Improving Productivity in Pillar Blasting – HZL, Sindesar Khurd Mine

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Abstract

Sindesar Khurd Mine (SKM), the largest underground mine in the Hindustan Zinc Limited portfolio, is located approximately 60 kilometers (37 miles) north of Udaipur. In the 2018 financial year SKM achieved an annual ore production of 4.5 Mt (4.42 million LT) and mined metal production of 247 kt (243,099 LT).

The mine employs a sublevel stoping method with vertical crater retreat (VCR) to provide the initial void required for blasting. VCR blasts are employed in 2.5-meter (8.2 ft) lifts while long hole raises can be blasted in one firing. The relatively small size of the VCR raise blasts can impede the rate of production however the drilling accuracy can lead long hole raising (LHR) to be prohibitive. Both can lead to ore production targets not being met.

These challenges are compounded when blasting crown pillars where accessibility issues require new blasting methods. One such challenge at SKM was to mine an approximately 35-meter (115 feet) thick pillar with one level in between and no access above for the 15 m (49.2 ft) block. One of the options was to develop a drive above the block & then drill downholes of 10 m (32.8ft) -12 m (39.3 ft) lengths. But considering the development costs associated and critical requirement of higher grade of ore, the value that could be realized later would be less. After technical considerations, one of the feasible solutions was that the pillar would be blasted through combination of 15 m (49 feet) upholes and 20 m (82 feet) downholes with a limited number of blasts and personnel entry. Additionally, due to the presence of a village around 200 m (656 feet) from the mine boundary, there were restrictions on vibration and maximum charge per delay.

This paper presents the technical challenges and solutions with regards to the blast design and charging for achieving successful firing of the stope. It also discusses the use of uphole charging technology such as a hose-pusher and better retentive bulk emulsion explosives, in conjunction with electronic blasting systems to break approximately 150,000 t (147,631 LT) of ore. The vertical uphole raise designed with LHR along with a few uphole rings and a few downholes including downhole raise were taken in single shot. Mechanized uphole charging significantly reduced the effort and time compared to manual charging of upholes. The modelling software used to simulate this blast was pivotal in the ability to control the vibration levels achieved and sequence the entire stope blast into four individual blasts. The successful execution of the project enabled the mining team at SKM to consider sub-level mining with approximately 25 m (82 ft) upholes & downholes which will eliminate one level of development equating to approximately 2500 m (8202 ft) of development.

Introduction

Hindustan Zinc Limited (HZL) is an integrated mining and resources producer of zinc, lead, silver, and cadmium. It is the world's second largest zinc producer with an FY18 revenue of $3.32b. SKM is one of the flagship mines in HZL's portfolio and is the largest underground mine in India having produced 4.5 Mt (4.42 million LT) of zinc, lead, and silver rich ore in FY18. SKM employs underground open stoping methods for ore extraction. The ore body has a strike direction of N10°E to N15°E, and a strike length of over 1000 m (3280 ft), and dips steeply. The average ore body width is 34 m (111.5 ft) (varying from 5 m (16.4 ft) to 55 m (180.4 ft)).

In the past 5 years, HZL has invested heavily in mechanization, expanding its production from 590 kt (580,682 LT) in FY13 to 4.5 Mt (4.42 million LT) in FY18. As part of this process it has become the first metal mine in India to introduce bulk emulsion explosive in both development and production blasting. Furthermore, SKM have also invested in advanced technologies such as electronic detonators, smart jumbos, longer drill feed lengths, mechanized explosive charging, and remotely operated loaders.

While there have been large scale improvements, the productivity of the mine has thus far been restricted by the presence of a village at a range of 200 m (650.16 ft). With advancements in technology, extraction of ore pillars which were once left behind for stability are now able to be targeted using artificial paste and backfill methods. This however has presented an additional challenge in mining the valuable 35 m (114.8 ft) thick crown pillars. This paper highlights the methodology developed to successfully extract these pillars while complying with strict environmental constraints. The successful execution of the project enabled the mining team at SKM to adopt a new mining method which allowed them to extract these valuable pillars safely and effectively while minimizing development required.

