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Effect of Rib Pillar Extraction on the Surrounding Rock Mass with Large Diameter Blasthole Stoping as Method of Extraction

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Abstract **-** Large scale production methods always pose a serious threat to the natural pillars left intact in underground metalliferrous mines. Rib pillar extraction in underground metal mines is a complex process that requires careful consideration of geo-mechanical factors to ensure stability and safety. The stability of rib pillars is influenced by various parameters, including mining methods, rock mass characteristics, and extraction sequences. Extraction of rib pillar between mined out stopes plays a crucial role in redistribution of stresses around excavated stopes as well as the natural pillars which maintains the stability of the underground structures. Effective design and optimization, often involving numerical modelling techniques, are essential to ensure the safety and efficiency of underground mining operations. The present study focuses on three-dimensional finite element analyses to analyze the behaviour of the surrounding rock mass subjected to rib pillar extraction in an underground copper mine. A remnant vertical pillar of 3 m is left intact on either side of the rib pillar and the rest rock mass of 14 m thickness is extracted. A total of 5 different sequence of extraction have been considered with elastic constitutive material model. Based on the results obtained from the numerical modelling simulation, some useful conclusions have been inferred for the barrier crown pillar, crown pillar between main levels and 3 m remnant pillars.

Keywords**:** Underground Metal Mining, Rib Pillar Extraction, Remnant vertical pillar, Finite Element Analysis

1. Introduction

Large scale underground mining methods are selected based on the geological characteristics of surrounding rock and the orebody, aiming to maximize productivity with consideration of safety and economic viability. Sublevel stoping mining method is usually applied to a relatively steeply dipping, competent orebody, surrounded by strong wall rock. Sublevel stoping encompasses three primary variations: open-ending method, vertical crater retreat (VCR) method and blasthole method. The open-ending method requires a slot but uses parallel drilling from top to bottom, allowing for larger drill holes and potentially more efficient explosive usage. The VCR method, employs a similar drill pattern to the open-ending method but blasts the ore in horizontal slices from the top sublevel, using plugs to seal drill holes before loading and blasting. The blasthole method involves creating a vertical slot at one end of the stope and drilling a radial pattern of holes from sublevels, which are then blasted to break the ore. One of the variations of blasthole stoping is large diameter blasthole (LDBH) method, which involves drilling and charging large diameter ring holes from the drill drive extending to the stope boundary. The large diameter holes drilled vary in the range of 105 – 165 mm, which are generally blasted from the hanging wall to footwall side in vertical slices with burden of 2.5 m – 3.5 m. In ring hole blasting, differential charging of holes is carried out for uniform distribution of powder factor throughout the stope dimensions [1]. The blasted muck is fragmented into the trough below, from where it is transported via the extraction cross-cut. All these variations of sublevel stoping method deal with large-scale production; thereby, involving huge consumption of explosives subsequently leading to damage to the surrounding natural pillars, i.e., rib pillar, crown pillar and sill pillar.

The natural pillars in underground metalliferrous mines play a crucial role in maintaining the structural integrity of the permanent as well as temporary structures built by providing support throughout the life of mine. These pillars are composed primarily of orebody/waste rock; and, are strategically placed to distribute the immense weight of overlying rock formations. Thus, it prevents catastrophic collapses and ensure the safety to the entire underground mine. The stability of rib pillars is influenced by various parameters, including mining methods, rock mass characteristics, crown pillar thickness, depth of mining and extraction sequences [2]. In general, rib pillars are vertical remnant rock mass of suitable dimension left intact between two primary stopes; thereby, providing stability to the underground structures subjected to stress redistribution as a result of stope extraction. The rib pillars not only provide structural stability, but also enhance ventilation, minimize ore dilution, control ground movement, and safeguard the well-being of miners. In sublevel stoping method, the orebody thickness plays a deciding factor to determine whether longitudinal or transverse method of ore extraction is to be carried out [3,4]. In longitudinal method of stope extraction, sill pillars are essential components for supporting the overburden, requiring meticulous design and recovery to prevent catastrophic failures. The important parameters which affect the rib pillar stability in this method includes sequence of mining, backfilling, and rock mass properties [5]. On the other hand, the dimensions and structural integrity of rib pillars must be carefully designed to withstand overburden loads and stresses in transverse method of ore extraction [6]. Transverse method of ore extraction involves huge portion of rib pillars left intact between the main levels, which may lead to huge economic losses if not extracted at a later stage. The economics of leaving rib pillars around stopes is a multifaceted issue that requires balancing safety, operational efficiency, and ore recovery. While leaving rib pillars may seem economically disadvantageous due to lost ore, the long-term benefits of stability and reduced risk of collapse may outweigh the immediate losses. The extraction of rib pillars in metal mines is a significant aspect of underground mining operations, particularly in the context of optimizing ore recovery while ensuring the stability and safety of the mining environment. Research indicates that recovery rates in underground mining can be significantly improved through the implementation of effective rib pillar extraction strategies, leading to enhanced economic returns for mining companies. However, the extraction of rib pillars in metal mines is a complex process that necessitates careful consideration of safety, stability, and economic factors.

