Interim report

SCIENTIFIC STUDY TO INVESTIGATE THE IMPACT OF SRP OC BLASTING ON A PROPOSED EXPLOSION-PROOF/ISOLATED STOPPING, WHICH ARE SITUATED WITHIN 125 M OF THE BLASTING AREA IN THE NUMBER 3 & 3A INCLINES, SRP AREA

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INVESTIGATION STATEMENT

The National Institute of Technology – Rourkela, carried out the scientific work documented in this report titled "**SCIENTIFIC STUDY TO INVESTIGATE THE IMPACT OF SRP OC BLASTING ON A PROPOSED EXPLOSION-PROOF/ISOLATED STOPPING, WHICH ARE SITUATED WITHIN 125 M OF THE BLASTING AREA IN THE NUMBER 3 & 3A INCLINES, SRP AREA**".

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1. INTRODUCTION

This report forms a part of the project work related to scientific study for investigating the impacts of Srirampur Opencast-II (SRP OC-II) blasting on proposed explosion proof/ isolation stoppings to be constructed in SRP No. 3 & 3A Incline underground mine.

SRP OC-II is an ongoing opencast project in Srirampur area. This project is dip side extension of SRP OCP-I up to a depth of 230 m. SRP OC-II Expansion Project is proposed by the mine management in which it is proposed to annex dip side property (which includes part of SRP 3 & 3A Incline property) to the existing SRP OCP-II.

SRP OC-II project is located in the southern part of the Somagudem–Indaram coal-belt in the Godavari Valley coalfield and forms part of Bellampalli Region of SCCL. The project is covered in Survey of India Topo Sheet No.56 N/5 and 56 N/9 and is bounded between the North latitude $18^0$48’02” and $18^0$51’18” and East longitude $79^0$28’46” and $79^0$31’44”. The block is falling in the Mancherial Mandal of Mancherial district in Telangana State.

The Project is connected to Mancherial/ Chennur Highway by 1.5 Km. Srirampur town-ship and Mancherial town are at a distance of 1.5 Km and 7.5 Km due west respectively. The nearest railhead is Mancherial Railway Station, which is at a distance of about 7.5 Km on Kazipet-Balharshah section of South-Central Railway.

1.1. Objectives

The main objective of the study is to assess the impact of SRP OC-II blasting on the proposed explosion proof/isolation stoppings, which will be situated within 125 m of the blasting area. Apart from the blasting impact analysis, the other objectives as follows:

- To suggest any modification to the proposed bench configuration planned by the project at annexing area where galleries are to be exposed or where parting is minimum.
- To assess and suggest the measures to be taken to prevent inundation of SRP 3 & 3A incline from SRP OC-II Expansion Project and vice versa.
- To assess the danger of fire/explosion and suggest suitable measures to prevent occurrence of fire/explosion due to annexing of part workings of SRP 3 & 3A inclines.

1.2. Methodology

In order to achieve the above objectives, the following methodology is followed:

- To attain the objective of estimation of safe explosive charge per delay for keeping the ground vibrations within the safe limits, field visits were made to collect general information about the mine and monitoring ground vibrations induced by blasting.
- A number of trial blasts were conducted to study various blast parameters related to blasting in overburden benches to understand the effect of the blast on the underground structures.
- Peak particle velocity, frequency of ground vibrations, and air overpressure due to blast at different distances from the blast site were measured using Minimate in the field and their readings were compiled for further analysis.
- Data related to explosives and blasting parameters is collected.
- Relevant data related to strata conditions, borehole data, hydrological conditions, status of boreholes, inundation, fire/explosion, proposed bench configurations are collected from SRP OC-II and SRP 3 & 3A inline mines.
- Conclusions were drawn based on the field investigations and modelling studies. Finally, suitable recommendations are made.

1.3. Field Investigations

A field visit was made, and a reconnaissance survey was done in August 2023. Explosives used, blasting pattern followed, method of working, bench configuration, details of proposed stoppings in underground mine, piezo metric data etc., were studied. Key plan of the project is presented in Figure 1. Due to the proposed expansion of SRP OC-II, part of workings of SRP 3 & 3A are needed to be annexed. Figure 2 shows the final quarry projections of proposed SRP OC-II expansion project and the 1-seam workings of SRP 3 & 3A Incline with proposed explosion stoppings.

There are ten coal seams namely IA, I, II, IIIB, IIIA, III, IVA, IV, V and VI were encountered in Srirampur OCP Block. Only six seams namely IA, I, II, IIIB, IIIA and III seams were considered for extraction in this project, which have attained workable thickness throughout the property and are extensively developed by underground method in SRP OCP-II area and virgin in the annexed property. Seams below III seam are very thin with huge partings in between, hence not considered for extraction. The status of workings of coal seams in SRP OC-II mine, proposed SRP OC-II extension area, and SRP 3 & 3A is presented in Table 1.