Geology and Mining Method

The SKM ore body is conformable with the host stratigraphy. The mineralization lies within silicified dolomite and graphite mica schist which are overlain by Quartzite, the mineralization has been traced over almost 2.5 km (1.55 miles) along strike and 1.3 km (0.8 miles) vertical extension. The lead-zinc mineralization occurs in fine grained disseminated banded form in mica schist, tuffaceous mica schist and carbonaceous schist, whereas in coarse grained form it occurs in calc silicate marble. The primary source was volcanic and was deposited as fine-grained layers along with volcano sedimentary rocks such as protore. This was remobilized and deposited in the available locales as coarse-grained mineralization due to metamorphism and deformation. The mine extends 1,300 m (4265 ft) along the strike from 120 m (393.7 ft) - 920 m (3018.4 ft) below the surface and ranges from 5 m (16.4 ft) – 60 m (196.9 ft) in thickness. The overall dip, which varies from 37-70°, is to the east but becomes overturned below the 120 mean reference level (MRL) elevation. The total reserves and resources as of 1 April 2013 are 88.6 Mt (87.2 million LT) at 4.50% Zn, 2.50% Pb and 156 ppm Ag up to 1,100 m (3609 ft) depth.

The geotechnical conditions at SKM vary widely with frequent local geological disturbances. There are two prominent joint sets with a third less consistent one, mostly forming wedges in the roof and sides, with calcite infillings rendering the joints weak. Two of the joints are steeply dipping (65° due west and at 80° due north) and the third at a shallow dip of 20-25°, with mild to heavy folding creating fractured strata at frequent intervals. The Rock Mass Rating (RMR) is between 35 and 55. The Hanging Wall which consists of mica-schist-chert formation, is weak in shear and tensile loadings. The host rock is calc-silicate bearing dolomite and is comparatively stronger, with RMR varying between 40 and 70.

