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Estimation of the Impact of Mining on Stresses by Actual Measurements in Pre and Post Mining Stages by Hydrofracture Method–A Case Study in a Copper Mine

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Additional information is available at the end of the chapter

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Abstract

To sustain and increase the productivity in a large underground copper mine in India the management of the mine decided to design and develop stopes below the mined out area. For the design of the stopes a detailed stress measurement programme was carried out by hydrofracture method at different depths from the developments available near the proposed stope. The result indicated a post mining induced high stress tensor with the direction of the maximum compression (maximum principal horizontal stress) rotated 70- 750 from the pre-mining stress tensor and oriented almost transverse to the ore body as against sub parallel to the orebody during pre- mining stage. A 3-D numerical modeling of the mine with pre mining stress tensor as input parameter substantiated the field result at the post mining stage. The generation of post - mining stress helped in understanding the impact of mining on the stress and was used for design and sequencing of the stoping operation for the safe and optimum extraction of the ore.

1. Introduction

Knowing the post mining stress condition is always of interest to the mine designer ahead of designing a mining method in the non-mined areas. This knowledge helps them in the design of stopes, mining sequence and rock reinforcement for the extraction of ores economically and safely. Previous work has examined the impact of mining on stresses as revealed by actual

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measurements at the site and included the use of 3D numerical methods to understand the impact vis a vis mining to help in the designing of openings below mined out areas (Whyatt-JK, Williams-TJ, Blake. W (1995).

In this study, in a deep underground copper mine, stress measurements using the hydrofracture method were carried out in two stages. At the pre-mining stage, when only few developments were available and at the post mining stage from the developments between the mined out area and the non-mined out area.

Stress data generated from the stress measurements produced a value for the mining induced stress gradient (post mining) which was found to be totally different from the stress gradients of the area measured in the pre mining stage. The orientation of the Maximum Horizontal principal Stress was found to be perturbed and lying perpendicular to the strike of the orebody as against parallel orientation found during pre -mining stage. To understand the impact of the mining on the stresses a 3-D numerical modeling study was carried out using a boundary element method. The initial stress ratio from the pre mining stage measurement was used with gravity loading to account for the surface topography, which is hilly. Three observation points were monitored for stress change in mining, resulting from excavation effects and this data was found to be in agreement the measured induced stresses. The study results helped in the design of stopes, mining sequences and rock reinforcement.

2. Background

Hindustan Copper Limited (HCL), a public sector undertaking under the administrative control of the Ministry of Mines, is engaged in mining, beneficiation, smelting, refining and casting of refined copper metal. HCL maintains focused on its mission and vision which include increasing the ore production by three times over a decade and implementing continuous improvement in productivity. To continue to achieve these goals, it has geared up to tap the resources from the un-mined areas by designing stopes below the mined areas.

The present study was undertaken in Kolihan Copper Mine, an important captive underground mine of Kolihan Copper Complex of HCL and this mine is situated near the village of Khetri, in the District Jhunjhunu, Rajasthan. The mine plan to develop stope blocks at lower levels below the mined out areas to sustain and increase the productivity.

For the design of stopes, in-situ stress is one of the most important factors which dictates the size of the stopes and the size of the pillars and the sequence of extraction. The main host rocks of Kolihan mines are garnetiferous chlorite quartz schist, quartzite and amphibolite quartzite. The strike length of the ore body is 600 m with a width varying from 30 m to 100 m and the ore dips steeply to almost vertical. The main mining method adopted is Large Diameter Blast Hole Stoping. The mine extends from 486 ML to 0 ML. (Hindustan Copper Limited internal notes)

A detailed stress measurement programme was undertaken before the commencement of any stoping activity (pre- mining stage) between 486 mL and 184 mL for the determination of stress

around the mine openings. Three locations with different depths (different rock covers) were selected inside the mine and stress measurements were conducted inside boreholes drilled from development tunnels (cross cuts), using the hydrofracture method.

Mining up to 306 ML is complete and presently mining is active at 246 ML and 184 ML. Mine development has to commence at lower level soon, below 184 ML.(Figure 2.) Thus it was felt to undertake a stress measurement programme again below the mined out area (post mining stage) to find the impact of mining activities on the stresses. Three levels with different rock covers were selected, similar to what was done in the pre-mining stage and stress measurements were conducted inside boreholes using the hydrofrac method.