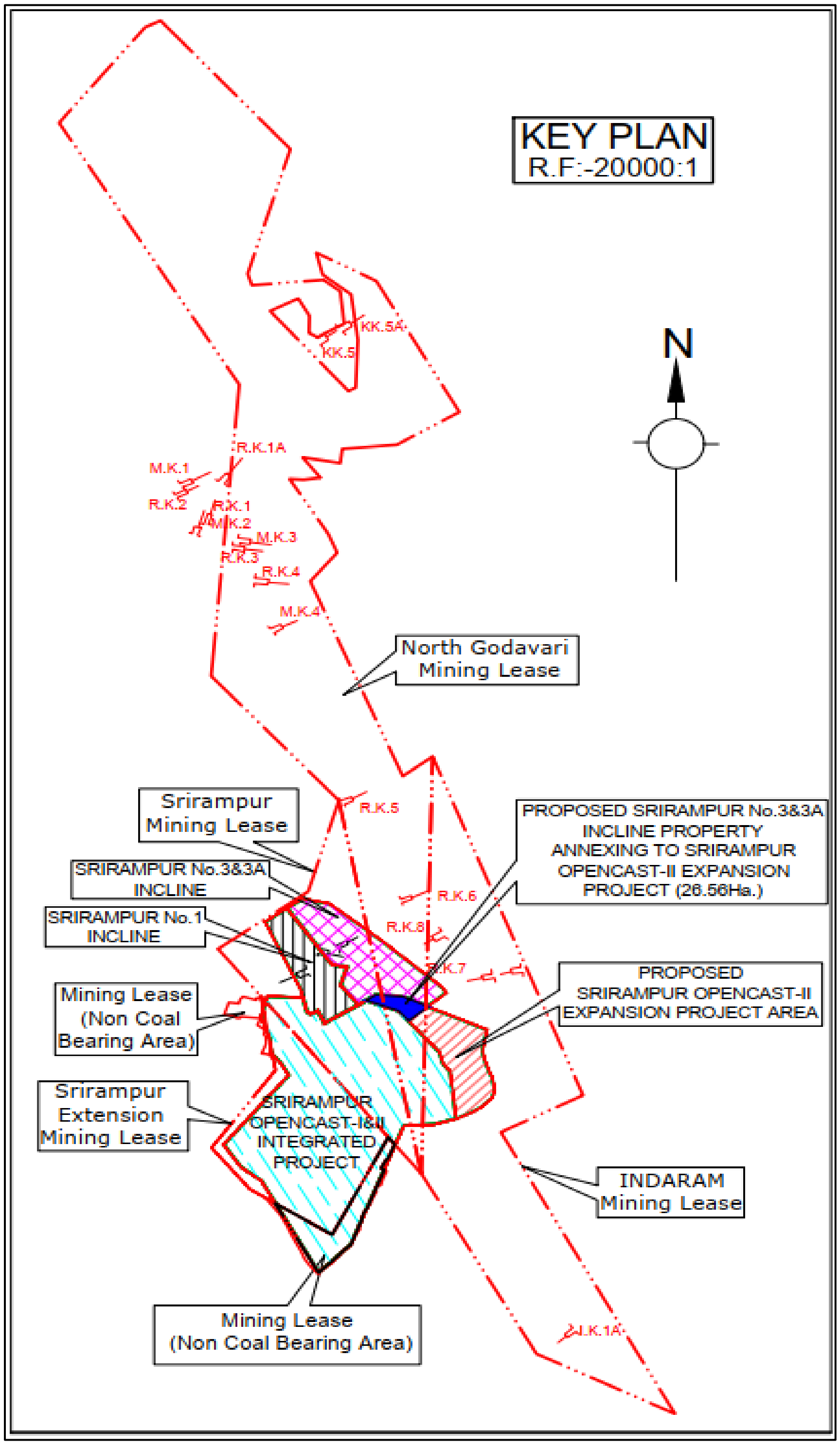

Figure 1. Key plan

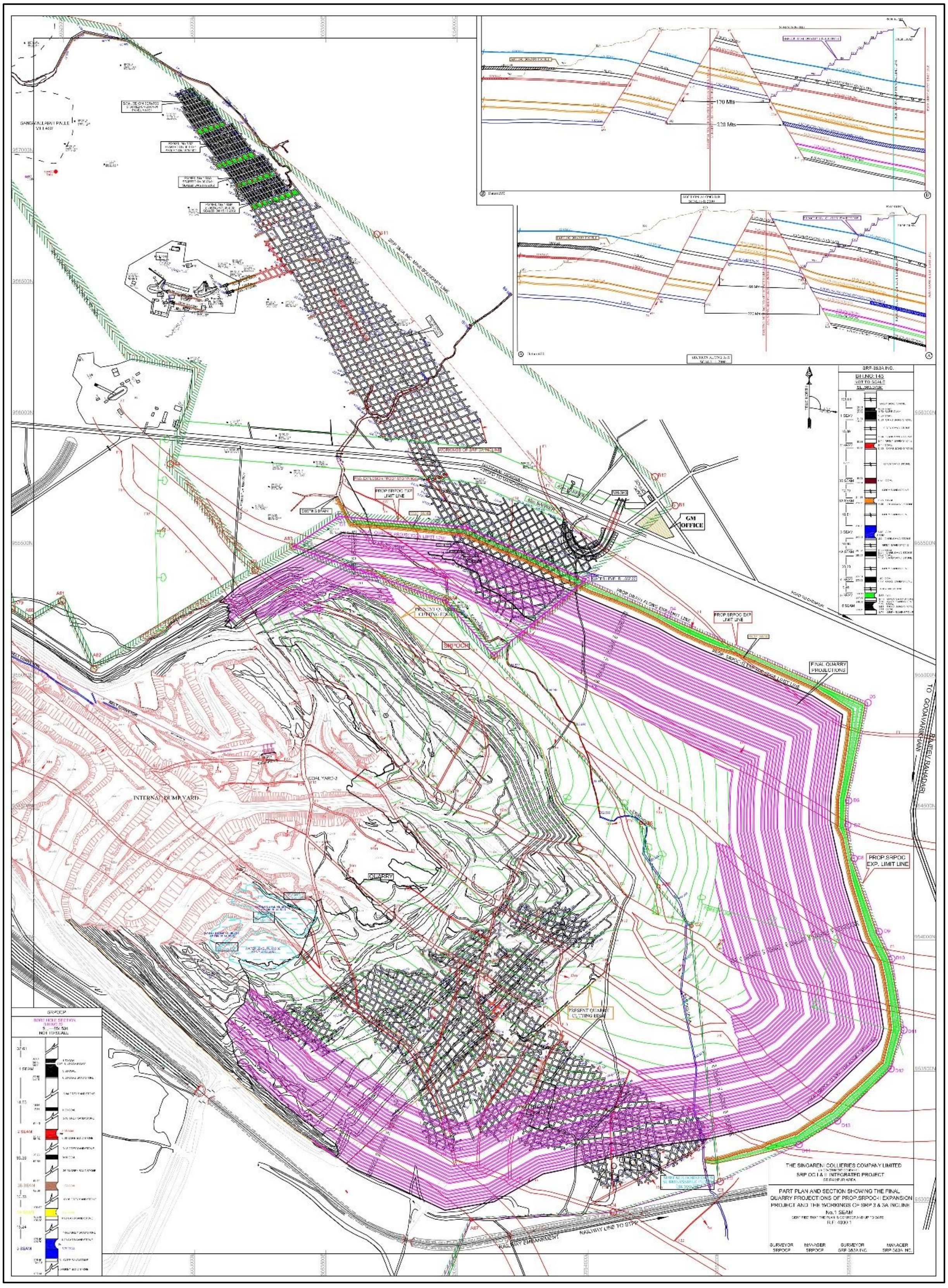

Figure 2. Mine boundary of proposed SRP OC-II Expansion project

Table 1. Status of coal seams

S. No.	Seam	SRP OC-II	Proposed Extension Area	SRP 3 & 3 A	
				Working	**RMR Value**
1.	IA	Virgin	Virgin	Virgin	
2.	I	Partly developed	Partly standing on pillars	Standing on pillars. Constructing explosion proof stoppings.	67.45
3.	II	Partly developed	Partly developed	Partly developed, non-vendable	53.10
4.	III B	Partly developed	Virgin	Standing on pillars	-
5.	III A	Partly developed	Virgin, Depillared with sand stowing	Depillaring with sand stowing	61.20
6.	III	Partly developed	Virgin, Depillared with sand stowing	Depillaring with sand stowing	55.00
7.	IV A	-	-	Partly developed.	-
8.	IV	-	-	South side partially Depillaring was completed.	51.03
9.	V	-	-	South side depillaring with stowing is under progress.	46.66
10.	VI	-	-	Goaf – Sand stowing completed	53.95

Figure 3 shows the preparation for trial blast. Trial blasting in overburden benches of SRP OC-II is done at different locations ranging from RL 706 to 760. For preparation of the overburden material, rectangular drill pattern is followed in different areas, 150mm diameter drills are used for drilling in the overburden material and coal seams. After drilling in the demarcated area drill holes are filled in with explosive material and explosive accessories are used in conjunction with main explosive material for initiation of the blast. NONEL initiation system with diagonal initiation connection is followed. The monitoring of the blast induced ground vibrations is done at various locations in both SRP OC-II and SRP 3 & 3A Incline mines as presented in Figures 4 and 5. The following are the average blasting parameters used for overburden during the trial blasts:

- Diameter of Blasthole (mm) : 150

- Burden (m) : 4
- Spacing (m) : 4.6
- Avg. depth of Blasthole (m) : 4.8

Figure 3. Preparation for experimental trial blast at SRP OC-II, SCCL

Figure 4. Ground vibration monitoring locations at SRP OC-II, SCCL

Figure 5. Ground vibration monitoring locations in 1 seam and 3 seam at SRP 3 & 3A, SCCL

2. GROUND VIBRATIONS AND AIR OVERPRESSURE

2.1. Generation of Ground Vibrations

When an explosive charge detonates, intense dynamic waves are set around the blast hole, due to sudden acceleration of the rock mass. The energy liberated by the explosive is transmitted to the rock mass as strain energy. The transmission of the energy takes place in the form of the waves (Figure 6). The energy carried by these waves crushes the rock, which is the immediate vicinity of the hole, to a fine powder. The region in which this takes place is called shock zone. The radius of this zone is nearly two times the radius of the hole. Beyond the shock zone, the energy of the waves is attenuated to some degree, which causes the radial cracking of the rock mass. The gas generated because of detonation enters into these cracks and displaces the rock further apart causing its fragmentation. The region in which this phenomenon takes place is called transition zone. The radius of this zone is twenty to fifty times the radius of the hole. As a result of further attenuation taking place in the transition zone, the waves although cause generation of the cracks to a lesser extent but they are not in a position to cause the permanent deformation in the rock mass located outside the transition zone. If these attenuated waves are not reflected from a free face, then they may cause vibrations in the rock. However, if a free face is available, the waves reflected from a free face cause further breakage in the rock mass under the influence of the dynamic tensile stress.

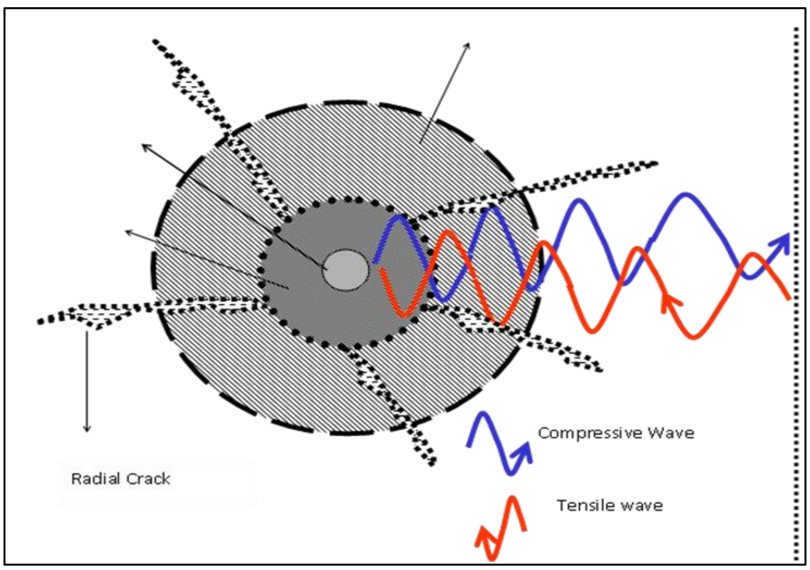

Figure 6. Various zones and the phenomenon of reflection of waves

2.2. Ground Vibration Waves

Blast induced ground vibrations, which are propagated in rock, can be divided into three categories:

i. Compression waves
ii. Shear waves
iii. Rayleigh waves.

The motion of the ground particle takes in three perpendicular directions viz. vertical, longitudinal, and transverse directions. For the compression wave, the particle moves along the direction of propagation (longitudinal), while the shear wave moves across this direction (transverse). The Rayleigh waves have elliptical particle movements in the vertical plane (vertical). The particles rotate backward in this plane.

The propagation velocity for the different wave types is dependent of the elasticity and density of the medium. Typical velocities for shear waves in rock vary from 2000-4000 m/s correspondingly for compression waves 3000-6000 m/s. For inhomogeneous and stratified rocks, the propagation of wave energy is complicated. During unfavorable conditions resonance and focusing effects may be created by the interference of incoming and reflecting waves. Under such conditions the vibrations may increase and not decrease when the distance from the blast source get larger. The three important wave characteristics, which are significant for blast damage, are amplitude, frequency and duration. The amplitude, which is given as acceleration, particle velocity or displacement, depends on detonating charge, length of the charge, confinement, damping conditions in the ground, the building response and the distance between the object and blasting. Concerning ground conditions and building response nothing can be done. Earlier peak particle velocity was the sole criterion for the ground vibration standards. However, after the role of frequency in the damage to the structures became known, it is now common to prescribe maximum permissible peak particle velocity along with corresponding frequency.

2.3. Prediction of Ground Vibrations

A number of investigators have studied ground vibrations from blasting and have developed theoretical analysis to explain the experimental data. The energy released is considered to be proportional to the square root of charge. Figure 6 shows the pictorial representation of the various zones and the phenomenon of reflection of waves. Earlier studies on wave propagation showed that the amplitude of particle displacement is be given by

$$A = K\,\frac{Q^{0.5}}{D}$$

Where, K is site constant; D is the distance and Q is the charge per delay.