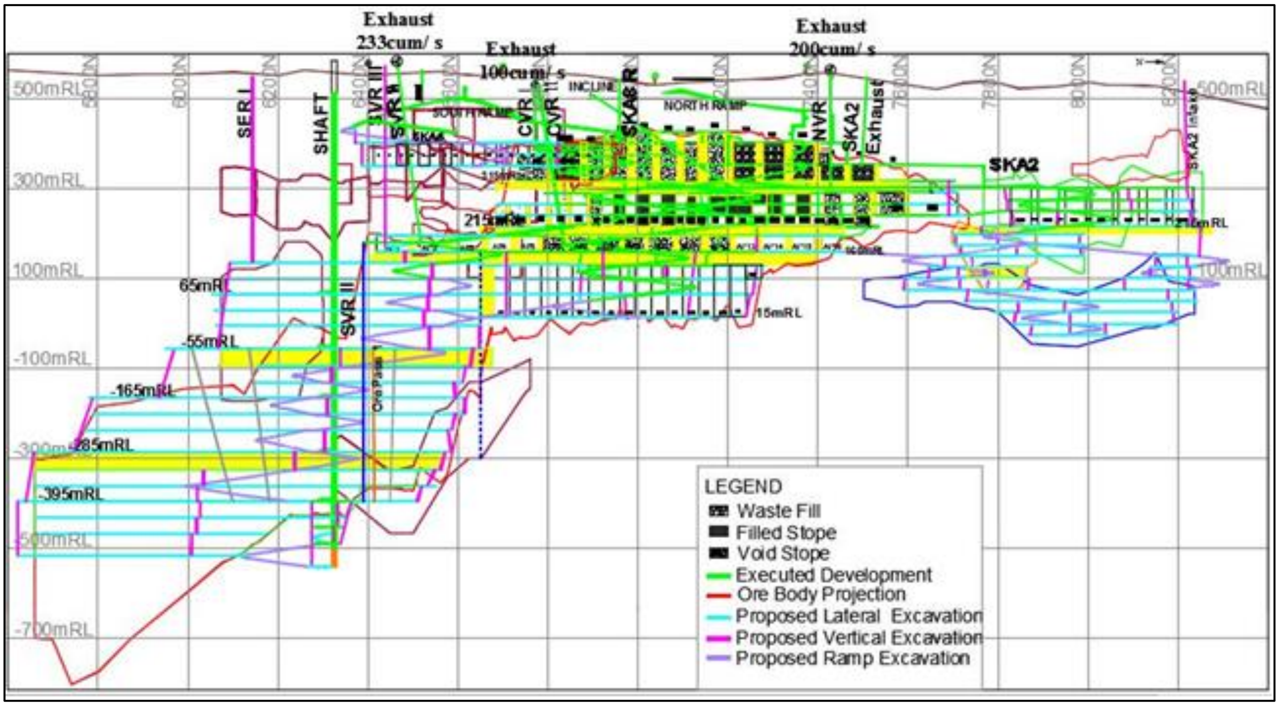

Figure 1. Longitudinal Section of the mine

The mine is currently accessed and supported from five openings comprising of two ramps, two ventilation raises, and an old incline (as shown in Figure 1). Both the north and the south ramp are of dimensions 5.5 m (18 ft) × 5 m (16.4 ft) and both have a gradient of 1 in 8, suitable for 50 t (49.2 LT) low profile dump trucks (LPDT) and 17 t (16.7 LT) load haul dump (LHD) units. The old incline has been dismantled and serves as a secondary escape and air intake. The north and central ventilation raises are equipped with suitable exhaust fans. Currently the mine is extracting ore by sub-level stoping methods in which the initial raising is done by drop raise VCR. The raise is the first void created against which the subsequent rings are fired, the productivity of the stope depends on the turnaround time of the raise. A typical stope of 35 m (114.8 ft) - 40 m (131.2 ft) would take around 15-20 blast cycles to develop the raise. This method has been selected due to the high degree of deviation of the drilled holes and the dip of the ore in the host rock and has given rise to higher turnaround times creating a major bottleneck in the productivity of the mine.

Stopes are drilled with EHS (Solo Sandvik) drills using 64 mm (2.5 inches) drill bits for upholes in the trough and 102/89 mm (4.01/3.5 inches) drill bits for downholes in production rings. For longer holes (>35 m) ITH (In the Hole) drills are used to drill 115 mm (4.53 inches) diameter holes. While stoping, ore pillars are left behind for support. The opened stope or void is backfilled by hydraulic or paste fill with the tailings of the site beneficiation plant. The mine has a hydraulic backfill plant using classified tailings with a capacity of 80 m^3/hr (47 ft^3/sec) at a pulp density of 1.73 g/cm^3. Paste fill is poured with a solids content of about 78-79%, at pour rates of 140-240 m^3/hr (82.4 – 141.2 ft^3/sec) and a cement binder ratio of >6%. After the given curing time, the stability of the fills is re-checked. Subsequently the supporting pillars are blasted in sequence to extract the remaining locked ore.

Pillar Blasting and Challenges

Pillar blasting requires detailed planning of accessibility, recoverability of ore, and blast design. A typical pillar at SKM is approximately 35 m (114.8 ft) - 40 m (131.2 ft) thick, 28 m (91.4 ft) -30 m (98.4 ft) wide, and 35 m (114.8 ft)– 40 m (131.2 ft) in height; pillars are left between levels and sometimes have very limited accessibility.

The existing excavation methodology begins with establishing the drill level, which provides access before the raise is excavated. A typical pillar will require both uphole and downhole raises (due to issues with accessibility) with subsequent ring patterns to fire into the void created by these raises. At SKM, the downhole and uphole raises will be excavated utilising a VCR method. When extraction of crown pillars is undertaken, with both limited accessibility and the instability of the rock mass, VCR is not viable because of the frequency of blasting events.

Blastholes are charged with either standard bulk emulsion or packaged explosives. The existing bulk emulsion delivery system deployed at SKM is not capable of charging upholes and as such uphole charging is conducted with packaged emulsion cartridges for holes greater than 8m (26.2 ft) - 10m (32.8 ft) in lengths. This is a time consuming and labor-intensive process. Additionally, retention in upholes with standard bulk emulsions at such lengths is not as reliable as that with uphole bulk emulsion.