3. Geology and tectonics

3.1. Geology

The rock formations of the area belong to the Alwar and Ajabgarh series of the Delhi system and are younger than the Aravalli system. Both rock formations are highly deformed and metamorphosed. Rocks occurring at Kolihan mines are Amphibolite quartzite/garnet chloride with principal economic mineral is chalcopyrite. Strike of the formation is N 30^0E - S 30^0W, dipping 50^0 - 85^0 westerly (Fig 1)

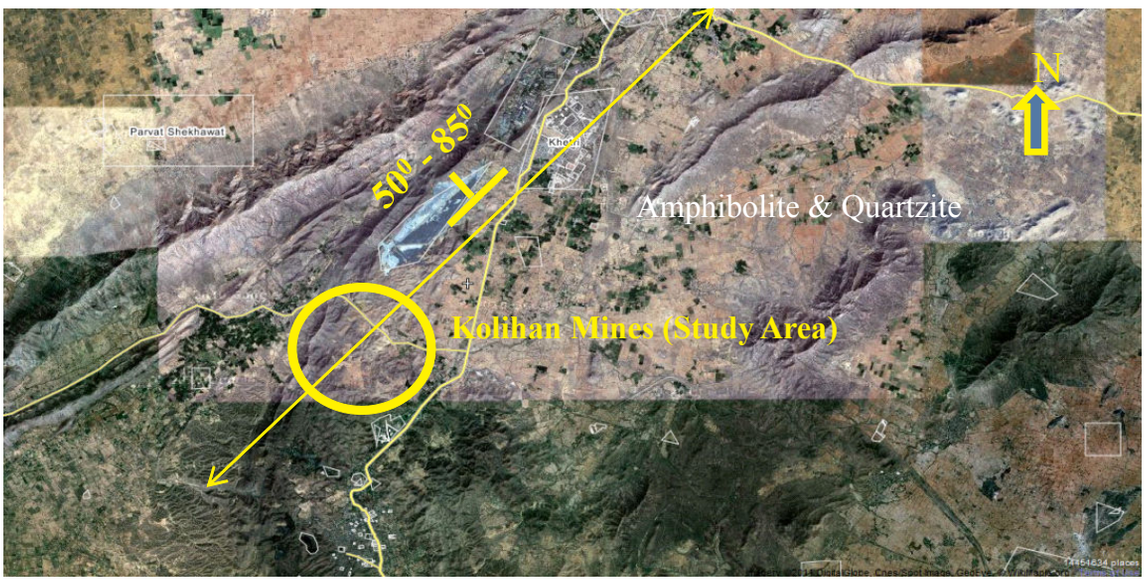

Figure 1. Geological and tectonic map of the project area

3.2. Tectonics

Structurally the thick prism of metasediments comprising rocks of Alwar and Ajabgarh series has been deformed into northeast –southwesterly trending longitudinal folds of large areal

extent. In the northern part of the belt the simplest structures are represented by Khetri anticlines and synclines with increasing intensity of deformation. The simple structure passes westward into overturned Kolihan syncline which is slightly compressed in the north.

In the central part of the belt the formations show as anticline structures.

The southern part of the belt is separated from the central part by a major transverse fault. The southern part of the fault is marked by anticlines and synclines. The asymmetrically overturned Kolihan syncline which is locally recumbent occupies a narrow zone. It plunged towards the SW and in the southern part the limbs are low dipping but gradually steepen northwards. The syncline is defined by the younger quartzites of the Ajabgarh series of reverse faulting (Dasgupta 1965).

4. Mining status

In the scheme of mining with respect to Kolihan Copper Mine the following methods have been adopted:

i. Sub-level Open Stoping method

ii. Blast Hole stoping Method

In the sub level open stoping method, sub levels are developed at vertical intervals of 18-20 m with a crown level at 9 m below uppermost levels. The size of the stope block is 30 m along strike which consists of 20 m of stope and 10 m of Rib Pillar.

