Evaluation and stability assessment of pillars of an underground mine under various conditions

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Abstract
Extraction of natural mineral resources is highly essential to meet the energy and other requirement of any country. Such resources can be extracted by means of open pit mining or underground mining. Under ideal conditions, 90% of ore can be extracted by open pit mining. But the production rate is not the same compared to underground mining. Underground mining has various limitations. One such limitation is leaving the ore in form of pillars. However, these pillars provide stability for safe extraction and also ensure the safety of men and machines. There is a huge economical loss due to such existing practice. The total left over ore which has high economic importance could not be retrieved once the activity is completed. Irrespective of the size of the underground openings, scientific analysis and design of rock excavations, profits are vastly from the knowledge and understanding of existing stresses within the rock mass.

In practice, parameters such as the magnitude of the stress, deformation, pore pressure and load on to the support system due to exploitation and the strength of the structures are estimated rather conservatively to provide an acceptable margin of safety. In this context, this study deals with assessing the safety factor of the pillars, mining the ore from foot wall (FW), parting and hangwall (HW) of an underground mine. To validate the same, a 2 dimensional model has been created and simulated under different conditions and its safety factor has been assessed.

Keywords: Stability, Scientific analysis, Numerical Modelling, Pillar, Safety factor.

Introduction

The rocks are non-homogeneous in nature. Theoretical and numerical evaluations of the state of strata behaviour are often just estimates that cannot take into account all contributing elements and conditions because the stress-strain equations developed for this purpose are all based on the assumption that the rock mass is linear-elastic, homogeneous and isotropic which is not always applicable. Classification of rock masses is highly important for carrying our any engineering design[1,2].

A number of techniques and equipment have and are being developed to monitor the strata behaviour. Worldwide extensive research is being carried out for understanding the strata behaviour in underground mines.

Rock mechanics investigations are highly essential for underground mining[3]. The knowledge of strata behaviour at depth using rock mechanics investigations will be helpful in identifying the high stress zones at any point of time and its implication in the safety of the underground structures[14]. The underground pillars contribute a lot when it comes to stability of the room of an underground mine[7].

Thus, it is decided to evaluate and assess the stability of the pillars of an underground mine[4-6]. An underground mine is being operated in Andhra Pradesh to mine the ore of huge economic importance and to meet the country’s energy requirement. This mine is being operated by Room and Pillar method of mining. For optimum utilization of the mineral ore, a different method of sequence for extraction of ore was proposed and later a study was conducted to assess the factor of safety of remnant pillars so formed by the new method. The behavior of support system in the rooms and their stability including the backfilling was also studied[8]. Representative rock blocks were also collected from the underground for determining physico-mechanical properties of these rocks[12]. The support plans were formulated and stoping parameters were determined later on[10,11].

Based on all these geotechnical data, the stress analysis using numerical modelling was conducted to evaluate the stability of the remnant pillars[9].This study mainly includes review of the existing pillar sizes for factor of safety and extraction ratio, study and evaluate the stability of the pillars so formed by the new approach and evaluation of the stability of the rooms with and without backfilling[15,16].

Material and Methods

Huge ore is being locked in form of pillars, it is decided to increase the productivity by planning long panels with new improved sequence of excavation / mining. The proposed sequence of operations is shown in figure 1. It is proposed to mine out the parting also after the FW ore body utilizes the same waste material of the parting for backfilling there by leaving the vertical remnant pillars of approximately 9.0min height. Accordingly the proposed sequence is analyzed by numerical modelling to evaluate the stability of pillars and the rooms.

The mine is developed up to 17th level in east and 20th level in western side. Level splitting between the levels is actively progressing in all the levels. The strike drives are 4.5m in width and 3m in height. Ramps of the same size have also been driven in each stope block to connect the top drives to the bottom drives. The mine development would also include 10m long loading points measuring 7m in width and 5.5m in height.

The drives in the hangwall ore body have the red shale as the roof strata and the drive in the footwall ore body has dolostone in the immediate roof. An ore block between 2East and 6East in eastern side and between 4West and 6West in western side of the mine has been identified for stoping operations with room and pillar mining method. More than 62km of development has taken place so far in the form of advanced strike drives (ASD's), declines, ramps, stope drives and cross cuts etc. Stoping operations were successfully completed in an experimental panel with optimized pillar dimensions.

Numerical Modelling: In order to ascertain the stability of remnant pillar, crown pillar, rib and sill pillars, a 2 Dimensional numerical modelling is performed. For this purpose section along the dip side of the panel is created. This study presents the results of the model i.e. the section along dip side of the panel. The model geometry for this section is shown in figure 2. It can be observed from the figure 2 that the actual lithology up to the surface is considered in the model.

The maximum depth of mining (200m) was also considered for the worst case simulation. All the material properties of the various rock mass that formed the model geometry were obtained from the laboratory testing of the representative samples collected from the mine. The results of the geo mechanical properties tested in the laboratory are presented in the table 1.

Numerical Analysis: As stated earlier, this model is created to study the stability of the remnant pillars of the proposed mining sequence.

