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GEOMECHANICS

Impact and Severity of Deep Excavations on Stress Tensors in Mining

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Abstract—Knowledge of the state of stress regime is important to the mine designers for deciding the method of mining and for strategic design in virgin areas. This knowledge helps them in deciding the mining sequence and rock reinforcement for extraction of ores economically and safely. Generally, as excavation progresses to deeper levels, the stress tensors are also equally affected. Elevated stress regime results in concomitant increase in rock fracturing and mining induced deformations. Rock failure in the periphery of the excavation is somewhat stress related, and it is therefore important to ascertain the extent of stress levels within a given rock formation. The role of stress regime in pre- and post-mining stages is discussed. The research is based on the in-situ stress measurements conducted at deeper levels in mines. The authors also tried to ascertain the redistribution of the stresses due to mining and detect any re-orientation of the stresses due to various other geological factors.

Keywords: Stress, hydraulic tests on pre-existing fracture, topography, anisotropy.

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INTRODUCTION

The safety of miners is too often compromised by failures of ground. One of the major reasons for the failure of rock is the influence of the state of in-situ stress. Thus, a better understanding of how in-situ stress varies and how these variations control the location and severity of hazards is the need of the hour. This paper describes about the in-situ stress variations, which have a significant effect on the spatial distribution of hazards encountered during driving of development openings in underground mines. Stress measurements using the hydrofracture method were carried out in the deep underground lead–zinc mine at different levels during the pre-mining stage, when only a few developments were available, and also during the post-mining stage from the developments between the mined out area and the non-mined area.

Data generated from the stress measurements revealed a value for the mining induced stress gradient (post mining). This gradient 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. Four observation points were monitored for stress change in mining, resulting from excavation effects. These data were found to be in agreement with the measured induced stresses. The study results helped in the design of stopes, mining sequence and rock reinforcement.

Hindustan Zinc Limited (HZL) of Vedanta group is engaged in mining, beneficiation, smelting, refining and casting of refined lead and zinc metals. It is India's largest and world's second largest integrated producer of zinc and lead. Keeping focused onto its mission and vision which include increasing the ore production and continuous improvement in productivity, it has geared up to tap the resources from the unmined areas by designing stopes below the mined areas.

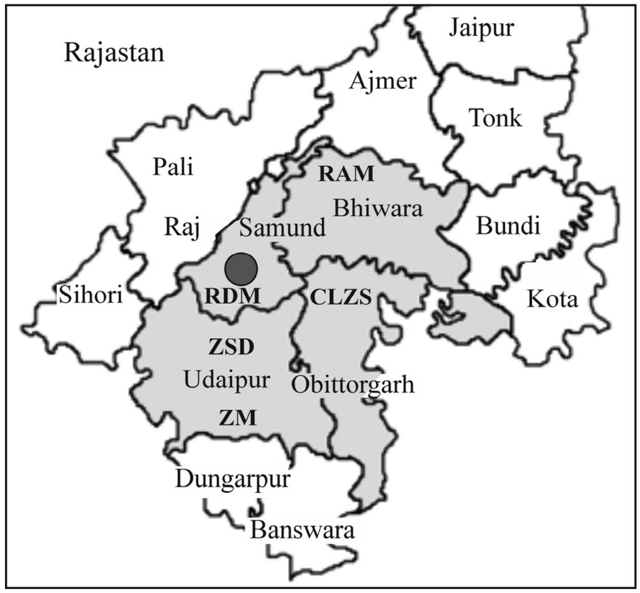

Fig. 1. Location of the study area.

The present study was undertaken in Rajpura-Dariba lead and zinc mine, an important captive underground mine of HZL situated at village Dariba, District Rajsamand, Rajasthan (Fig. 1). It is planned 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 dictate the size of the stopes besides the size of the pillars and sequence of extraction. The main host rocks of Dariba mines are dolomite and graphite mica schist. The main lode extends over a strike length of 1700 m and is separated by a barren stretch of 300 m into two ore bodies (South and North lode). The formations, in general, strike N-S with moderate to steep easterly dips. Vertical Retreat Mining method is being adopted in the ore blocks where the ore body width is more than 10 m and is in practice in L1 Lens (100–180 mRL) and South (50–180 mRL). Blast Hole Stoping Method is being applied in the mining blocks where the ore body width is narrow and varying from 8 to 15 m.