In the blast hole stoping method a drill level is prepared below the crown pillar of 9 m. The size of the stope block is 30 m along the strike, which includes 16.6 m stope and 13.4 m Rib Pillar. The proposed stopes will be developed at the lower levels.

The mine extends from 486 ML to 0 ML with the surface RL of 486 m. Mining up to 306 ML is complete and presently it is active at 246 ML and 184 ML. Mine development has to commence at lower level soon.

5. Methodology

In-situ stress measurement using the hydrofracture method was carried out both during pre mining and post mining stages. Three boreholes were drilled, one each from 184 ML, 124 ML and 64 ML, for post mining stress determination.

The in-situ stress measurement was carried out by using HTPF (Hydraulic Tests on Pre existing Fracture) as introduced by Cornet et al. 1986]. The advantages of HTPF method are

i. The boreholes are not required to be oriented along one of the principal stress direction like in classical methods

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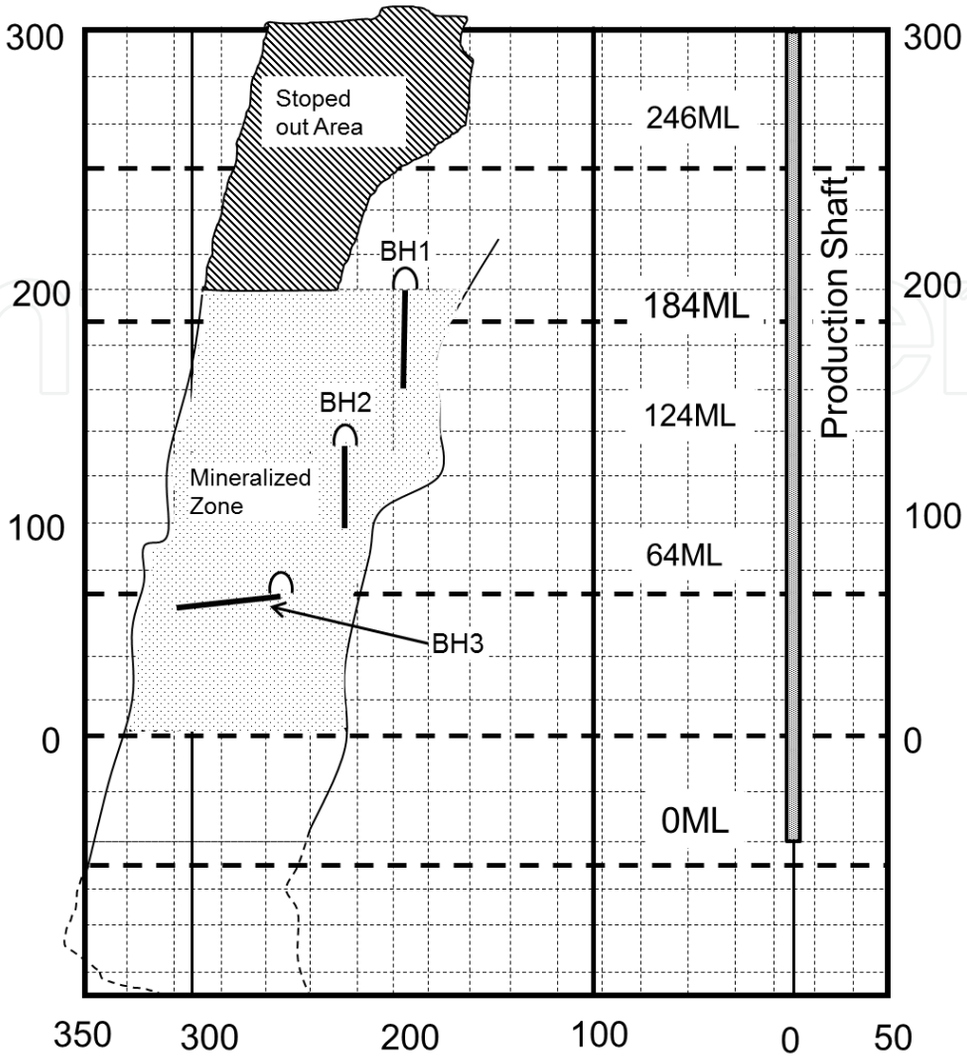

Figure 2. Status of Mining activities in Kolihan mine (ML= Meter level which indicates altitude from mean sea level)

ii. A new induced fracture is not essentially required to be created for stress evaluation. Stress can be evaluated both from preexisting/induced fractures

A schematic diagram showing set up of the hydrofracture system assembly is shown in Fig.3.