Assuming the cylindrical explosive geometry for long cylindrical charges, researchers working on blast-induced ground vibrations concluded that any linear dimension should be scaled with the square root of the charge weight. Blasts should be scaled to the equivalent distance, which is the actual distance divided by the square root of the charge per delay. The corresponding relation known as USBM predictor equation takes up following form:

$$A = K\left(\frac{D}{Q^{0.5}}\right)^{\beta}$$

Where, K and β are site-specific constants, which depend on local geology and ground characteristics and other terms have their usual meanings. The USBM predictor equation is used in India for calculating maximum safe charge per delay for different distances according the standards fixed by DGMS. The value of K and β are determined by regression analysis of the data generated by trial blasts in terms of A, D and Q.

2.4. Damage Criteria

The damage criteria were proposed by many organizations including USBM and DGMS. Based on the permissible Peak Particle Velocity (PPV) in mm/s and Frequency of the ground vibrations for various types of structures as per DGMS Circular no. Tech 7 of 1997 as presented below in Table 2 are followed to estimate safe charge per delay and safe charge per round to keep the ground vibrations within safe limit in Indian geo-mining conditions.

Table 2. Permissible PPV at the foundation level of structures in mining areas in mm/s as per DGMS Circular no. Tech 7 of 1997

Type of structure	Dominant Excitation Frequency, Hz		
	<8 Hz	**8-25 Hz**	**>25 Hz**
(A) Buildings/structures not belong to the owner			
(i) Domestic houses/structures (kuchha brick & cement)	5	10	15
(ii) Industrial Buildings (RCC & Framed structures)	10	20	25
(iii) Objects of historical importance & sensitive structures	2	5	10
(B) Buildings belonging to owner with limited span of life			
(i) Domestic houses/structures (kuchha, brick & cement)	10	15	25
(ii) Industrial buildings (RCC & framed structures)	15	25	50

2.5. Parameters Influencing Propagation and Intensity of Ground Vibrations

The parameters, which exhibit control on the amplitude, frequency, and duration of the ground vibration, are divided in two groups as follows:

i. Non-controllable Parameters
ii. Controllable Parameters.

The non-controllable parameters are those over which the Blasting Engineer does not have any control. The local geology, rock characteristics and distances of the structures from blast site are non-controllable parameters. The controllable parameters are those over which Blasting Engineer has control. The amount of explosive per delay, stemming height, spacing, burden, and depth of hole are controllable parameters.

2.6. Air-Overpressure Pressure

Waves emanated in the atmosphere by the detonating charge is called air-overpressure/noise. The air overpressure is calculated in dB (A) or Pa. The frequency of the pressure waves in the range of 20 Hz to 20 kHz are in the audible range. The intensity of noise depends upon the quantity of the charge and its confinement. The principle sources of air-over pressure are:

- Detonation of unconfined charges.
- Too short stemming or improper stemming material
- Venting of high velocity gases through poorly designed blasts.

The dB (A) is calculated by the following formula:

$$dB = 20\log\left(P/P_o\right)$$

Where, P is measured pressure and P_o is the reference pressure of 0.00002 Pa. A low level of air-over pressure plays an important role in causing distress because of rattling windows. At present, there are no standards regarding levels of air-over pressure. However, type of the damage that occurs by air-overpressure (as established by different researchers) is reproduced in Table 3.

Table 3. Type of damage due to air overpressure

Structural Damage	Value in dB-L
Plaster Cracks	180
Loose Windows sash rattles	176
Failure of Badly Installed Window Panes	140-145
Failure of Correctly Installed Window Panes	Over 168
All Window panes Fail	176

Based on the USBM Standard for surface mining (RI 8485) as given in Tables 4 and 5, the air overpressure level of 134 dB(L) has been considered as safe limit for large scale surface mine blasting. Table 6 shows Central Pollution Control Board (CPCB) permissible levels for noise exposure for work zone area, India’s permissible levels for noise exposure for work zone area as prescribed under Model Rules of Factories Act, 1948. The standard limits for impulse sounds as per World Health Organization (WHO) guidelines for Noise is 120-140 (peak sound pressure (not LAmax, fast), measured 100 mm from the ear).

Table 4. Air overpressure limits by USBM for surface mining (RI 8485, 1980)

134 dB	0.1 Hz high pass measuring system
133 dB	2.0 Hz high pass measuring system
129 dB	5.0 or 6.0 Hz high pass measuring system
105 dB	C-slow (Events not exceeding 2 sec duration)

Table 5. Typical air overpressure criteria (Oriard, 2002)

171 dB	General window breakage
151 dB	Occasional window breakage
140 dB	Long-term history of application as a safe project specification
134 dB	Bureau of Mines recommendations following a study of large-scale surface mine blasting

Table 6. Central Pollution Control Board permissible levels for noise exposure for work zone area

Peak sound pressure in dB	Permitted number of impulse or impact/day
140	100
135	315
130	1000
125	3160
120	10000

2.7. Instrument used for Monitoring

Minimate Blaster is used for blast monitoring at various sites in and around the mine. Table 7 shows details of the instrument used for the study. The Minimate Blaster is a reliable blast monitoring in a simple and economic package.

- Small, rugged package for portability and easy setup.
- Simple menu driven operation.
- Easy one button.
- Download and reporting with Instantel Blastware software.

- Continuous monitoring.
- Integral monitoring log records time and duration of monitoring jobs.
- Auto Record mode allows for continuous recording as long as activity cycles about the trigger level.
- Fully compliant with the International Society of Explosives Engineers (ISEE) "Performance Specifications for Blasting Seismographs" requirements with the ISEE Linear Microphone and an ISEE Geophone (2250Hz).
- Fully compliant to the DIN 456691 Standard with optional DIN Geophone (1315Hz).

Table 7. Details of the instrument used for the study

Key Features	Easy to use Auto Record stop mode, Built for blasters
Channels	Microphone and Triaxial Geophone
Available Memory	30 events
Record mode	Manual and Continuous
Available sample rate	1024 to 4096 S/s per channel
Unit Dimensions	81 X 91 X160 mm
Unit weight	1.4 kg
User Interface	8 domed tactile keys
Product rank	Medium cost

2.8. Observations and Analysis

Monitoring stations in both SRP OC-II and SRP 3 & 3A incline mines and blasting sites during the trial experiments are shown in Figure 7. Red icons indicate the blast sites, blue icons represent monitoring stations in SRP OC-II and violet icons represents monitoring stations in SRP 3 & 3A underground mine.

The Minimate blaster, used for monitoring of PPV is placed at varying distances up to 1300 m from the blast sites in SRP OC-II mine. Monitoring in the SRP 3 & 3A underground mine is done in I, III and IIIA seams. The closest distance from blast site to the underground monitoring point is 610 m.

2.8.1. Observations

Ground vibration data obtained from different monitoring locations varied between minimum of 0.331 mm/sec to maximum of 6.525 mm/sec, which are, less than 10 mm/sec and are in safe limits for structures belonging to owner with limited span of life as per DGMS Circular no. Tech 7 of 1997. During the trial blasts, no PPV value is recorded at the monitoring stations placed in the SRP 3 & 3A incline underground mine.

Figure 7. Blast and monitoring locations

2.8.2. Analysis

Ground vibration monitoring stations for 22 experimental blasts in the mine were located during the investigations in between 150 m to 1300 m from the blast site. The data without PPV are excluded for regression analysis. Experimental blasts were conducted with explosive charge per delay in the range of 40 to 55 kg.

To predict the safe charge per delay for reducing the damage potential for various distances from the blast site, regression analysis is done. Details of monitoring distance, PPV, and blasting parameters collected during the experimental blasts are shown in Table 8. Scaled distance (SD) is calculated using the formula

$$SD = \frac{\mathrm{D}}{\sqrt{\mathrm{Q}}}$$

Where D is distance (m) from blast site and Q is maximum charge per delay (kg) as compiled in Table 8.

The scaled distance and PPV are compiled for regression analysis in Table 9. Figure 8 shows regression analysis for estimation of safe charge per delay.

Table 8. Ground vibration and other parameters collected from experimental blast

Sl. No.	Date of Blast	Burden (m)	Spacing (m)	Avg. Depth of Blasthole (m)	No. of Blastholes	Maximum Charge / Delay (kg)	Distance to Instrument 1 (m)	PPV 1 (mm/s)	Distance to Instrument 2 (m)	PPV 2 (mm/s)
1.	10.08.2023	4	4.6	4	285	45.0	154	6.08	391	2.522
2.	10.08.2023	4	4.5	4.5	293	55.0	250	1.714	500	2.160
3.	11.08.2023	4	5	5.3	298	50.0	789	1.222	813	1.51
4.	12.08.2023	4	4.5	5.7	247	55.0	185	3.000		
5.	13.08.2023	4	4.5	4.9	263	50.0	272	1.821		
6.	13.08.2023	4	4.8	5.5	215	55.0	150	6.525		
7.	14.08.2023	4	4.5	5	246	50.0	250	2.016		
8.	15.08.2023	4	4.5	5.3	261	50.0	498	1.699	549	1.967
9.	15.08.2023	4	4.7	4.7	160	50.0	350	1.635		
10.	16.08.2023	4	4.7	5.3	160	50.0	575	1.841		
11.	16.08.2023	4	4.8	5.2	306	50.0	450	2.461		
12.	17.08.2023	4	4.7	5.6	566	55.0	550	0.746	600	0.772
13.	18.08.2023	3.5	4.3	4.3	441	50.0	650	1.222	697	1.088
14.	20.08.2023	4	4.7	3.8	242	50.0	991	1.079		

15.	20.08.2023	4	4.8	4.7	237	50.0	750	0.937		
16.	21.08.2023	4	4.6	3.5	109	45.0	914	0.698		
17.	21.08.2023	4	4.7	5.1	269	50.0	850	0.82		
18.	22.08.2023	4	4.7	4	162	40.0	739	0.536		
19.	22.08.2023	4	4.9	5.2	349	40.0	1000	0.473		
20.	23.08.2023	4	4.7	5.2	223	50.0	1050	0.73	1100	0.536
21.	24.08.2023	4	4.7	5	374	50.0	1200	0.331		
22.	25.08.2023	4	4.6	5	326	50.0	1250	0.524	1300	0.457

