Stability Analysis of Shaft and Raise Pillars Against Open Pit and Underground Stoping - A Case Study

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Abstract

Hindustan Zinc Limited has the richest lead zinc deposit in the country with a reserve of 107.4Mt having 1.98% Pb and 13.92% Zn. The ore occurs at more than 450 m depth from the surface and about 50 m below the ultimate open pit bottom i.e. +18 m RL. The sulphide deposit is a lens shaped ore body with a NE-SW strike length of about 1550 m and width varying from a few meters in the NE widening to as much as 100m in the central to SW section. The Rampura Agucha mine is planning to exploit this deposit by cut and fill stoping method and going up to -728m RL at the dip most portion. For transportation of men and material from underground a hoisting shaft of a finished diameter of 6.2 m and excavation diameter of 6.8 m and depth of 900 m has been proposed at S270 and W600. Two raises of 4.5 m diameter and 400 m depth have been proposed in North side {(N360, W415) and (N320, W415)}. Similarly, two raises of the same depth have been proposed at South side (S645, W520) and (S685, W520). All the four raises will be used as ventilation return. To analyse the shaft pillar stability and effect of open pit and underground mining on shaft and raises, 3D numerical modelling has been conducted using FLAC 3D software. In the present paper, the authors have modelled the shaft and raise pillars along with proposed ultimate open pit and underground mining propositions, and analyzed the results for estimating their stability. Empirical formula has also been applied for estimating the minimum required safe distance from the shafts.

Based on the empirical formula for shaft pillar design, the required safe distance for shafts at Rampura Agucha Mine has been calculated to be 50m, 350m and 700m away from the mine workings at (+400mRL), 0m RL and -500m RL respectively. The actual proposed distance of the Main Hoisting shaft from the ultimate limit of open pit and underground workings will be 320m, 870m and 1034m at the surface (+400m RL), 0m RL and -500m RL respectively. Similarly, the actual proposed distance of the North and South ventilation raises from the proposed workings will be (160m & 690m) and (260m & 760m) away at the surface (+400m RL) and 0m RL respectively. Therefore, the main hoisting shaft and ventilation raises are very well placed in the safe zone. On the other hand, Numerical modelling studies revealed that the local safety factors in the vicinity of the proposed Shafts remain almost unchanged due to the proposed open pit and underground stopes, even after considering underground stopes as open. The local safety factor in the vicinity of the main Hoisting shaft remained more than 2.5 after all the proposed excavations. Similarly, for North and South ventilation raises, the local safety factors remain more than 3.0 after all the proposed extraction.

Introduction

Hindustan Zinc Limited is planning for exploiting the orebody continuing below ultimate open pit by underground stoping methods, leaving a vertical parting (crown pillar) of a predetermined thickness. Though the exact method of underground stoping is yet to be finalized, it is almost certain that the extraction will be done in tandem with a paste back filling method. Since the open pit and the underground stoping will be operational simultaneously, this will help in restricting the rock mass movement due to underground excavations on the working open pit. CIMFR, Dhanbad has already submitted a report for the design of surface crown pillar between ultimate pit and underground stope at Rampura Agucha Mine, which concluded to leave a surface crown pillar of 60m for the safe extraction (CIMFR, 2010a).

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For transporting the men and material from underground a hoisting shaft of a finished diameter of 6.2m and excavation diameter of 6.8m and depth 900m has been proposed by the mine management. Similarly, for ventilation return purposes four numbers of ventilation raises of 4.5m diameter and 400m depth has been proposed. Empirical approach and 3-D numerical modelling has been used to conduct scientific study for estimating the stability of shaft and raise pillars against open pit and underground stoping with different mining propositions at Rampura Agucha mine, HZL using numerical modelling (CIMFR, 2010b).