The present study focuses on the three-dimensional finite element analyses of an underground copper mine with transverse method of stope extraction. Two stopes are extracted simultaneously at each level to meet the production requirement of the underground mine. Rib pillar of 20 m thickness are left intact between two primary stopes along the entire orebody thickness. After backfilling the primary stopes, the rib pillars will be extracted leaving remnant pillars of 3 m thickness on either side to provide support to the backfill material. The effect of rib pillar extraction on 3 m surrounding remnant pillar, crown pillar and barrier crown pillar has been analyzed for the present study. The material constitutive behaviour is considered to be elastic. Results are evaluated along predefined paths in terms of safety factor, vertical displacement and extent of tensile zones around the excavated stopes. Based on the results obtained from the numerical study, some useful conclusions have been inferred.

2. Description of the Mine Site

The case study mine is situated in the Malanjkhand district of Madhya Pradesh, India. Malanjkhand copper mine is the largest base metal copper open-pit mine positioned 90 km northeast of Balaghat. The Malanjkhand Cu-Mo-Au (copper-molybdenum-gold) deposit is a strategically important porphyry-style mineralization, with a deformational history spanning approximately 50 million years after its formation [7]. The Malanjkhand granitoid complex is primarily composed of coarse-grained, hornblende and biotite-bearing granodiorite/tonalite, indicative of a single significant granitic event. The mineralized zone is primarily located along the arcuate Malanjkhand Hill, which extends approximately 2.6 km and reaches an elevation of around 600 meters above mean sea level. The open pit mining has reached it ultimate pit bottom; hence, the extraction of ore is carried out by underground mining method. Large scale blasthole stoping method is adopted for stope extraction along the transverse direction to meet the production target of 2.5 million tonne per annum. Six stopes with two working stopes in a level are preferred as mode of operation for the North mine. A crown pillar of 40 m thickness is considered for the stopes below the open pit mine. Backfilling of mined out stopes in a level is carried out before mining the stopes in the subsequent levels below.

3. Development of Numerical Model and Cases Analyzed

A three-dimensional finite element model has been developed to study the effect of rib pillar extraction on the surrounding rock mass considering *ANSYS Workbench Version 2023* [8]. Two cases are considered for the analyses: Case 1) All the primary stopes of the first level are backfilled followed by rib pillar extraction, leaving an intact pillar of 3 m on either side to provide support to the backfilled material in the mined-out stope and also the crown pillar. The stopes of subsequent levels below the 1st level are not extracted till the 1st level stopes and extracted rib pillar are backfilled. Case 2) The mined out primary stopes and rib pillar of the 1st level are backfilled, followed by rib pillar extraction in the 2nd level, leaving an intact pillar of 3 m on either side of the pillar. The stopes of subsequent levels below are not extracted till the 2nd level stopes and extracted rib pillar are backfilled. A 3 m remnant pillar is left in both sides to prevent dilution of backfill material.

Figure 1 (a) and (b) show the North mine model for the above two cases: Case 1 and Case 2 respectively. The figure shows the stope 1, 2 and 3 with 14 m portion of the rib pillar mined-out leaving out a remnant vertical pillar of 3 m on either side. For this study, 60 m level interval in the first level followed by 75 m level interval in the subsequent levels with 12 m crown pillar thickness is considered. The geo-mechanical properties of rock mass determined from the laboratory are reduced to equivalent rock mass properties using RocData User's Manual Version 4.0 [9] and are used as input data for the numerical model. The constitutive behaviour of rock is modeled as elastic material for all the mine models. Table 2 shows the rock mass properties considered for the present study. The density (ρ), E and ν of the cemented backfill are taken as 2200 kg/m^3, 200 MPa and 0.3 respectively. Results are evaluated along four predefined paths in terms of safety factor, vertical displacement and extent of tensile zones around the excavated stopes. Table 1 shows the different scenarios analysed for the present study. A total of 6 different scenarios or mining sequence have been analyzed in this study, including the insitu model. Figures 2 (a) and 2 (b) show the plan view of sequence 2 and 3 respectively; whereas, Figure 3 (a) and 3 (b) show the plan view of sequence 4 and 5 respectively. In the figures, 'P' refers to the primary stope which will be extracted first; whereas, 'R' denotes the rib pillar.

