Problem Statement

Cable bolting the HW of relatively shallow dipping open stopes is a common practice for the support of underground openings. This helps control dilution (thus reducing cost) and increases stopes turnover.

3D Numerical modelling represents a valuable tool to understand the behaviour of the rock mass, ground support and the interaction of these two elements. In fact, numerical modelling can be used in conjunction with empirical analysis (Mathews, 1981; Potvin 1988; Hadjigeorgiou and al. 1995), field observations and experience to further optimize cable bolting practice in an underground mine.

The purpose of this example is to demonstrate the effect of cable bolting on the stability of an open stope's hanging-wall (HW) in a blocky ground and how to improve a given cable bolting pattern. It is important to note that there are other methods for achieving the same results. This example has been published for educational purposes and not to replicate the same recommendation for a given mine without proper tailored engineering.

Figure 1 shows the geometry of the studied area. The stope is modelled to be mined using a top and bottom accesses. Two drifts in the hanging wall of the stope have also been modelled. Cable bolts will be installed from the top HW access, so the cable bolts can be as perpendicular to the orebody as possible

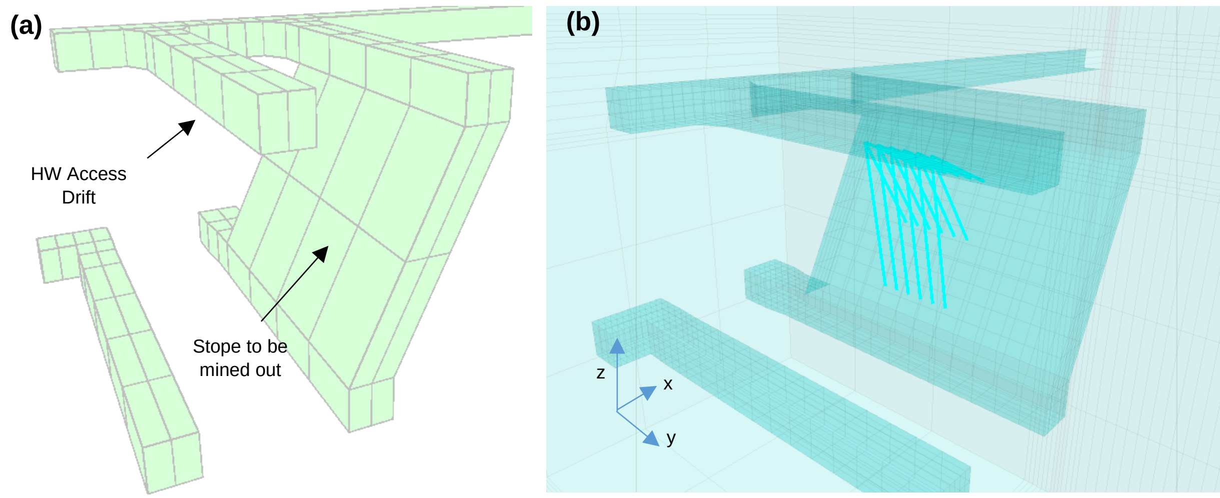

Figure 1: (a) Isometric view showing the geometry of the mining area consisting of top and bottom drifts and a shallow dipping stope to be mined-out. (b) Addition of structural elements to the model representing cable bolts

Four (4) scenarios have been modeled to analyze the impact of specific parameters on the results. The scenarios are listed in Table 1:

Table 1: Host Rock and Structural Elements Properties

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Constitutive Model		Linear Elastic	Ubiquitous Joint	Ubiquitous Joint	Ubiquitous Joint
Rock Mass Material Properties	Young's Modulus (E)	10 GPa	10 GPa	10 GPa	10 GPa
	Poisson's Ratio (v)	0.2	0.2	0.2	0.2
	Rock Friction (ϕ)	NA	40	40°	40°
	Rock Cohesion (c)	NA	25 MPa	25 MPa	25 MPa
	Dip/Dip Direction of Joint*	NA	80/270	80/270°	80/270°
	Joint cohesion	NA	200	200 kPa	200 kPa
	Joint friction	NA	25	25°	25°
Structural Element Pattern	Angle between the cable and stope HW	NA	NA	Set 1 ~ 90 Set 2 ~ 70 Set 3 ~ 35	Set 1 ~ 90 Set 2 ~ 80 Set 3 ~ 55
Structural Element Properties	Young's Modulus of cables (E)	NA	NA	45 GPa	45 GPa
	Yield Tension of cables	NA	NA	540 kN	540 kN
	Grout Cohesion (cg)	NA	NA	10 MPa	10 MPa

