Geotechnical Risk Assessment and Management with Underground Controls and Monitoring System for Sill Pillar Recovery at Tüprag Efemcukuru Gold Mine

Muammer Berber
Tüprag Metal Madencilik,Izmir, Turkey

ABSTRACT: Geotechnical assessment was used to define the mining method, the production schedule, and potential risks for the recovery of sill pillar left at two levels, namely 555 Level and 595 Level. According to geotechnical assessment production was planned for the pillar by using transverse blind up-hole stopes, which are accessed via drift driven in orebody, on the hanging wall side where was planned to monitor the ground movement with smart cable bolt. Consequently, records and cracks along hanging wall, potential risk was detailed with re-assessment that involved the elastic deformation of the paste fill measured in UCS tests were used to anticipate the regional displacement. Also, another instrument named smart MPBX's were used for modelling accurate movement. All results of monitoring have been recorded and correlated with mining activities. In conclusion, a new access drift on the footwall has been designed and the production sequence and schedule has been updated.

Keywords: Smart, Cable, MPBX, Monitoring, Assessment, Geotechnical.

1 DEFINATION OF THE MINE PRODUCTION

Efemcukuru Gold Mine is in Izmir province, located in west of Turkey. Ore body consist of four parts that are named SOS (south ore shoot), MOS (middle ore shoot), NOS (north ore shoot) and KBNW (kestanebeleni northwest). The widest zone of ore body is in MOS and has 30m thickness, 60° dip and 75m strike length. This zone incorporates various structures and rock quality is predominantly poor. LHOS (Long Hole Open Stopping), Blind-up Hole and DAF (Drift and Fill) are two used mining methods. The mining method selection and the production sequencing are done though risk identification using the geotechnical assessment. Preferred geotechnical logging is a logging according to Q system, which is used as guide for the geotechnical assessment in Efemcukuru Gold Mine. In addition to that, related geotechnical software, are RS2 and Map3D, and graphic, is Matthew's Stability Graph, are used for the geotechnical assessment. Q and N' parameters are defined and calculated to use for geotechnical assessment in Matthew's Stability Graph (Figure 1).

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF} \qquad Q' = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \qquad N' = Q' \times A \times B \times C$$

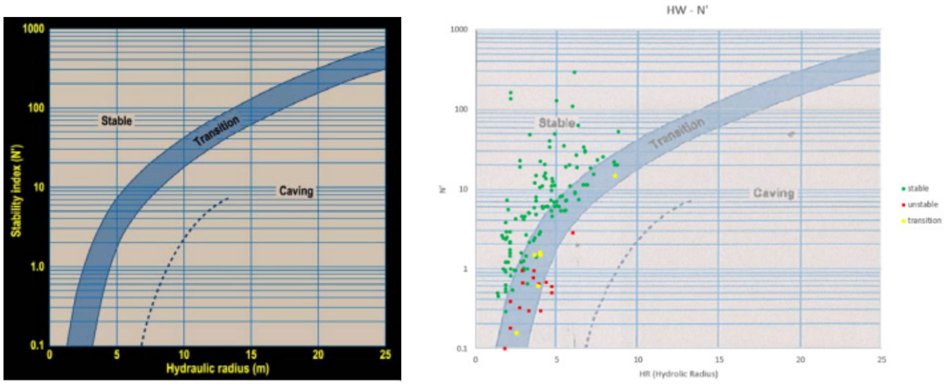

Figure 1. Matthew's Stability Graph for geotechnical assessment and stability results of LHOS and Blind-up hole panels in Efemcukuru Gold Mine.

2 PRODUCTION PLAN FOR SILL PILLAR R ECOVERY

In MOS, the production began concurrently as Drift and Fill (DAF) in four different levels, named 535, 575, 615 and 635. It was decided to mine 10m pillar left below each level with transverse blind up-hole method for ensuring safe production in MOS. There was necessity of an access drift in the orebody from footwall or hanging wall for each transverse stopes (Figure 2).