The straddle packer assembly (Hydrofrac assembly Fig 4) was used for fracture initiation/ opening and further extension. The straddle packer assembly consisted of a test interval of length 200 mm and two 250 mm steel reinforced packer (42 mm dia, burst pressure = 70 MPa) units attached at either end of the test interval. In the case of hydrofrac experiments in the 48 mm diameter boreholes at the present Project, the straddle packer unit was operated by 1500 mm long and 32 mm diameter tubes (dual line packer inflation + injection unit combined in one). The maximum injection rate of the electrically driven pump was 10 lit /min using water for pressurisation. All the events of injection were recorded in continuous real time digital mode.

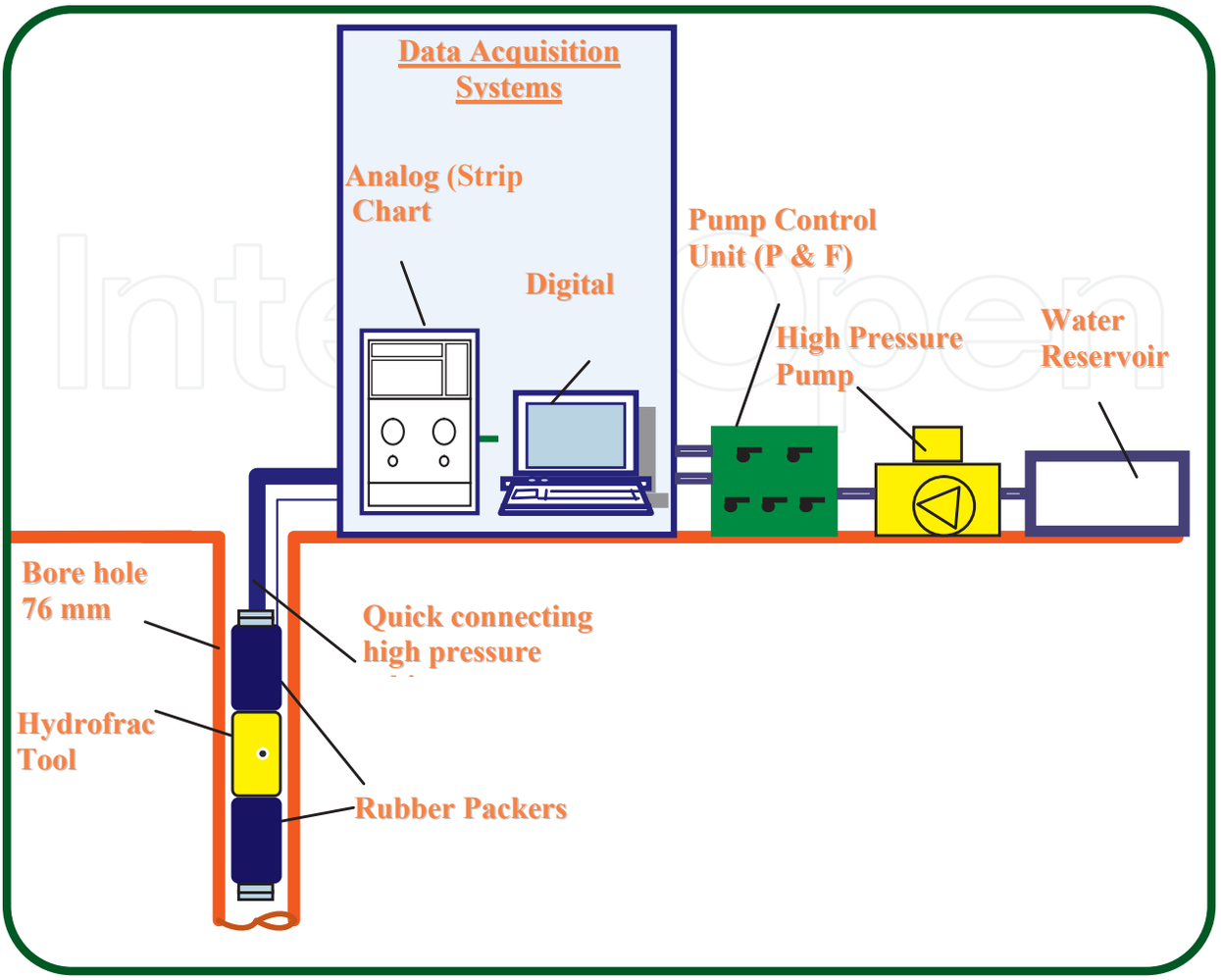

Figure 3. Schematic diagram of Hydrofrac Experiment Set-up

After all the hydraulic fracturing tests were conducted in all the boreholes, an impression packer tool with a soft rubber skin together with a magnetic single shot orientation device was run into the holes to obtain information on the orientation of the induced or opened fracture traces at the borehole wall.