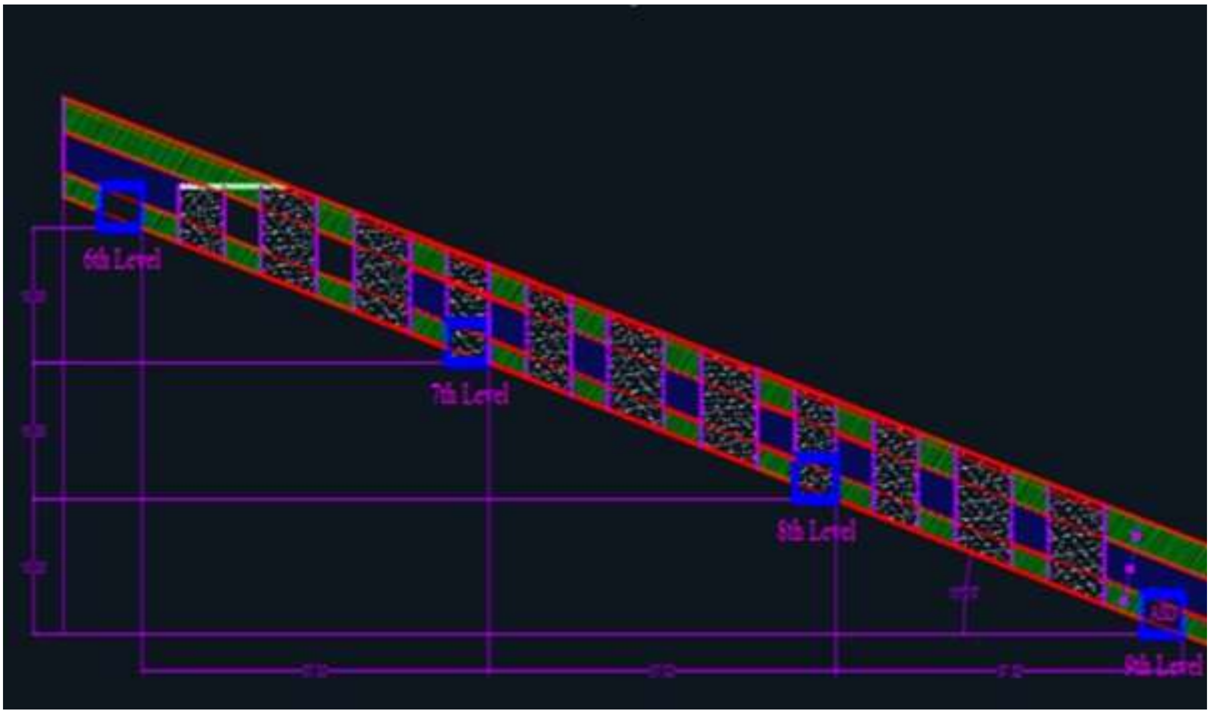

Figure 1: Dip side section of the proposed mining sequence

Table 1
Geomechanical properties of various rockmass units.

Rockmass	Tensile Strength (MPa)	Young's modulus (MPa)	Poisson's ratio	Cohesion (MPa)	Friction angle (deg)
FW Lode	10	5530	0.25	10	35
HW Lode	10	5530	0.25	8	35
Parting	10	5530	0.25	10	35
Shale	5	4320	0.29	8	35
Shale-weak	10	3110	0.30	5	42
Limestone	15	9950	0.25	12	32
Soil (surface)	0	100	0.32	0.5	30
Backfill	0	1	0.32	1	30

All the pillar dimensions are as per the proposed design of pillar sizes. It also aimed to examine the stability of the rooms under the following scenarios: (a) When only advanced strike drive is developed (b) When the FW Lode mining (without support) (c) When both the FW Lode mining and Parting mined (without support) d) When all FW, Parting and HW mining are done (No backfilling) (e) When FW and Parting are backfilled and HW is mined with rock bolt support. The mining induced stress and the FOS values over the pillars due to the above mining scenario are examined.

The stability of the pillars with and without backfilling / supports is also examined. All the material properties for the analysis are obtained from the laboratory testing of the relevant rock samples collected from the mine. For the purpose of *in situ* stress conditions, vertical loading was calculated for vertical stresses and the horizontal stresses were taken as twice the vertical stresses. A finite element model with various materials and the pillars formed is taken for analysis and shown in figure 3. Results of the analysis were obtained in the form of mining induced stresses and strength factor (FOS) around excavations.

Results and Discussion

Only when advanced strike drive is developed: The mining induced stresses and the strength factor around pillars after both the upper and lower ASD's developed are shown in figure 4 and figure 5 respectively. For the convenience of the visibility, part of the model containing the representative mining scenario is zoomed to show the condition of the pillars. It can be observed from the results shown in figure 5 that the maximum stress induced due to ASD's opening is of the order of 18.00MPa.

The FOS values around the ASD opening are shown in figure 5. It can be observed that the openings around ASD are exhibiting a high FOS of around 3.5 on the sides and around 1.8 in the roof even without any supports installed.