SKM also has very strict vibration controls set due to its proximity to a local village which is situated at radial distance of 200 m (656 ft). The nature of the dwellings only compounds this issue as generally they are poorly constructed. Voids created by previously extracted stopes help to create barriers which blast vibration waves are unable to travel through, however the governing statutory bodies have restricted the MIC (Maximum Instantaneous Charge) and total charge. The mine blasts are kept below the MIC with respect to requirement of blasting in different level to ensure vibrations at the surface are kept below safe limits peak particle velocity (PPV) of 15 mm/s (0.59 in/s) or less and frequency of greater than 40 Hertz, as recommended by Directorate General of Mine Safety, Government of India). These highly restrictive parameters can lead to lower productivity outcomes for SKM.

Finally stope stability, being a standalone pillar with the stope beneath (from the 65 level to the 15 level) being already extracted. Hence, there was a need for reduction in the number of blast events and entry of personnel.

Current Scenario

The stope in 85 level, named BP 07 was approximately 35 m (112 ft) thick, 30 m (98.4 ft) wide and 35 m (112 ft) in height and situated between the 100 level and 65 level (as shown in Figure 2 & Figure 3). The pillar was only accessible via the 85 level with the 15-level utilised for bogging. The overall grade of ore produced for the month was planned to be 5%, with this stope containing an average ore of grade 8%, making it critical to achieve the monthly targets.

Standard practice at SKM was to employ packaged explosives and standard UG bulk emulsion for charging in upholes with lengths up to 10 m (33 ft) and dump angles of between 40º–50º for their trough blasting on the extraction level. In this blast however, the upholes were 15 m (49 ft) long with dump angles of 10º-20º. Charging with packaged explosive is a labour intensive and time-consuming process.

Figure 2. Current Scenario of the Pillar to be extracted

Figure 3. Blast Design

The drill and blast design of raises at SKM is as per VCR. Hence the downhole raise at BP 07 stope was also drilled as per VCR design; with uphole raise and rings to be drilled yet. The use of an LHR has the potential to reduce the blast cycle. The diameter of blastholes and reamers along with the burden and spacing of the design of the raise plays an important part in determining the void ratio, which is the ratio of the volume of rock mass to be blasted and the volume of void typically in the form of reamers. Usually the ratio should be > 40% for a good blast in single shot blast in LHR considering the swell of the broken rock [5]. As the void ratio increases, the probability of a successful blast increases. The major bottleneck that SKM possess is drilling accuracy and inaccurate drilling has caused a bottleneck in achieving production targets in the past. LHR (Long Hole Raising) requires accurate drilling and any deviation can freeze the blast and damage the entire stope/pillar.

SKM uses Datamine® Studio-3 software to plan the extraction of mine with targeted ore grade, however blast plan software is not used to decide the sequence of blast to get the desired result. Blasting softwares which are used to simulate the results and maintain the QA (Quality Analysis) & QC (Quality Check) of D&B (Drilling and Blasting) practices are essential to scrutinize the blasting operation.

Electronic detonators have reduced the vibration, but its limited usage has led to stagnation of knowledge among a handful of engineers. The accuracy of electronic detonators integrated with the initiation pattern of the blast plan can help to decide the plan and execute accordingly. SKM would need a software to plan the initiation pattern to improve its productivity in pillar blasting. This can help to determine the throw, burden relief, void ratio for reliability, and vibration for efficient and optimized blasting.

Proposed solution

Drilling

To address the above concerns, various solutions were discussed based on charging productivity, ore productivity, safety and availability of technology. The final approach after agreement from both teams, was to drill smaller diameter upholes of 64 mm (2.5 inches) and 89 mm (3.5 inches) downholes throughout slot drives and drill drives (as shown in Figure 4). The uphole raise was designed as per LHR, unlike downhole raise where holes were already drilled as per VCR pattern.

