SOURCE PARAMETERS OF SEISMIC EVENTS IN A COAL MINE IN INDIA

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ABSTRACT

Longwall mining is one of the most widely used mining methods in underground coal mining. Longwall mining results in a large volume of coal being taken from underground; this changes the stress distribution and causes roof strata to deform and fracture near the working face. As a result many microseismic events and roof falls are observed. Microseismic monitoring in mines is a unique technique to locate the high stress zone areas which ultimately lead to the occurrence of roof falls.

The Integrated Seismic System from South Africa was used to monitor strata behavior in real time during longwall mining operation at the Rajendra longwall mine of South Eastern Coal Fields Limited (SECL) in India. The geophones were installed through boreholes at different depths covering the area of the longwall face in three dimensions and the data were recorded continuously in real time at the central computer system on the surface. Analysis of the seismic events revealed that the local magnitudes of these events were between -3.4 and 0.5, seismic moment varied between 1.4xE+05 and 3.6xE+09 Nm, seismic stress drop between 0 and 39.93 bars, Brune radius between 3 and 16.5m, apparent stress between 0 and 8.61 bars, radiated energy between 1.0E-03 and 9.2E+07 Joules, and predominant frequency between 10 and 500 Hz. After the coal mine face advances a certain distance, the strata behind the face typically caves in. If the roof does not cave, the entire mass of strata may detach from the layer above and try to rest on the powered supports, leading to failure and ground control problem. To help mitigate the situation, blasts were detonated behind the face after every 30 m of face advance. The quantity of explosives used was from 400 to 1500 kg. The source parameters of the blasts were obtained. Local magnitudes of these events were between -0.8 and 1.8, seismic moment varied between 7.1xE+07 and 8.5xE+10 Nm, seismic stress drop between 3.10 and 556 bars, Brune radius between 2.7 and 34.62 m, apparent stress between 2.27 and 326 bars, radiated energy between 5.4xE+02 and 9.2E+07 Joules and predominant frequency between 20 and 250 Hz. The details are discussed in this paper.

OBJECTIVES

The longwall technique is one of the most productive and safest mining operations. There were difficulties in the past when longwall technology was first introduced in many coal mines. This was due to incomplete understanding of the mechanism of caving. The characterization and understanding of strata behaviour immediately above the extraction panel is important for effective mine design.

India was the world's fourth largest (presently 3rd) coal producer in 1997. The international longwall census report notes that early efforts in longwall mining in India were poorly implemented, but experience, better equipment specification and improved infrastructure have increased the chances of success. Today in India, there are examples of moderately successful mechanized longwall faces, which produce on an average 1500 Mt per day. Powered support longwall technology contributes nearly 50% of the global production of coal from underground mines and is the most prevalent methodology in the leading coal producing countries, as reported by Mehta et al. (2003).

The longwall technique was introduced in India during the 1960s and powered support longwall mining was introduced in the1970s. In most longwall faces, the main problem was caving of the roof strata. This was mainly due to the presence of massive sandstone which is generally difficult to cave and caves in dynamically and violently. At present, instrumentation used in the longwall panel includes convergence measurement, leg pressure monitoring, stress and strain measurement; this will give only site specific information and only at the final stages of caving. These techniques and methods were found to be insufficient because of their limitations in locating high stress zones which ultimately result in roof collapses. The microseismic technique has been tried in one of the longwall faces at Rajendra Longwall mine of (SECL).

A Science and Technology project entitled "Monitoring of Strata Behaviour During Longwall Coal Mining Using Microseismic Monitoring Technique and Estimates of Caving Height" was undertaken jointly by SECL and NIRM at Rajendra Colliery (Sivakumar et al., 2004). The introduction of modern digital seismic systems to the mines and progress in the theory and methods of quantitative seismology enabled the implementation of real time monitoring to quantify rock mass response to mining in a better manner as reported by Mendecki and Van Aswegan (2001). During the period of microseismic monitoring several thousands of microseismic & roof fall events were recorded. Blasting was carried out on the surface of the working panel through drilled boreholes to release the buildup of stresses and avoid overload on the powered support. All the blasts during the monitoring period were recorded and analyzed. The source parameters of microseismic events, roof falls and induced blasts are discussed in this paper.