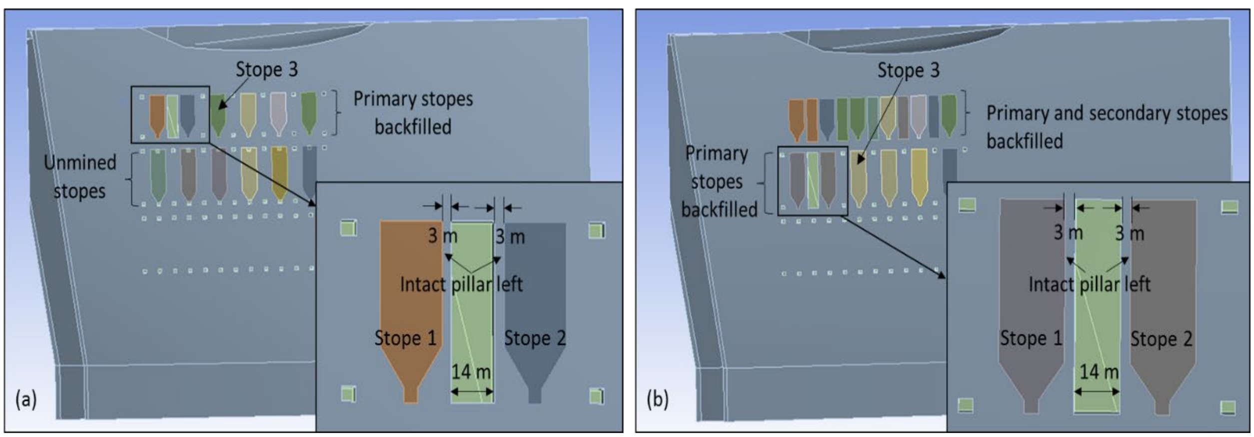

Fig 1: North mine underground model for (a) Case 1 and (b) Case 2.

Table 1. Models considered for numerical analyses.

Mining sequence	Description
Sequence 1 (S1)	Insitu model without extracting primary stopes and rib pillar
Sequence 2 (S2)	Rib pillar half extracted between stope 1 and 2
Sequence 3 (S3)	Rib pillar full extracted between stope 1 and 2
Sequence 4 (S4)	Rib pillar full extracted between stope 1 and 2 + Rib pillar half extracted between stope 2 and 3
Sequence 5 (S5)	Rib pillar backfilled between stope 1 and 2
Sequence 6 (S6)	All the primary stopes of 1st level backfilled + No mining in 2nd level

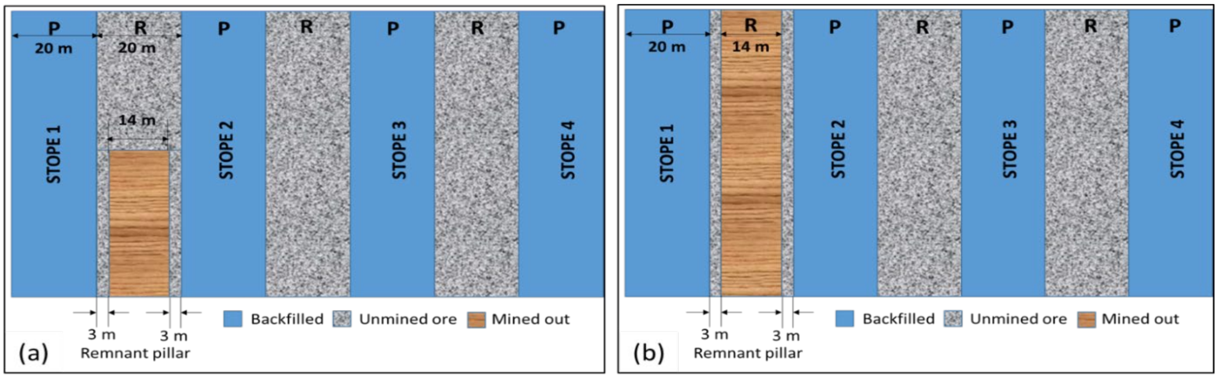

Fig 2: Plan view showing (a) sequence 2: S2 and (b) sequence 3: S3.