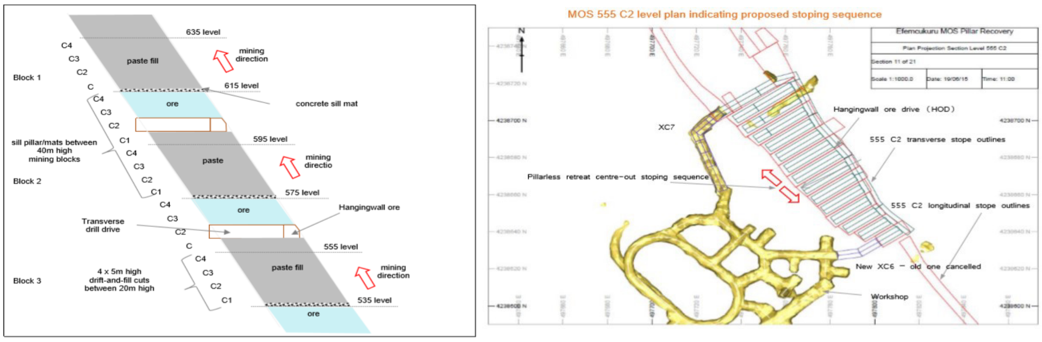

Figure 2. The production plan for sill levels on the cross section and plan section.

The production of 555 and 595 levels were scheduled step by step based on the potential geotechnical risks, identified by geotechnical assessment. These levels were between two paste fill blocks of mined upper and lower levels. In the geotechnical assessment, cross sections of footwall and hanging wall production access drifts were compared with each other. It was possible to design the back width of hanging wall drift narrower than the back of footwall drift. In addition to the design advantages of hanging wall, the footwall contact was 4m thick fault zone and footwall side of the orebody was defined as very poor rock according to Q rock mass classification. Hanging wall drift appeared to be better choice in managing stability with the support designs rather than the footwall in the first plan. According to the geotechnical assessment, access drift for each transverse stope was designed to the hanging wall inside orebody. During the production, ground support was designed 7m, 9m and 10m length cement grouted cable bolts as 1.5m x 2m. it was decided to monitor potential displacement of the hanging wall with an instrument, named smart cable bolt on the hanging wall, in cable bolt design (Figure 3).

An alternative production method was to use DAF for 555 and 595 levels, instead of transverse LHOS, for the remaining 10m thick sill pillar, however, in that case there was possibility of the stability problems and low mine recovery caused by stress relaxation and poor rock quality, during mining.

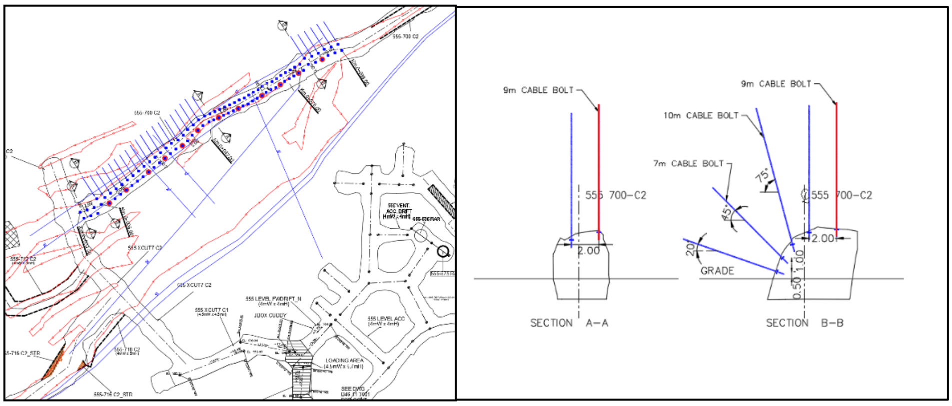

Figure 3. The support design for hanging wall which includes cable bolts (blue dots and lines) and smart cable bolts (red dots and lines).

3 STABILITY PROBLEMS DURING PRODUCTION IN SILL PILLARS

Smart cable bolts were installed to the hanging wall access drift at planned intersections of each transverse stopes, and recorded data during the production in 555 and 595 levels. 595 level production front was ahead of 555 level, approximately 30m strike length. As a result of that, the pressure of all hanging wall was transferred directly to 555 level (Figure 4).