RESEARCH ACCOMPLISHED

Project site

Rajendra underground mine is operated by SECL and is situated in the Sohagpur area of Rewa Coal fields. It is located in the Western Part of the Sohagpur Area in the District of Shahdol in Madhya Pradesh between 23^0 08' 12'' and 23^0 10' 10'' North and 81^0 28' 05'' & 81^0 30' 50'' East. It is about 8

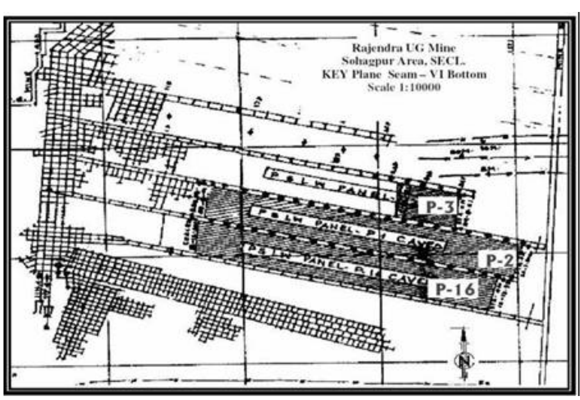

Figure 1. Plan showing the Rajendra Longwall underground Coal mine.

km from Burhar Railway station. The Area is close to the workings of the Burhar-Dhanpuri group of collieries. Figure 1 shows the location of longwall panel P-2 where investigations were undertaken.

Geology of the site

The coal bearing area is largely covered by the younger Supra-Barakars formation and is chiefly composed of grayish-white coarse-grained sandstone, a few coal seams are carbshale. The recent/sub-recent formation is alluvium with a lithology of soil and alluvium. The Upper Cretaceous age Lemeta formation has a lithology of reddish & greyish sandstone & modular limestone. The Triassic age Supra-Barakars formation has a lithology of pink, buff and red sand stone & shales. The Lower Permian age Barakars formation has a lithology of coarse to medium grain sandstone, subordinate shale & coal seams. The bottom seam VI is 1.30m to 4.75m thick and is presently being worked at the longwall Rajendra coal mine.

Mine workings

Rajendra underground mine was initially planned to be worked by Board and Pillar but due to the large demand for the high quality coal, the Powered Support Longwall Technique (PSLW) of coal mining was introduced. The details of PSLW panel-P2 are given below.

Working Height	: 2m to 3m
Length of face	: 150m
Length of Panel	: 1000m
Coal available	: 0.54 MT (3.1m thick)

The panel-P2 where the bottom seam is extracted lies at a depth of 68m to 74m below the surface. The roof of the seam consists of alluvium, sandstone and shale.

Instrumentation and monitoring systems

At Rajendra Colliery P-2 longwall face the microseismic monitoring system Integrated Seismic System (ISS) procured from South Africa was installed. The ISS system has sophisticated hardware and powerful software features for data acquisition and data analysis. The system was developed around network technology and built using distributed Data Acquisition Units (DAS) with central access to an online data processing system. Figure 2

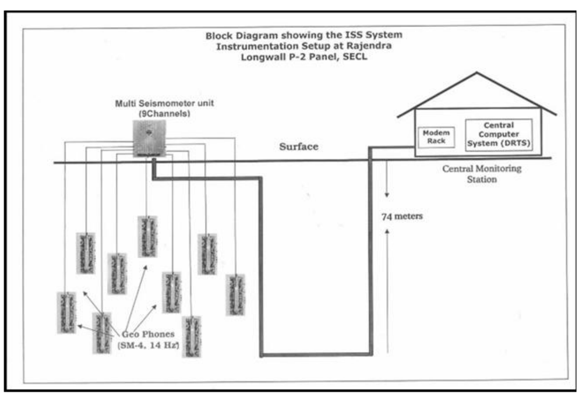

Figure 2. Block diagram of ISS instrumentation setup.

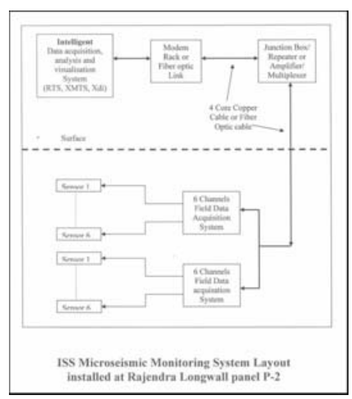

Figure 3. Block diagram of ISS monitoring system.

illustrates the block diagram of the ISS system used at Rajendera mine. The geophones were installed from the surface through boreholes, ahead of the face, behind the face and at the Main gate and the Tailgate. A total of 8 geophones at a time covering a volume of 200m length, 150m width and 75m depth were connected to the ISS system.