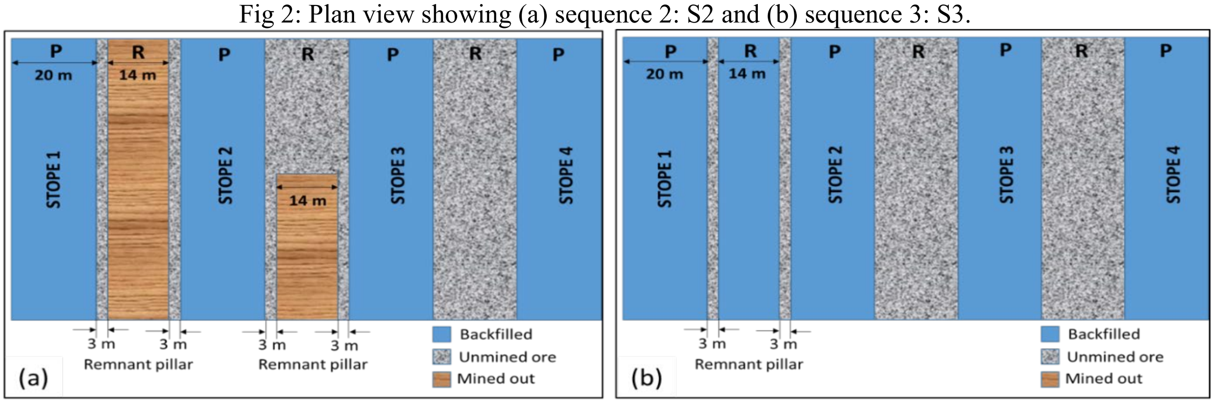

Fig 3: Plan view showing (a) sequence 4: S4 and (b) sequence 5: S5.

Table 2: Material properties considered for the numerical analyses

Particulars	Orebody	Basic Dyke	Waste Rock
Geological Strength Index *GSI*	60	60	60
Uniaxial compressive strength of rock mass σ_{cm} (MPa)	7.9	7.3	12.8
Youngs' modulus of rock mass E_m (GPa)	5.2	6.9	8.8
Angle of internal friction of rock mass ϕ_m (deg.)	51.3	49	55
Cohesion of rock mass c_m (MPa)	2.9	2.7	3.6

4. Results and Discussions

Remnant pillars of 3 m thickness are left on both sides to prevent dilution of backfill material during rib pillar extraction as shown in Figures 2 and 3. Extracting the vertical rib pillars may result in high stress concentration in the 3 m remnant pillars which not only provides sufficient confinement to the backfill material but also supports the crown pillar between two levels. Figure 4 shows the pre-defined paths along with the results are assessed in terms of vertical displacement and safety factor. Figures 5 (a) and (b) show vertical displacement plots along path 1 due to extraction of rib pillar in 1st and 2nd level respectively. It is observed that the maximum percentage increase in vertical displacement in the bottom of the crown pillar between stope 1 and stope 2 is found to be around 78 % more for sequence 4 as compared to sequence 2. Backfilling of the rib pillar (sequence 5) leads to reduction in vertical displacement values by 4 – 6 mm as compared to sequence 3 and 4 due to rib pillar extraction in 1st and 2nd level, respectively. These results points to the importance of backfilling in proper time.