Proposed Location of the Hoisting Shaft and Ventilation Raises

A main hoisting shaft of a finished diameter of 6.2m, excavation diameter of 6.8m and depth 900m has been proposed by the mine management at S270 and W600 in footwall side (Fig.1). Two numbers of raises of 4.5m diameter and 400m depth has been proposed in north side at locations {(N360, W415) and (N320, W415)} as shown in Fig.1. Similarly, two numbers of raises of same depth has been proposed at South side at locations {(S645, W520) and (S685, W520)} as shown in Fig.1. All the above four raises situated in the footwall side will be used as ventilation return. The coordinate of the centriod of main hoisting shaft and ventilation raises are given in table 1. The coordinates of the cross section of the proposed ultimate open pit and underground stoping section passes through north ventilation raise N 300, hoisting shaft S 300 and south ventilation raise S 600 have been provided by mine management for the analysis.

Objectives of the Study

I Stability analysis of the proposed shaft and raise pillars against ultimate open pit and proposed underground mining (without filling and with paste back filling).

II Study to analyze the effect of open pit and underground mining (without filling and with paste filling) on proposed shaft and raises.

To cover up the above objectives, authors have conducted 3-D numerical modelling of the shaft and raises along with ultimate open pit and underground mining propositions and results were analyzed for estimating their stability based on local safety factor. An empirical approach has also been applied for confirming the safe distance of the shafts from the proposed workings.

Calculation of Required Radius of Shaft Pillar using Empirical Relation

An empirical relationship has been established for calculating the required radius of the shaft pillar in mines based on depth of cover, angle of draw and thickness of alluvial soil present on the surface (Anon, 2000). According to this relationship, minimum required radius of the shaft or raise pillar should be as:

$$R = k_1 + h_1 \tan 45^0 + h_2 \tan \phi \ meters \quad (1)$$

where, k1 is a constant which may be taken

Table 1: Location of the main hoisting shaft and ventilation raises

	E / W	N / S	Remark
N_RAR_1	-415	360	North vent. Raise
N_RAR_2	-415	320	
S_RAR_1	-520	-645	South vent. Raise
S_RAR_2	-520	-685	
H_shaft	-600	-270	Hoisting shaft

as 50, it may be increased if other important structures like winding installations etc are also to be protected; h1 is thickness of alluvial soil or similar material, 20 m has been taken in case of Rampura Agucha Mine, h2 is thickness of cover excluding the alluvial soil, m; ø is the angle of draw which may be taken as 350 for steep orebody, but in this case the shafts are existing at the rise side of the steep ore body, and therefore the rise-side angle draw applicable will be much lower than 350. However to err on the safer side ø is taken as 350 for the current calculation.

According to this equation, minimum required distance of the ultimate open pit and underground mining periphery from any shaft must be more than 50m, 350m and 700m on surface, 0mRL and -500mRL respectively as shown in Fig. 2. This 0mRL & -500mRL is the ultimate depth of the proposed ventilation raises and main hoisting shaft respectively.

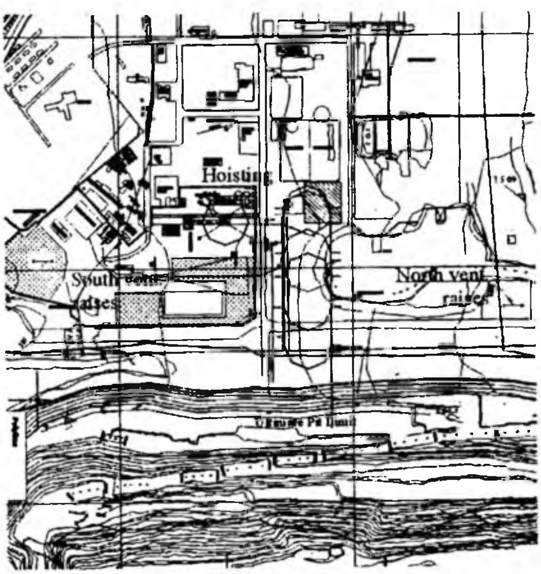

Fig. 1. Position of the Hoisting Shaft, Ventilation Raises and Ultimate open pit limit

a) Main hoisting shaft

On surface, the proposed hoisting shaft is more than 320m away from the ultimate limit of open pit which is > 50m minimum required distance on surface (Fig.2). At 0mRL, the proposed hoisting shaft is more than 870m away from the ultimate limit of open pit and underground stoping which is > 350m minimum required distance on 0mRL (Fig.2). At -500mRL; the proposed hoisting shaft is more than 1034m away from the underground mining areas which is >700m minimum required distance at this level.