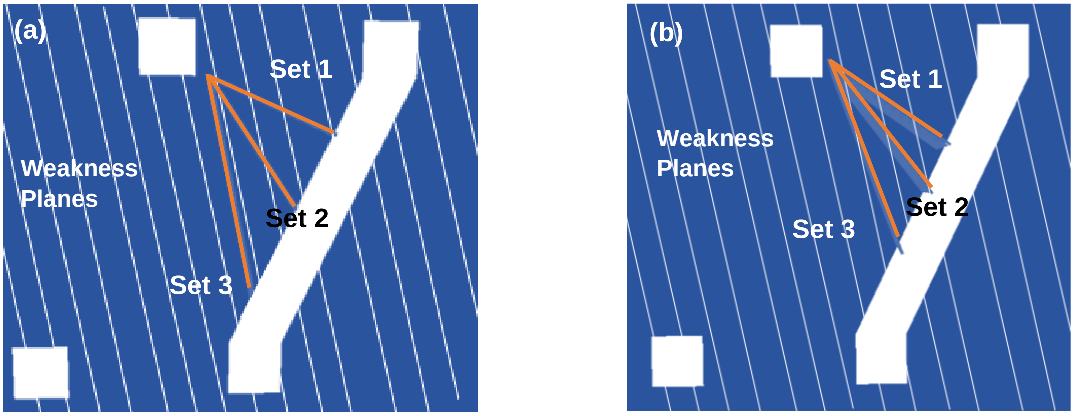

Figure 2: Cross-section at the mid-strike length of the stope showing the planes of weakness and installed cable bolts according to (a) pattern 1 - larger cable bolt toe spacing and (b) pattern 2 -smaller cable bolt toe spacing.

The rock mass is characterized by weakness planes as shown in figure 2. It is assumed that the weakness planes are joint discontinuities, weathered and infilled with stiff clay material. It is assumed in this example that Equivalent Linear Overbreak Slough (ELOS) analysis has been carried out and that there is a fairly good correlation between this parameter and the displacement magnitude of the HW (obtained from numerical modelling) from previous mined-out and reconciled stopes.

The pre-mining stress state is characterized by a major principal stress direction of 90° (East-West) and a plunge of 0°. The stress magnitude in the study area is 40, 20 and 20 MPa for the major, intermediate and minor principal stress components respectively.

The modelled stope is 40 m long (strike-length) and 30 m in height and has a 65° HW dip angle.

Modeling Procedure

The software used in this example is FLAC3D (Itasca, 2018). FLAC3D is an explicit finite difference program to study, numerically, the mechanical behaviour of a continuous three-dimensional medium as it reaches equilibrium or steady plastic flow.

Two types of boundary conditions have been used: roller boundaries along the sides and bottom of the model and applied stresses corresponding to the principal stresses.

The first step of the simulation is to model the in-situ stress prior to any mining. Results are verified to ensure initial boundary conditions have been properly assigned. The next step is to excavate the top and bottom drifts and to run the model to reach equilibrium. Ground support installation (in this case cable bolts) is then added using structural elements. This example illustrates an installation of cable bolts from the HW access drift as illustrated in figures 2(a) and (b). The model is run into equilibrium again to account for in situ stresses on the structural elements. The last step is to excavate the stope.

Four scenarios have been studied in this example: 1)- Linear elastic model without cables; 2)- Ubiquitous Joint Model without cables; 3)- Ubiquitous Joint Model with cable bolting according to pattern 1 : 3 cables per ring (twin cables), 12 rings spaced at 2m; 4)- Ubiquitous Joint Model with cable bolting according to pattern 2 : 3 cables per ring (twin cables), 10 rings spaced at 2m.