Two data analyses programmes were used in the analyses. They are called Plane and Gensim.

The *software Plane* incorporates the impression data with the compass data as input parameters and gives the strike, dip and dip direction (fracture orientation data) as the output.

The Software Gensim computes the stress field on the basis of measured shut in pressure and fracture orientation data. The vertical stress is assumed to be a principal stress and its magnitude is taken as equal to the weight of the overburden. The powerful Gensim programme requires only the shut in pressure and the orientation of an induced or pre-existing fracture

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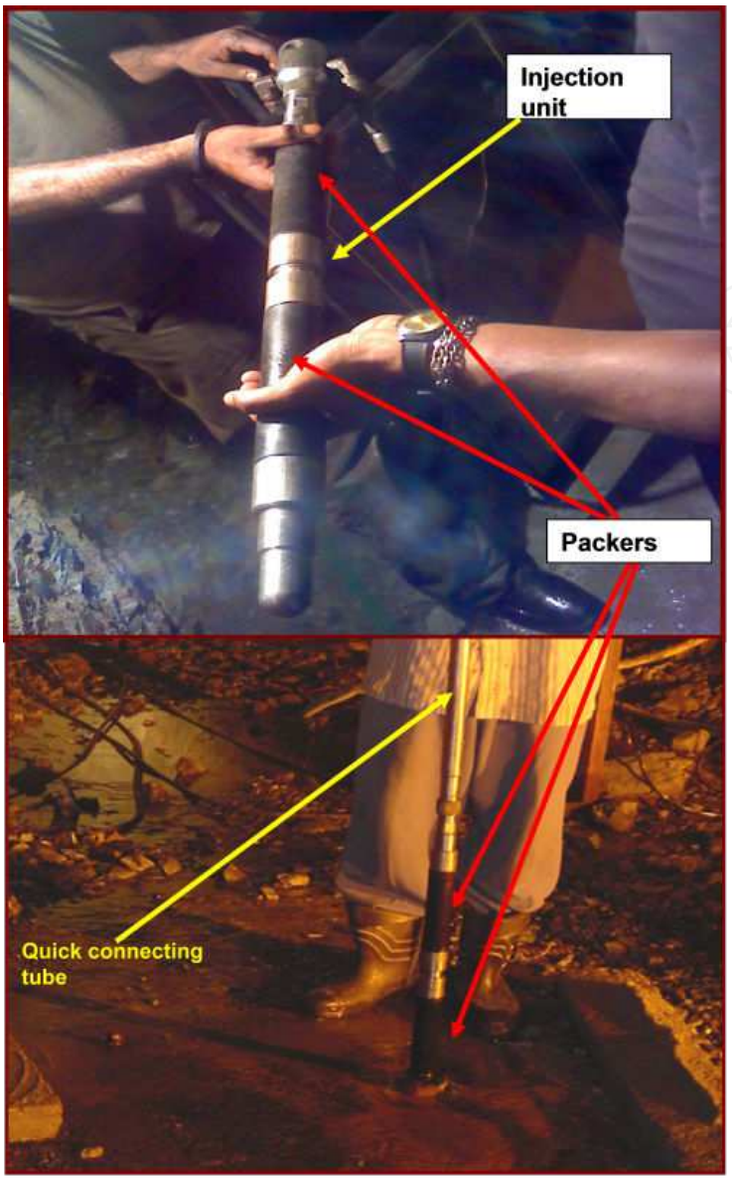

Figure 4. Hydrofracture equipment used

6. Stress evaluation procedures and results

The in-situ stress measurement were made from inside two vertical and one horizontal boreholes drilled from three levels. Tests were conducted with the following situations:

i. Presence of anisotropic rock.

ii. Presence of mining induced stress.