b) North and south ventilation raises

On surface, the distance of the proposed north and south ventilation raises are more than 160m and 260m away from the ultimate limit of the open pit respectively which is much greater than 50m minimum required distance on surface (Fig.2). Similarly, at 0mRL, the distance of proposed north and south ventilation raises are more than 690m and 760m away from the ultimate limit of the open pit and underground mining areas respectively which are again much greater than 350m min. required distance on 0mRL.

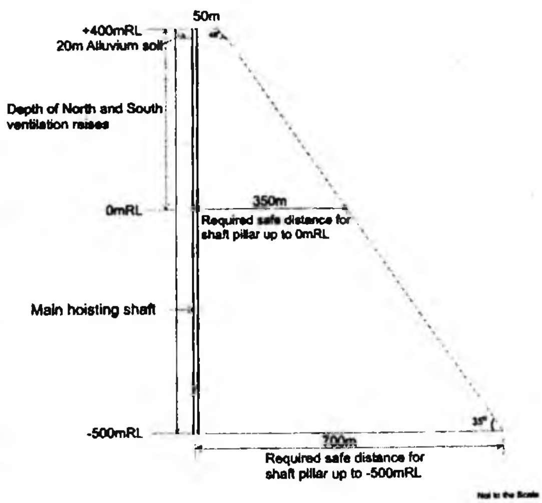

Fig. 2. Required safe distance for the proposed hoisting shaft and ventilation raises

From the above analysis it is clear that the positions of the hoisting shaft and ventilation raises are found to be at safe distances as per equation (1). However to study the effect of open pit mining and underground stoping on the proposed shafts more precisely, numerical modelling studies are also investigated.

Numerical Simulation

Numerical modelling has been conducted using Finite Difference software, viz., FLAC3D of ITASCA Consulting Groups of U.S.A (FLAC 3D Manual). Rock properties generated from tested rock core samples used for the numerical modelling are given in Table 2a (CIMFR, 2010a). Rock properties used for Hoek & Brown criterion6 derived from triaxial tested data is given in Table 2b. The strength and deformation properties of the fill material (CIMFR, 2010a), as supplied by HZL, for 15% PPC53 cement paste fill with 55 days curing is given in below table 3. The stress-strain curve of the paste fill material is given in Fig. 3.

Table 2a: Properties used for the numerical modelling

E, GPa	N	σ_c Mpa	σ_t Mpa	Density, kg/m^3	RMR
11.57	0.15	40.48	7.03	2814	45

Table 2b: Rock properties used for Hoek & Brown criterion based on Table 7b

Compressive Strength, σ_c	Constant, m	GSI	RQD
44 Mpa	14.376	58	86%

Table 3: Properties of paste fill material used for the numerical modelling

E,Mpa	N	σ_c Mpa	σ_t Mpa	Wet density, kg/m^3
194	0.2	2.0	0.2	1800

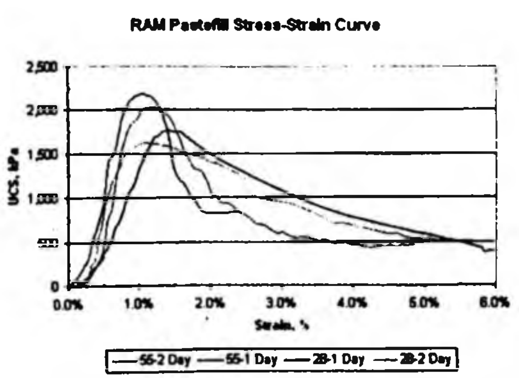

Fig. 3. Stress-strain curves for the paste fill material

a) In situ stresses

In the absence of the in situ measurements of stress values, theoretical values were calculated using the below equation (Bieniawski, 1989)