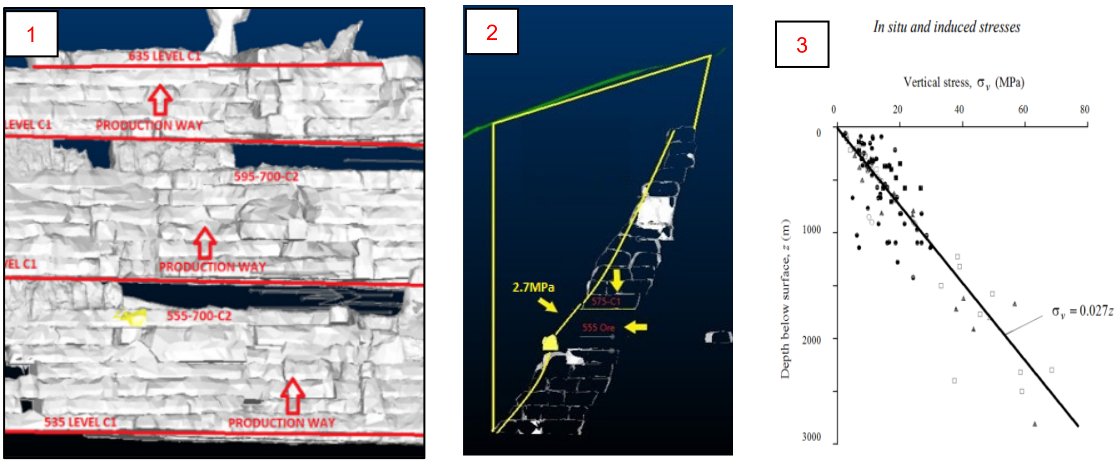

Figure 4. The production on sill pillars (1), the pressure of hanging wall is directly to 555 level (2), vertical stress measurements from mining and civil engineering projects around the world. (After Brown and Hoek 1978) (3).

The cracks occurred related with stability problems at the surface and these levels. In addition to the cracks, displacement and load records from smart cable bolts were plotted on graph, which indicated a movement.

The rock behavior creates signs as the cracks and deformation on supports. It was necessity to assess the type of crack to determine the required support rehabilitation for the potential risky area.

All cracks were mapped and identified to determine movement scale. One of the cracks occurred along strike of the major structures in 555 level production access drift. Other structures were in the type of tension cracks, having strike perpendicular to 595 level access drift and 45° dip. In addition to underground cracks, displacement on paste fill of previously mined levels have created cracks along thick footwall fault at the surface and tension cracks on the hanging wall side of the surface (Figure 5).

Figure 5. Underground cracks, the surface cracks on the footwall and hanging wall.

Surface cracks meant that movement was in large scale. Initially, each occurrence was evaluated in themselves. The next step was correlation of cracks assessment. At the end of the correlation, a possible scenario was created regarding the mechanism this stability problem.

The records of smart cable bolts indicated displacement connected with mining operations in 555 and 595 levels. The loads on some of smart cable bolts reached the critical limits, between 20 tons and 25 tons. Therefore, it was decided to install new smart cable bolts near these smart cable bolts. After completion of each transverse blind up-hole production, irregular additional 9m and 12m cement grouted cable bolts were installed to prevent movement, reported by smart cable bolts records. The timeline of the mining operations was reflected on the graph, created by each smart cable bolt data, to determine movement continuity.

4 GEOTECHNICAL RE-ASSESSMENT

The stability problems encountered at levels 555 and 595 had not been modelled and a possible scenario had not been proven in terms of the sustainability of production. For this reason, two 15m Multipoint Borehole Extensometers (MPBX) were installed to examine the movement in the large scale (Figure 6). The movement in hanging wall was monitored in these two levels by MPBXs and assessed considering the mining activities. Movement points on all the instruments were digitized and the cracks were modeled. It was observed that the identified aperture on the cracks didn't change at 555 and 595 levels when there was no production activity, however, displacement increased with any production activity in these levels. According to the production activities in the levels mentioned above, the changes on the graph looked like a step view. Since the last transverse blind up-hole production, named 555-703-C2, the displacement increased linearly on the graphs, although there was no operation.

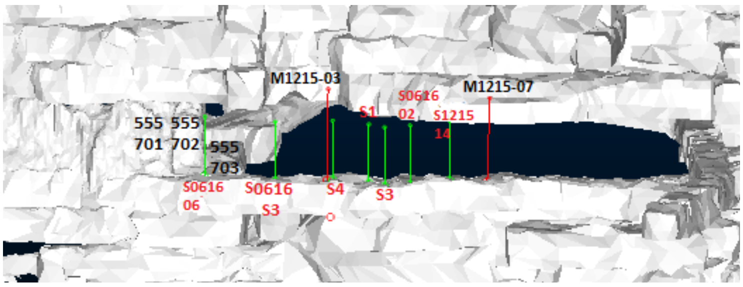

Figure 6. Smart cable bolts (green lines) and smart MPBXs (red lines) on 555 level access drift.