Due to the above aspects a medium to large scatter in fracture orientation data were noticed which negated the use of classical simple hydrofrac hypothesis suggested by Hubert and Wills (1957). Therefore data analysis required a more sophisticated meth-

od, namely the interpretation of measured normal stress acting across arbitrary oriented fracture planes.

In this method the shut-in pressure P_{si} is used to measure the normal stress component under the assumption that the vertical stress is a principal stress axis and the vertical stress magnitude σ_V is equal to the weight of the overburden.

The analysis program *GENSIM* was used to calculate the magnitude and the direction of principal stresses on the basis of the following equation:

$$\sigma_h = (P_{si} - n^2.\sigma_V) / (m^2 + l^2.\sigma_H/\sigma_h) \quad (1)$$

Where, l, m, n is the cosines of the direction of the induced fracture plane related to the principal stress axis.

The calculations involve obtaining the best fit based on using all shut-in pressure data derived from the measurements in the boreholes and varying the ratio σ_H/σ_h and the strike direction of σ_H.

The pre-mining and post mining stress tensors as revealed are given in tables 1 and 2

Principal Stresses			
σ_V MPa	σ_H MPa	σ_h MPa	Rock Cover Depth m
6.97	8.4	5.6	203
7.88	8.89	5.93	268
10.7	12.65	7.7	364

Table 1. Pre mining stress tensor as revealed by hydrofrac stress

Principal stresses	***184 ML***	***124 ML***	***64 ML***
Rock cover	*195m*	*184 m*	*530 m*
Vertical Stress (σ_V) MPa (2.7 gm/cc + 1.4 gm/cc density of solid and loose rocks respectively)	9.28	9.89	14.02
Maximum Horizontal principal Stress (σ_H) in MPa	21.78	22.78	23.94
Minimum Horizontal principal Stress (σ_h) in MPa	10.89	11.39	15.96
Maximum Horizontal principal Stress direction	N 80^0	N 80^0	N 90^0
$K = \sigma_H/\sigma_v$	2.35	2.30	1.71

Table 2. Post mining stress tensor as revealed by hydrofrac stress

Table 3 shows the comparison of pre and post mining stress gradient

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Stresses	Pre – Mining Stage (486 mL to 184mL)	Post Mining Stage (184 mL to 0 mL)	Remarks
Maximum Horizontal principal Stress (σ_H) orientation	N 10^0 to N 20^0	N 85^0 to N 90^0	Rotation of horizontal stress orientation due to stoping
Stress gradient ($\sigma_{H)}$	0.031 Z +1.5968 $R^2 = 0.91$	0.0048 Z + 21.379 $R^2 = 0.7627$	Change in stress gradient due to mining
Stress gradient ($\sigma_{h)}$	0.0145 Z +2.3892 $R^2 = 0.93$	0.01437 Z + 8.412 $R^2 = 0.9862$	Change in stress gradient due to mining

Table 3. Comparison between pre and post mining stress gradient

7. Numerical modeling

A numerical modeling was carried out using the boundary element method to understand post mining induced stresses vis a vis mining. The initial stresses gradient of the pre mining stage was used with gravity loading as the surface topography is hilly. Three observation points were monitored for stress change in mining, due to excavation effects. The stress contour of the model is shown in figure 5

