

Techno-economic Analysis for Development of a Drive in View of Geo-Mining Conditions – A Case Study

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Abstract

This paper presents all the rock mechanics studies carried out at an underground metal mine in Kadapa, Andhra Pradesh. The rock mechanics investigations in this mine include optimization of pillar dimensions by numerical modeling, the feasibility of Hang-wall lode mining at shallow depth, support design for deeper levels, instrumentation to monitor the strata for an experimental hang wall stope. The main aim is to improve extraction ratio and the mine safety levels from these rock mechanics studies to develop a mine. The Effect on the linear advance in both Footwall lode and Hang-wall lode is studied, monitored and found that there is almost 25 % increase in Total cost per round of blast due to difficult Geo-mining conditions and affecting total cost per tonne of ore extracted from Hang-wall in contrast to Footwall lode development and safety aspects. A critical case study with Techno-Economic Cost analysis in view of their Geo-Mining conditions has been discussed.

Key words

Metal mine, Rock mechanics, Development, Supports, linear progress, blasting.

1. Introduction

In the erstwhile development era of the 20th century, the world has seen an innumerable number of products flourishing the market. The consumption power of people has increased which in turn has led to higher demand for products. This demand has led to a greater burden on the core sectors. Mining as core sector is considered as the corner stone for any industry as the raw material required for almost all the needs are derived from mining. Most of the metals, in India, come from underground metal mines and thus the development of underground metal mines is the base for

ore production from a mine. Considering the increasing demands on base metals, there is a need to develop new underground metal mines or deepen the existing ones. During this process, there are number of factors influence the decision of selecting an opening for an underground mine. Some of these factors include the depth of the deposit, geotechnical aspects, production rate, dimensions, availability of capital, and operating costs [1]. A critical study was conducted in metal mine with the techno-economic analysis in view of its geo-mining conditions.

2. Mine Details

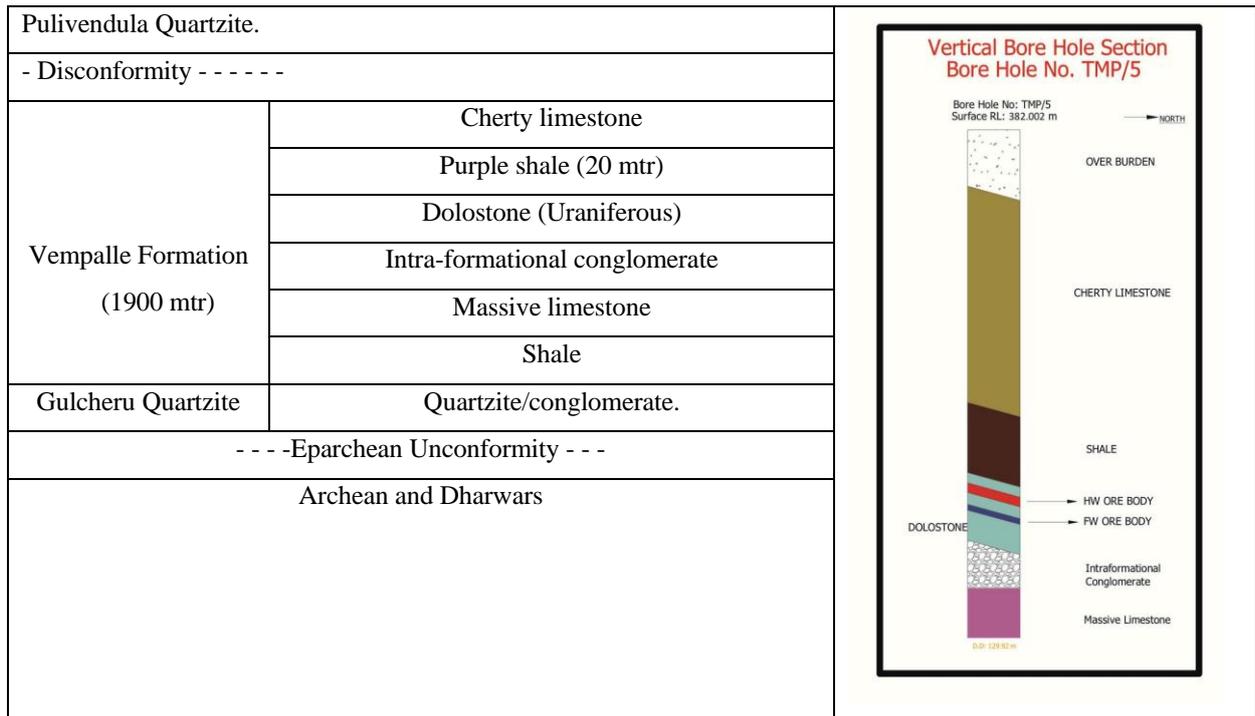
The study was conducted in an underground metal mine near YSR district, Andhra Pradesh, to mine the ore of mineral / Pitchblende hosted by the dolomitic limestone. Geologically the area falls in the SW part of the “Cuddapah” basin. The mine (14°18'36.6"N 14°20'20"N: 78°15'16.57"E 78°18'3.33" E) situated in the Cuddapah district of Andhra Pradesh.

