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Determination of stoping methodology for mining secondary stopes by *FLAC3D*

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1 INTRODUCTION

Sindesar Khurd Mine (SKM) is India's largest underground zinc-lead mine with production of 4.5 million MT in FY 2018. With an average reserve grade of 7%, the mine differentiates itself with its silver-rich zinc-lead deposit, highly mechanized and low cost of operations. The mineralization at Sindesar Khurd forms the western limb of a concealed NNE-SSW trending broad, open and asymmetric antiformal fold with sub-horizontal to gently northerly plunging fold axis. The upper limit of mineralization lies at a depth of about 100 m below surface. The general strike of the ore body is N10°E to N15°E while dip varying from 45° to 60° towards west and in deeper levels steep easterly with a swelling and pinching characteristic. The ore body is divided into upper and lower blocks. The mining method followed at SKM is Blast Hole Open Stoping in upper block and Long Hole Stoping with backfilling in lower block with Primary and Secondary stoping sequence. The excavations are supported as per the systematic support rules of SKM, for e.g. shotcrete, wire-mesh, rock bolts, cable bolts and the open stopes are backfilled with paste. Primary stopes are currently being mined in C block and a suitable stoping methodology for safe extraction of ore from the secondary stopes in the C block needs to be determined to meet with the production requirements.

2 DESIGN AND ANALYSIS

CS02A stope is selected as a base Case for mining of secondary stopes in C block of Sindesar Khurd Mine between -55 mRL and 65 mRL for the current study and three-dimensional numerical modelling studies have been carried out using *FLAC3D* (Itasca 2012) to determine the extents of the yield zones and understand the behavior of rock mass during and post stoping operations. The in-situ stress regimes are determined from the results of the hydro-fracture tests carried out at the site and the output from these tests are used as an input to the numerical model. The ore and stope boundaries are collected from the mine site and developed as per the excavation profile of different stopes in various blocks of SKM. The intact rock and the paste fill properties are provided by M/s Hindustan Zinc Limited (HZL). The Geological Strength Index (GSI) values and Hoek-Brown rock mass failure criterion is used to estimate the rock mass properties combining the geotechnical mapping outcomes with that of the laboratory test results of intact rock samples.

Three-dimensional numerical model is developed in *FLAC3D* incorporating the ore body extents obtained from the 3D ore block model comprising of various lithological units like Graphite-Mica-Schist, Calc-Biotite schist, Biotite Schist and Quartz Mica Schist. The 3D numerical model with different stopes in C block is shown in Figure 1. Six alternative stoping methodologies are simulated in *FLAC3D* and the model outputs are examined to determine the most appropriate stoping methodology for CS02A stope.

Six different stoping methodologies considered for the study of CS02A stope are as follows:

- Case 1 – Stoping Sub-Level Wise
- Case 2 – Stoping Sub-Level Wise Leaving Ore Skin
- Case 3 – Split Stoping Method (North South)
- Case 4 – Split Stoping Method (East – West)

- Case 5 – Stoping Sub-Level Wise with Temporary Crown Unmined
- Case 6 – Stoping Sub-Level Wise [Part A (-55 mRL – 30 mRL) – Part B (65 mRL – 130 mRL – Temporary Crown (30 mRL – 65 mRL)]

