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FLAC3D modelling of rock support arches

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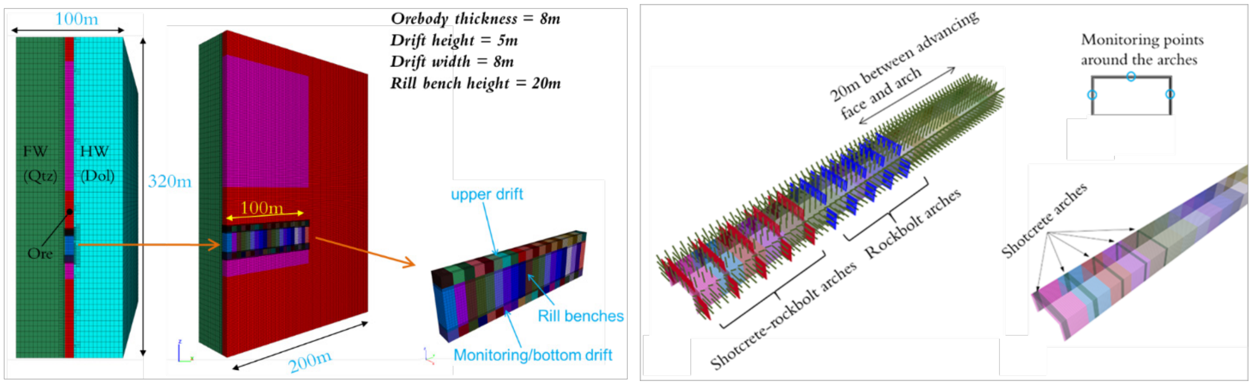
1 INTRODUCTION

This paper presents the *FLAC3D* modelling of rock support arches in trial stope at Boliden's Garpenberg mine in Sweden. The objective was to evaluate the effectiveness of rock support arches in stabilizing the ground when rill stopes heights are raised beyond the current heights. Boliden utilizes the rill mining method to mine most of its orebodies that are hosted in poor ground conditions; weak rock and high stresses. This mining method requires the development lower and upper drifts and extracting the block of ore between the drifts by a sequence of benching, mucking and backfilling cycles. The block of ore between the two drifts is generally referred to as rill bench. Presently, the rill bench heights are restricted to 10-15 m so as not to expose the stopes to high walls comprising weak rock in high stress conditions. However, it has been routinely observed that, much of the ground deformations appear to occur during the early stages when the lower and upper drifts are developed and significantly diminish when the rill benches are mined. This observation gave the reason to investigate the possibility to raise the rill bench heights, with additional reinforcement provided by rock support arches. Boliden has successfully used rock support arches at the Garpenberg mine as well as in its other mines (Boliden 2016). The view is that, by installing optimally spaced rock support arches, stable ground conditions can be achieved thereby permitting the rill bench heights to be raised to 20 or 25 m. To test this hypothesis a series of numerical models were run in *FLAC3D* with different rill heights and different arch spacings, along with regular support, to investigate the performance of the arches. These simulations also preceded the field trial to identify the optimum arch spacing and the likely outcome of the field investigations. The field trial itself is presently conducted in the orebody called Dammsjön at a depth of 890 m with a rill stope height of 25 m (i.e. 20 m rill bench plus one 5 m drift). Monitoring of the trial stope is currently on-going. Some initial data from this monitoring have been made available for the first pass calibration of the *FLAC3D* models presented in this paper.