The mineralization occurring in Underground metal mine of kadapa is of two lodes i.e. hang wall lode (average width 3.2 m) and footwall lode (average width 2.5 m), separated by 1.5 to 3 m thick lean zone. The ore body is uniform in its thickness and trend, with an average dip of 15° due N22°E. The extent of the ore body is 5.6 km along the strike and 1 km along dip, with overburden depth ranging from 15 m to 275 m. The depth of present mine workings are below 100m. The weathering zone (weathering grade W2) extends for 40 to 50 m below the surface. Three declines, 5 m in width and 3 m in height, along with an apparent dip of 9° due NE, are being driven 15 m apart to work the two lodes at different levels. Various rock mechanics investigations are carried out at this mine to come out with the optimum solution for better safety and extraction ratio.

2.1 Geology and Geo-Mining Conditions

The mineralization of mine in Kadapa area is hosted by Vempalle Dolomites of Papaghni group of Cuddapah super group. Mineralization is of strata bound type, confined between two lithological units' viz., Red Shale and massive limestone. The different lithologies observed from the vertical bore hole section are overburden (~14.4 m), cherty limestone (~55.34 m), shale (~17.94 m), Dolostone (~17.3 m), intraformational conglomerate (impersistent) and massive limestone. The rock formations in the area are mostly bedded dolomitic limestone. The strata have an average dip of 15°- 17° due N22°E. The extent of the ore body is 5.6 km along the strike and 1 km along dip, with overburden depth ranging from 15 m to 275 m. The ore body consists of two bands: Hang-wall lode (average width 3.2 m) and footwall lode (average width 2.5 m), separated by 1.5 to 3 m thick lean zone. The stratigraphy of the mine and bore hole section is furnished in Table1.

Table 1. Stratigraphy and Borehole section of the Mine



2.2 Method of Mining

The mine is a highly mechanized underground mine, which is developed with three set of declines (5m x 3m) at a 15m interval, driven at 9o gradient in apparent dip direction in the ore body. The advanced strike drives (ASDs) of size 4.5m (W) x 3m (H) are driven in strike direction from both service declines at vertical intervals of 10m. Levels are connected with the Ramps developed at 9° apparent dip with an interval of 120m.