The ISS system consisted of 18 uni-axial geophones which were deployed in boreholes drilled from surface. The 18 uni-axial geophones were installed in three phases, 8 at each phase, replacing the unusable geophone sets which were buried in the goaf from time to time as the face advanced. These sensors were installed at boundaries of the roof strata at a different depths varying from 36m to 67m and covering about 150 to 200m in length and 150m in width (face of the panel) on the surface. The cables from all geophones were brought to a junction box situated in the middle of the panel on the surface and connected to a MS-9 data acquisition unit, housed in a moveable metal box to protect it from environmental conditions. This box was shifted from time to time with the face advancement of every 200m. The central computer was situated about 3 km away from the MS-9 microseismic unit; the area in-between is inaccessible on surface. A borehole was drilled from the surface to the underground workings (74 m) at the end of the panel into the tailgate and a two pair twisted armored annealed copper cable was used for data transmission. The cable was brought out to the surface from the ventilation shaft, which was close by the central computer monitoring station. This cable connected to a modem and to an HP Kayak Xu 800 workstation through a RS232 port on a communication board placed in the PCI slot. The central computer was capable of setting and changing the data acquisition parameters of the MS-9 unit and received the data collected on demand once an event was detected by satisfying the prerequisite conditions (e.g., trigger levels on a number of channels). The ISS microseismic monitoring system layout installed at Rajendra mine is shown in Figure 3.

Analysis

Source parameters extracted from the waveforms of microseismic events, roof falls, and blasts were local magnitude, seismic moment, seismic stress drop, Brune radius, apparent stress, radiated energy and predominant frequency. The energy release during fracture and frictional sliding was due to the transformation of elastic strain into inelastic strain. Seismic energy is proportional to the integral of the squared velocity spectrum in the far field and can be derived from recorded waveforms. Seismic moment is a scalar that measures the co-seismic inelastic deformation at the source. Stress drop estimates the stress release at the seismic source. The comparison of radiated seismic energies for seismic events of similar moment provides information about the stress change in the source areas. The ratio of radiated seismic energy to seismic moment multiplied by rigidity is called apparent stress and is recognized as a model independent measure of the stress change at the seismic source, as described by Mendecki (1997).

Signal characteristics

A typical microseismic signal picked up by the ISS system is shown in Figure 4. The seismogram is a graph of velocity of ground motion versus time at the location of the sensor. The background noise level is within ± 0.01mm/sec., the microseismic signal is superimposed on this background level. The frequency content of the signal was 200 Hz, duration 0.56 sec and the maximum amplitude recorded was at frequency 83.33 Hz. Depending on the distance, direction and source medium, the signals were picked up with different onsets, frequencies, durations and amplitudes. Low frequencies in the seismogram indicates soft strata (predominantly sandstone), whereas in the case of hard sandstone signals with high frequencies were observed.

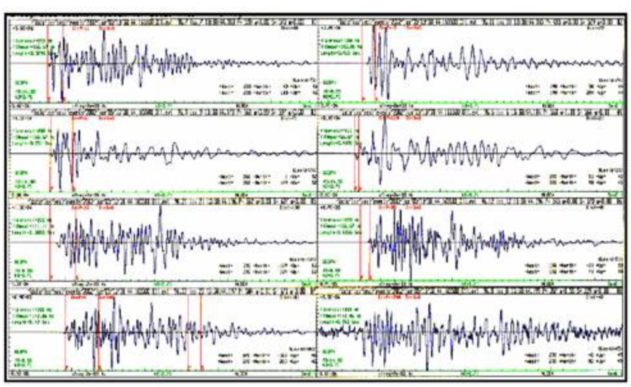

Figure 4. Microseismic signal recorded by ISS monitoring system.

Examples of three types of microseismic signals that were recorded during the longwall monitoring at Rajendra Mine are shown:

a) High frequency and short duration (Figure 5.)
b) Low frequency and long duration (Figure 6.)
c) Between low & high frequency and duration (Figure- 7.)