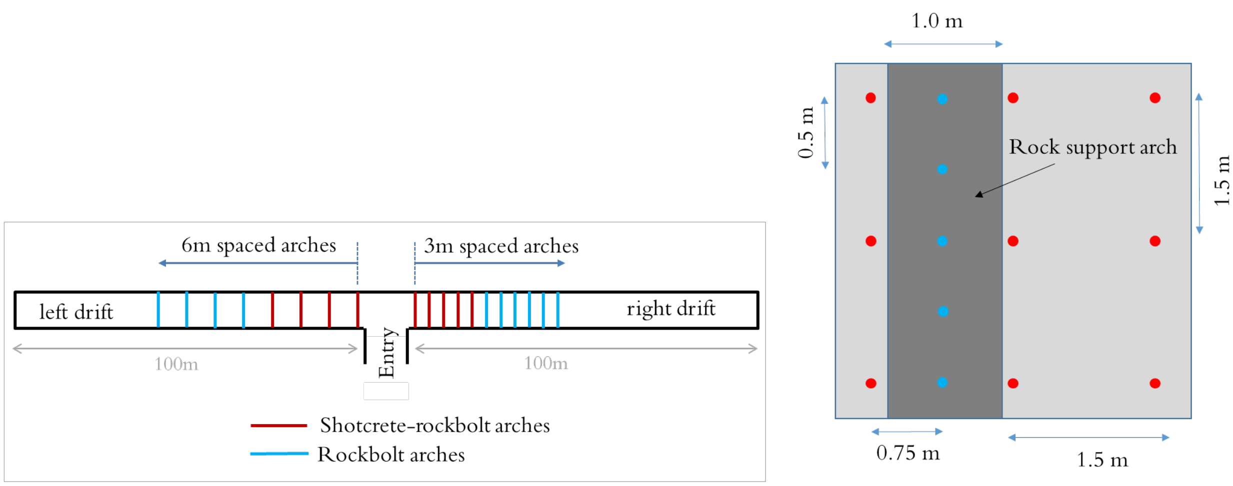
2 *FLAC3D* MODEL SETUP AND EXECUTION

After a series of trials with *FLAC3D* and *3DEC* it was eventually decided that, *FLAC3D* was the best option given the pressing time constraints and efficiency in modelling to provide immediate guidance for field trials. The details of model as setup in *FLAC3D* 6.00 (Itasca 2017) are shown in Figure 1. The test stope for the raised rill bench is located at a depth of 890 m from the ground surface. The drift in the trial stope is 5 m high and 8 m wide, with the rill bench height raised from 15 m to 20 m. The stope length is 100 m in each direction from the central access into the stope, resulting in a total of 200 m long stope. Figure 2a shows the plan of the rock support arches that were implemented in the *FLAC3D*, which are also the actual layout for the field trial. Figure 2b shows the arch specification within the routine rock support plan. The arches are spaced 3 m and 6 m apart respectively to the right and left of the drift from the entry intersection. The first rings of arches consist of additional layer of shotcrete and rockbolts (red lines in Fig. 2a) over a distance of 15 to 20 m. Thereafter, arches consisting of only rockbolts are installed to a distance of about 50 m from the face. The installation of the arches follow 20 m behind the advancing face (see Fig. 1b).



(a) (b)

Figure 1. (a) Model setup in *FLAC3D* (b) arch installations on bottom drift along with routine ground support. On the upper drift only routine ground support is applied.



(a) (b)

Figure 2. (a) Plan of the rock support arches for the field trial and (b) specification of the support arch within the routine rock support plan; the routine rock bolt spacing is 1.5 × 1.5 m, while the rock bolt arch is 0.5 × 0.75 m.

However, the routine support system, which consists of 2.7 m long rebar rockbolts (ϕ25 mm) and 5 cm thick shotcrete are installed immediately after mucking as part of the excavation cycle.

The execution of the models, i.e. excavation and routine support installation cycles in the *FLAC3D,* followed precisely the rill mining excavation sequence as practiced by Boliden in longitudinal stoping. The models were allowed to relax by using the "relax excavate" and "solve convergence" commands in *FLAC3D* to allow energy dissipation, essentially to ensure the rock supports are not affected by high energy dissipation.

Numerical history points were located on the arch in the roof and sidewalls to monitor the displacements (see Fig. 1b). In the field trial the displacements around the arch rings are monitored using survey prims, borehole extensometers and total station surveys. Results from this field monitoring will used to calibrate the *FLAC3D* models. The inputs used in the models are shown in Tables 1 and 2. The rock bolts were modelled as cable structural elements while the shotcrete was modelled as liner structural elements.

Table 1. Rockmass parameters (Storvall 2012).

Mechanical Parameters	Ore	Hangingwall dolomite	Footwall quartzite
Density, ρ (t/m^3)	2.7	2.7	2.7
Modulus, E (GPa)	28	55	28
Poisson's ratio	0.25	0.17	0.25
Cohesion (MPa)	2.94	3.72	2.27
Friction (°)	45	44	40
Dilation (°)	10	10	10

Table 2. Rock support and backfill parameters (Malmgren 2005, Saiang 2014).

Mechanical Parameters	Rockbolt	Shotcrete	Backfill
Modulus, E (GPa)	200	20	0.1
Poisson's ratio	-	0.25	0.3
Density, ρ (t/m3)	7.8	2.7	2.7
Yield strength (kN)	200	-	-
Rockbolt grout cohesion (MPa)	1.0	-	-
Rockbolt grout friction (°)	25	-	-
Rockbolt grout stiffness (MPa)	60	-	-
Cohesion (MPa)	-	3.72	0.01
Friction (°)	-	44	36

3 RESULTS AND DISCUSSION

For the purpose of this paper the displacements recorded in the roof of arch #1 is shown in Figure 3 for the cases of; no arch installed, 3 m spaced arches and 6m spaced arches. Arch #1 is the most critical as it is located near the entry and is expected to experience the largest deformation. Numerical histories were located in the midpoints of the roof, hangingwall, and footwall to measure the displacements on the arches.

The results from numerical modelling show displacements in the range of 10 to 15 mm in Arch #1 when the bottom drift was completed. With the excavation of the top drift the displacements reached up to about 65 mm (i.e. 40 to 50 mm during the excavation of the top drift alone). Less than 10 mm of displacements occurred during the stoping of the rill bench. The impact of the arches on the deformation is quite noticeable between cases with arches and without arches. There is not much difference between the 3 m and 6 m spaced arches though. The final results from the field monitoring, when they become available, will validate this observation. However, one of the early data set from prism monitoring on arch #1, shown in Figure 4, shows results that more or less agree with the *FLAC3D* results of the vertical displacement in the roof of arch #1.