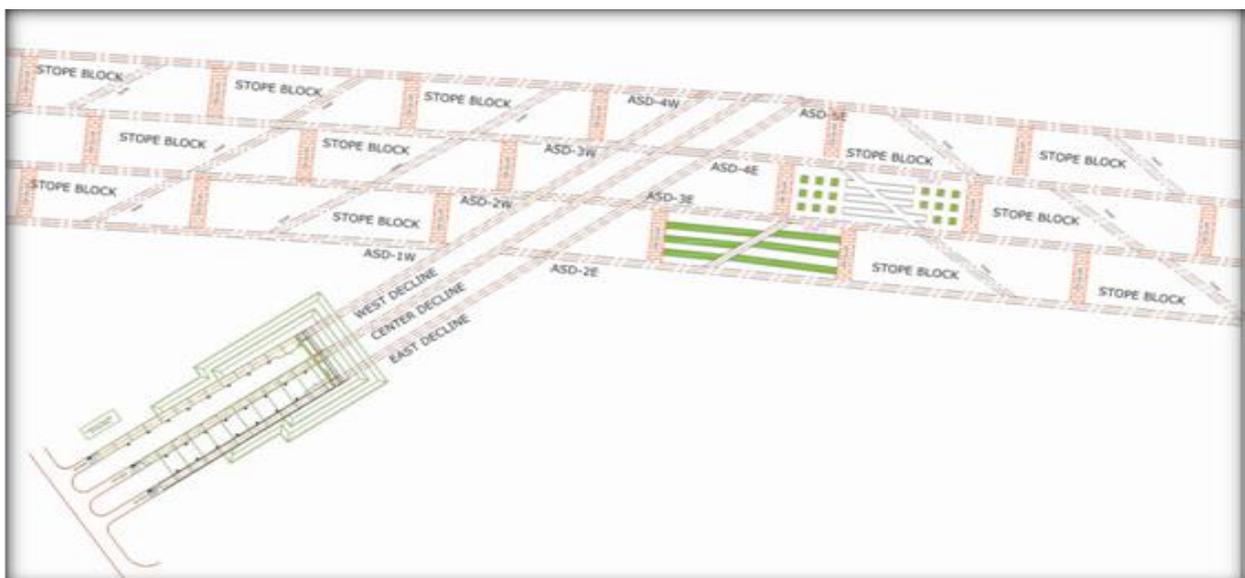


Fig.1. Schematic Diagram of Underground Mine Development

Ore extraction (stopping) is carried by room and pillar method of mining. Stope blocks of dimension (120m Length X 39m width) has been developed by driving ramps at every 120m interval between the rib pillars of 7mtr wide, which are left at 120m interval for supporting the roof. After developing the ramps, stope drives developed on either side of the ramp up to the limit of the rib pillars. These stope drives are interconnected by forming room and pillar of dimension 4.5m X 4.5m as shown in Fig .1

3. Geo-technical Parameters & Geo-Mining Issues of the Mine

3.1 Geotechnical Parameters

The rock mass classification parameters such as rock quality designation (RQD), joint set number (Jn), joint roughness number (Jr), joint alteration number (Ja), joint water, reduction factor (Jw), stress reduction factor, UCS, average spacing of discontinuities, joints conditions, orientation of discontinuities and hydro-geological conditions were estimated from direct field observation in the geological mapping. Based on these parameters, rock masses have been characterized using Q-system [2], and RMR system [3]. a) The joint properties observed in the field, b) RMR values, and c) Q values estimated for the different locations mapped.

3.2 Hangwall (HW) lode mining at shallow depth

Host rock for ore mineralization at this mine is Dolostone. Carbonate content of Dolostone, when exposed to water, gets washed away and forming the cavities. Intensity and occurrence of cavities progressively decrease with depth. It has been observed that up to a depth of 100m from the surface, roof protection requires additional support. Series of solution cavities due to weathering of host rock (Dolostone) and roof rock (Shale) impeded the underground development. Solution cavities of shale and Dolostone are shown in Figures 2.



Fig. 2. Solution Cavities of Shale and Dolostone of the H/W Lode

3.3 Shale Roof Problem

Lithologically, Red shale (Ferruginous) is an argillaceous rock formed due to compaction of clay minerals (Mud). The major part of the reserves in the mine is confined to hangwall lode which is capped by red shale with adverse physical properties on stability considerations. However, efforts are being made to assess the properties at different depth with an aim to recover ore from hangwall lode. Experimental hangwall drives and trial hangwall stope have been opened randomly at vertical depths of 70m, 90m, 100m, and 120m to ascertain the ground conditions. The support design which is followed for supporting the dolostone has been practiced for shale rock, which is the roof for hangwall lode. Fig 3 (a,b,c,d) shows the following problems were encountered in the hangwall lode drive developments while supporting the roof.

- Continuous heavy water seepage from the roof i.e. from Red Shale (Fig.3a).
- Wash out of full column cement grout, due to the pressure of seepage water(Fig.3b).
- Collapsing of drilled holes constraining installation of Rock bolts (Fig.3c).
- Collapsing of layers (50cm transition zone) from the roof (Fig.3d).



Fig. 3. (a,b,c,d): Showing the Shale Roof Problems

4. 2D Numerical modeling

With a view to ascertaining the stability of the hangwall lode workings at the shallow depth between 2nd and 6th levels, a 2-Dimensional numerical modeling is performed. This modeling is also aimed to confirm the empirical design results. For these purpose models were created to

ascertain the stability of the workings. The model geometry for this is shown in Fig. 4 which indicates that the actual lithology up to the surface is considered in the model. The maximum depth of mining (100m) was also considered for the simulation.