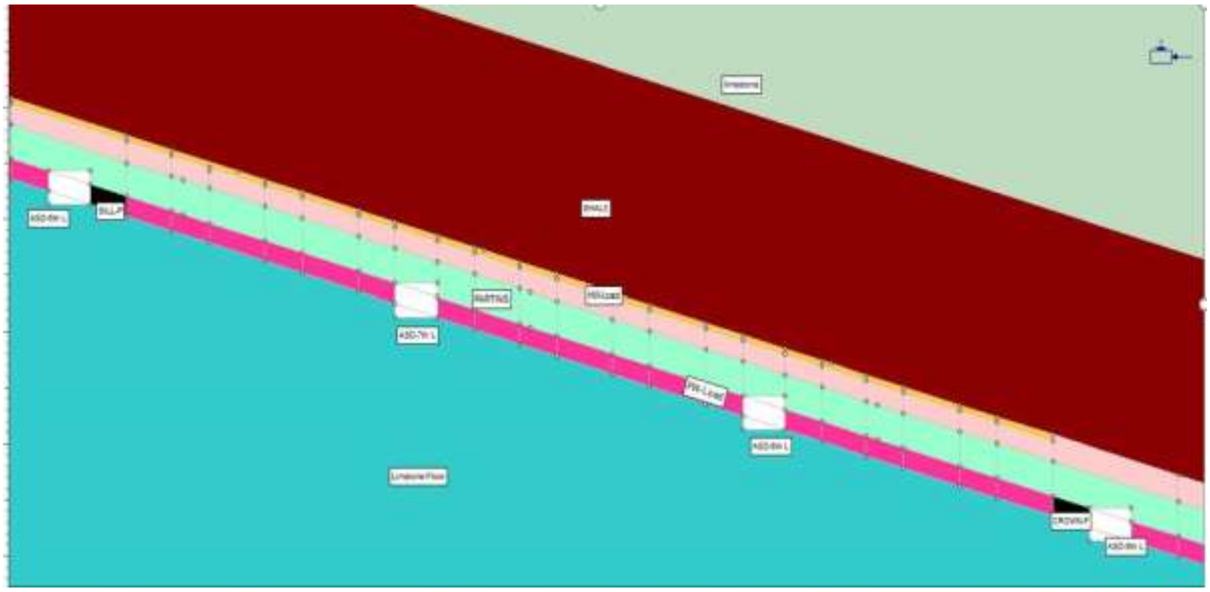

Figure 2: Model geometry (Partial) for Model-I

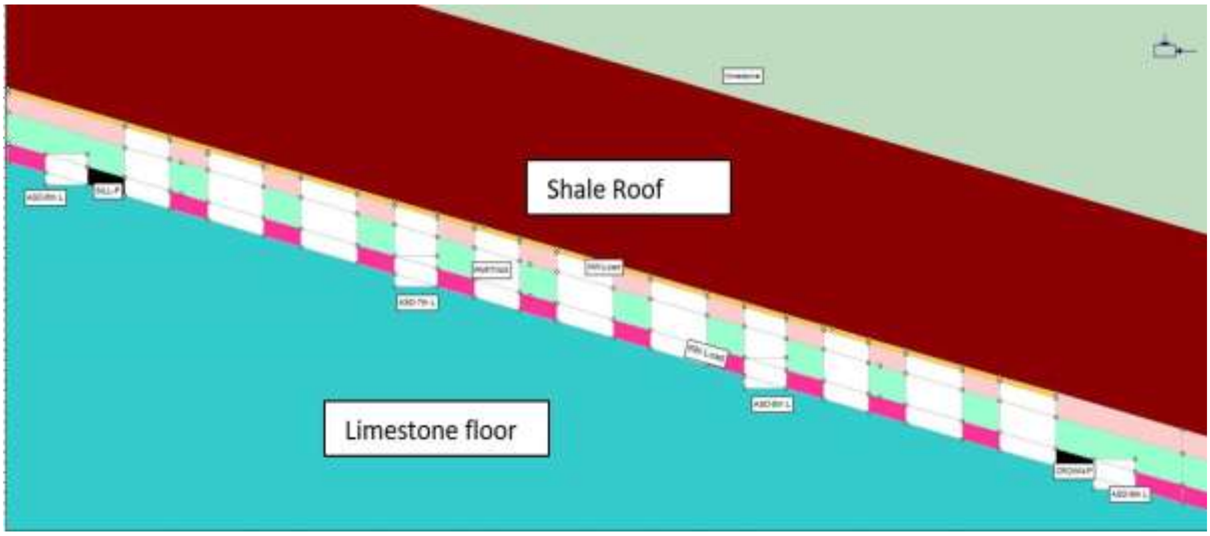

Figure 3: Part of the FE Model with various litho units and Pillars

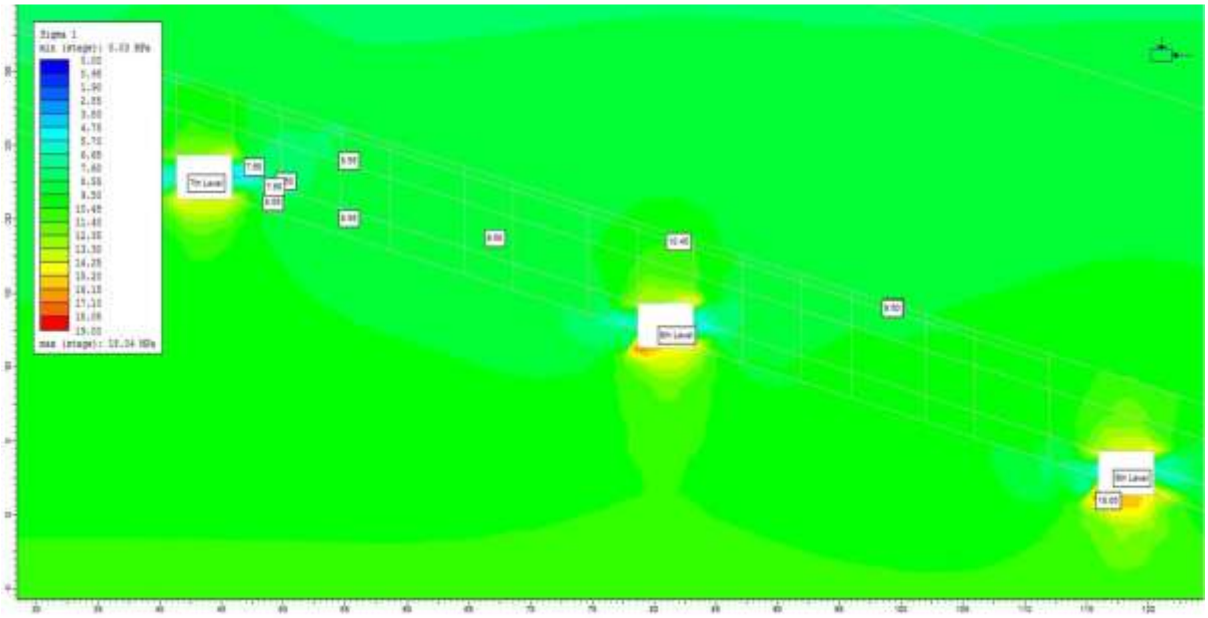

Figure 4: Mining Induced Stresses around the ASD

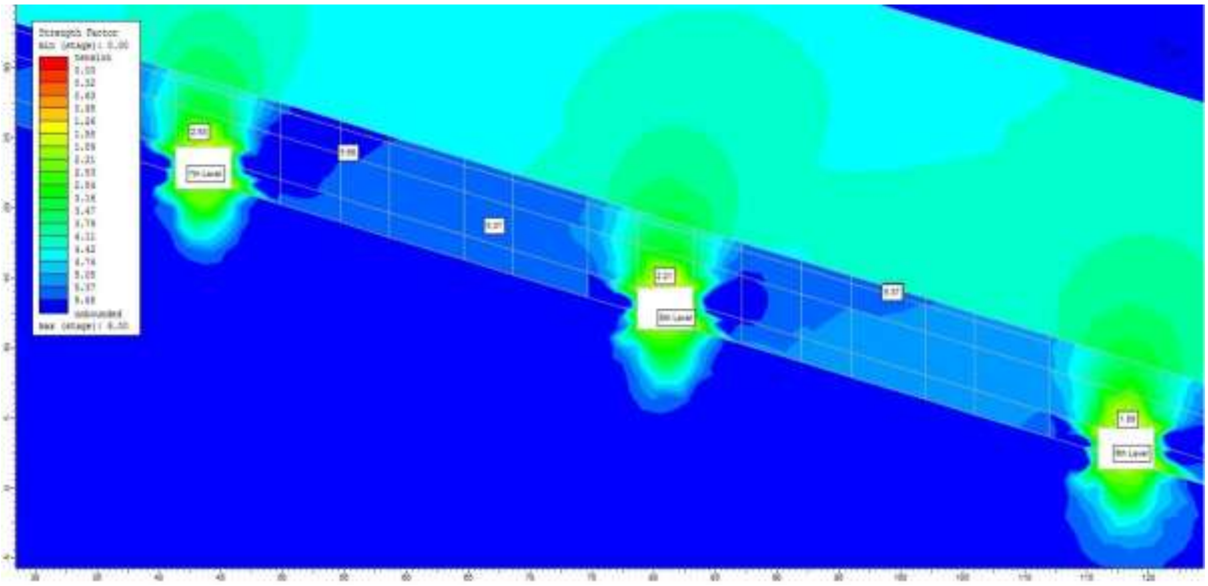

Figure 5: FoS values around the ASD

FW Lode mining (Without Support): The mining induced stresses and the strength factor (FOS) around remnant pillars after FW lode mining are shown in figure 6 and figure 7 respectively. For the convenience of the visibility, part of the model containing the representative remnant pillar is zoomed to show the condition of the remnant pillars and rooms.

It can be observed from the results shown in the figure 6 that the maximum stress induced due to the FW lode mining is of the order of 24.00MPa only and is concentrated in the corners of the pillar. The stress concentration at centre roof of the gallery/room is of the order of 11.00MPa only. It can also be observed that the maximum stress at the parting between FW and HW is of the order of 11.00MPa. The remnant pillars of HW lode also exhibit the stress in the same order. The FOS values of the pillar and around the excavation are shown in figure 7. It can be observed that the remnant pillars are exhibiting a high FOS ranging from 3.47 to 6.0 and it was observed that the FOS values are 1.89 at the walls of the FW lode galleries. The roof of the galleries of FW lode also exhibits FOS of 2.21.

FW lode and parting mined (without support): The mining induced stresses and the strength factor (FOS) around remnant pillars after both FW lode and the parting are mined out as shown in figure 8 and figure 9 respectively. For the convenience of the visibility, part of the model containing the representative remnant pillar is zoomed to show the condition of the remnant pillars and rooms.

It can be observed from the results shown in the figure 8 that the maximum stress induced after mining the FW lode and parting is of the order of 30.00MPa and is concentrated in the bottom corners of the pillar. The stress concentration at the centre roof of the gallery/room is of the order of 10.20MPa only and it is reduced to minimum in the gallery walls there by creating relaxation in the gallery walls. The strength (FOS) values of the pillar and around the excavation are shown in figure 9. It can be observed that the remnant pillars are exhibiting a FOS ranging from 1.58 to 4.42 with occasional low value of 0.95 and the roof of the galleries also exhibit high FOS after the mining of both FW lode and parting.