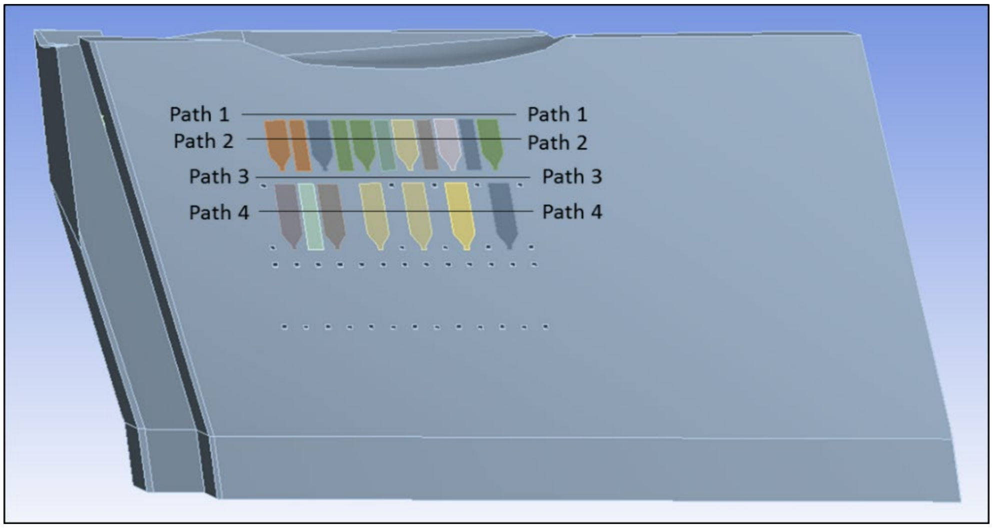

Fig 4: Pre-defined paths considered for the numerical study.

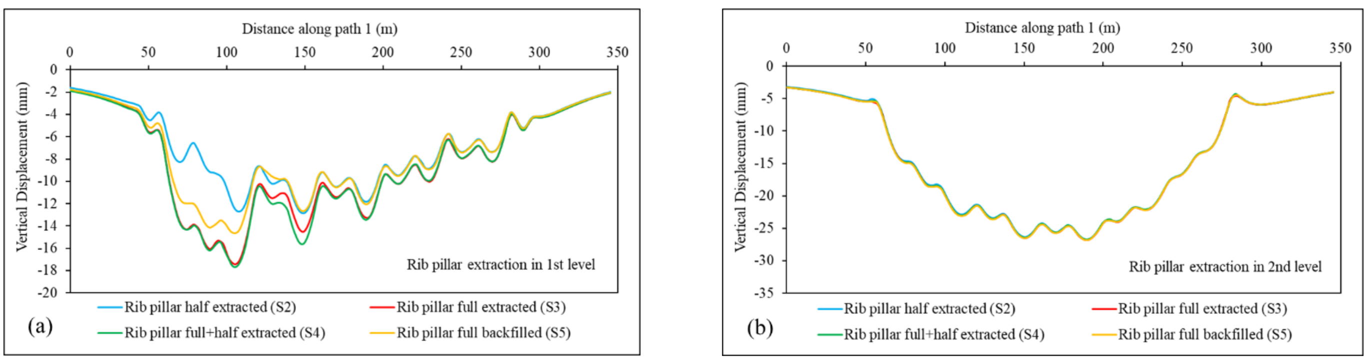

Fig 5: Vertical displacement plots along path 1 for different mining sequence.

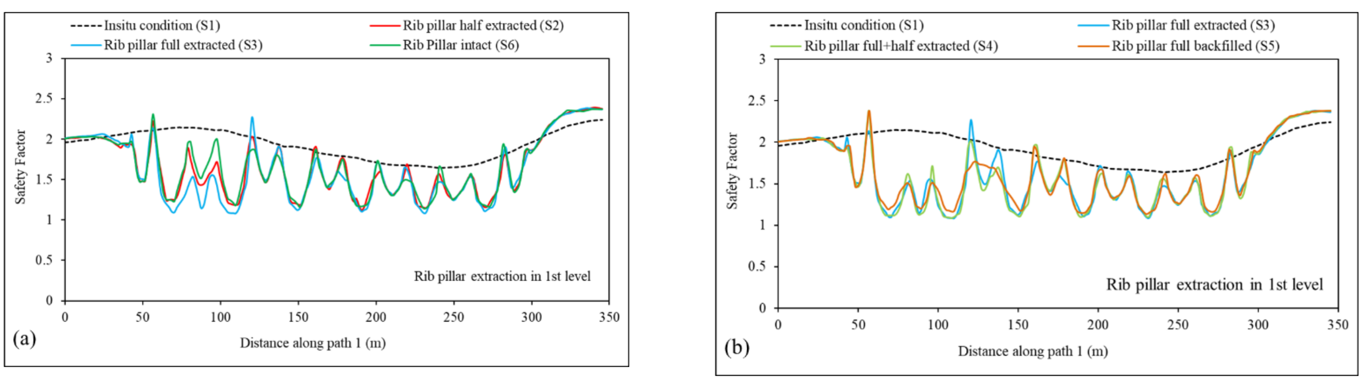

Fig 6: Safety factor plots along path 1 for different mining sequence.