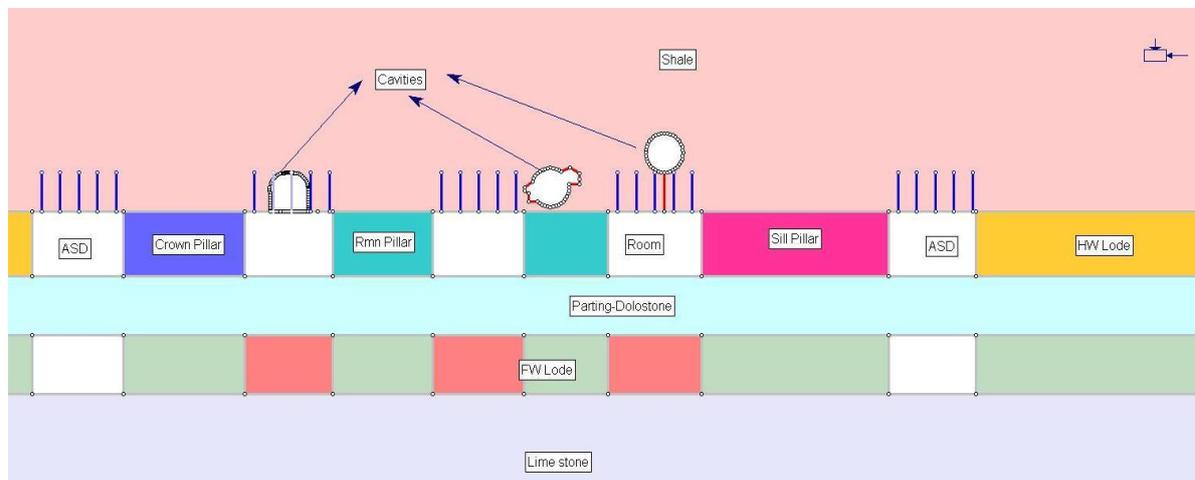


Fig. 4. Model Geometry of HW Lode Mining [4]

4.1 Discussions & Observation of Numerical Modelling

The model results yielded in the form of the mining induced stress and the strength factor (FOS) values over the pillars and over the roof of the gallery due to the footwall (FW) and hangwall (HW) mining. The effect of back filling on the stability of the pillars is also simulated in this analysis. All the material properties for the analysis is 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. The model was simulated under various mining options such as FW mining alone, both FW and HW mining, and also the backfilling of FW stopes. Results of the analysis were obtained in the form of Stresses and Strength factor (FOS) around the excavations. The mining induced stresses and the strength factor around excavations after FW lode & HW lode mining is shown in Fig. 5 & 6 respectively.

The results in terms of mining induced stresses as shown in Figure 5, indicates that the tension failure occurs over the roof of the rooms due to the HW lode mining and leading to the collapse of the rooms. Even the pillars are experiencing this phenomenon which will eventually lead to weaker and unstable pillars. It can be observed from the Figure 5 that the ASD's are also experiencing the failure which cannot be maintained during the mining operation. The results in the form of strength factor (FoS values) as shown in Figure 6, indicates the low FoS values (less than 1.0) in and around the rooms due to HW lode mining. It can also be observed that the roof

over ASD's also shows the low FoS values, which will lead to the collapse of the excavations. In both the cases, it can be observed that the failure of the shale roof is extended to a few meters leading to highly unsafe conditions. The support system in the form of rock bolts was installed in the HW lode mining rooms and was simulated for their efficiency and behavior. The results in the form of yielded bolts after the HW lode mining is obtained and shown in Figure 7. It can be observed from the figure 7, that almost all the bolts yielded except a couple of bolts in the ASD. This clearly indicates the failure of the rock mass around the openings. The negligible axial force on the rock bolts can also be observed in this case.

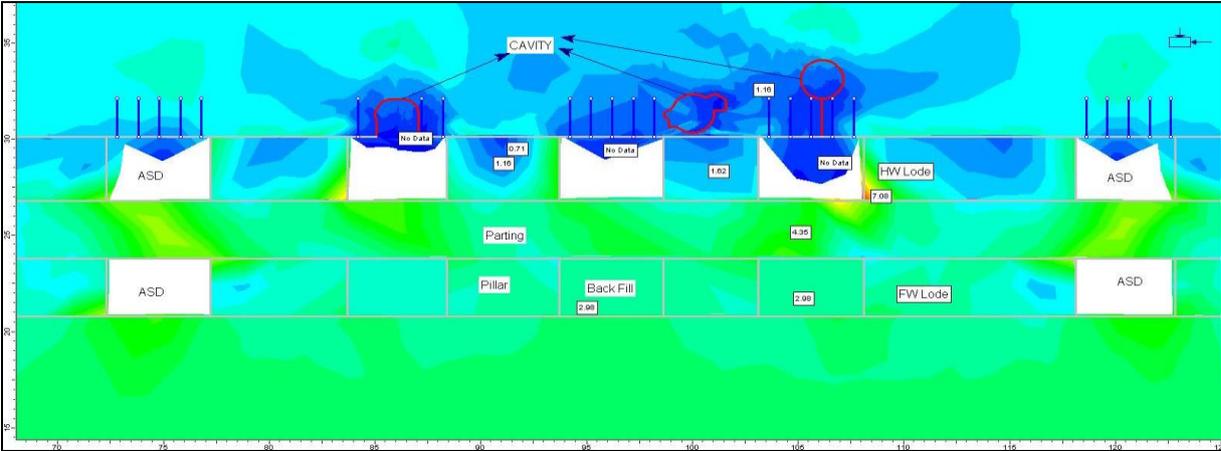


Fig. 5. Mining Induced Stresses around Excavations [4]