A detailed stress measurement programme was undertaken during pre-mining stage, i.e. before the commencement of any stoping activity between 100 and 0 mRL for determination of stress around the mine openings. Two locations with different depths (different rock covers) were selected inside the mine and stress measurements were conducted inside boreholes drilled from development tunnels (crosscuts), using the hydrofracture method.

Mining up to 100 mRL is complete and presently mining is active at 50 and 0 mRL. Mine development has to commence soon at lower level, that is, below 0 mRL (Fig. 2). Thus it was felt to undertake a stress measurement programme again during the post mining stage, i.e. below the mined out area to find the role of stress regime in deeper horizons. Two 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.

1. GEOLOGY AND MINING STATUS

Dariba mine is located at the southern extremity of the Dariba–Bethumni metallogenic belt. The mine area is constituted mainly by a sequence of a meta-sedimentary consisting of quartz mica schist, calcareous biotite schist and graphite mica schist (from footwall to hanging wall). Calc-silicate bearing dolomite occurs within the graphite mica schist horizon towards its contact with the calcareous biotite schist. The South lode, striking N-S and dipping 60–70° towards East, has a strike length of 500 m. The North lode has a strike length of 900 m. It strikes N-S and dips 70–75° towards east. The east lode, with a length of 600 m, also strikes N-S and dips easterly at 60–70°. It is located about 150 m away from the hanging wall side of the south lode. The average widths of south, north and east lodes are 24, 18 and 18 m, respectively.

Blast hole stoping (BHS) method is adopted when the width of ore body is narrow, varying from 8 to 15 m. The entire strike length is divided into 20 m long panels, designated as primary and secondary stopes. The stopes are mined using down drilling (115 mm) from the upper drill level and the blasting is done against a slot raise. The stopes are back filled with cement fill after removal of ore. BHS method is in practice in North lode L2 L4 lens (200–375 mRL), East lode (50–75 mRL) and lower level (–119 ± –55 mRL). Vertical Retreat Mining (VRM) Method is adopted when the width of the ore body is >10 m. At Rajpura-Dariba mine, it is in practice in L1 lens (100–180 mRL) and South lode (50–180 mRL). VRM stopes are mined by drilling down large (165 mm) diameter holes from the upper levels.

2. METHODOLOGY

In-situ stress measurement using Hydraulic Tests on Pre-existing Fracture (HTPF) method was carried out both during pre-mining (100 and 0 mRL) and post mining stages (–55 and –87 mRL).