FW Lode, parting and HW Lode Mining (no back filling): The mining induced stresses and the strength factor around pillars and rooms after FW lode, Parting and HW lode mining without back fill are shown in figure 10 and figure 11 respectively. This model was attempted to study the stability of the proposed full height of the remnant pillars in the event of no backfilling of the workings. For the convenience of the visibility, part of the model containing the representative remnant pillar and rooms is zoomed to show the condition of the pillars and rooms.

It can be observed from figure 10 that the increase of maximum stress induced due to the above scenario is of the order of 38.00MPa and is concentrated at the bottom corner of the Sill pillar. The stress concentration at centre of the pillars and the roof of the gallery was normal only and not increased considerably from the previous mining condition.

However, the sides of the pillar seem to be relaxed and may lead to tension failure. Low FOS values over the edges of the pillars can be observed during this mining case as shown in figure 11. At few locations FOS value of less than 1 is also observed leading to pillar failure. It can be observed that the pillars are exhibiting FOS values ranging from 1.26 to 4.47 in the centre of the pillar. The roof of the rooms also shows the FOS values of 1.26 and above and seems to be stable with the installation of rock bolts.

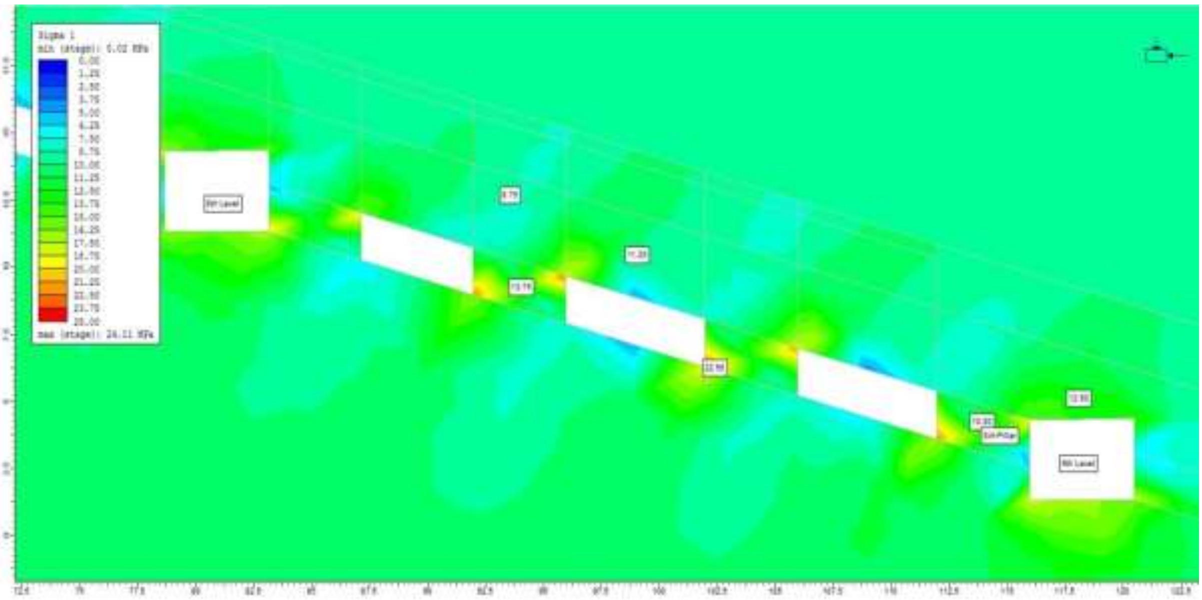

Figure 6: Mining Induced Stresses around the remnant pillars after FW lode mining