Table 9. Scaled Distance of experimental blasts

Sl. No.	Date of Blast	Distance from Blast site (m)	Maximum Charge / Delay (kg)	Scale Distance	PPV (mm/sec)
1.	10.08.2023	154	45	22.96	6.080
2.		391	45	58.29	2.522
3.		250	55	33.71	1.714
4.		500	55	67.42	2.160
5.	11.08.2023	789	50	111.58	1.222
6.		813	50	114.98	1.151
7.	12.08.2023	185	55	24.95	3.000
8.	13.08.2023	272	50	38.47	1.821
9.		150	55	20.23	6.525
10.	14.08.2023	250	50	35.36	2.016
11.	15.08.2023	498	50	70.43	1.699
12.		549	50	77.64	1.967
13.		350	50	49.50	1.635
14.	16.08.2023	575	50	81.32	1.841
15.		450	50	63.64	2.461
16.	17.08.2023	550	55	74.16	0.746
17.		600	55	80.90	0.772
18.	18.08.2023	650	50	91.92	1.222

19.		697	50	98.57	1.088
20.	20.08.2023	991	50	140.15	1.079
21.		750	50	106.07	0.937
22.	21.08.2023	914	45	136.25	0.698
23.		850	50	120.21	0.820
24.	22.08.2023	739	40	116.85	0.536
25.		1000	40	158.11	0.473
26.	23.08.2023	1050	50	148.49	0.730
27.		1100	50	155.56	0.536
28.	24.08.2023	1200	50	169.71	0.331
29.	25.08.2023	1250	50	176.78	0.524
30.		1300	50	183.85	0.457

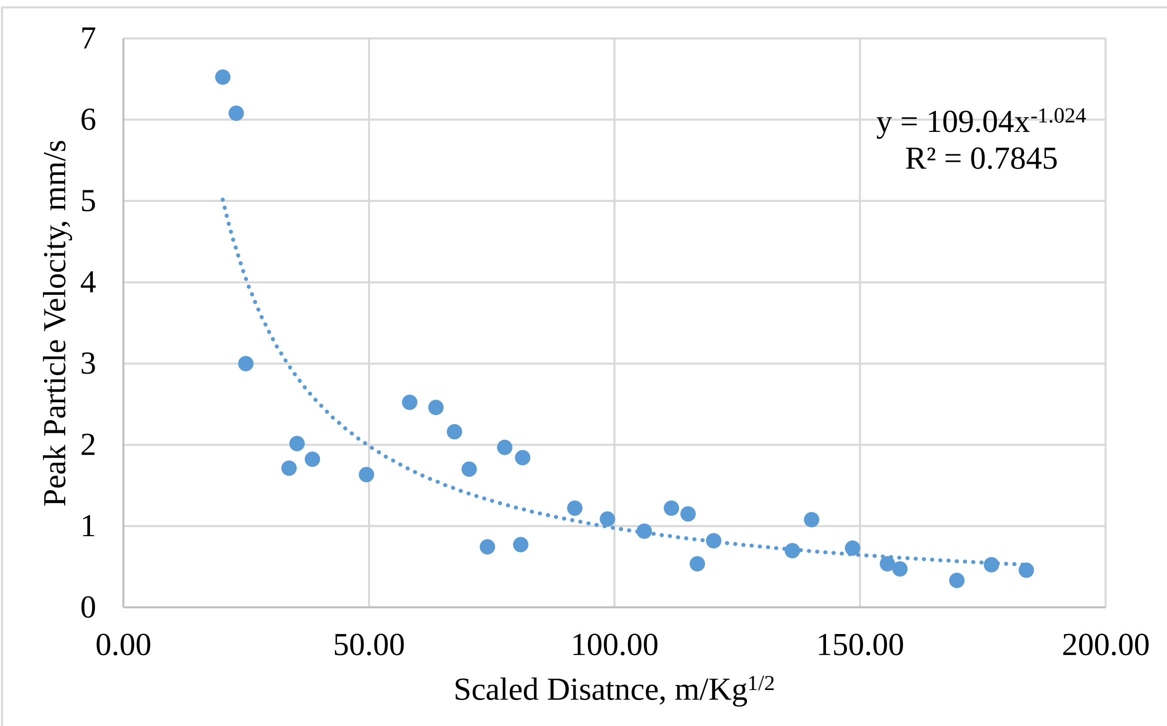

Figure 8. Regression analysis for estimation of safe charge per delay for the conditions of SRP OC-II mine

PPV = 109.04*(Scaled distance) $^{-1.024}$ (1)

Predictor equation (1) is developed from regression analysis in terms of the scaled distance (x) and PPV (y) for estimation of safe explosive charge per delay to keep the vibration level within the safe limits in SRP OC-II project.

Damage criteria vis-à-vis buildings / structures not belonging to the owner and buildings belonging to owner with limited span of life was considered for design of safe blast in the above geo-mining condition. Based on the regression analysis, safe charge per delay is estimated for different PPV limits as prescribed in DGMS Circular no. Tech 7 of 1997. The blasting pattern may be followed with the respective explosive charge per delay as shown in Table 10 for various distances from the blast site.

The Fly rock, fragmentation and muck pile compactness was assessed qualitatively using visual inspection. Air Overpressures measured in the above trial blasts was in the range of 88 to 136.6 dB, which is within the damage limits for any structures. Figure 9 shows the post blast fragmentation and muck pile obtained during trial blast.

Table 10. Safe Charge per Delay (Kg) for Different PPV values based on Regression Analysis

Monitoring Distance (m)	Predicted Charge per Delay (kg) for safe PPV limit of						
	2 mm/s	5 mm/s	10 mm/s	15 mm/s	20 mm/s	25 mm/s	50 mm/s
50	1	6	24	52	91	141	546
75	2	14	53	117	205	317	1228
100	4	24	94	208	364	564	2184
125	7	38	147	324	569	882	3412
150	10	55	212	467	819	1269	4913
175	13	74	288	636	1115	1728	6687
200	17	97	376	831	1457	2257	8734
225	22	123	476	1051	1844	2856	11054
250	27	152	588	1298	2276	3526	13647
275	32	184	711	1570	2754	4267	16513
300	39	219	847	1869	3278	5078	19652

350	53	298	1152	2543	4461	6911	26749
400	69	389	1505	3322	5827	9027	34938
450	87	492	1905	4204	7375	11425	44218
500	107	607	2352	5191	9105	14105	54590
550	130	735	2846	6281	11017	17067	66054
600	154	874	3387	7475	13111	20311	78609

Figure 9. Post blast fragmentation and muck pile obtained

2.9. Influence of Opencast Blasting on Proposed Explosion Proof/Isolation Stoppings

It is a known fact that the safety and stability of underground mine openings, coal pillars close to operating open-pit mines is often affected by blast induced ground vibrations. A study is conducted to evaluate the effect of heavy blasting in SRP OC-II opencast coalmine on the stability of explosion proof/ isolation stoppings constructed in SRP 3 & 3A, an adjoining underground coalmine.

In SRP OC-II opencast mine, six seams i.e., IA, I, II, IIIB, IIIA and III seams are planned to be extracted. Currently, IA, I, II seams are being worked. In SRP 3 & 3A incline mine, four coal seams are being worked, viz. I, IIIA, III, VI seams. Seam-I is completely developed and proposed to be sealed after construction of explosion proof stoppings. Explosion proof stopping are constructed in level 13 and 14; and being constructed in level 11 and 12. In IIIA and III seams depillaring with sand stowing is being done. Seam-VI is sealed after completion of sand stowing. The sectional view of opencast and underground workings are shown in Figure 10.

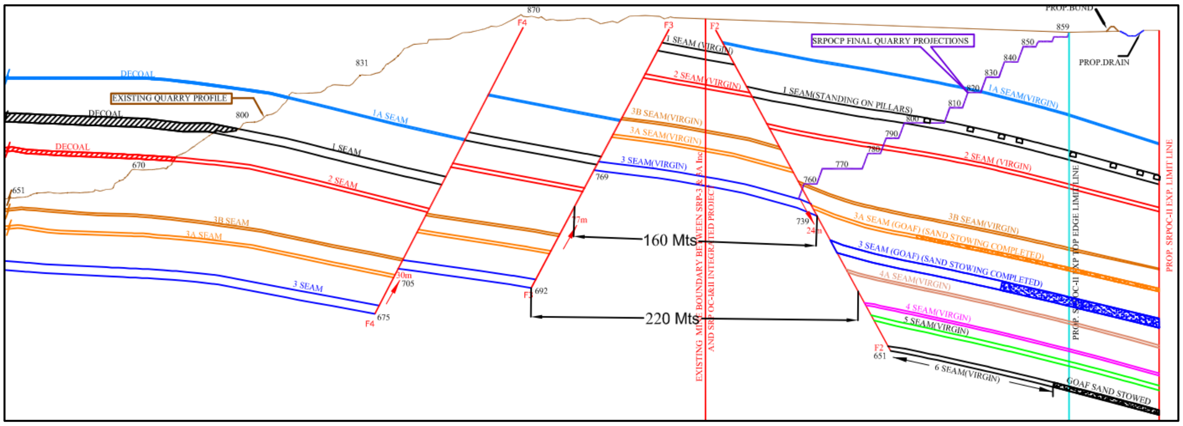

Figure 10. Sectional view of SRP OC-II and SRP 3 & 3A

The distance between the proposed explosion proof stoppings in I seam of SRP 3 &3A to current approved mine boundary is 644 m and to proposed extension boundary is 245 m as shown in the Figure 11.