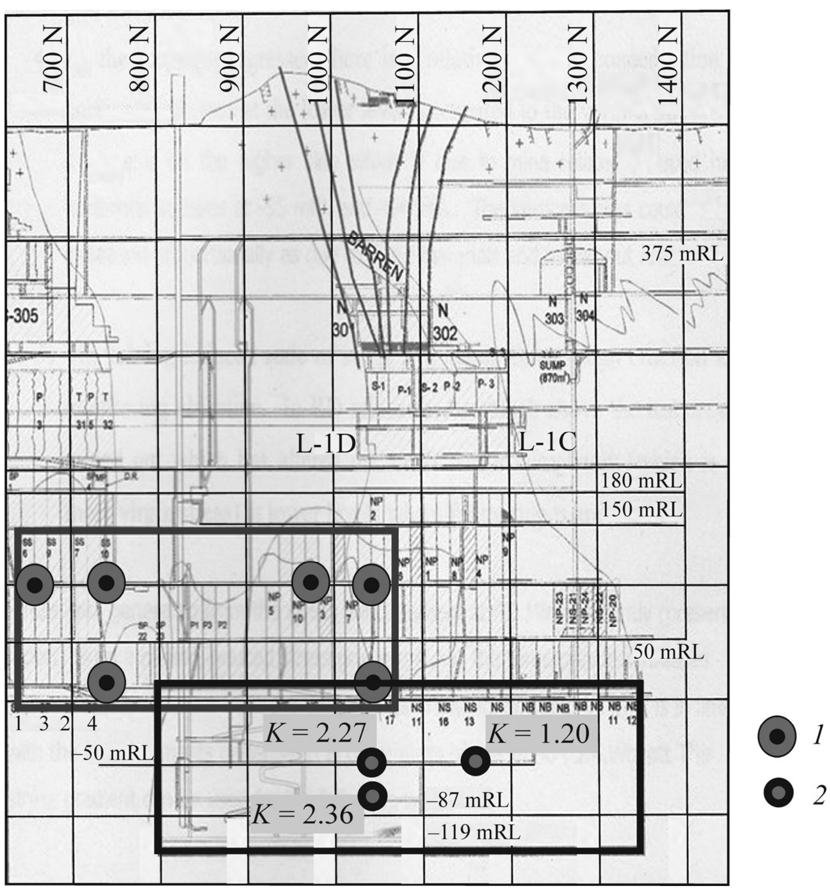

Fig. 2. Status of mining activities with their test location: *1*—test during pre-mining stage; *2*—test during post-mining stage.

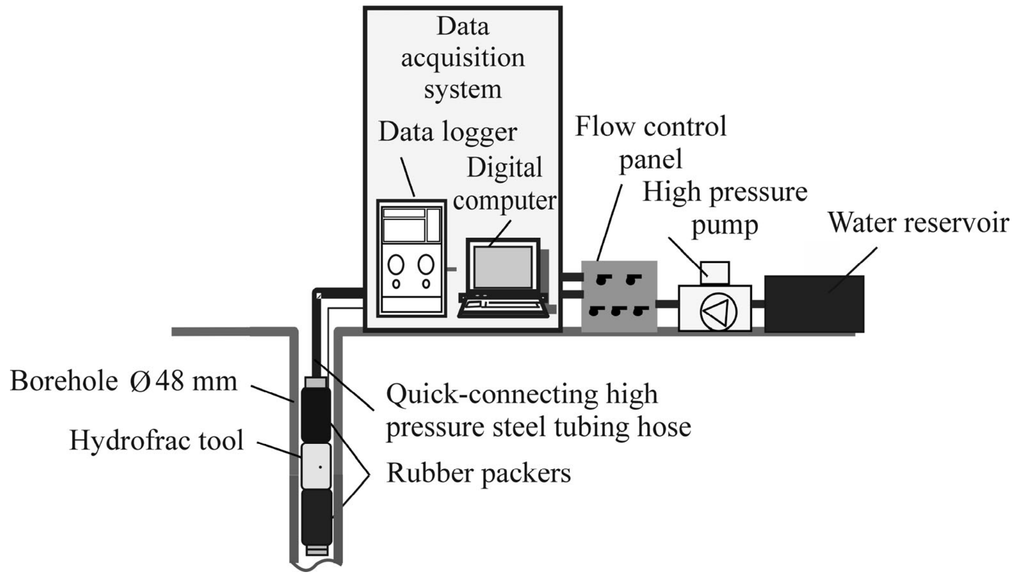

Fig. 3. Schematic diagram of Hydrofrac experiment set-up.

The advantages of HTPF method are:

• unlike classical methods, the boreholes are not required to be oriented along one of the principal stress direction;

• a new induced fracture is not essentially required to be created for stress evaluation. Stress can be evaluated both from pre-existing or induced fractures [1].

A schematic diagram showing set up of the hydrofracture system assembly is shown in Fig. 3. The straddle packer assembly was used for fracture initiation/opening and further extension. The straddle packer assembly consisted of a test interval of length 200 mm and two steel reinforced packers (length = 250 mm, Ø = 42 mm, 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 and injection unit combined in one). The maximum injection rate of the electrically driven pump was 10 L/min using water for pressurization. All the events of injection were recorded in continuous real time digital mode. 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.