Figure 6 (a) and (b) show safety factor plots along path 1 due to extraction of rib pillar in the 1st level for different sequences respectively. It is observed that the extraction of rib pillar and backfilling of the primary stopes in the 1st level has resulted in substantial change in safety factor as compared to model 1, i.e., insitu condition. It is observed that the safety factor decreases for sequence 4, i.e., when a rib pillar is fully extracted in level 1 between stope 1 and 2, and a rib between stope 2 and 3 is half extracted without filling. The maximum percentage increase in safety factor is found to be along path 1 for model 6 as compared to sequence 2 and 3 are 10.3 % and 35.5 % respectively. From the plots, it is clearly observed that safety factor rises from 1.2 – 1.4 to 1.3 – 1.6 due to backfilling operations. However, for 2nd level of extraction, it is found that there is no significant change in safety factor values with extraction of rib pillar in the 2nd level for the different scenarios. Backfilling of stopes contributes to a greater extent in stabilizing the safety factor values for the above-mentioned scenarios.

Figure 7 and 8 show the minor principal stress plots and extent of tensile zone around mined out stopes and crosscut due to rib pillar extraction in 1st level for sequence 2, 3, 4 and 5 respectively. It is observed that the tensile zone extends throughout the 3 m remnant pillar. The tensile stress generated in the pillar varies between 0.4 – 0.8 MPa, which may not cause failure of this pillar. It suggests that if 3 m remnant pillar and backfilled stope as a system carry the overburden load, the tensile zone in 40 m crown pillar as well as 3 m remnant pillars can be reduced drastically.

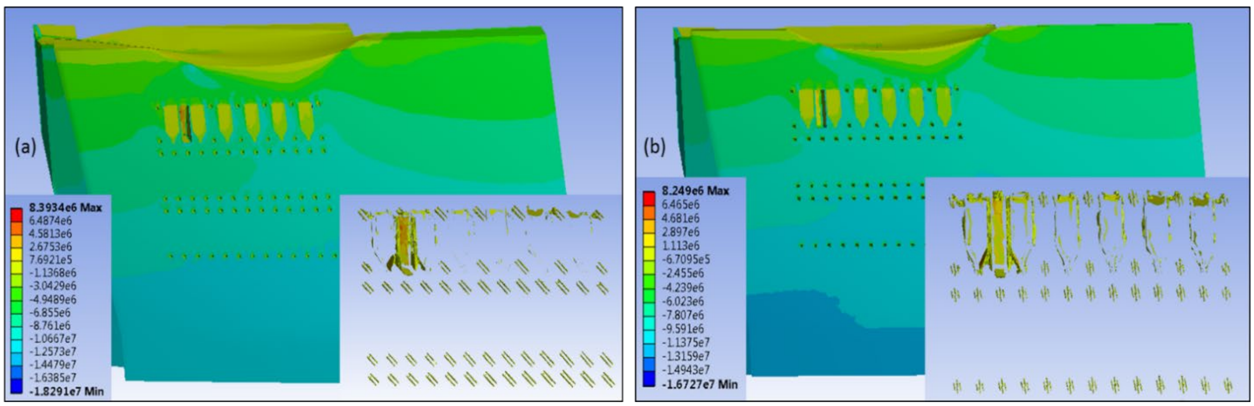

Fig 7: Minor principal stress plots due to extraction of rib pillar in 1st level for (a) S2 and (b) S3.