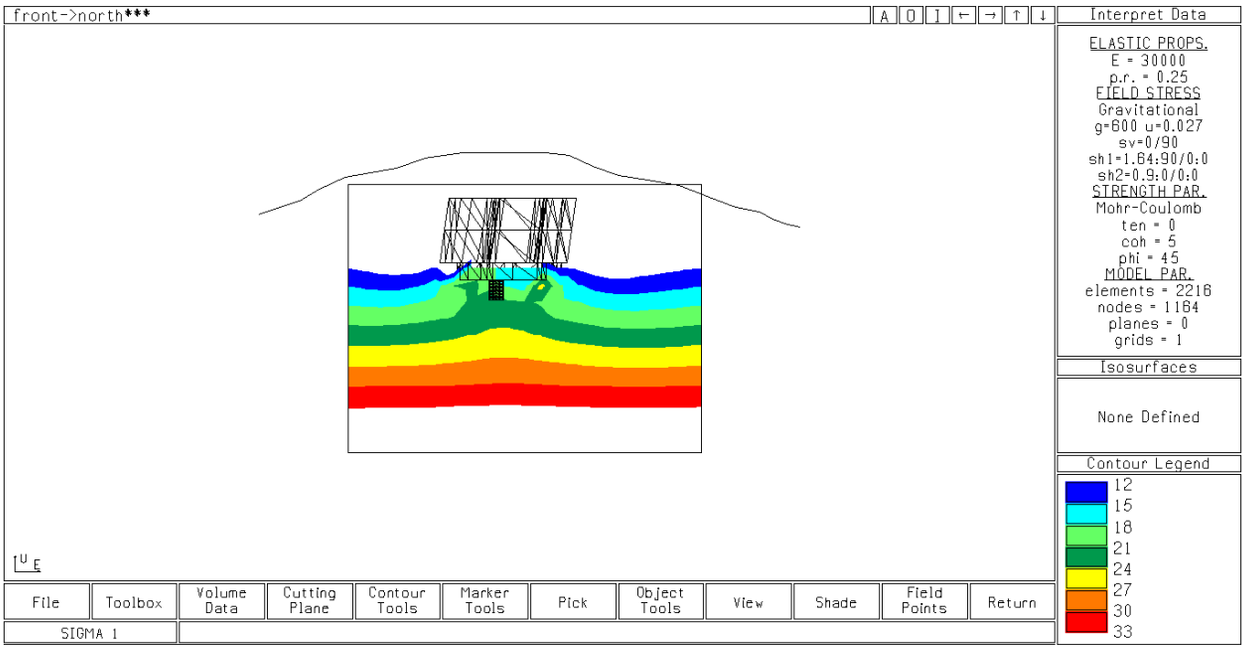

Figure 5. Major principal stress contour of the modeled stope.

The results of the stress output as revealed by the numerical model are given in Table 4.

ML	Sigma 1			Sigma 2			Sigma 3		
	Magnitude	Dip	Direction	Magnitude	Dip	Direction	Magnitude	Dip	Direction
ML - 184	21.15	7.32	272.59	10.9	30	178	6.99	58.25	14.59
ML - 124	23.33	2.32	92.52	11.48	10.29	182.94	6.36	79.43	349.94
ML- 64	24.66	6.3	90.43	13.07	12.28	181.81	10.47	76.14	333.81

Table 4. Stress magnitude and orientation as revealed by numerical model

The modeling studies reveal that the measured value of the stresses agree reasonably with the computation values which is compared in Table 5

Stresses	Post Mining Stage (184 mL to 0 mL)	Numerical modelling
Maximum Horizontal principal Stress (σ_H) orientation	N 85^0 to N 90^0	N 90^0 to N 92^0
Stress gradient ($\sigma_{H)}$	0.0048 Z + 21.379 R^2 = 0.7627	0.0069 Z + 20.924 R^2 = 0.5943
Stress gradient ($\sigma_{h)}$	0.01437 Z + 8.412 R^2 = 0.9862	0.0055 Z + 10.158 R^2 = 0.9188

Table 5. Stress magnitude and orientation as revealed by numerical model

8. Discussion and conclusion

The availability of stress results during pre - mining stage and subsequent measurement of stresses at the post mining stage has refined our understanding of the in-situ stress vis a vis mining. The change in the orientation of the major compression from a favourable N10-20 ^{0} (Strike of ore body N 30^0 and crown pillar oriented parallel to ore body) during pre- mining stage to unfavourable N85-90 ^{0} at the post mining stage has prompted to redesign the stopes and support systems below the mined out area.

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