Cable bolt grips and friction bolt plates were deformed regarding to the movements, which was indicating that the production was under high risk with the existing plan. Smart cable bolts reflected to linear movements on the graph after 555-703-C2 production (Figure 7) and the records of smart cable bolts were noted as until MPBX es installation and the last records. Smart cable bolt, is named S1215-14, was installed instead of old one which reached to capacity limits. Records of

S1215-14 increased to 43.56 mm movement in 59 days. It is an alert to operational risk on 555 level production. Displacement points on smart cable bolts were matched to create wireframe as a movement surface on hanging wall.

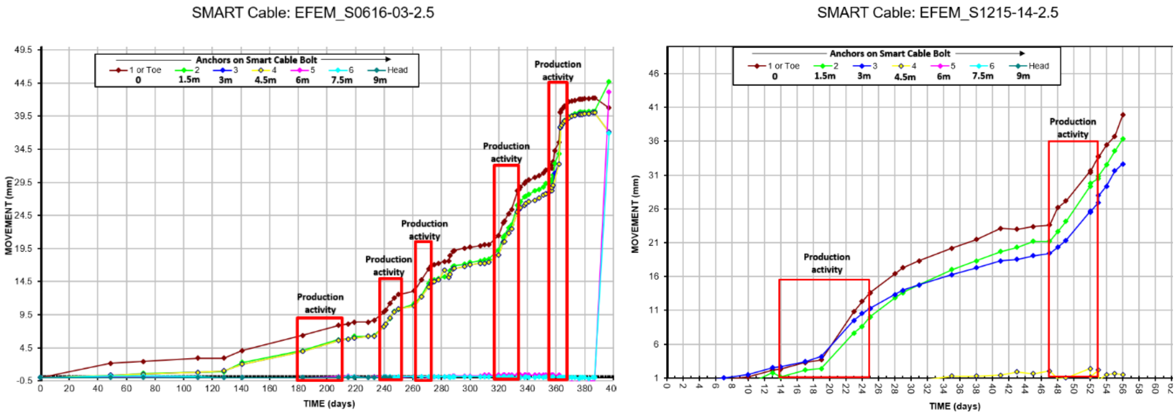

Figure 7. S0616-03 and S1215-14 Smart cable bolts displacement results correlation with production activity.

Grouted MPBX es installed to model deepest points of movement in hanging wall. MPBX, is named M1215-07, showed movement on 2.5m and it is named M1215-02 showed movement on 12.5m. These instruments were also reflected displacement increasing linearly on the graphs after the last transverse blind up-hole production (Figure 8).

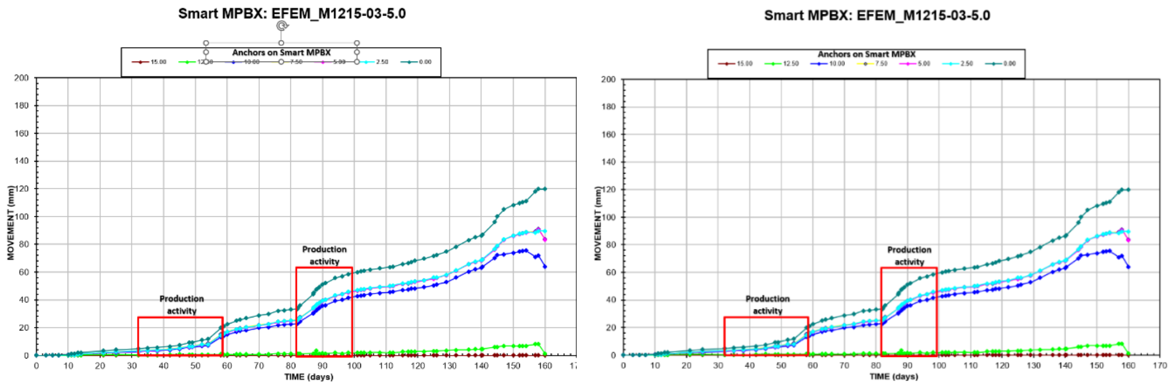

Figure 8. M1215-03 and M1215-07 Smart MPBX displacement results correlation with the last transverse production activity.

The paste fill displacement is another issue in terms of the production risk assessment. The paste fill is sampled by every shift in Efemcukuru Gold Mine. UCS tests and displacements are recorded for production schedule and geotechnical assessments.

The pressure of hanging wall on the mined areas was calculated between 2.7 – 3.5 MPa. According to the test results, paste fill UCS is between 0.45 and 0.65 MPa, which is lower than critical strength range as mentioned above (Figure 9).