$$\sigma_v = \gamma .\ H \quad \text{and} \quad \sigma_h = \frac{\nu}{1-\nu}\sigma_v + \frac{\beta E G}{1-\nu}(H+1000) \qquad (2)$$

where σ_v and σ_h are the vertical and horizontal stresses (Mpa); ? is the Poisson's ratio, 0.15; E is the Young's modulus, 11570 Mpa; β is the coefficient of thermal expansion, 1×10^{-5} /^{0}C; G is the geothermal gradient, 0.024 ^{0}C/m and H is the depth of cover, m; γ 0.02814 Mpa/m.

After substituting all the above values in Eq. (2), vertical and horizontal stresses can be obtained as:

$$\sigma_v = \gamma .\ H = 0.02814\ H \qquad (3)$$

$$\sigma_{h\ avg} = 3.267 + 0.00824\ H \qquad (4)$$

b) Rock mass failure criterion

The most general form of the Hoek-Brown criterion (Sheorey, 1994), which incorporates both the original and the modified form, is given by the equation

$$\sigma_1 = \sigma_3 + \sigma_c\left(m_m \frac{\sigma_3}{\sigma_c} + s\right)^a \qquad (5)$$

where m_m is the value of the constant m for the rock mass, s and a are constants, whose values depend upon the characteristics of the rock mass.

The relationships between mm, s, a, and the Geological Strength Index (GSI) are as: For GSI > 25 (Undisturbed rock masses), (case of Rampura Agucha Mine)

$$\frac{m_m}{m} = \exp\left(\frac{GSI - 100}{28}\right)$$

$$s = \exp\left(\frac{GSI - 100}{9}\right)$$

$a = 0.5$

The constant m has been determined for intact rock based on triaxial data tested. From the output of principal stresses obtained from the numerical model runs and the rock mass failure criterion equation (5), the safety factor is defined as

$$F = \frac{\sigma_1 - \sigma_{3i}}{\sigma_{1i} - \sigma_{3i}};$$

except when $\sigma_{3i} > \sigma_{tm}$ $F = \dfrac{\sigma_{tm}}{-\sigma_{3i}}$ (6)

In equations (6) 1i and 3i are the major and minor induced stresses from the numerical model output. The sign convention followed here is negative for tensile stresses.

Modelling procedure

Truncated three-dimensional numerical models using the planes of symmetry are prepared for all three cases as show in Fig. 1.This has been used to minimize the number of elements and running time for solution by iterative method. Three sets of the elastic models were run to study the effect of ultimate open pit and underground stoping on main hoisting shaft and North and South ventilation raises. Elastic material properties are assigned to the rock mass with paste fill material proposed to be used as back fill in the underground stopes. One more model was run by assigning elastic material properties to the rock mass and without any back fill material using in the underground stopes to compare the results. Stability of the rock mass between proposed shafts and open pit and underground stoping is analysed using local safety factors corresponding to Hoek and Brown's rock mass failure criterion. Stability analysis of the shaft pillars has been studied using numerical modelling technique in the following stages.

Stage 1 : Three different virgin 3-D models are run for hoisting shaft and north and south ventilation raises separately using plane of symmetry in each model.

Stage 2 : For simulating the ultimate open pit and underground stopes, these excavations have been created as per coordinates limit provided by the mine management. One model was run without fill and other with proposed paste fill material for all the three cases.

Stage 3 : Post-processing of the above models to evaluate safety factor of the rock mass.