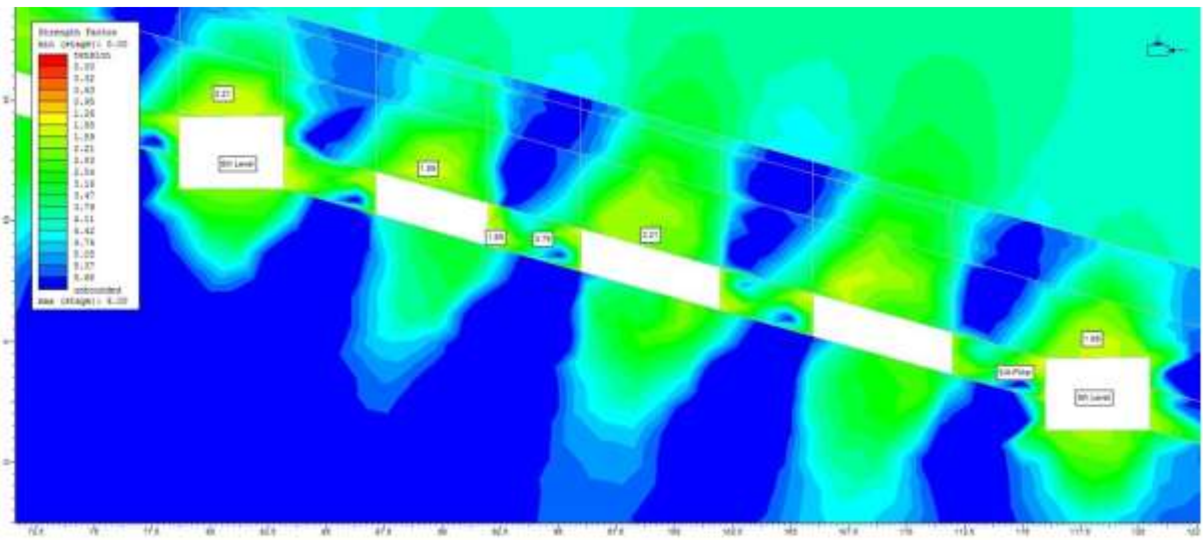

Figure 7: FoS values around remnant pillars after FW lode mining

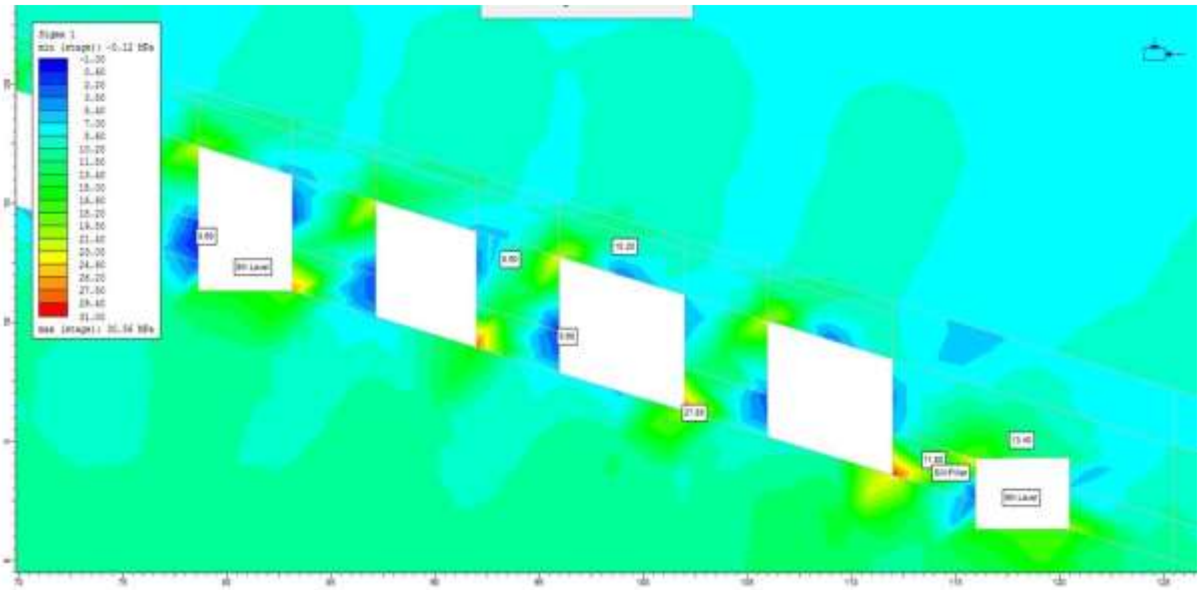

Figure 8: Mining Induced Stresses around the remnant pillars after FW lode and Parting mined

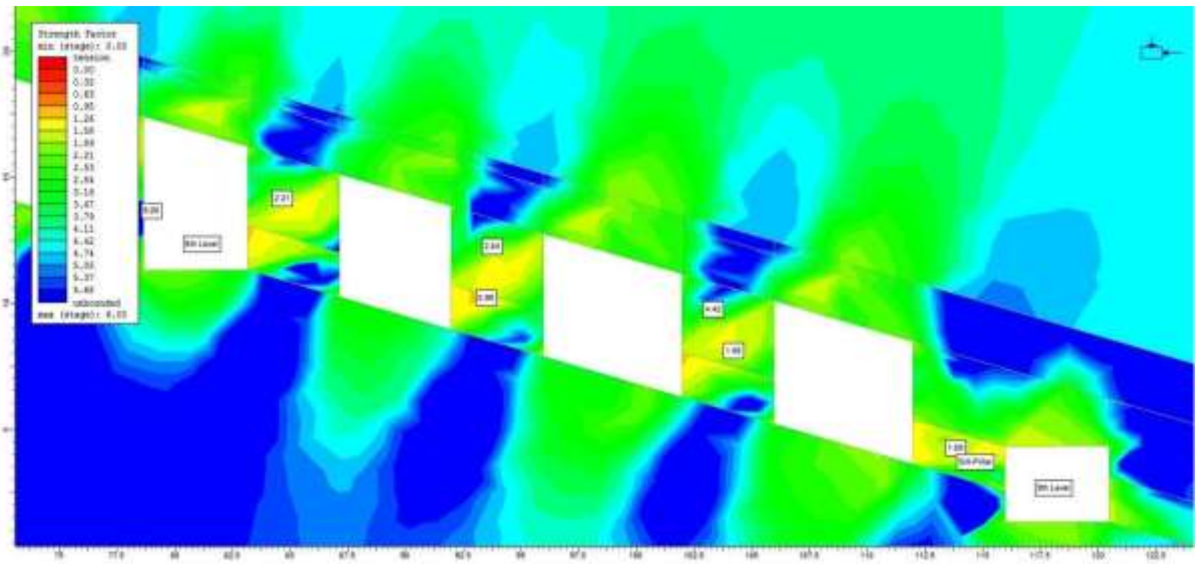

Figure 9: FoS values around remnant pillars after FW lode and Parting is mined

FW Lode, parting and HW lode mining with back filling of FW lode and parting: The mining induced stresses and the strength factor (FOS) around remnant pillars and rooms after the above mining condition are shown in figure 12 and figure 13 respectively. This model was attempted to study the stability of the proposed remnant pillars stability in the event of backfilling of both FW lode and parting. For the convenience of the visibility, part of the model containing the representative remnant pillar is zoomed to show the condition of the remnant pillars and rooms.