A key observation is that, there is insignificant deformation during the rill bench stoping, which confirms the experience from the mine. Much of the deformation occurs during the development of the top drift, which is critical for the performance of the rock support arches. However, this observation will be validated once the top drift is completed and the associated monitoring data is analyzed.

4 CONCLUSIONS

Results from the *FLAC3D* simulations showed that the rock support arches assisted in reducing the deformation in the bottom drift. While the field trials are currently conducted for a 20 m rill bench height the numerical modeling showed stable conditions for this rill height with rock support arches installed. Significant amount of convergence on the bottom drift occurred during the drifting of the top drive and less during the stoping of the rill bench. This is a key observation as it conforms to the field observations. It also indicates that, the timely installation of the arches is an important criterion for their performance.

The difference in displacement between the 3 m and 6 m arch spacing is less obvious from the numerical modelling results. However, this will be validated when the field trial is completed and the full monitoring data becomes available. The monitoring results will also be used to validate the response of rock support and to observe if another modelling approach is required or not.

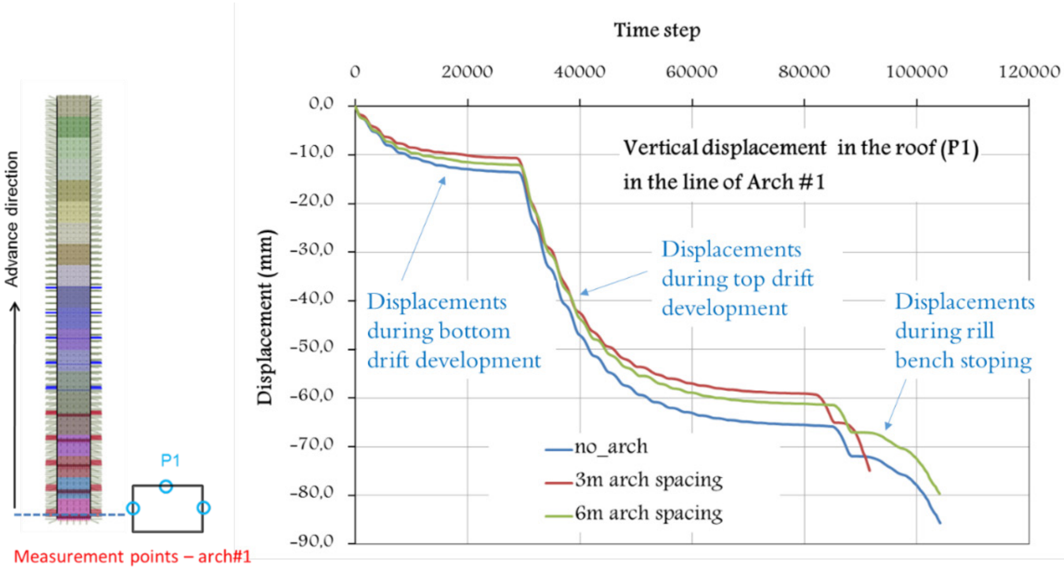


Figure 3. Vertical displacement in the roof at P1 in the line of arch #1.

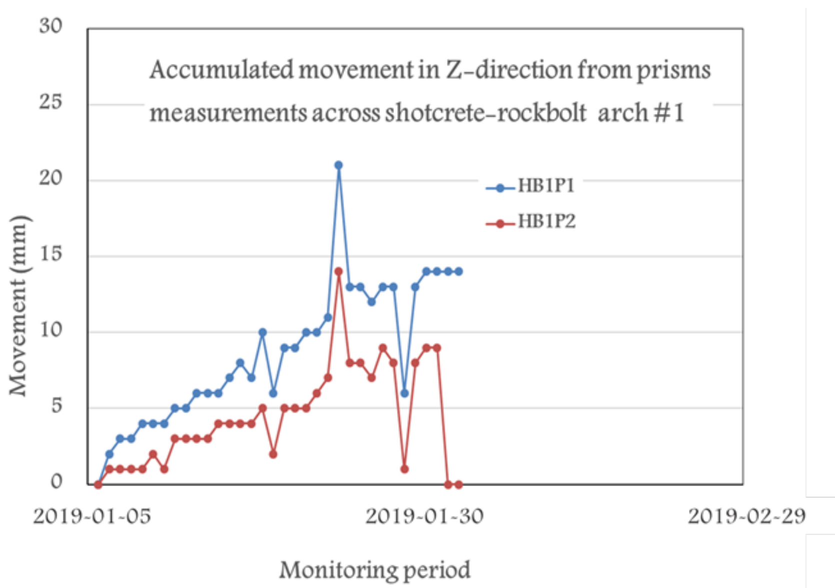


Figure 4. Accumulated vertical movement (Z-direction) measured from the prisms located in line of rock support arch #1.

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