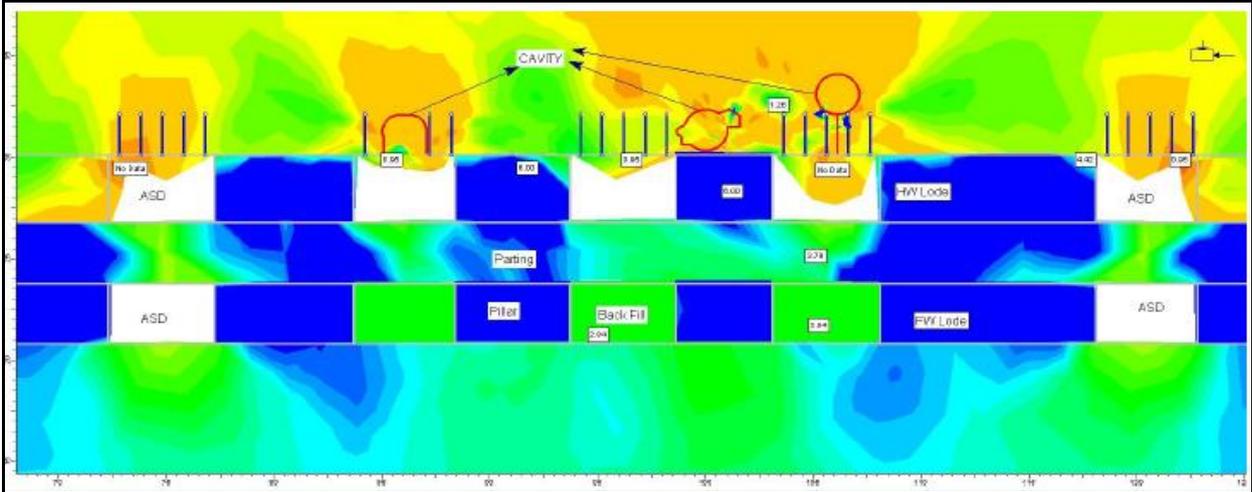


Fig.6: Factor of Strength Values around Excavations [4]

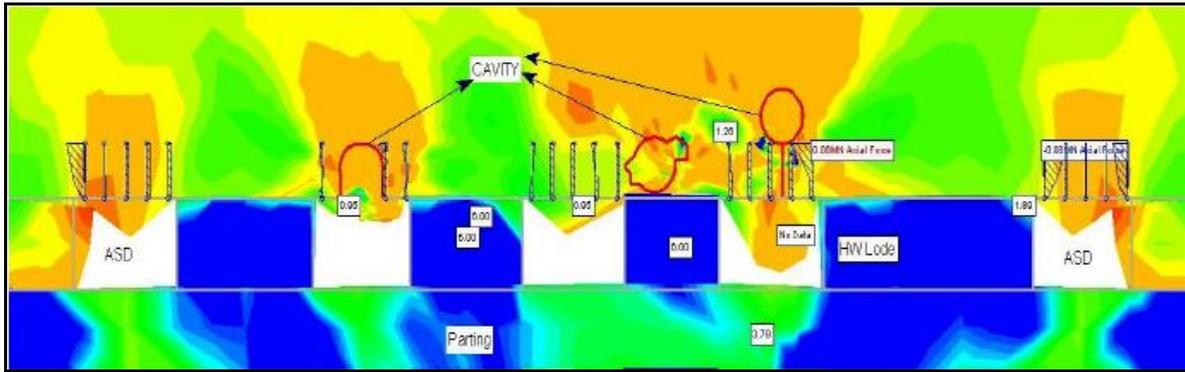


Fig. 7. Yielded Bolts in the Rooms of HW Lode [4]

4.2 Extraction Ratio Vis-À-Vis Safety Factor

The present remnant pillar size is 4.5 x 4.5m square pillar. The rib pillar is 7m wide and the crown and sill pillars of 5m thick. The factor of safety and the extraction ratio of the present pillar sizes are estimated and detailed below in Table 1.