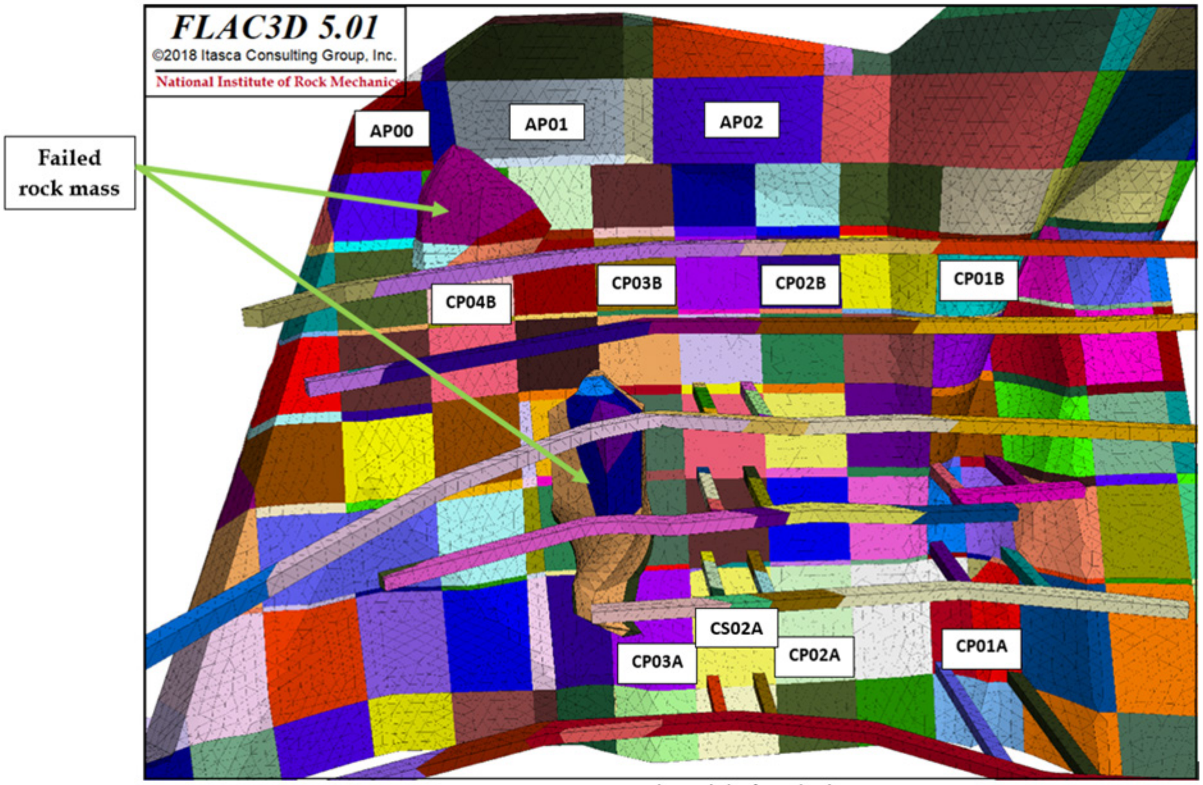

Figure 1. 3D numerical model showing different stopes in C block of Sindesar Khurd Mine.

3 RESULTS AND DISCUSSION

In Case 1, stoping is carried out in full length to full width, height being restricted to the existing sub-level intervals. Case 2 is like Case 1 with an exception of leaving 5 m of ore skin on northern and southern stope ends where the stope length is restricted to 25 m in this Case, i.e. between 6515N and 6540N. In Case 3, the stope is extracted in two parts with the strike length being restricted to 15 m (due South) and 20 m (due North) respectively where as in Case 4, the stope is split into eastern and western parts to maintain a vertical face within the ore body post mining eastern half. In Case 5, the method of mining shall be more or less similar to that of Case 1 between -55 and 30 mRL, leaving temporary crown between 30 and 65 mRL unmined till end, followed by excavation of upper part of CS02 between 65 and 130 mRL. The influence of extraction of ore, followed by backfilling of secondary stope between -55 mRL and 130 mRL, like that of Case 1 is studied in Case 6. The feasibility of extraction temporary crown post excavation of part A and part B is also assessed during the study. An overall stability of excavations and backfill post stoping between CP01 and CP04 is analyzed in Case 7.

Comparing the results of Case 1 and Case 2, it is observed that the displacement magnitudes are relatively higher in Case 1 than that of Case 2. The magnitude of maximum principal stress is at par in both the Cases. The destressed zone is larger in Case 1, as indicated in minimum principal stress contours. The temporary crown pillar above 65 mRL is likely to be yielded in shear in Case 1 whereas the same is not observed in Case 2. In totality, Case 2 is suitable stoping methodology from CS02A amongst the two. Comparing the results of Case 3 and Case 4, it is observed that the displacement magnitudes are at par in both the Cases. In Case 4, the fill material in the eastern half is likely to yield more than that of Case 3. Maximum and

Minimum principal stress distributions patterns and their magnitudes are almost similar. While the influence of intermediate principal stresses marks the development of tensile zone in stope back in Case 4. In a nutshell, Case 3 is suitable stoping methodology for CS02A amongst the two. From Case 5, it is observed that during extraction of ore from lower part of secondary stope between -55 mRL and 30 mRL, followed by extraction of ore in the upper part, i.e. 65 mRL and 130 mRL, the temporary crown between 30 mRL and 65 mRL is stable. However, from Case 6, it is observed that when the temporary crown is mined out at the end, there is a likelihood of failure of fill from the upper part and further yielding of geological hangwall. This could result in posing instability issues while stoping of temporary crown in the secondary stopes. Post excavation of the temporary crown, stresses are getting concentrated in the abutment temporary crowns in the adjacent primary stopes. While carrying out the overall stability analysis through Case 7, by excavation and backfill of all primary and secondary stopes between CP01 and CP04, it is observed that the strength to stress ratios fall below 1 in CP04A. The contours of strength to stress ratios for Case 2 and Case 3 are shown in Figure 2. The crown and hangwall displacements and the results from 3D numerical modelling for various modelled cases are presented in Table 1.