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

Parameter	100 mRL	0 mRL
Rock cover, m	404	504
Vertical stress σ_v, MPa (density of solid rock 2.8 g/cm^3)	11.09	13.83
Minimum horizontal principal stress σ_h, MPa	9.14±0.89	11.38±0.36
Maximum horizontal principal stress σ_H, MPa	18.28±1.78	22.76±0.72
Maximum horizontal principal stress direction	North 10°	North 30°
$K = \sigma_H / \sigma_v$	1.64	1.64

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

Parameter	–55 mRL			–87 mRL 1035 N
	Horizontal hole 1035 N	Vertical hole 1035 N	Vertical and horizontal holes 1150 N	
Rock cover, m	$502+55=557$			$502+87=589$
Vertical stress σ_v, MPa	14.74			15.58
Minimum horizontal principal stress σ_h, MPa	15.63±2.55	22.33±0.80	11.83±2.06	24.59±2.71
Maximum horizontal principal stress σ_H, MPa	23.45±3.83	33.50±1.20	17.74±3.09	36.88±4.06
Maximum horizontal principal stress direction (North, deg.)	120	120	110	120
$K=\sigma_H/\sigma_v$	1.59	2.27	1.20	2.36

3. STRESS EVALUATION PROCEDURE AND RESULTS

Determination of in situ stress inside the borehole was conducted with consideration of the pronounced topography and presence of anisotropic rock. Due to the above aspects, a medium to large scatter in fracture orientation data was noticed which negated the use of classical simple hydraulic fracture hypothesis [2]. Therefore the data analysis required a more sophisticated method, 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 is a principal stress axis and the vertical stress σ_v is equal to the weight of the overburden. The determination of shut-in-pressure is straight forward when a sharp break after the fast pressure decline following pump shut off. We calculated the shut-in-pressure from the third cycle of the pressure-time curve [3]. The pre-mining and post-mining stress tensors as revealed are given in Tables 1 and 2.

The K values showed an increasing trend at 1135 N with increasing rock cover (with rock cover of 557 m, $K=2.27$, and with rock cover of 589 m, $K=2.36$). The K value at 1150 N with rock cover of 557 m is only 1.20. This implies that the mining induced stress did not influence the site as much as at 1135 N with the same rock cover. This may be due to less stoping activities above the measurement site and its proximity to the unmined barren patch above 180 mRL.

The virgin stresses measured in 1994 at 100 mRL (850 and 950 N) with rock cover of 404 m and at 0 mRL (950 N) with rock cover of 504 m, indicated $K=1.64$. As the stoping progressed there was a relatively higher concentration of horizontal stresses at lower levels compared to the vertical stress. The K value is on the higher side which is due to mine related induced high horizontal stresses at –55 and –84 mRL. The vertical stress did not increase proportionally due to mined-out areas. The comparison between pre- and post-mining stress gradients are given in Table 3.

Table 3. Comparison between pre- and post-mining stress gradient

Parameter	Pre-mining stage 100 to 0 mRL	Post-mining stage –55 to –87 mRL	Remarks
Maximum horizontal principal stress orientation σ_H	From 10 to 30°	From 110 to 120°	Rotation of horizontal stress orientation due to stoping
Stress gradient σ_H	$0.0448Z+0.1808$ $R^2=1$	$0.0722Z-12.686$ $R^2=0.3644$	Change in stress gradient due to mining
Stress gradient σ_h	$0.0224Z+0.0904$ $R^2=1$	$0.0693Z-20.756$ $R^2=0.5336$	Change in stress gradient due to mining

CONCLUSIONS

The mining induced state of stress is a major mine design criterion. In RD mines the ore block above the test area was mined out, and this has altered the stress tensor completely at lower levels where future stopes are planned.

Acquisition of mining stress data helps in understanding of mining impact on the stress and could be used for designing and sequencing of the mining operations for safe and optimum ore/mineral extraction.

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