Table 1. Details of Existing and Recommended Pillar Dimensions

Pillar	Existing Dimensions (m)	FOS	Recommended Dimensions (m)	FOS (Empirical)	FOS (Numerical)
Remnant Pillar	4.5 x 4.5	4.97	4.0 x 4.0	4.08	4.0-6.0
Rib/Barrier Pillar	7.0	14.51	4.0	10.80	4.0-6.0
Sill/crown Pillar	5.0	13.46	4.0	11.85	3.0-5.5

Table 2. Average Q and RMR Values

S.No.	Location	Average RMR	Average Q
1	ASD-5E HW R/Dn (40m in bye)	44.20 (Fair)	2.86 (Poor)
2	ASD-5E-P1-E2 (60m in bye)	45.85 (Fair)	2.77 (Poor)
3	ASD-5E-P1-E3 (30m in bye)	44.50 (Fair)	3.35 (Poor)
4	ASD-5E-P1-W2 (13m in bye)	41.60 (Fair)	2.26 (Poor)
5	ASD-6E HW Drive West (70m in bye)	55.5 (Fair)	5.67 (Fair)
6	ASD-1E (130m in bye)	34.50 (Poor)	2.94 (Poor)
7	ASD-2E (150m in bye)	33.50 (Poor)	2.50 (Poor)
8	1E to 3E (120m in Decline)	41.62 (Fair)	3.56 (Poor)

Relevant data required for the classification of Rock mass of deeper levels (beyond 10th level) was collected from the mine during the field visits by NIRM. Representative rock blocks were also collected from the underground mine, for determining physico-mechanical properties of these rocks in the laboratory at National Institute of Rock Mechanics [4]. Based on all these studies, the rock mass characterization is made and the rock mass are classified to establish its quality for the stability of the workings during and after mining in these levels and to design the appropriate support system. The average ‘Q’ and ‘RMR’ values estimated for the deeper levels is presented in Table 2.

4.3 Instrumentation

Stopping is being carried out at 5E HW lode panel, on an experimental basis. To understand the strata behavior during and after stopping operations, the above panel is instrumented using the variety of instruments such as Stress Cells, Load Cells, Extensometers to monitor the stress in the remnant and barrier pillars, load on the rock bolt support system and deformation in the roof and walls. The location and the type of instruments installed in the above panel are shown in Fig.8.

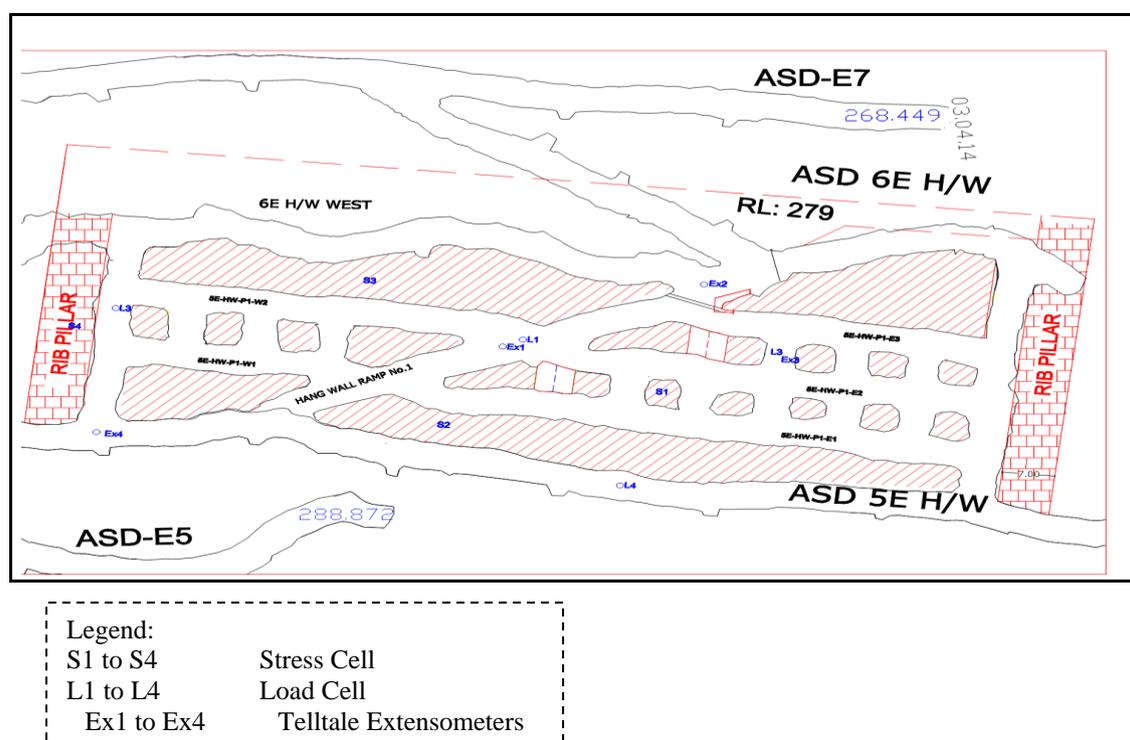


Fig. 8. Plan Showing Instruments Installed at 5E HW Lode Panel

4.4 Feasibility of HW Lode Mining

The feasibility study of mining of the HW lode between 2nd and 6th levels was carried out.