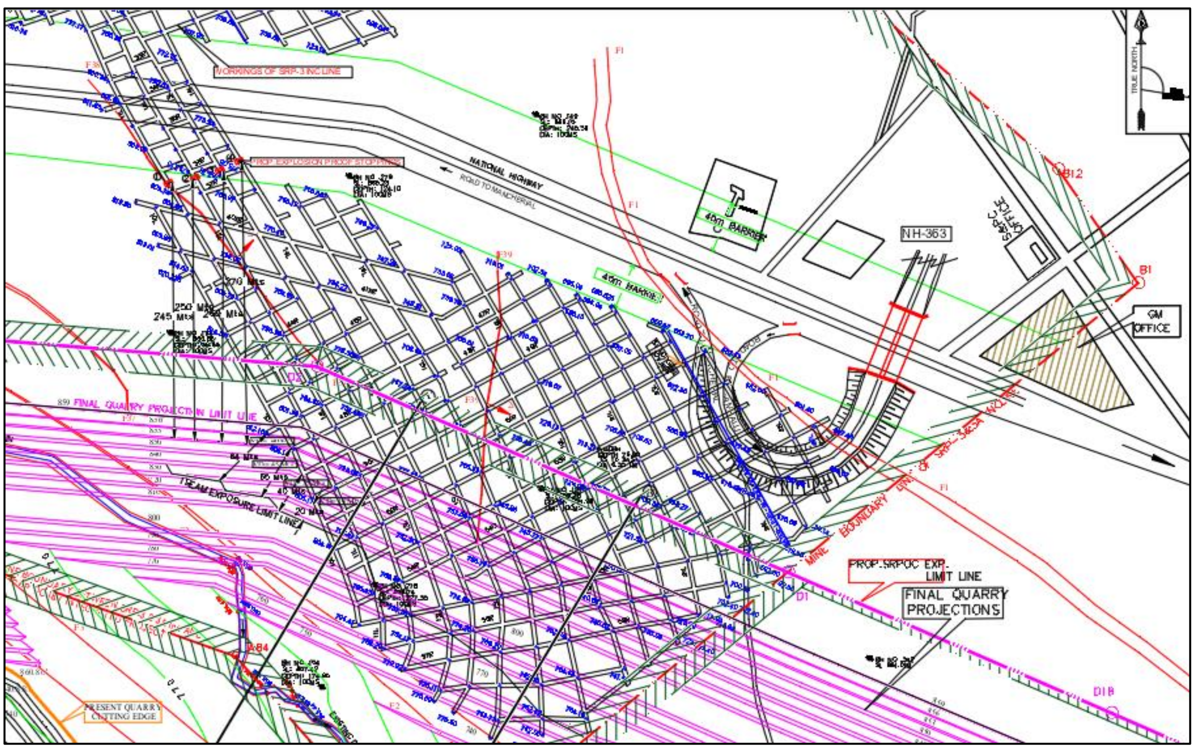

Figure 11. Part Plan of proposed SRP OC-II expansion project and workings of seam-I, 3 & 3 A incline

Previous studies conducted in other mines indicated damage in the roof and the pillars from surface blasting. These were in the form of cracks, fall of coal blocks and spalling of pieces of coal and rock materials in loose contact. The degree of damage depended upon the level of vibration produced from surface blasting. The roof of underground workings vibrated with higher PPV compared to the pillars. The amplification of vibration in the roof was further higher at junctions. The threshold value of vibration for the safety of underground workings is recommended based on the RMR of the roof rock according to the investigation done is shown in the Table 11.

Table 11. Threshold value of vibration for the safety of underground workings

RMR of Roof Rock	Threshold Value of Vibration in terms of Peak Particle Velocity (mm/s)
20-30	50
30-40	50-70
40-50	70-100
50-60	100-120
60-80	120

In the study, the vibration monitoring is carried out in I, III and IIIA seams. No PPV value is recorded in the underground monitoring stations due to blasting in opencast mine. Onsite blasting investigations were carried out on 11-12th August 2023 to evaluate effect of production blast undertaken in 3SP2 Panel of SRP 3 & 3A underground mine. The recordings are as shown in Table 12. Two vibration analyzers were stationed. One geophone is attached to the roof of the gallery and other is placed on the floor of the gallery. The maximum PPV value observed is 12.19 mm/sec, which falls well within acceptable limit.

Table 12. PPV observed in III seam of SRP 3 &3A mine

Sl. No.	Date of Blast	Maximum Charge / Delay (kg)	Distance to Instrument (m)	Roof Sensor - PPV (mm/s)	Floor Sensor -PPV (mm/s)
1.	11.08.2023	9.2	300	Nil	Nil
2.	12.08.2023	9.6	30	12.19	10.67
3.	12.08.2023	8.1	45	5.21	4.95

3. SLOPE STABILITY ANALYSIS

Different rock properties like density, compressive strength, tensile strength etc., were collected from the available borehole data from the mine management. Cohesive strength and angle of internal friction were estimated based on compressive strength and tensile strength using the RocScience's RocData software. Combining all these properties, a suitable set of rock properties were assigned bench wise as shown in Table 13 for modelling studies.

Table 13. Rock properties incorporated in modelling studies

Depth wise from top (m)	Unit Weight (KN/m^3)	Cohesion (KN/m^2)	Friction Angle (deg)
0 - 10	18.6	84.0	24.0
10-20	19.0	91.6	24.8
20-30	20.0	161.0	25.0
30-40	19.1	176.0	27.0
40-50	19.9	236.0	26.2
60-70	20.6	267.7	28.0
70-80	19.9	283.0	27.0
80-90	19.2	318.0	24.5
90-100	20.2	337.5	25.2
100-110	18.9	341.0	24.0
110-120	20.0	358.0	24.2
120-130	20.6	308.0	27.0
130-140	21.0	373.0	29.0
140-150	19.8	313.0	26.6
150-160	20.5	281.0	25.0
160-170	19.5	311.0	24.9
170-180	19.8	299.0	25.0
180-190	19.9	324.0	27.2

As per the scope of work, it has been decided to access the stability of benches in the annexing area towards 3 & 3 A incline underground mine under the following conditions:

- Case 1: Stability Analysis of Multiple Benches - Based on Surface Mine Plan with Ultimate Pit along Section A-A`
- Case 2: Stability Analysis of Multiple Benches - Based on Surface Mine Plan with Ultimate Pit along Section B-B`

3.1. Case 1: Stability Analysis of Multiple Benches along Section A-A`

The rock properties presented in the Table 1 are assigned to benches of the pit for carrying out the stability analysis. This case gives the stability analysis of 20 benches with a slope angle of 700 and with varying height and width, up to a depth of 167m. The bench configuration is presented in Table 14. The overall slope angle of the bench configuration is 32^0.

Table 14. Bench configuration – Section A-A`

Bench No. from surface	RL	Bench Height (m)	Bench Width Exposed (m)	Slope Angle (degrees)
1.	860-857	03	8.5	70
2.	857-854	03	8.5	
3.	854-850	04	8.5	
4.	850-840	10	8.5	
5.	840-830	10	8.5	
6.	830-820	10	8.5	
7.	820-810	10	8.5	
8.	810-800	10	8.5	
9.	800-790	10	26.6	
10.	790-780	10	8.5	
11.	780-770	10	8.5	
12.	770-766	04	8.5	
13.	766-760	06	43.0	
14.	760-750	10	7.6	
15.	750-740	10	7.6	

16.	740-730	10	7.6	
17.	730-720	10	7.6	
18.	720-710	10	7.6	
19.	710-700	10	7.6	
20.	700-693	07	7.6	

Under this condition, circular failure has resulted in 2.096 Factor of Safety (FOS) with Bishop's method and 1.927 with Janbu's method as shown in Figures 12 and 13 respectively. As the FOS values are more than 1.5, this case can be considered as safe.

During rainy season, the saturation level of rock mass goes up resulting increased density and pore pressure which may influence the stability of slopes. So, by increasing the density marginally, the entire above case is reassessed under wet condition. Under wet condition, the FOS was found to be 1.993 and 1.840 for circular failure condition with Bishop's and Janbu's methods as presented in Figures 14 and 15 respectively. In this case also, as the FOS values are more than 1.5, this case also can be considered as safe.

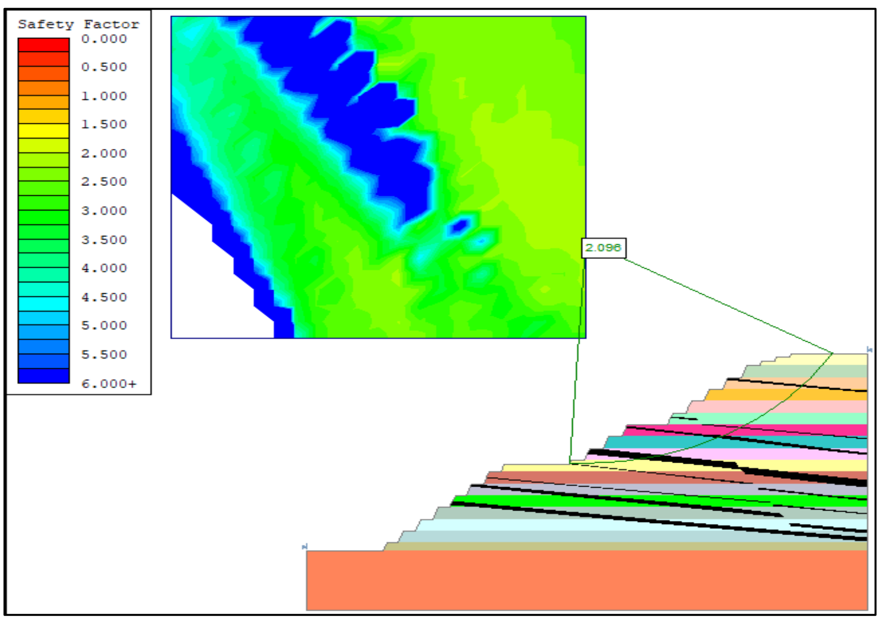

Figure 12. FOS of multiple benches along section A-A` under circular failure using Bishop Method