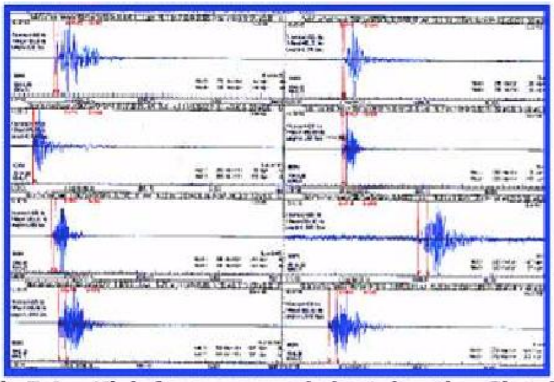

Figure 5. Microseismic signal (High Frequency and short duration)

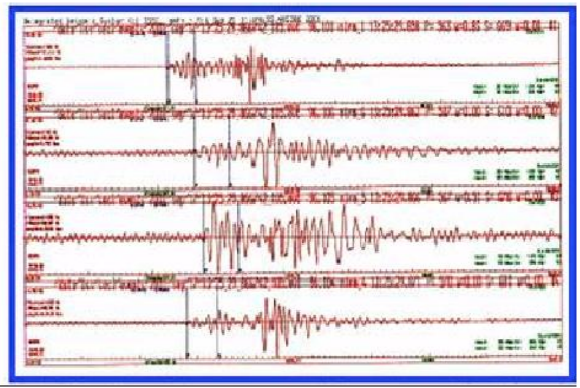

Figure 6. Microseismic signal (Low Frequen and long duration)

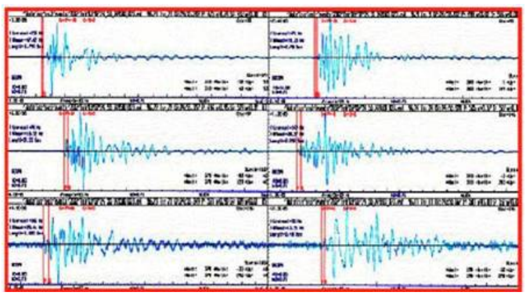

Figure 7. Microseismic signal (In between high and low frequency and duration.)

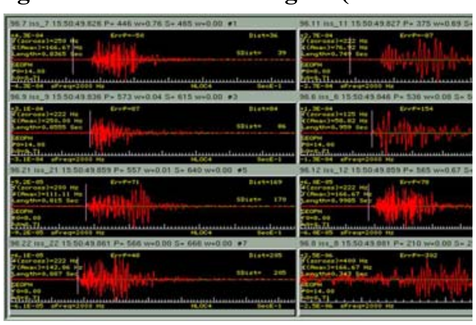

Figure 8. Seismogram of Roof Fall on 18-11-2001 at 20:39:52 Hrs.

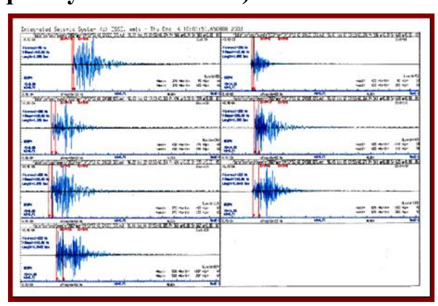

Figure 9. Blast signal recorded on 19-03-2002 at 12:53:40 Hrs.

In order to monitor the panel P-2 (1200m length x 150m width x 75m depth) very closely, the whole panel was divided into smaller segments of 200 to 300m in length and populated with 8 to 14 sensors (geophone stations). The network was shifted with a new set of geophones as the face advanced.

The microseismic events associated with longwall mining, roof falls (Figure 8) and blasts (Figure 9) were recorded at the Rajendra mine. The recorded waveforms were used to compute the source parameters. These events were recorded by a minimum of five geophones in the network and their locations are available. The events were located within an accuracy of less than 5 m. STA and LTA criteria were used to detect and record the events in real time. Signal characteristics are shown in Table-1. These parameters are site specific, depending on the strength of the rock mass and the stress profile at the time of recording.

Table 1. Details of Source Parameters computed from Rajendra mine.