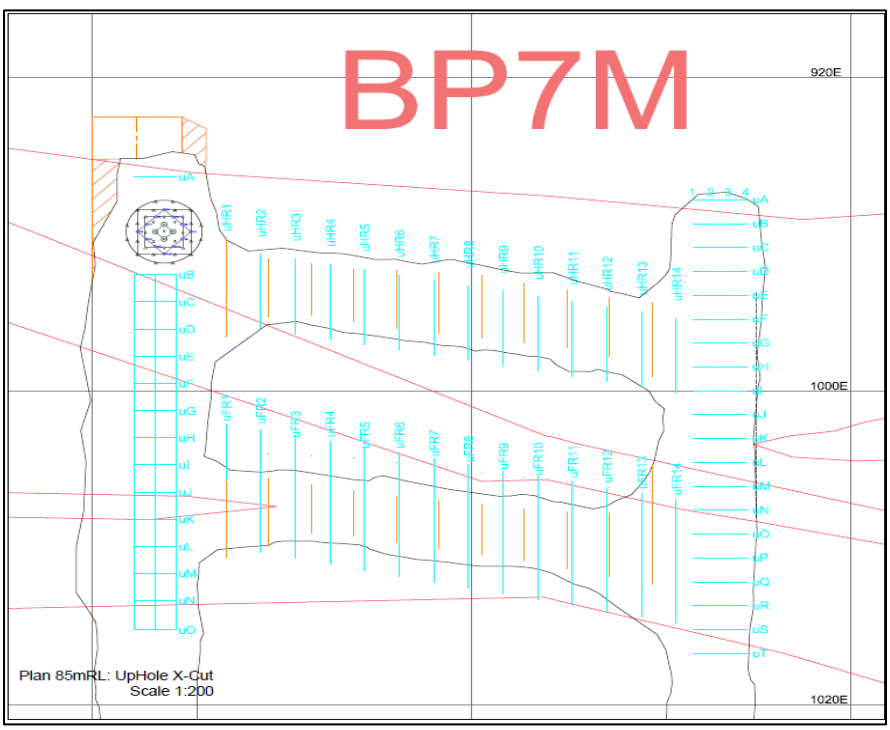

Figure 4. Stope drilling design

Charging

The existing bulk emulsion delivery system SKM is capable of charging downholes however it is not capable of charging upholes, hence this must be conducted with packaged explosives. Uphole charging with packaged explosives requires lot of time and manpower which subsequently increases the turnaround time for ore recovery; additionally, the retention is doubtful during blasting due to shock energy from subsequent holes and air blast. For efficient blasting of the pillars, SKM would need mechanized charging units for upholes and special bulk product to retain in the blastholes. Upholes in the slot drive would be charged employing packaged explosives and red caps (uphole retention devices) would be used at the collars to aid in up hole retention.

The charge design for the entire raise and slot drive was planned by Orica. it was determined the blast would be taken in two separate blasts. The uphole charging in the slot drive was done manually with the help of elevated working platform using packaged explosives. The down holes were charged with standard UG (Underground) bulk emulsion for better charging productivity although there are other associated benefits.

During the two charging phases in the slot drive, the uphole raise and subsequent raise-expansion holes were loaded with around 5.6 t (5.51 LT) of packaged explosives and 156 electronic detonators. Charging productivity of around 30 kg (66 lb) per man-hour was observed during this manual charging process. Uphole raise and center holes in raise-expansion rings were double-primed to lower the risks of misfire and hole dislocation. The downhole raise was blasted in slices upto 7 m (23 ft) lengths in the conventional way because it had already been drilled with VCR designs. After that downholes in the expansion slots were charged with around 4.3 t (4.23 LT) of ammonium nitrate emulsion and 88 electronic detonators.

Initiation

This blast utilized electronic blasting system to fire the entire slot drive in two phases. The electronic detonator system provided high accuracy delay timings and a large degree of flexibility. In the single shot blast in the uphole raise, the timing regime was designed to provide adequate burden relief for the rock to break into and create the necessary void for the other holes to break. The blast was timed in such a way that downholes would always fire ahead of the upholes to allow the broken rock to accumulate at the 15 level directly. The downhole raise was drilled earlier as per the conventional VCR design, with a void ratio of 12%. Since the ratio was found to be less than recommended for single shot blast as per LHR design, hence raising was done with firing in lifts of 2m (6.56 ft), till the length of the raise reached approximately 7 m (23 ft) from an initial length of 20 m (65.6 ft).