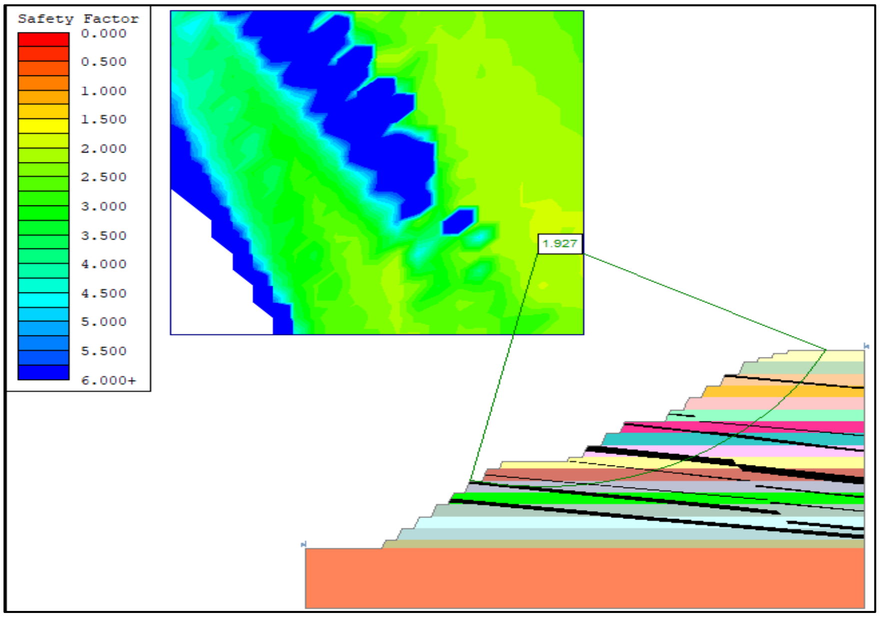

Figure 13. FOS of multiple benches along section A-A` under circular failure using Janbu Method

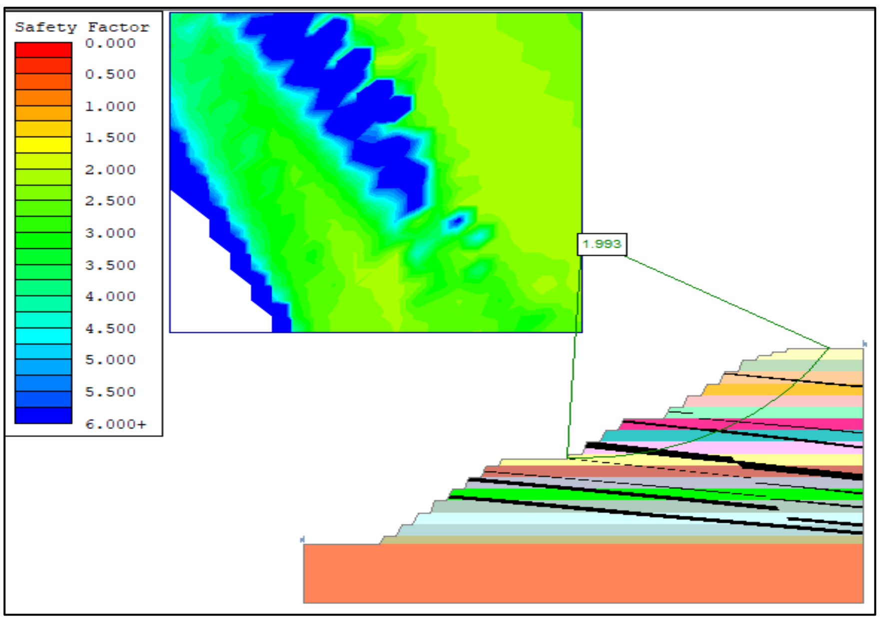

Figure 14. FOS of multiple benches along section A-A` under circular failure using Bishop Method – Wet condition

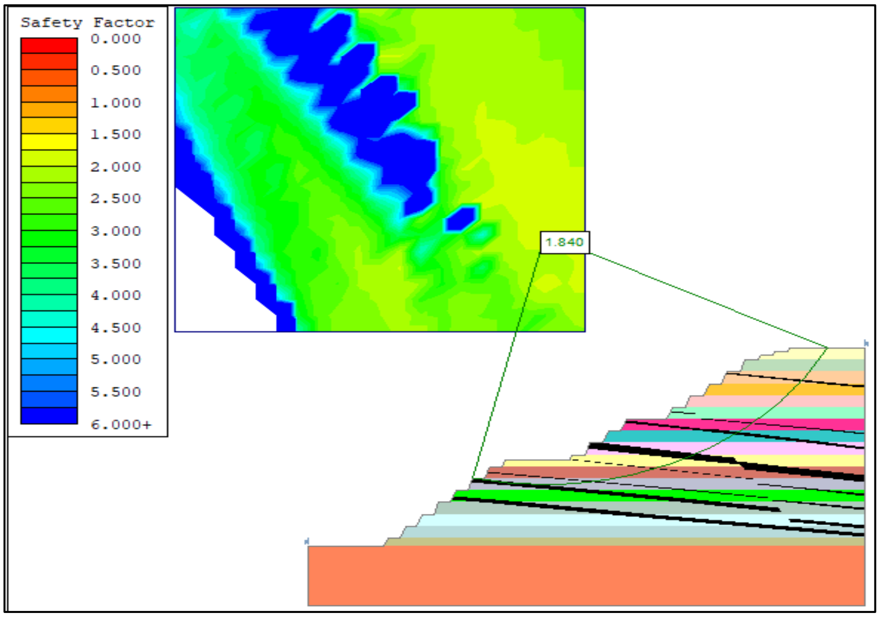

Figure 15. FOS of multiple benches along section A-A` under circular failure using Janbu Method – Wet condition

3.2. Case 2: Stability Analysis of Multiple Benches along Section B-B`

This case gives the stability analysis of 21 benches for a depth of 180m. The benches configuration is presented in Table 15. The overall slope angle of the bench configuration is 23^0.

Table 15. Bench configuration – Section B-B`

Bench No. from surface	RL	Bench Height (m)	Bench Width Exposed (m)	Slope Angle (degrees)
1.	860-857	03	8.5	
2.	857-854	03	8.5	
3.	854-850	04	8.5	
4.	850-840	10	8.5	
5.	840-830	10	8.5	70
6.	830-820	10	8.5	
7.	820-810	10	8.5	
8.	810-800	10	8.5	
9.	800-790	10	26.6	

10.	790-780	10	8.5	
11.	780-770	10	8.5	
12.	770-760	10	26.6	
13.	760-750	10	8.5	
14.	750-740	10	8.5	
15.	740-736	04	26.6	
16.	736-730	06	138	
17.	730-720	10	6.5	
18.	720-710	10	6.5	
19.	710-700	10	6.5	
20.	700-690	10	6.5	
21.	690-687	10	6.5	

Under this condition, circular failure has resulted in 2.018 FOS with Bishop's method and 1.894 with Janbu's method as presented in Figures 16 and 17 respectively. As the FOS values are more than 1.5, this case can be considered as safe.

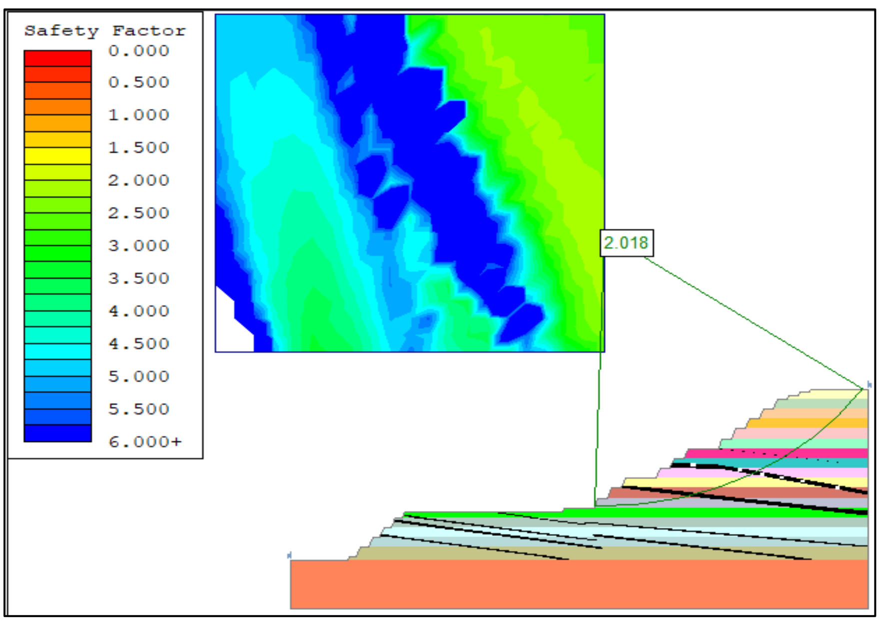

Figure 16. FOS of multiple benches along section B-B` under circular failure using Bishop Method

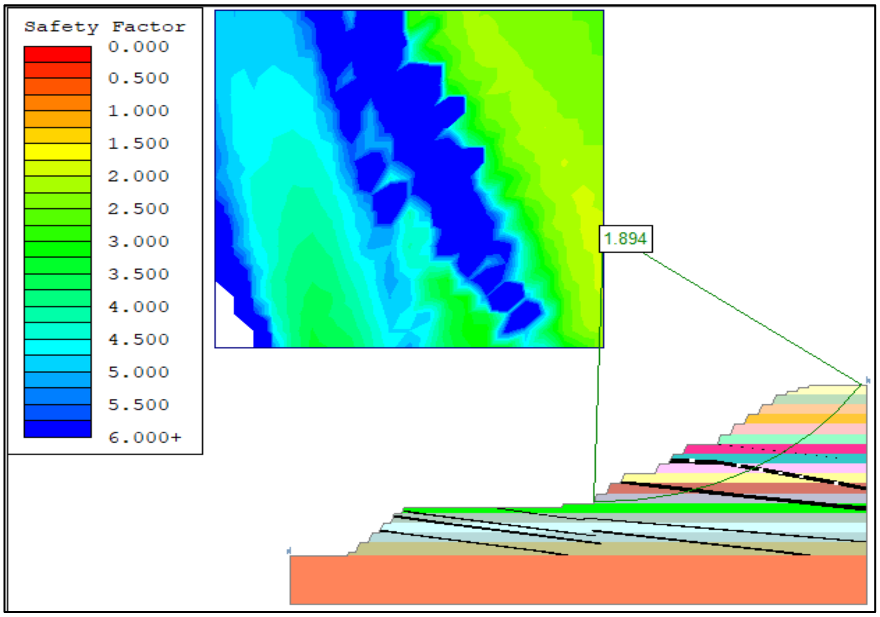

Figure 17. FOS of multiple benches along section B-B` under circular failure using Janbu Method

Under wet condition, the FOS was found to be 1.929 and 1.811 for circular failure condition with Bishop's and Janbu's methods as shown in Figures 18 and 19 respectively. In this case also, as the FOS values are more than 1.5, this case also can be considered as safe. The summary of the stability analysis of different cases are represented in Table 16.