As part of this study, classification of the rock-mass was also carried out between 2nd and 6th levels to study its quality and evaluation of the mineability of HW load under shallow depth up to 100m. Numerical modeling for the feasibility of HW load mining using the rock mass properties was determined.

All the instruments are being monitored regularly and the data is being analyzed to understand the strata behavior during and after de-pillaring which will enable to plan for effective strata control program in the future panels.

4.5 Conclusion on Feasibility Study on Mineability of HW Lode

Feasibility study on mineability of HW lode of Underground metal mine, Kadapa is conducted. Geological and geotechnical investigations were carried out in the mine between the 2nd and 6th levels with a view to studying the mineability of HW lode by both empirical and numerical methods. It was observed that most of the crown/ roof area of the hang wall portion (Transition zone) is weak due to the contact between shale and Dolostone and the intersection of the joints. A number of cavities were observed in the HW drives. Most of the cavities were formed due to the dissolution of calcium carbonate rocks with water interaction, the intersection of the sub-horizontal and verticals joints. The width of the cavities ranges from 0.5 m to 3.5 m. Water seepage is recorded along the vertical joints at some channels of the ASD 1E and ASD 2E. The rock mass was characterized using the Q and RMR systems. It was found that in both the systems the rock mass was classified as poor to fair category. The present rock mass of HW lode requires fair amount of support system. The maximum stable span estimated was less than 4.0 m for Q value of 2.26. It is also found that at the lower and average RMR values of 33 and 40, the HW lode workings are within “immediate collapse” zone and hence not offer any stand-up time. The results of 2D numerical modeling to study the feasibility of HW lode mining also confirms the failure and impending collapse of the workings, which makes mining operations in HW lode between 2nd and 6th levels not safe due to the strata control point of view.

5. Mining in F/W and H/W Lode and Its Effect on Linear Progress and Cost of Operation

5.1 Mining in Footwall Lode

In the Footwall lode, Advance strike drive (ASD) of size 4.5m x 3m, was taken for full one month in 4th Level of the mine (Fig. 9). The cycle time per round of blast is 3 shifts in Footwall

lode. The calculation is done for production cycle for each component. With a much-planned allocation of all type of resources available in the mine, Following are the achievements:

- The total number of days worked – 25 days.
- The total number of shifts worked – 75 shifts.
- Total linear progress achieved per month -75 m.
- Total successful blasts have taken in a month -25 nos.
- The average pull per blast – 3m.



Fig. 9. Drilling by Extra Low Profile Drill Jumbo in Development Face of FW Lode

5.1.1 Brief of Total Cost of Operation Per Round of Blast in Footwall Lode (F/W)

- The drilling cost per meter = Rs.56.40/ m
- Total meterage of drilling per blast with 33+3 Reamers

$$= 3.2\text{m} \times 33 + 3 \times 3.4\text{m holes} = 115.80 \text{ m}$$
- Total cost of drilling = Rs 56.40 \times 115.80 m = Rs.6531/-
- The total cost of charging and blasting = Rs.9616/-
- Total cost of mucking = Rs.4763/-
- Total cost of preparation of face & Supporting with Rock bolt = Rs.18083/-

Total cost of operation per round of blast =Rs.38993/- (F/W Lode)

5.2 Mining in Hangwall Lode

In spite of the weak hang wall lode, an advance strike drive (ASD) of size 4.5m x 3m was taken for full one month in 6th Level of the mine. The cycle time per round of blast is found to be 4.5 shifts in hangwall. Due to above-mentioned geo-mining constraints, the use of welded mesh

and Hydra-bolts from South Africa were tried and tested. With a much-planned allocation of all type of resources available such as Hydra bolt, wire mesh etc. in the mine (Fig.10), Following are the achievements:

- The total number of days worked – 25 days.
- The total number of shifts worked –75 shifts.
- Total linear progress achieved per month -51 m.
- Total successful blasts have taken in a month -17 nos.
- The average pull per blast – 3m.