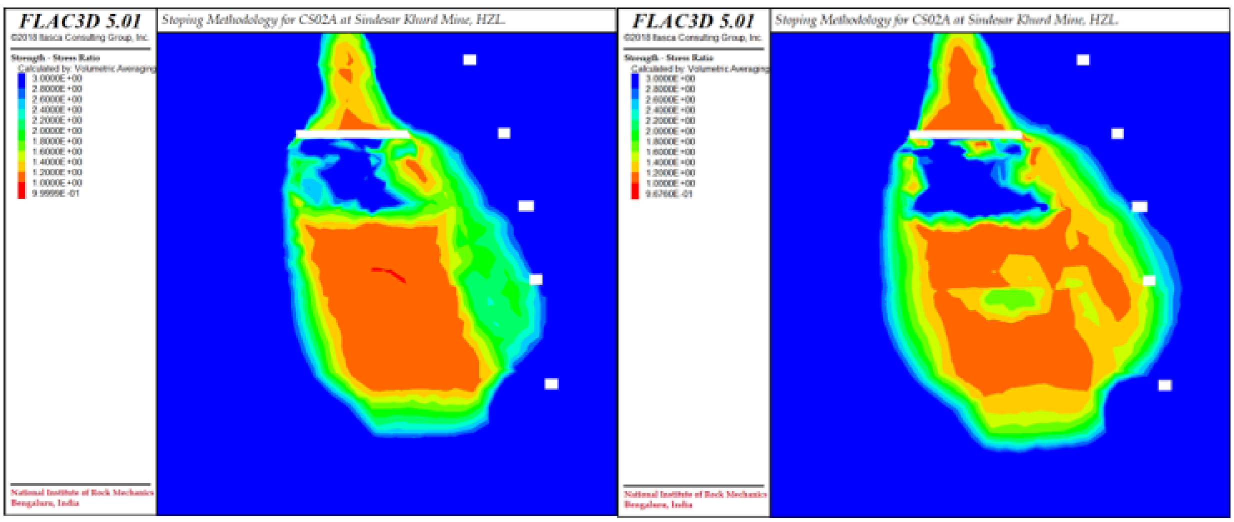

Figure 2. Contours of strength to stress ratios for Case 2 (left) and Case 3 (right).

Table 1. Results from 3D numerical modelling for various modelled cases.

Case	**1**	**2**	**3**	**4**	**5**	**6**
Crown displacements, mm	42.0	21.5	33.4	41.2	53.3	30.2
Hangwall displacements, mm	79.6	64.0	78.0	79.9	78.2	75.0
Strength to stress ratios (crown)	1.0	1.4	1.2	1.1	0.9	1.1
Strength to stress ratios (hangwall)	1.0	1.8	1.2	1.1	1.0	1.3

From the results, it is observed that crown and hangwall displacements are least in Case 2 followed by Case 3 when compared with the results from all other cases. Moreover, the factor of safety or the strength to stress ratios at both crown and hangwall is also higher in Case 2 indicating relatively stable conditions than others. From the contours of displacements and strength to stress ratios, it is also seen that the yield zone extends up to the eastern haulage drives (EHD) at -5 mRL and 30 mRL in Case 1 and Case 4 while in Case 5 and 6, the EHD at 100 mRL and 130 mRL is under yielding condition.

4 CONCLUSIONS

Based on the results, observations and discussions, the following conclusions are drawn:

- For safe extraction of ore from CS02A stope, the stoping methodology as mentioned in Case 2 or Case 3 is recommended.

- The stoping sequence in all Cases must be bottom up.
- The haulage drive must be developed in western side or geological footwall.
- The excavated stopes must be backfilled with paste completely till crown as soon as possible post mining.
- Cable bolts shall be installed at the stope back up to a depth of 10 m and up to 6 m depth at brow in a grid pattern of 2 m × 2 m.

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