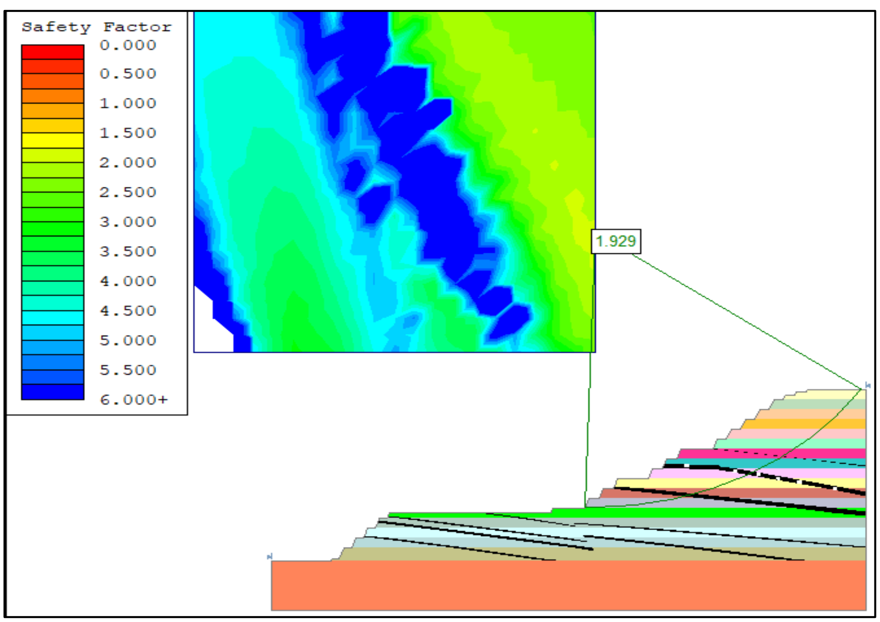

Figure 18. FOS of multiple benches along section B-B` under circular failure using Bishop Method – Wet condition

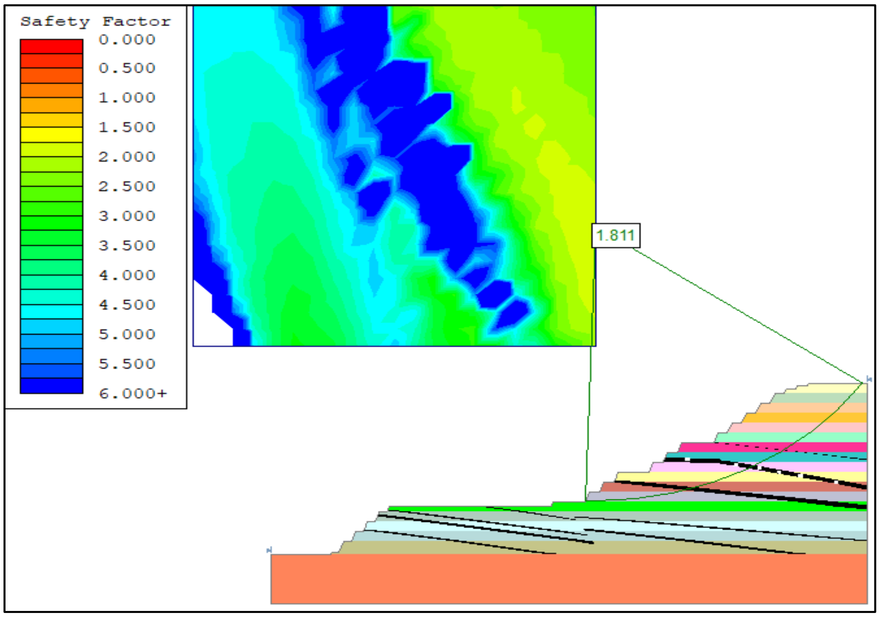

Figure 19. FOS of multiple benches along section B-B` under circular failure using Janbu Method – Wet condition

Table 16. Summary of FOS values

Bench Condition	Dry/wet Condition	Type of failure	Method	FOS	Remarks
Case 1	Dry	Circular	Bishop	2.096	Safe
			Janbu	1.927	Safe
	Wet	Circular	Bishop	1.993	Safe
			Janbu	1.840	Safe
Case 2	Dry	Circular	Bishop	2.018	Safe
			Janbu	1.894	Safe
	Wet	Circular	Bishop	1.929	Safe
			Janbu	1.811	Safe

4. ASSESSMENT OF INUNDATION AND MINE FIRE/ EXPLOSION

To assess the probability of inundation and mine fire/explosion in SRP 3 & 3A incline, and SRP OC-II project, qualitative risk assessment is conducted.

4.1. Assessment of Inundation

The sudden or gradual inflow of water from either surface or underground may lead to mine inundation. Gradual inflow of water can be easily managed by pumping out water. However, the sudden inflow of water in mines is hard to control and created maximum damage by drowning equipment, workings, and people.

The source of inundation can be from surface or underground water. Tanks, reservoirs, rivers, nallah, accumulated water in old opencast mines or low-lying areas are the sources of surface water. Sump in same seam or another seam, water logged working in adjoining mine, old water logged workings in same or another seam, and highly water bearing strata overlying the working seam are the sources of underground water. Annexing a part of the workings of SRP 3 & 3A incline introduces new hazards to both SRP 3 & 3A incline, and SRP OC-II projects. The risk of inundation in SRP 3 & 3A incline and SRP OC-II project in the proposed annexed area are presented in Tables 17 and 18 respectively. Only the risks associated with the annexure of SRP 3 & 3A are included in the analysis.

Table 17. Risk of inundation in SRP 3 & 3A incline

S. No.	Hazard(s)	Recommended Control(s)
1.	Nallah No. 2 is a drainage nallah of SRP colony and other hutment area passing over the south side property of all seams.	Bushes in the nallah are to needed to be cleared as and when required.
2.	In the annexed area, water may enter in to seams of underground mine through exposed developed seams.	1. Exposed developed coal seams/pillars are need to be clearly marked in plans. 2. Wherever the opencast workings reach within 10 m, from the side of underground workings, the area is to be identified as critical zone and to be marked on ground. 3. Fencing/caution boards shall be erected.

		4. Provide and maintain proper drainage in the working benches of the SRP OC-II. 5. The exposed galleries are needed to be filled/ compacted with overburden material from the benches of SRP OC-II before forming the ultimate pit. 6. Arrangements shall be made to monitor the accumulation of water on the dip side of 1 seam by using piezometer / water level indicator through surface borehole or through flowmeter connected to inter seam boreholes. 7. Arrangement shall be made to provide water level alarms. 8. Arrangements shall be made to drain the accumulated water on the dip side of 1 seam by drilling surface borehole with a submersible pump, when the accumulated water reaches the danger limit.

Table 18. Risk of inundation in SRP OC-II project

S. No.	Hazard(s)	Recommended Control(s)
1.	Nallah No. 2 is passing though the proposed annexing area	Nallah need to be diverted to proposed mine boundary of SRP OC-II expansion project.
2.	In the annexed area, water may enter in to opencast mine through identified or unidentified geological disturbances.	1. Regulations150 (2) and Reg.149 (9) & (10) of CMR, 2017 shall be strictly complied. 2. Provide and maintain proper drainage to let the water flow into designated sumps away from working areas

4.2. Assessment of Mine Fire / Explosion

The degree of gassiness in I, II, IIIB, IIIA, III, IVA, IV, V, VI seams of SRP 3 & 3A incline underground mine is Degree-I. The seams susceptibility to heating ranges from highly susceptible to moderately susceptible in both SRP 3 & 3A incline, and SRP OC-II projects. Annexing a part of the workings of SRP 3 & 3A incline introduces new hazards to both SRP 3 & 3A incline, and SRP OC-II projects. Fire in pillars of seam-I of SRP 3 & 3A incline can lead to failure of surface cover, which in turn can lead to inundation. The risk of mine fire/explosion in SRP 3 & 3A incline and SRP OC-II project in the proposed annexed area are presented in

Table 19. Only the risks associated with the annexure of SRP 3 & 3A are included in the analysis.