Modelling Results

a) Stability analysis of hoisting shaft

The finite difference grid pattern across a section for the stability analysis of main hoisting shaft is given in Fig. 4. The results are shown in terms of safety factor contours plotted in and around different condition of open pit and underground mining as discussed above. Fig. 5 and Fig. 6 show stability of the main hoisting shaft against ultimate open pit and underground stope without fill and with paste fill material respectively. From the figures it can be seen that the minimum value of contours of safety factor more than 2.5 is always around the shaft even with ultimate open pit and underground stope without fill. Therefore, it can be concluded that main hoisting shaft is fully at safe distance from ultimate open pit and underground stoping, and will remain unaffected by all the proposed mining operations.

b) Stability analysis of north and south ventilation raises

The grid pattern used for modelling of north ventilation raises is shown in Fig. 7. The model has been made taking a vertical plane of symmetry cross sections passing through the centre of the two north ventilation raises and another vertical plane passing 50m away from the raises, as shown in Fig. 1.

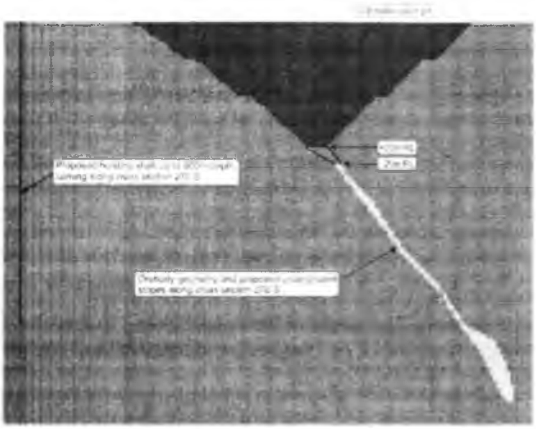

Fig. 4. The grid pattern used for modelling the hoisting shaft shown across section S 270.

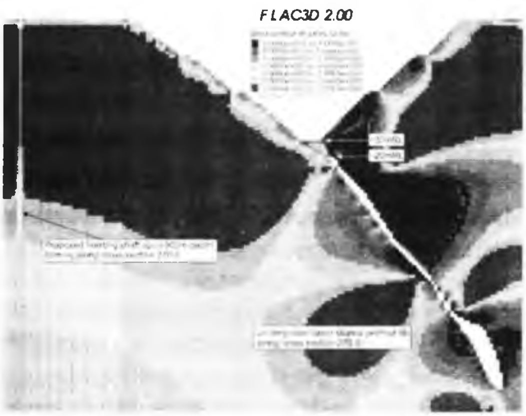

Fig.5. Stability of the hoisting shaft against ultimate open pit & underground open stopes

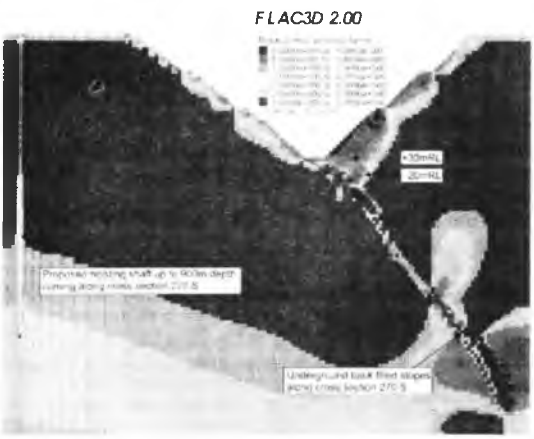

Fig.6. Stability of the hoisting shaft with ultimate pit & paste filled underground stopes

However, in Fig. 6, the model is shown only along a section through the raise. The local safety factors are contoured along this section passing through the raise for the excavation of the ultimate open pit along with underground open stoping and with paste filled stoping as shown in Fig. 8 and 9 respectively. The above figures indicate no