It can be observed from the figure 12 that the induced stress has not increased further from the previous case with the back filling of the FW lode and parting ensuring the better confinement.

Also, the stress concentration over the roof of the rooms is of the order of 15.00MPa only. The FOS values around the pillars after backfilling of both FW lode and parting with HW lode workings bolted are shown in figure 13. It can be observed that the remnant pillars are exhibiting improved FOS values ranging from 1.58 to 4.47 except at a remote location where the FOS of 1.26 can be observed at the contact of dolostone and shale in the HW lode. This shows the effect of backfilling ensuring the stability of the remnant pillars for the long term safety.

Conclusion

The strength and the FOS of the remnant pillars formed by the proposed sequence were examined by numerical modelling for their stability in this study and the following conclusions can be drawn from the results obtained. The proposed pillar dimensions in the new mining method appear to be optimum and stable during the mining operation under all conditions except when FW lode mining, parting and HW lode mining are done without backfilling.

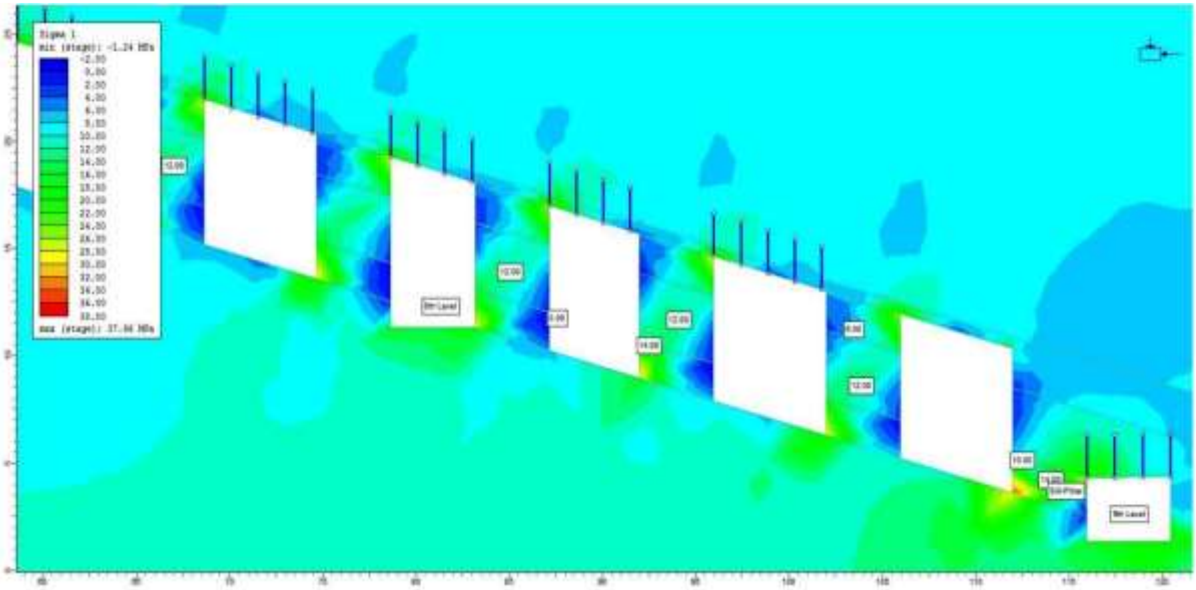

Figure 10: Mining Induced Stresses around the pillars after FW, Parting and HW lode mining without backfilling.

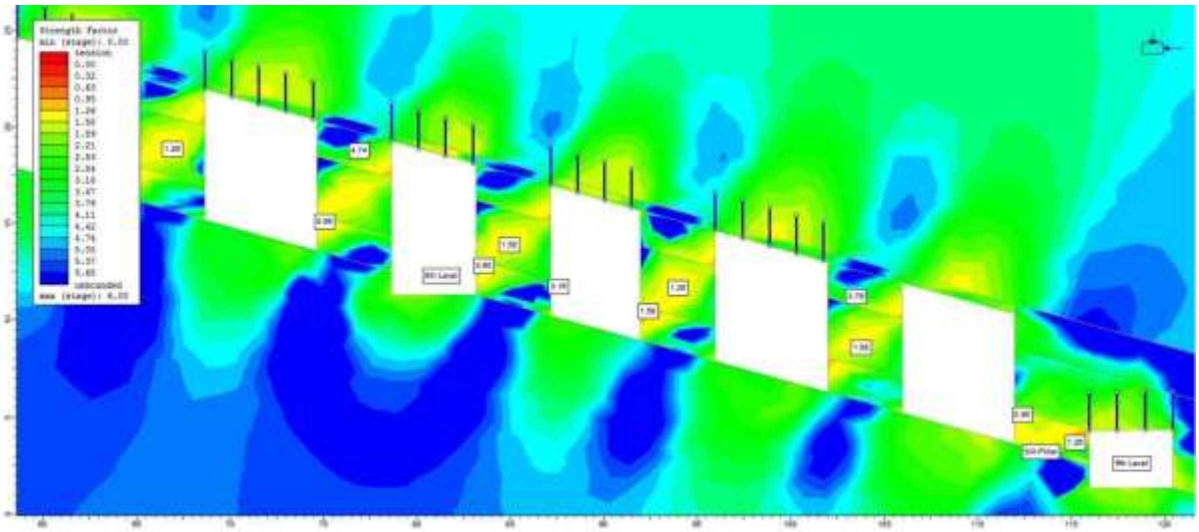

Figure 11: FoS Values around the pillars after FW, Parting and HW lode mining without backfilling