Sl. No.	Source Parameters	Microseismic events	Roof falls	Blasts
1	Amplitude in m/sec	10^{-06} --10^{-05}	10^{-06} -- 10^{-04}	10^{-04} --10^{-02}
2.	Magnitude	-4.0 -- 0.0	-3.0 -- 0.5	-0.8 -- 1.8
3	Seismic Energy Joules	1.9X10^{02} -1.6X10^{04}	1X10^{-03} -- 1X10^{05}	5.4X10^{02} --9.2X10^{07}
4	Seismic Moment in Nm	8.9X10^{07} - 7.3X10^{08}	1X10^{05} -- 4X10^{09}	7.1X10^{07} --8.5X10^{10}
5	Apparent stress in Bars	0.64 -- 3.33	0 -- 8.0	2.27 -- 326
6	Static stress drop in Bars	2.16 -- 10.58	0 -- 40	3.0 -- 556
7	Source radius in m	3.66 -- 6.25	3.0 –16.5	2.0 -- 34
8	Predominant Frequency. Hz	37 -- 500	10 -- 330	21 --250

Blasts

Blasting was carried out on the surface of the working panel through drilled boreholes for every 30m interval in the goaf area to release the build up of stresses in the center of the panel. This helped avoid overload and the possibility of an air-blast. The microseismic monitoring system recorded all the blasts during the monitoring period. Several seismic parameters were obtained by analyzing the blast data, such as magnitude, source radius, static stress drop, corner frequency and predominant frequency. After blasting many roof falls occurred. From their time of occurrence, location and other details it was possible to understand the result of blasting. Continuous monitoring of stress levels before and after blasting helped to carry out blasting and further helped to optimize blasting. The correlation of blasting with computed source parameters and other details are explained below. A typical induced blast signal is shown in Figure-9. The details of blasts are listed in Table 2. The effects of blasting on the mine strata were explained by Srinivasan et.al (2004). The magnitudes of blasts recorded were in the range of –0.8 to 1.8 on the local magnitude scale

Table 2. Details of Induced Blastings carried out at Rajendra mine.

Date / Time	Explosives in Kgs.	Local Magnitude	Seismic Moment	Energy in Joules
21.10.01 / 20:27:15	1500	1.3	2.1 E+10	6.4E+06
21.10.01 / 20:37:22	1500	1.4	3.5E+10	1.1E+07
27.10.01 / 23:20:59	1425	1.8	8.5 E+10	9.2 E+07
06.11.01 / 16:57:34	1500	1.2	1.4 E+10	5.1 E+06
15.11.01 / 16:00:39	872	1.2	2.1 E+10	4.9 E+06
23.11.01 / 20:47:16	462	0.3	1.5 E+09	6.3 E+04
30.11.01 / 19:47:40	563	-0.6	1.2 E+08	1.3 E+03
13.12.01 / 13:51:23	450	1.2	2.8 E+10	1.8 E+06
31.12.01 / 13:50:40	700	1.2	3.1 E+10	2.1 E+06
16.01.02 / 18:46:49	400	0.4	3.4 E+09	5.6 E+04
19.01.02 / 15:23:15	1300	0.4	2.6 E+09	1.2 E+06
31.01.02/15:24:12	1050	1.1	1.7E+10	2.2E+06
11.03.02/20:13:12	122	0.2	1.6E+09	3.8E+04
15.03.02/13:35:21	233	0.6	4.1E+09	3.3E+05
19.03.02/12:53:40	350	-0.3	3.9E+08	4.9E+03
23.03.02/13:08:23	347	0.9	7.6E+09	1.2E+06
14.04.02/14:39:23	275	0.0	5.3E+08	3.0E+04
09.05.02/15:53:01	391	0.7	5.0E+10	8.8+04

Magnitude and source radius

Fracturing in rock took place due to a blast near the source; this is quantified by the radius of the spherical volume which was fractured. Table 1 gives an indication of the fracturing radius for different blasts. It was observed that the source radius increased as the magnitude of the blasts increased. The magnitude of the blast depends on the quantity of explosive used as shown in Table 2. Although there is a clear increasing trend between magnitude and explosive used, there is scatter in the magnitude up to 600Kg of explosives used. The scatter is caused by blasts of the same quantity of explosive giving rise to different magnitudes and different fracture radii. Especially with the use of explosive up to 600Kg of explosive the fracturing taking place in the rockmass varies between 2.5m to 10.25m radius. The fracturing created due to blasts depends on the stress regime at the time of the blast, the distance of the blast from the longwall face, and the strength and hardness of the roof (sandstone layer).

Stress levels before and after blasting

In order to understand blasts and their effects on the longwall strata, the energy index versus time before and after blasts was examined. Energy index is a measure of the stress regime in the rock during blasts. Out of many blasts recorded only two blasts are shown as examples below to show the effect of blasting seen in real time.