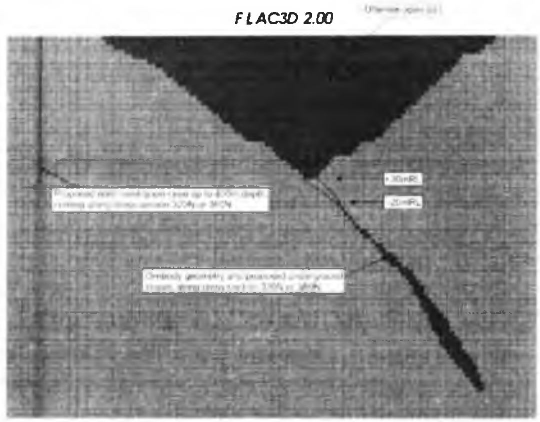

Fig. 7. The grid used for modelling of North ventilation raises

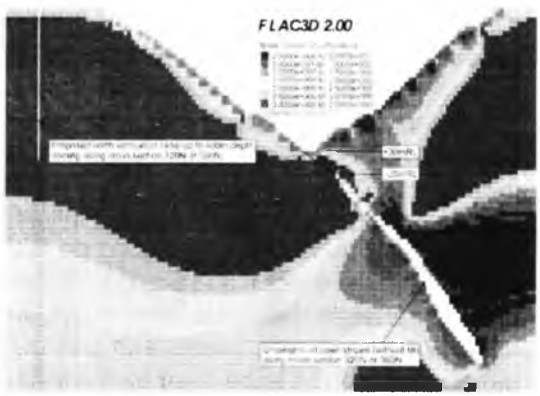

Fig. 8. Stability of the North ventilation raises against ultimate pit & underground open stopes

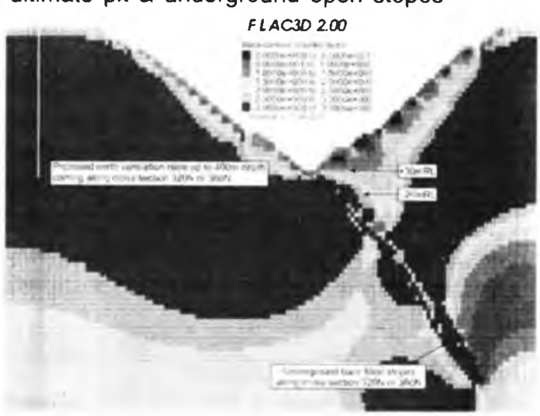

Fig.9. Stability of the North ventilation raises against ultimate pit & underground filled stopes

significant changes in the contours levels in the vicinity of the North raise due to proposed mining operations. Even in the case of open underground stoping, the north raise can be seen unaffected.

Similar model has been constructed for the stability analysis of south ventilation raises also. From the model analysis it has been found that the value of safety factor in the vicinity of the south ventilation raises are >3.0, means they are almost un-affected due to all the proposed excavations

Conclusions

Based on the empirical formula for shaft pillar design, the required safe distance for shafts at Rampura Agucha Mine has been calculated to be 50m, 350m and 700m away from the mine workings at (+400m RL), 0m RL and -500m RL respectively. The actual proposed distance of the main hoisting shaft from the ultimate limit of open pit and underground workings will be 320m, 870m and 1034m at the surface (+400m RL), 0m RL and -500m RL respectively. Similarly, the actual proposed distance of the north and south ventilation raises from the proposed workings will be (160m & 690m) and (260m & 760m) away at the surface (+400mRL) and 0mRL respectively. Therefore, the main hoisting shaft and ventilation raises are very well placed in the safe zone.

Numerical modelling studies revealed that the local safety factors in the vicinity of the proposed shafts remain almost unchanged due to the proposed open pit and underground stopes, even after considering underground stopes as open. The local safety factor in the vicinity of the main hoisting shaft remained more than 2.5 after all the proposed excavations. Similarly, for north and south ventilation raises, the local safety factors remain more than 3.0 after all the proposed extraction.

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