Table 19. Risk of mine fire/explosion in SRP 3 & 3A incline and SRP OC-II project

S. No.	Hazard(s)	Recommended Control(s)
1.	In the annexed area, air may enter in to seam-I through exposed developed seams leading to spontaneous heating.	1. Exposed developed coal seams/pillars are need to be clearly marked in plans. 2. Wherever the opencast workings reach within 10 m, from the side of underground workings, the area is to be identified as critical zone and to be marked on ground. 3. The exposed galleries shall be sealed off by isolation stopping from outside of pillar corner. The isolation stoppings shall be plastered with cement and white washed. Where construction of isolation stopping is not possible, there the exposed galleries shall be filled/compacted with overburden/inert material from the benches of SRP OC-II before forming the ultimate pit. 4. Water jets or firefighting equipment shall be provided near exposed galleries. Wherever the coal pillars are exposed towards opencast mine, water spraying should be practiced. 5. The entire surface and inter seam bore holes shall be properly plugged. 6. Arrangements shall be made to monitor the temperature, accumulation of gases in seam-I.

5. CONCLUSIONS & RECOMMENDATIONS

Conclusions and recommendations on the basis of the scientific experimental studies conducted from 03/08/2023 - 27/08/2023 and analysis of blasting practices being adopted before start of experimental blast for blasting in overburden benches in SRP OC-II project are as follows:

5.1. Conclusions

- Ground vibration data obtained from different monitoring locations varied between minimum of 0.331 mm/sec to maximum of 6.525 mm/sec, which are, less than 10 mm/sec and are in safe limits for structures belonging to owner with limited span of life as per DGMS Circular no. Tech 7 of 1997.

- The Blasting practices being adopted in the mine before conducting experimental blast were designed to keep the Ground vibration under safe limit as Prescribed under DGMS Circular no. Tech 7 of 1997.

- There is no impact of opencast blasting on the underground explosion proof stoppings.

- Air overpressures were observed to be within damage limits for the existing blasting practices.

- All blasts conducted during the experimental studies were safe with respect to vibration, air overpressure and fly rock.

- From the Table 16, it can be concluded that, the FOS values of proposed bench configurations are higher than critical value of 1.5, indicating a safe condition.

5.2. Recommendations

5.2.1. Influence of Blasting

- The blasting in SRP OC-II mine has no influence on SRP 3 & 3A explosion proof stoppings. However, change in blasting pattern or other blasting parameters can increase the ground vibrations and as the proposed boundary of SRP OC-II reaches up to 125m from the explosion proof stoppings being constructed in levels 11, 12, 13, 14 of 1 Seam, the impact of opencast blasting on the underground explosion proof stoppings may be observed.

  As per Table 11, the threshold value of vibrations for the safety of SRP 3 & 3A explosion proof stoppings is 120 mm/s. The basis of reduction in ground vibration is to control maximum charge per delay. Hence, it is recommended to use the respective explosive charge per delay as shown in Table 10 to keep ground vibration within damage limit for various distances from the blast site. The acceptable techniques for controlling the charge per delay are:

  - Reducing the hole depth.
  - Using small diameter holes.

- Delayed initiation of deck charges in the blast holes.
- Using more numbers of delay detonators series.
- Using sequential blasting machine.
- Maintaining a minimum of 8 ms delay between any two holes in the whole blasting patch.

- The Central Government have prohibited the manufacture, possession and import of the electric detonator (explosive of Class 6 Division 3 or UN Class 1 Division 1) throughout the country with effect from the 1st day of April 2025. In view of that, electronic detonators are suggested to be utilized for initiation. Electronic detonators many have advantages over electric detonators:
  - Precise delay can be set through the programme with an accuracy of ± 1 ms.
  - Unlike electric detonators, the wire leads of electronic detonators do not attach directly to a match head or bridge wire.
  - Electronic detonators feature additional protection from extraneous energy sources, such as a spark gap device to protect against static discharge events, as well as current limiting resistors.
  - Although both types of detonators are susceptible to damage by an electromagnetic pulse, electronic detonators typically have built-in protection from electromagnetic pulse.
  - Whereas electric detonators can be used with any appropriate firing device, electronic detonating systems remain unique and must never be interchanged.

- However, in order to provide maximum protection to the proposed explosion proof stopping in the 1 seam of SRP 3 & 3A incline mine, following additional precautions may also be adopted:
  - Limit the explosive confinement to bedrock if the overburden can be excavated by other means.

- Square patterns produce more vibrations.
- Limit frequency of blasting
- Time the blasts with high ambient noise levels
- Use controlled blasting techniques.
- Use a low VOD and low-density explosive.

- Further steps for reduction of Air Over Pressure:
    - Use of NONEL in place of D-cord in the blasts near the residential area.
    - Reduction in the size of the blast.
    - Avoiding top initiation.
    - Avoiding excessive delays between the rows.
    - Avoiding blasting in early morning, late afternoon and evening when temperature inversions are likely to occur.
    - Avoiding blasting when the wind is blowing towards residential area as the sound waves travel in the direction of the wind.

5.2.2. Stability of Slopes

SRP OC-II and SRP 3 & 3A incline projects consist of highly non homogeneous formation with multiple fault planes with different orientation. It's very difficult to model all the field conditions. The modelling is done on the preliminary investigations. Even though the modelling studies under different conditions indicated safe conditions, the following additional recommendations are made for maximizing the safe conditions in working and highwall benches in SRP OC-II project.

- As far as possible, the working bench should be wider to the possible extent in all the cases, except in highwall cases. It is better to maintain a 25m wide or as per the guidelines of regulating bodies.

- The mine management should inspect the benches periodically to see if any minor or local discontinues/disturbances, which may cause slope failures. A competent officer may be given this responsibility.

- The stabilities of pit slopes and dump slopes shall be reviewed once at least in 6 months with the progress of the excavation.

- As far as possible benches should not be parallel to fault planes to avoid failures.

- It is always better to inspect the benches after the blasting operations, as blasting being a dynamic activity may influence bench stability. If any loose /hanging rock found, it is better to clear before taking the next cyclic operations.

- It is also always advisable to clear the fragmented material before the next blast, as the fragmented material acts as external load on the bench.

- After every blast, a competent officer should inspect the blasted bench and adjacent benches for any slope failure/possible failure.

- The mine management should maintain an effective drainage system in order to avoid inrush of water during rainy season on to the benches. An effective drain management system should be in place. Even in peak rainy day, the water should move away from the benches/workings.

- Effective channels should be maintained to channelize the rain water which is falling within mine premises/on the benches. Every step to be taken to avoid the rock mass to move from dry condition to fully saturated condition. As saturation level increases, the stability of rock decreases.

- It is advised to monitor the Godavari River water flow during rainy season in consultation with the local government officials to assess any danger to the mine workings from time to time.

- All other recommendations of DGMS Circular No 02 of 2020, Dated 09.01.2020 & Circular No. 3 of 2020 Dated 16.01.2020 shall be strictly complied.

- Any modelling study assumes the rock is homogeneous to some extent and assigns the properties to analyze the slopes. But in reality, the rock is non-homogeneous, and there could be many other discontinuities as the benches progress, or any other factor which is not included in the study may lead to failure of benches. In such cases any failure can be avoided by regular monitoring and physical inspection of benches.

5.2.3. Extraction of Developed Coal Seams

- Extraction of pillars in developed coal seams by opencast method is beset with the following problems:

  1. The HEMM may sink into the galleries, if overburden is too thin

     - To avoid the HEMM sinking into the galleries, hydraulic shovels with back-hoe are preferred for removal of overburden.
     - For blasting pillars, horizontal drilling will offer advantages in view of difficulty to position the drill on the top of the pillar.
     - Front-end loaders could be used for loading coal as well as for cleaning the overburden rock fallen during blasting.
     - Where ever the opencast workings reach within 10 m, from the roof of underground workings, the area is to be identified as critical zone and to be marked on ground.
     - Water pipe lines are to be laid nearer to the critical zone, to deal with the anticipated fire.
     - Where ever the opencast workings reach within 6 m, from the roof of underground workings, the area is to be identified as danger zone.
     - To ascertain the exact position of the gallery, test holes are to be drilled, before going for blast hole drilling to avoid puncturing of holes into the galleries.

- All the blasting operations in the danger zone shall be carried out scrupulously in overburden and coal up to the floor level of the gallery, after taking precautions towards fire if any.
- Compaction of the galleries should be done by blasting from the surface.
- No machinery shall be deployed over the contact plane of compacted and non-compacted zone. The deployment of HEMM may be limited at 5 m away from the contact plane
- As fare as possible, deployment of men and machinery in the danger zone (Compacted) is to be restricted to the bare minimum and shall be allowed only under constant supervision of overman

2. Intermixing of stone with coal
    - To avoid intermixing of OB and coal, tight blasting in coal is achieved by doing blasting operation on the advanced cut without removing the blasted material from the preceding one.
3. Blown-through shots which may result in coal dust explosion
    - As a precaution against explosion of coal dust in the old galleries by blown-through shots, precautions laid out by DGMS Circular No. 3 of 1980 and Circular No. 4 of 1983 should be strictly followed.

5.2.4. Inundation and Mine Fire/ Explosion

To prevent the risks associated with the annexing of seam-I workings of SRP 3 & 3A incline workings, the recommended controls presented in Table 17-19 are to be followed. Additional recommendations are as follows:

- In case of an abnormal seepage of water observed in below seams of SRP 3 &3A, working should be stopped and persons should be evacuated from underground mine.
- Before monsoon, an assessment should be made to identify the possible inundation dangers and adequate precaution measures should be framed and followed.

- Ensure proper drainage of nallah no 2. Also ensure proper monitoring, communication system.
- In suspicious areas for spontaneous heating/mine fires, the work area to be inspected on daily basis by a competent officer before commencing the operations.
- Safety Management Plans, geological plans and survey plans are needed to be updated periodically.
- Provide adequate training to all concerned persons to create awareness to identify the hazards which may result into fire/inundation or other dangerous incident and assess the risks associated with the incident of fire/ inundation or other dangerous incident
- Provide fencing/caution boards in the danger/ fire area/ near sliding area to prevent inadvertent movement of persons

The above conclusions and Recommendations are based on the preliminary studies. SCCL management is advised to follow the same for the better and safe operation of the mine.

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