It was planned to take the entire slot drive in two blasts with the concept of dynamic void creation. In Phase I, the uphole raise, along with seven expansion rings at the top, the downhole raise of length 7m (23 ft), and along with eight downhole rings in the slot drive were fired. The downhole were fired sequentially ahead of uphole rings so that the broken rock from top had a clear path to the 15 level. In Phase II, remaining rings in the slot drive (consisting of 9 uphole rings and 5 downhole rings) were fired sequentially (as shown in Figure 5). This created the void for the footwall and hanging wall rings to fire against.

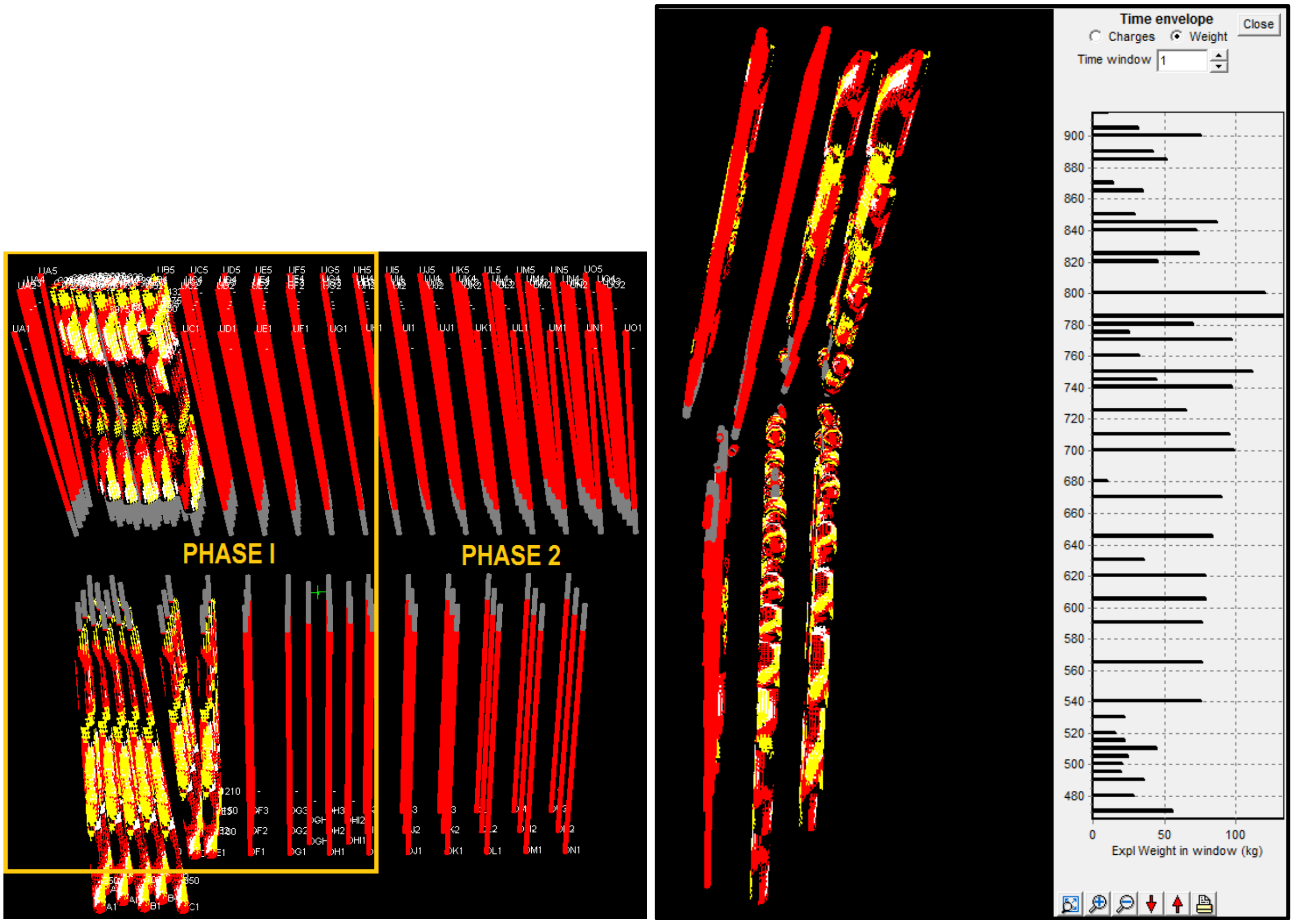

Figure 5. Blast Sequence Design

New Challenges

After successful firing of the entire slot drive in two phases, the uphole and downhole rings in the footwall and hanging wall rings were fired one by one into this generated void. One entire section of footwall and hanging wall ring containing upholes and downholes was fired in single shot with proper sequencing, considering the constraint of charging capability in 8-hours shifts. After firing five to six rings in both the footwall and the hanging wall sections, the side walls in the stope as well as the approaching drives developed cracks. With due caution, the authorities made the significant decision to extract the remaining 25000 t (24605 LT) of ore in a single blasting event (as shown in Figure 6), if possible without further exposure of personnel to such stressed ground conditions.