Results and Discussion

Contours of the major principal stress Sxx on a vertical and horizontal cross-section, as well as on a 3D view are presented in figure 3 for scenario 1 (linear elastic model). One can easily notices that the excavation of the stope induced a large relaxation zone (loss of confinement) in the HW of the opening, particularly as the major principal stress direction is sub-perpendicular to the ore body. Figure 4 shows the difference in displacement isocontours in the HW of the stope between an elastic and a plastic model using Ubiquitous joint model that accounts for planes of weakness. As one would expect, given the unfavourable joint orientation relative to the HW of the stope, the results clearly indicate a much larger displacement expected for the plastic model as compared to the elastic. In fact, the maximum displacement at the HW stope center is shown to be around 10cm for the elastic model, whereas it could reach 55cm approx. for the plastic model that accounts for the weakness planes.

Figures 5(a) and (b) represent displacement isocontours for scenario 3 and 4 which call for cable bolts in the HW of stope. These figures show that adding cable bolts reduces significantly the displacement of the HW boundary. The cable bolting pattern 1 (scenario 3) was able to reduce the displacement to 37 cm in between cable bolts set 2 and 3 and even further reduction around cable bolts set 1 (30cm max).

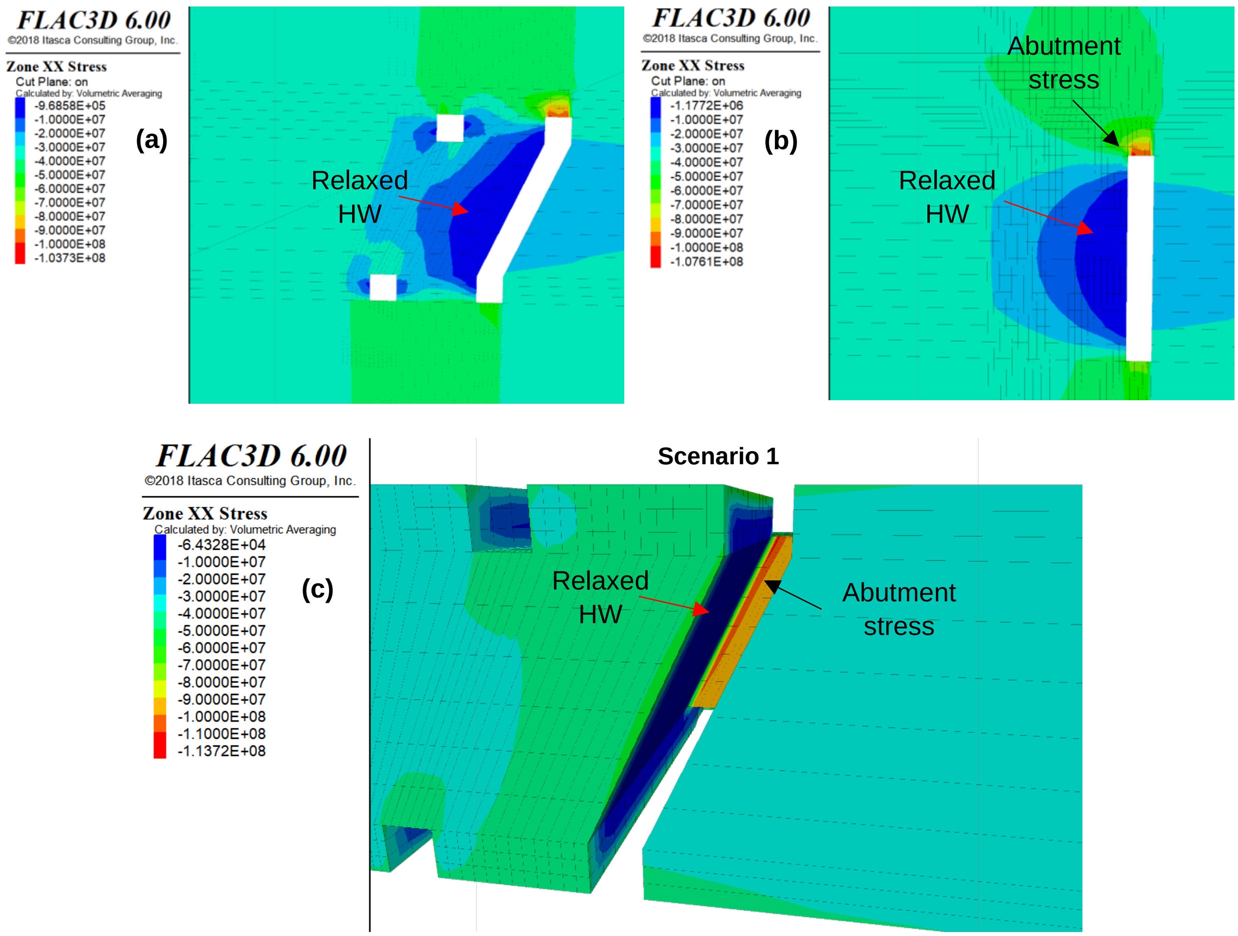

Figure 3: Isocontours of the horizontal *stresses* (Sxx) on *(a)* cross section view at mid-strike length; (b) plan view at mid-height of the stope and (c) 3D clip box of the mining area showing the relaxed HW

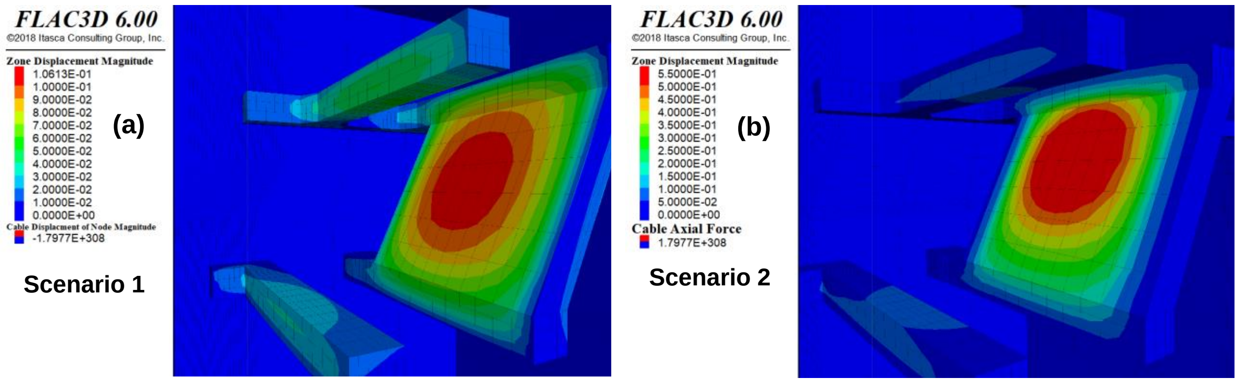

Figure 4: Isocontours of displacements (magnitude) shown on the HW of the mined out stope for (a) the Linear Elastic Model (scenario 1) and (b) the Ubiquitous Joint Model without cable bolts (scenario 2)

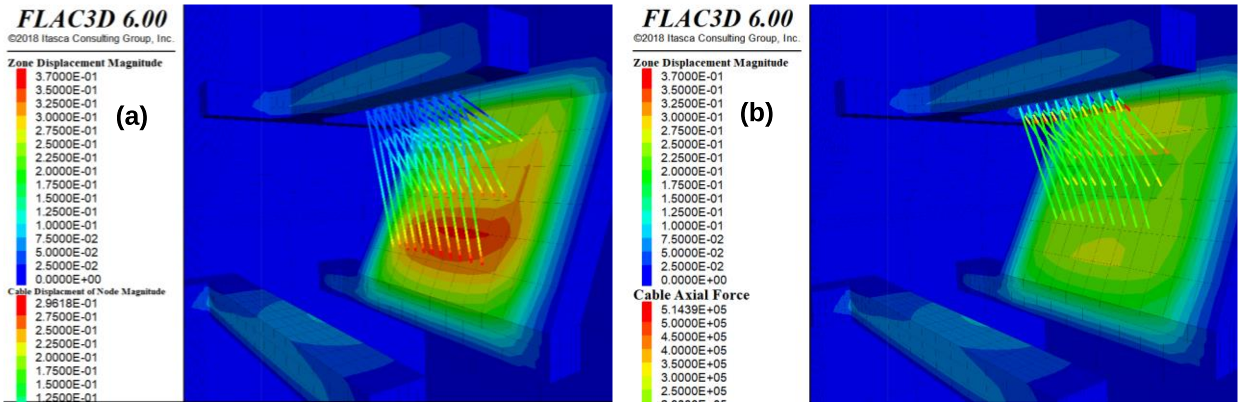

Figure 5: Isocontours of displacements (magnitude) shown on the HW of the mined out stope for the UJ Model with (a) cable bolt pattern 1 (scenario 3) and (b) cable bolt pattern 2(scenario 4)

On the other hand, a tighter patter in the middle and with higher angle between the cable bolts and the HW dip of the stope yields even better results as shown in figure 5 (b). The displacement is reduced to less than 20cm in at the center of the stope HW and up to a maximum of 27.5cm in localized areas.

