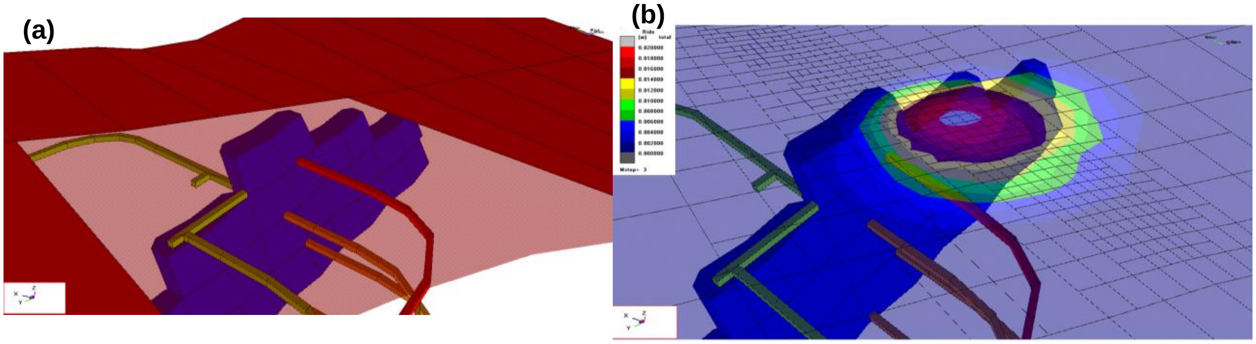


Figure 5: (a) View from the top of the shear and the mining zones showing HW, end-access and FW accesses. (b) Shear displacement contour in relation to the location of the accesses

While it is noteworthy to mention that fault slip analyses are very sensitive to underlying model assumption (particularly the orientation and magnitude of far field stresses, as well as the geometry and the geotechnical properties of the shear zone), this type of analysis gives a good overall appreciation of where the potential unstable area of the shear zone could occur (Cooke 1997; Ryder 1988). Furthermore, a properly calibrated plastic fault-slip model will provide a good representation of the actual site response and will be extremely valuable for rock engineering and mine planning purposes. In fact, to preserve the integrity of the top access, it is recommended to opt for an end access or a FW access rather than a HW access. This latter would be in the close proximity to the problematic area of the shear zone (Figure 5) and is not recommended.

Efforts should be made to characterize the geometry of the shear zone, particularly the part adjacent to mining (adjacent to stopes, accesses and infrastructures). This is key in assigning different strength distribution along the shear zone as it has been carried out in this example.

Calibration of the model is also of the essence. The modeled stresses on the shear zone should be correlated with the observed instrumentation and seismic data as mining progresses.

Appendix

Example of a fault identified in the rock core from a diamond drill hole.

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