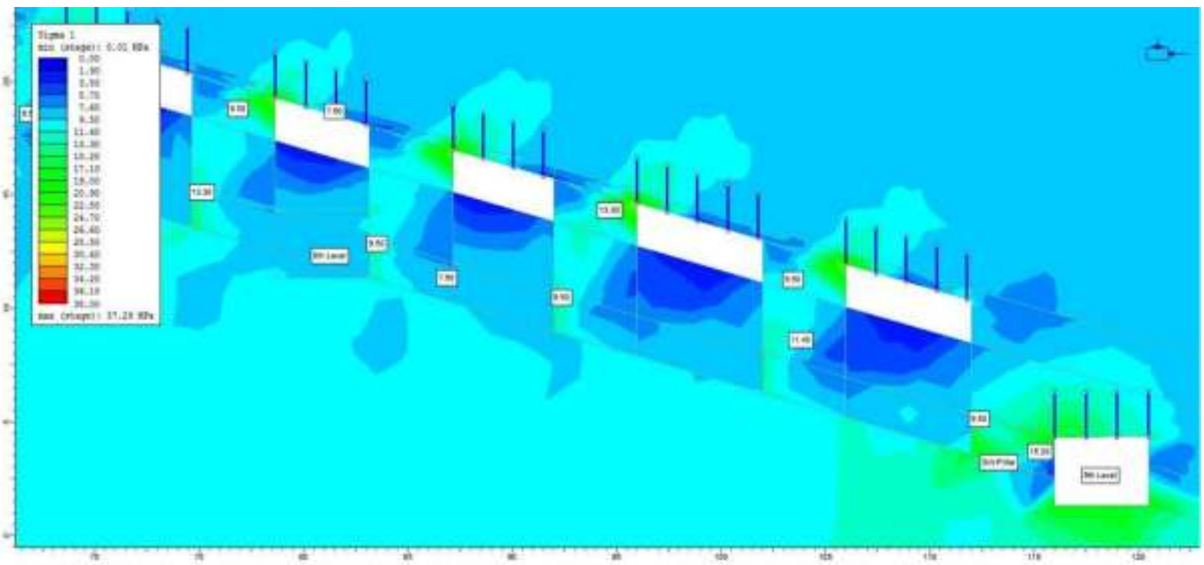

Figure 12: Mining Induced Stresses around the remnant pillars after FW lode, Parting and HW lode mining with back filling of FW lode and Parting

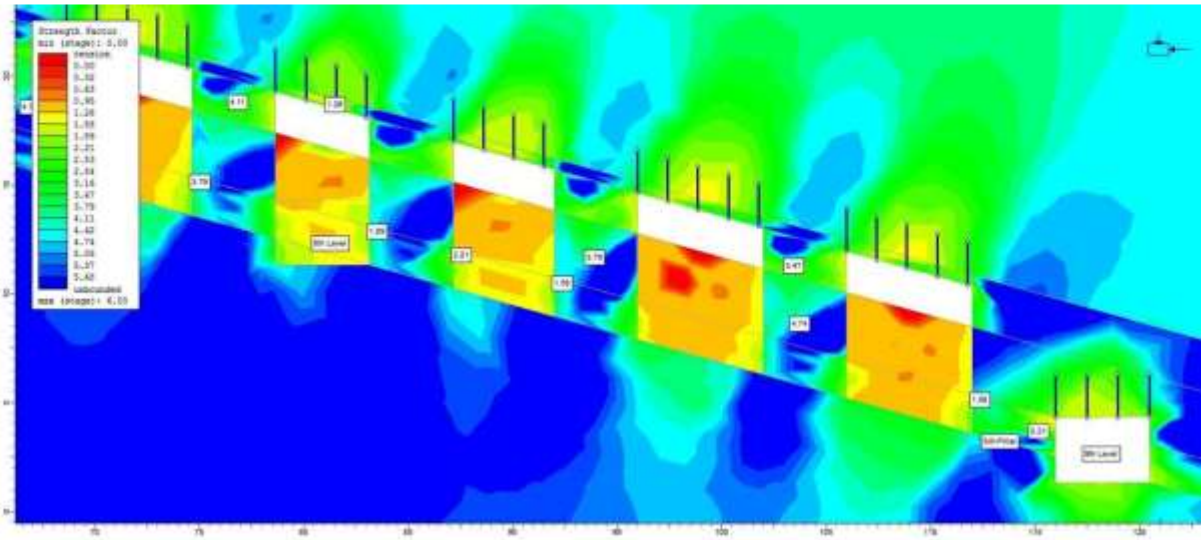

Figure 13: FoS values around the remnant pillars after FW lode, Parting and HW lode mining with back filling of FW lode and Parting

However, it was observed that the edges of the remnant pillars are showing failure when the full height of pillar is exposed and when there is no back filling. The walls of the remnant pillars appear to be failing in tension. The FOS when FW, HW and parting is mined without backfilling appears to be very low and even less than 1 in few locations.

For all other scenarios studied in the mine, the pillars and the rooms appear to be stable and safe with considerably high FOS values and comparatively low induced stress. The maximum mining induced stress observed is of order of 38 MPa while mining FW, HW and parting without backfilling. The opposite corners of the pillars seemed to be highly stressed in this case. It appears that the backfilling of the FW lode and parting increases the stability greatly with increased FOS and no failure of pillars is observed under this scenario. However, the roof of the rooms should be supported with rock bolts to increase its stability.

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