The displacements of paste fill samples are between 1% and 3% in UCS test database; that is, the displacement on 30m thick MOS levels, which were paste filled, created a deformation between 30cm – 100cm eventually. Pressure result of hanging wall was re-calculated as 5.35 MPa on 555 level on RS2, which was the critical bending strength of the host rock (Figure 10).

Consequently, geotechnical re-assessment emerged the production not to be managed on hanging wall ore drift safely. Therefore, it was necessary the production plans on 555 and 595 levels to be revised for sill pillar recovery.

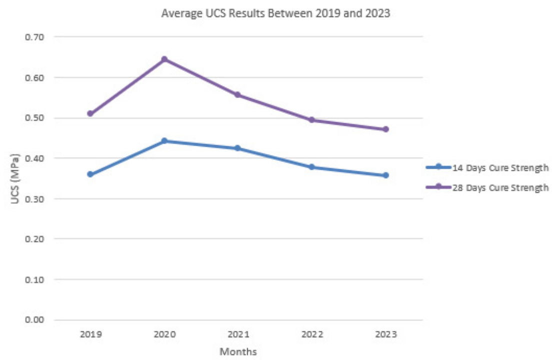

Figure 9. Paste fill UCS strength in 14 cure days and 28 cure days.

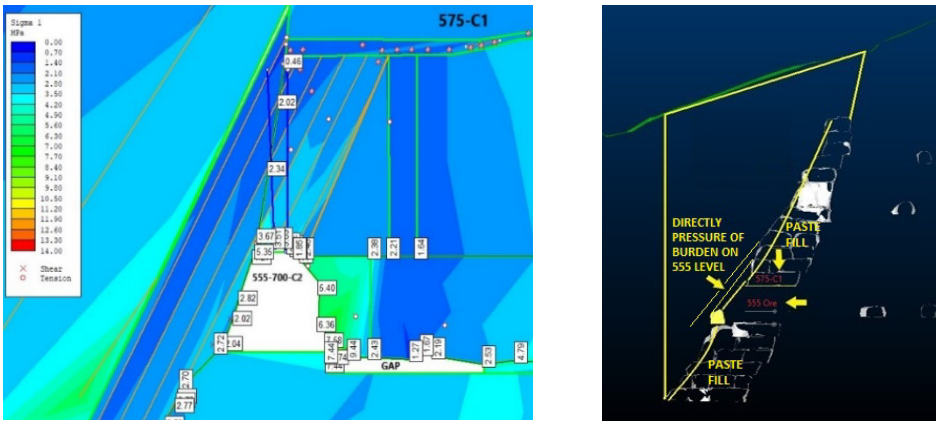

Figure 10. Stress model on RS2 and Pressure of burden creates deformation on hanging wall structures of 555 level.

5 CONCLUSION

The last production levels on the widest ore body were designed according to geotechnical parameters and risks with consultancy guide. Monitoring was planned with smart cable bolts for hanging wall during the production. The cracks and the monitoring records reflected movement on hanging wall during production activities in these levels. Smart MPBX es were installed to know how deep movement is. Some smart cable bolts reached critical limits and new smart cable bolts were installed instead of failed smart cable bolts. After the last transverse production, was named 555-703-C2, displacement increased linearly on the graphs. This is an alert to failure of production. Therefore, hanging wall access drift for transverse up-hole production was paste filled. The access drifts at 555 and 595 levels were planned in ore body of footwall. Footwall was supported to stop thick footwall fault with rigid supports combined with mesh, strap, and cable bolts. 595 level production was stopped until 555 level production reached to 595 level production boundaries. Smart cable bolts were installed at each transverse up-hole production intersection. Cable bolts were installed to prevent possible back breaks after each up-hole blast in transverse stopes. Periodic scans on access drifts were planned to define any movements. 555 and 595 level productions were completed successfully with maximum recovery.

REFERENCES

Brown, E.T. and Hoek, E. 1978. Trends in relationships between measured rock in situ stresses and depth. Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. 15, pp.211-215.

Mathews, K.E., Hoek, E., Wyllie, D.C., and Stewart, S.B.V. (1981) Prediction of Stable Excavations for Mining at Depth Below 1000 Metres in Hard Rock. CANMET Report, Department of Energy, Mines and Resources

N. Barton, R. Lien, and J. Lunde, Engineering classification of rock masses for the design of tunnel support, (1974)