Figure 5(b) also shows the axial force on each structural element. It is shown that all cable bolts are carrying load because of the HW displacement and that the range of this axial load on each cable is from 200 to 500 kN, suggesting factors of safety between 1.1 to 2.7. The same plot could be generated for the grout state. This also suggests that further optimization of the cable bolting pattern is possible.

Figure 6 illustrates the cable state of element of pattern 2 (scenario 4) suggesting that none of the simulated cables reached the yield zone (assumption of failure).

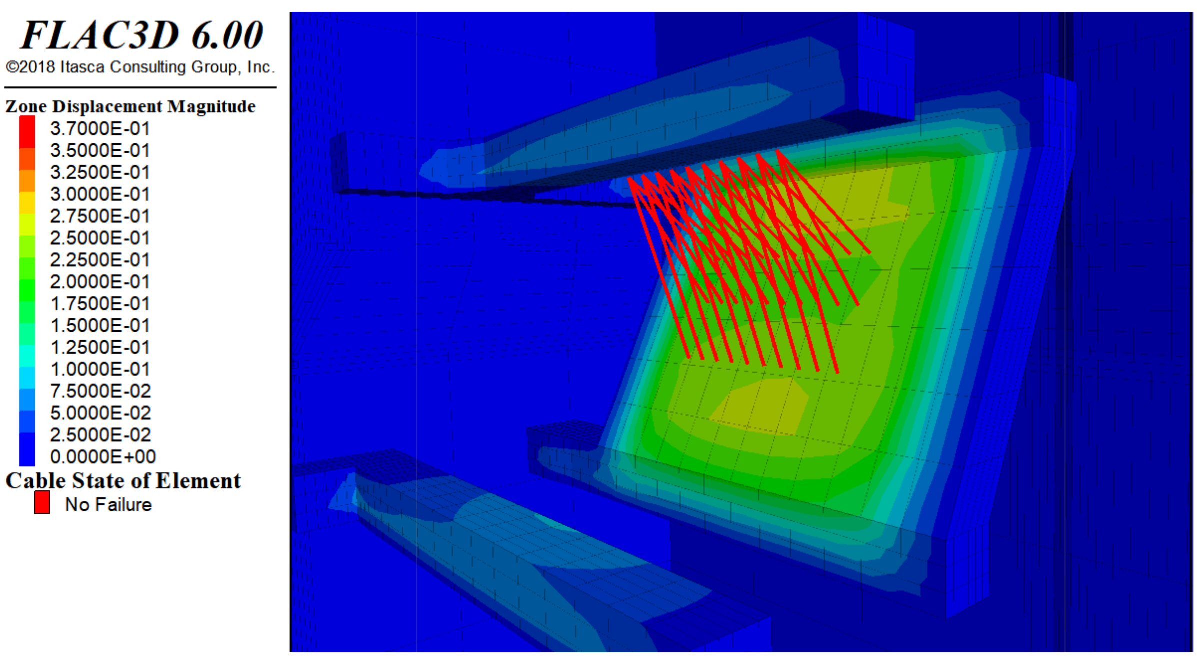

Figure 6: Isocontours of displacements (magnitude) shown on the HW of the mined-out and the cable bolts state indicating no tension failure occurred on any of the structural elements.

In this example, it has been determined that cable bolting pattern influences the performance of the HW of a 65° dipping stope given the assumptions stated above. Again, calibration of the model is of the essence. Ideally, each stope should be reconciled to increase site-specific ground condition awareness and to improve cable bolt practices. Calibration will also help correlate host rock displacement magnitude obtained from numerical modelling to expected ELOS to further provide confidence to the model.

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