The mechanized bulk delivery system in uphole with better retention bulk emulsion was arranged in time for this blast. Hence, the mining team planned to blast the remaining 25000 t (24605 LT) of ore in a single blast helping to reduce worker exposure to the challenging ground conditions.

The final blast in the stope containing approximately 280 holes were loaded with 12 t (11.8 LT) of bulk emulsion and 320 electronic detonators. Upholes were loaded with the help of hose-pushers utilizing and a newly formulated highly viscous UG (Underground) bulk emulsion. This helped increase charging productivity increased to 1000 kg (2204 lb) per hour. The rings were differentially charged as per plan with accurate depth measurement undertaken. The boosters were placed in spider shells (booster holding devices in uphole) and positioned at the toes of the holes once a pillow charge (small amount of bulk emulsion at the toe of the hole) had been placed in the hole. Since there was no ingress of water and holes were clean, there were no requirement of bottle brushes (uphole retention devices) to aid in the retention of emulsion, however red caps (uphole retention devices) were placed at the collar as per the plan leaving behind pre-determined uncharged collars.

The entire section of footwall and hanging wall was fired with an intra-ring delay of 3-5 ms/m (0.9-1.5 sec/ft) of column charge and an inter-ring delay of 30-40 ms/m (9.14 – 12.2 sec/ft) of burden providing adequate burden relief and space. The delay in the last ring was further delayed to prevent freezing of the muck.