Blast 1 (27.10.2001 at 23:20:54 Hrs.)

It was observed that one hour before this blast the stress level showed an increasing trend indicating build up of stress and after the blast within 20 minutes the stress level dropped indicating release of stress, as seen in Figure 10.

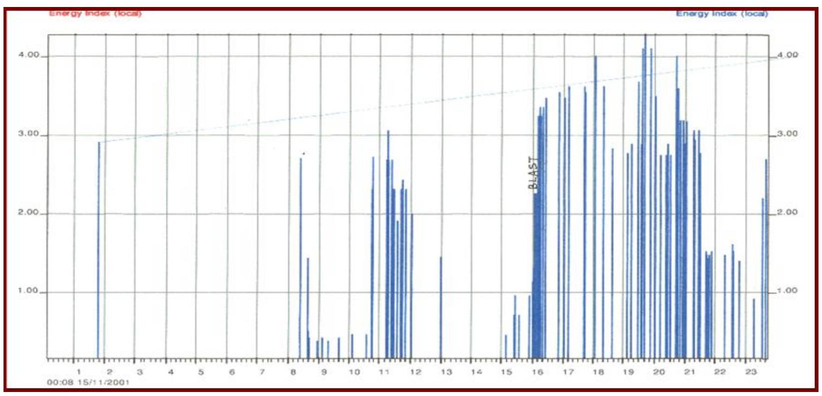

Figure 10. Stress level before and after Blast 1.

Blast 2 (31.12.2001 at 23:20:54 Hrs.)

One hour before the blast there was high stress level, as can be seen in Figure 11. The stress level came down within two hours after the blast and gradually decreased further.

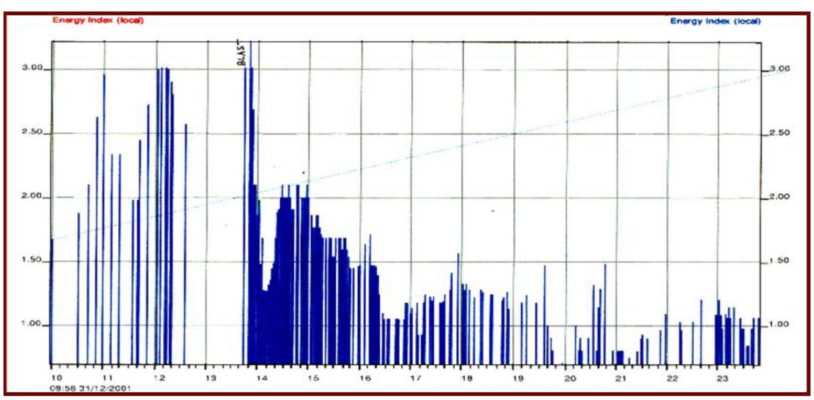

Figure 11. Stress level before and after the Blast 2.

The ISS system used at the Rajendra mine captured all information pertaining to ground strata behaviour during the period of monitoring. The data obtained were number of microseismic events along with the source parameters of individual events. Plotting different source parameters against time gave clear indication of high stress zones and unstable conditions developing in strata which ultimately resulted in ground failure. The locations of microseismic events plotted on the plan view of the mine gave the location of cluster of events and contours gave an indication of high stress. The high stress zone ultimately resulted in roof falls endangering the safety of men and machinery. To avoid major problems, blastings were used. The details are described below.

High stress zone

Longwall mining results in a large volume of coal being taken out from underground in relatively a short period. This causes changes in stress, roof strata deformation and fractures near the working face. Behind the face supports the fractured roof strata are encouraged to collapse in a controlled manner by blasting. Carrying out blasting at the right time and right location is important to get optimum results of the induced caving technique. There is no conventional monitoring available to obtain scientific information on location and time to carry out blasting. The microseismic technique provides appropriate scientific information in real time in this respect. Figure 12 shows the contour plot of the stress zone before blasting on 21.2.02. The high stress zone is concentrated towards the tailgate side. By identifying the high stress zone area the location that needs to be blasted and the approximate time is obtained. Blasting was carried on 21.02.02 at 10:30 hrs. After the blast the high-stress-zone area has disappeared and development of a fresh zone in another area is seen in Figure 13.