Fig. 10. Fixation of Welded Support Firmly to the Immediate Roof near the Development Face

5.2.1 Brief of Total Cost of Operation per Round of Blast in Hangwall Load (H/W)

- The drilling cost per meter = Rs.56.40/ m
- Total meterage of drilling per Blast with 33+3 Reamers

$$=3.2\text{m} \times 33 + 3 \times 3.4\text{m holes}=115.80 \text{ m.}$$
- Total cost of drilling = Rs.56.40 \times 115.80 =Rs.6531/-
- The total cost of charge &blasting =Rs.9616/-
- Total cost of mucking =Rs.4763/-
- Total cost of preparation of face & supporting with welded mesh & friction bolt

$$=Rs.27, 791/-$$

Total cost of operation per Round of Blast =Rs.48, 701/- (H/W Lode).

The brief details of the above-calculated cost for development of drive in footwall and hangwall drive are given in Table 3 and plotted in Fig.11.

Table 3. Comparison of Cost Components for Operation of Single Round of Blast in both FW & HW Lodes

Lode	Total cost of drilling (Rs.)	Total cost of charging and blasting (Rs.)	Total cost of mucking (Rs.)	Total cost of preparation of Face & supporting with bolt (Rs.)	Total cost of operation per round of blast (Rs.)
FW Lode	6,531	9,616	4,763	18,083	38,993
HW Lode	6,531	9,616	4,763	27,791	48,701

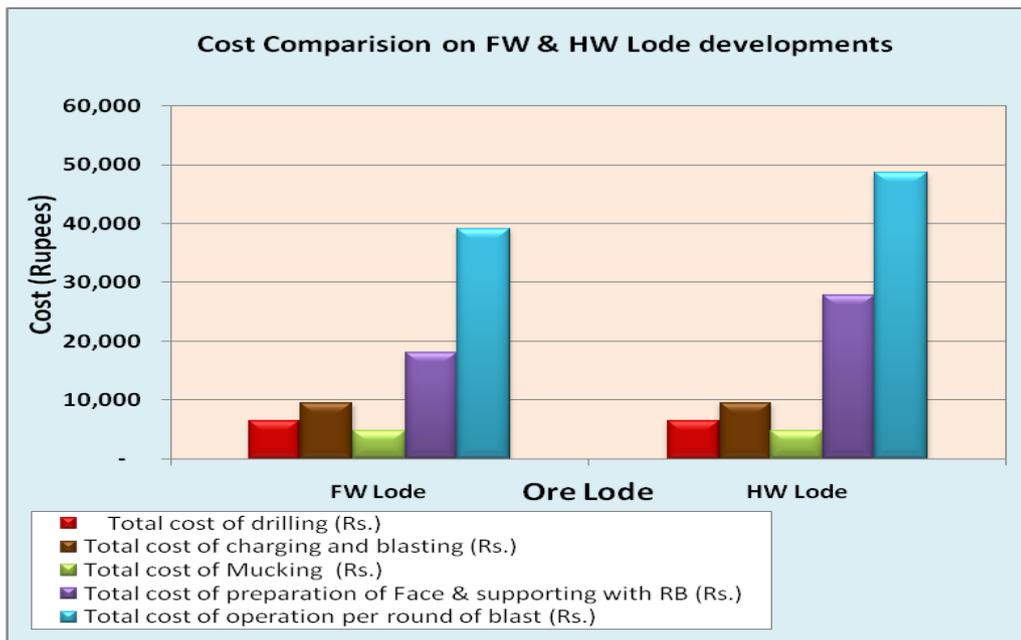


Fig.11: Cost Comparison of all Mining Components for Both HW & FW Lodes

Conclusions

Extensive problem centric rock mechanics investigations have been carried out at Mine such as optimization of pillar sizes, the feasibility of HW lode mining, support design for deeper levels, instrumentation for strata behavior monitoring. New supporting items like friction bolts and welded mesh from South Africa are being used as additional supports in the weathered zones of the mine, which has proven beneficial in safe mining practices.

In-spite of a technical recommendation of leaving hangwall lode ore due to difficult geo-mining conditions, an experimental stope was developed and stopped out to monitor with instruments. Due to the difficult geo-mining condition, it affected the cost of mining and on linear advance/progress. The cost analysis shows that the increase in mining cost due to the contribution of extra expenditure on manpower for preparation of face and supporting with a combination of hydra bolt and wielded mesh i.e. 53.30% than expended on footwall lode while other cost

components nearly remain same. The installation of supports are found successful and had led to consumption of additional 1.5 shifts than practiced in footwall that resulted in 24.90% increase in Total cost per round of blast, there by significantly, affecting total cost per tonne of ore extracted from hangwall in contrast to footwall.

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