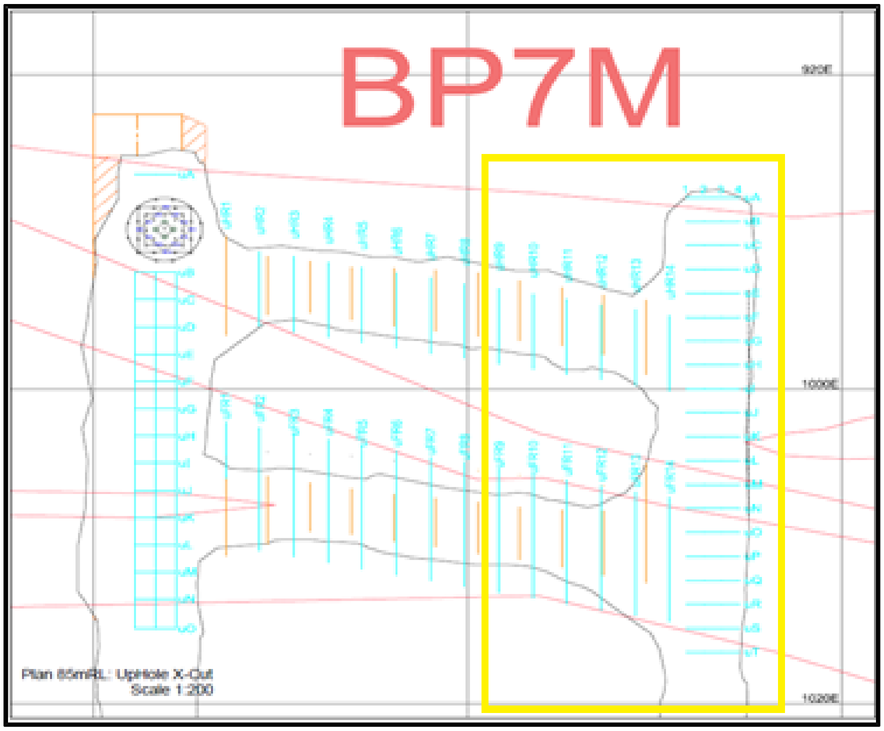

Figure 6. Demarcation of next blast in Stope

Conclusion and Future Work

The management at SKM were extremely satisfied with the results of the blast. The uphole blind raise was fired through in a single shot along (as shown in Figure 7) with crown of the floor creating void for the expansion holes in slot drive to be fired into. The charging time was reduced by around 60% with mechanized up hole charging technology with more robustness and control over the charging process. After a Cavity Monitoring System (CMS) scan was conducted it was found that the recovery of the stope was per the expectations for overall grade and dilution. The vector sum Peak Particle Velocity at SK village for stope blast was recorded to be 4.009 mm/s (1.2 ft/s) at 9.069 Seconds which was within mine permissible limits (as shown in Figure 7). With successful firing of the uphole raises in single blasting events; the mine is planning to eliminate one level of development which will save 2500 m (8202 ft) of development over a vertical level of 100 / 130 m (328 ft / 427 ft).

The mine has realized the potential benefit of Bulk emulsion with better ore recovery and efficient blasting (due to better coupling and variable density to minimize dilution).

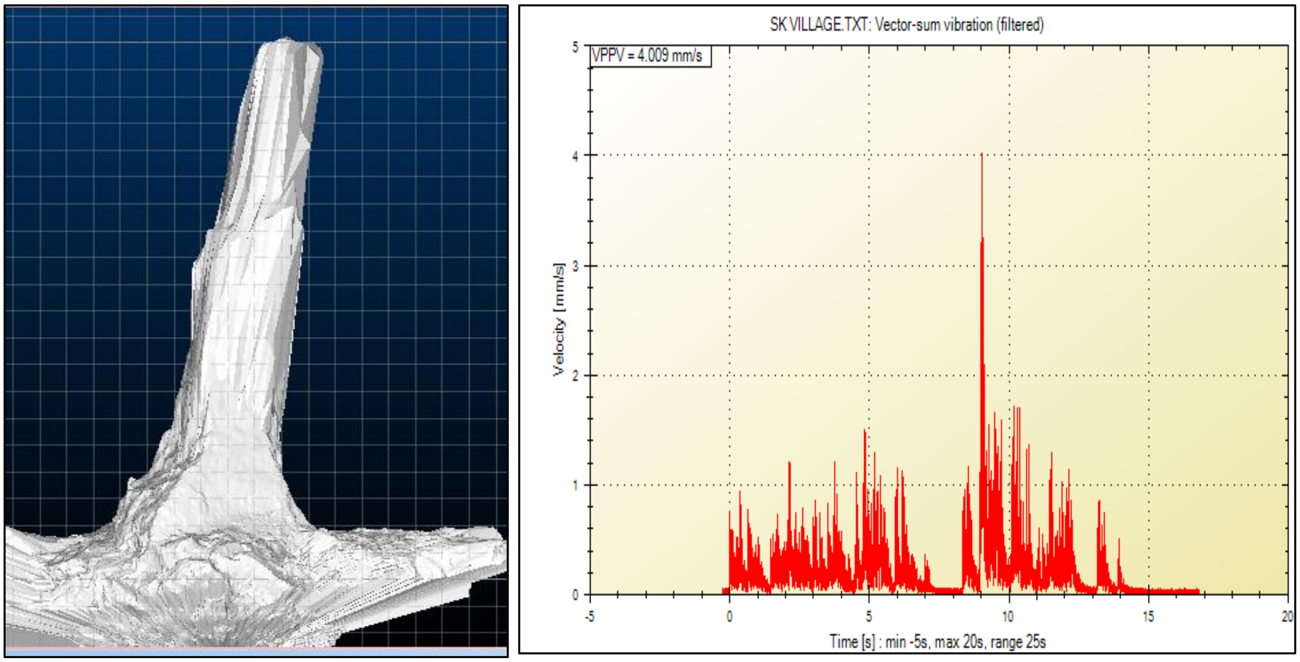

Figure 7. Excavated pattern and actual vibration

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