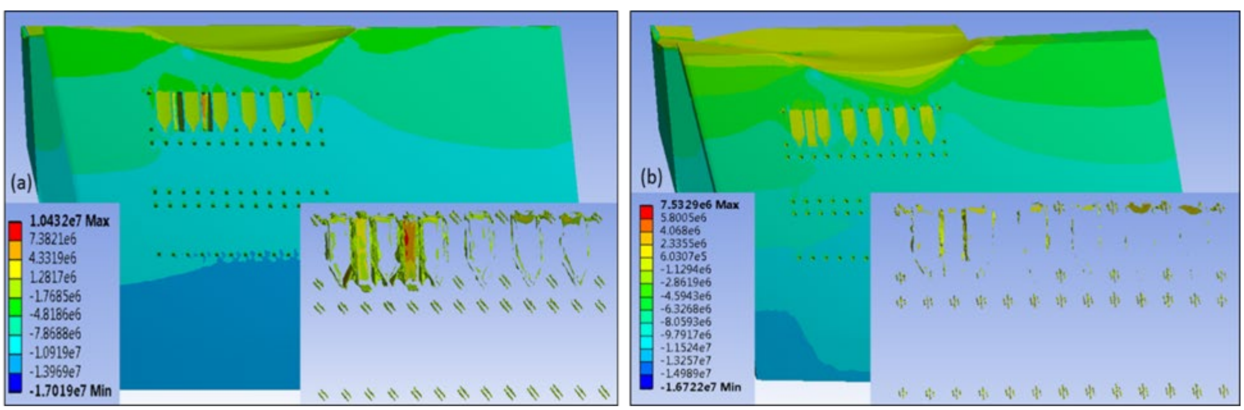

Fig 8: Minor principal stress plots due to extraction of rib pillar in 1st level for (a) S4 and (b) S5.

4. Conclusions

The present study focused on the effect of rib pillar extraction on the 3 m remnant pillar considering three-dimensional finite element analyses. The numerical simulation results show that the 3 m remnant pillar is sufficient enough to provide support to the backfill material but also the 40 m solid parting between 300- 340 mRL as well as the crown pillars between two main levels.

The following conclusions have been drawn from the present study:

1. Tensile stress generated in the 3 m remnant pillars is nominal. Moreover, the tensile strength of the rock mass varies between 1.6 – 1.8 MPa which is higher than the tensile stress which ranges between 0.4 – 0.8 MPa. Backfilling of the extracted rib pillar further diminishes the extent of tensile zone in the remnant pillars.

2. The 3 m remnant pillar will reduce the dilution of extracted orebody from mixing with filled material.
3. Displacement in the crown pillar is also nominal, which varies between 15- 20 mm. Backfilling of the extracted rib pillar further results in reduction of displacement values to 5- 7 mm.

It should be noted that the present study does not consider any artificial support such as rock bolt in the numerical simulation; thereby, indicating that safety factor will increase in the field, imparting stability to the surrounding rock medium.

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References

[1] D. Deb, S. Mohanto, Y. K. Patanwar, and R. Shrimali. "Stability Analysis of LDBH Stopes Below an Open Pit Mine Due to Blast Load." *in ISRM International Symposium - EUROCK 2016*, Turkey, 2016.

[2] Y. K. Patanwar and D. Deb, "Development of Coupled FEM and Fuzzy Rules–Based Procedures for Mitigation of Uncertainty in Forecasting Stability of Underground Pillars", *International Journal of Geomechanics*, vol 22(2), 04021276, 2022.

[3] S. Mohanto and D. Deb, ""Prediction of Plastic Damage Index for Assessing Rib Pillar Stability in Underground Metal Mine Using Multi-Variate Regression and Artificial Neural Network Techniques", *Geotechnical and Geological Engineering*, vol. 38(1), pp. 767-790, 2020.

[4] S. Mohanto, D. Deb and A. Senapati. "Stability Assessment of Crown Pillar for an Underground Mine Using K-Cross Validation Technique" *International Journal of Civil Infrastructure*, 2024, vol. 7, pp. 73-83.

[5] A. Eremenko, "Stability Risk Assessment of Underground Rock Pillars Using Logistic Model Trees", *International Journal of Environmental Research and Public Health*, vol. 19(4), pp. 2136, 2023.

[6] A. A. Baryakh, A. V. Evseev, I. S. Lomakin, and A. A. Tsayukov, "Operational control of rib pillar stability." *Eurasian mining*, 10-17580, 2020.

[7] H. Stein, A. Zimmerman, J. L. R. J. Markey, "Late Archaean-Early Proterozoic timing for an Andean-style porphyry Cu-Mo deposit and Malanjkhand, Central Indian Tectonic Zone: Implications for a late Archaean supercontinent", *Geophysical Research Abstracts*, vol. 5, 67496, 2003.

[8] ANSYS Workbench User's Manual. Version 23.0. Pennsylvania. United States

.[9] RocData User's Manual, Version 4.0. RocScience. Saint Patrick St. Toronto.