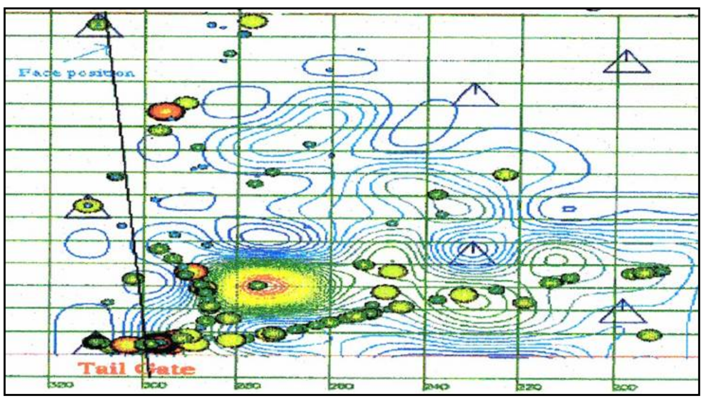

Figure 12. High stress zone before Blasting on 21.02.2002.

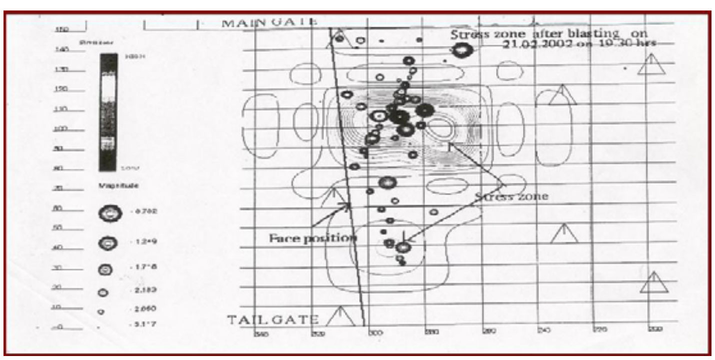

Figure 13. High stress zone after Blasting on 21.02.2002.

Discussion

Microseismic emissions are generated by deformation and cracking of rock around an opening inside a mine. The typical characteristics of these microseismic event patterns is shown to be of diagnostic value in sensing in advance roof fall that invariably follow such events. The source parameters of microseismic events are found to be less than those of roof falls in terms of amplitude, seismic energy, seismic moment, apparent stress, stress drop, source radius and magnitude, whereas the predominant frequency is higher for microseismic events compared to roof falls and blasts. The source parameters of blasts are higher than microseismic events and roof falls except for the predominant frequency, where it is less than microseismic events and roof falls.

Blasting was carried out from the surface of the working panel through drilled boreholes for every 30m interval in the goaf area to release the build up of stresses. A microseismic monitoring system recorded the blasts during the monitoring period. Source parameters obtained after analyzing the waveform data were magnitude, seismic moment, radiated energy, source radius, static stress drop, corner frequency, and predominant frequency. These seismic parameters helped understand the effects of each blast with respect to quantity of explosives used and stress levels before and after every blast. These results will help in the future to take decisions regarding the time and location to carry out blasts and to optimize the quantity of explosive. The stress levels in the various locations of strata before and after the blast can be quantified.

CONCLUSIONS AND RECOMMRNDATIONS

The microseismic investigation carried out at Rajendra colliery has obtained source parameters of microseismic events, roof falls and blasts. Brune's simple dislocation model has been used to compute the source parameters. The computed source parameter values of blasts are found to be higher than the values obtained for roof falls and microseismic events, except in the case of predominant frequency content where it is lower. The effects of blasting on strata can be identified using stress concentration zones. The results are listed below:

1. Various seismic parameters quantified for microseismic events, roof falls and blasts are local magnitude; radiated energy, seismic moment, apparent stress, source radius and seismic stress drop showing an increasing trend with respect to magnitude of blast; corner frequency showing a decreasing trend.
2. The magnitudes of blasts recorded were from -0.8 to 1.8.
3. The extent of fractures (source radius of fracture) was from 3.296m to 34.627m.
4. The predominant frequency recorded was from 22Hz to 250Hz.
5. The duration of blast vibration was from 0.5sec to 4.5 Sec.
6. Blasts have induced microseismic events within two hours after the blast and the stress level before and after blasts can be quantified.
7. One may delineate high stress zone and know the time to carry out a blast
8. The above information can be used for optimization of the blast.
9. The above information has helped to better understand the performance and effects of induced blasts carried out at Rajendra Colliery.
10. Discrimination of man-made and natural seismic events is possible.

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