EVALUATION OF STRATA BEHAVIOUR AND GOAF ATMOSPHERE IN THICK SEAM MINING - A CASE STUDIES

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ABSTRACT

This paper presents overview of strata behaviour in thick seams extracted by Blasting Gallery (BG) method of underground mining. After few years of discontinuance of blasting gallery method due to spontaneous heating and loss of considerable coal in goaf, the mehtod was reintroduced in typical underground mine – GDK-11 of SCCL. Salient results of strata monitoring along with evaluaiton of goaf atmosphere are presented besides few cases of strata monitoring studied over three decades by the first author. Compilation of performance of all the BG workings in various mines of Godavari Valley coalfield would also be useful for understanding the caving behavior and strata mechanics at different stages of extraction with due regard to optimization of panel size, area of extraction etc. so as to minimize the chances of Fire and spontaneous heating of coal. Overview of performance of previous BG panels at GDK 10, and cavability of roof indicated that in near future, BG panels may be planned with panel sizes of about 120x120 m, so that the major fall with adequate span may occur at an area of about 8000 m^2. This size of panel may minimize the chances of premature sealing/closure of panels reducing chances of fires/spontaneous heating in subsequent BG panels besides goaf treatment with inert gas. Different ratios related to evaluation of goaf atmosphere shows different status in which Graham's ratio (GR),Young's ratio (YR), Jones and trickett ratio (JTR) and CO/CO2 Ratio shows no sign of heating, Active Fire, coal dust Explosion and no sign of heating respectively indicating the need of further evaluation of the ratios with meticulous monitoring of goaf atmosphere through various continuous gas real time monitoring systems including Wireless sensor communication systems for understanding the status of fire.

INTRODUCTION

In general, the conventional systems of monitoring condition of the mine including mine atmosphere and mine equipment are associated with personal observation and intermittent readings and offline analysis of the data. A person go to the mine working place (for gas analysis, load on supports, electrical parameters of mining equipment to assess the machine condition etc.) and then these readings are analyzed offline. This time taking process is performed in different shifts and has to carefully note down the readings. Therefore, for improved evaluation of mine conditions, wireless systems may be applied for online monitoring of the mine atmosphere, and equipment including supports-hydraulic props, chock shields, loading and cutting equipment and associated machinery. The study of may remote monitoring of UG mining gases lead to autonomous decision in real time using ambient intelligence which provide better results than through common decision making based on intermittent tests and conventional procedures of sample collection and analysis in the laboratory. Emphasis is made on urgent requirement of application of trans-disciplinary research and study the underground mine conditions including online monitoring of mine atmosphere and mine equipment by application of wireless sensor networks and IoT devices.

CASE STUDY

GDK11 incline is situated in RG-1 Area of Godavari Khani, Peddapalli Disctrict of Telangana state. There are four workable seams, namely 1, 2, 3 & 4 seams with maximum depth from surface to # 4 seam of about 450 m. Method of extraction n 3 1 an d2 seams are continuous miner and B&P development and depillaring. Thickness of No.3 seam is about 10.0 m. Blasting gallery method was introduced in this seam in the year 2002. BG panels 1 A, 1 b, and 1C were extracted in Block A during 2002-2008. Similarly BG panels No BG D,E,F,G,H,I,J1, J2, J3 were extracted during 2008-2015 in Block-B. The seam #3 was developed by board and pillar method by January 2017. The area of the proposed BG panels is ranging from 20,000 to 35,000 m^2, whereas the area in previous panels is about 14,000m^2. Extraction of the pillars in # 4 seam lying under the BG panel was done by sand stowing with adequate filling of goaf by proper barricades and hydraulic filling of sand (Fig 4). Installation of Telescopic convergence indicators, load cells, and remote convergence indicators at strategic places near mid of the panel in the middle of the dip rise and level galleries in both the panels of two seams.

Fig 4: Arrangements for sand stowing with barricades and hydraulic filling of sand in seam #4

Instrumentation plan along with location of Tell tales, Strain bars, Load cells, and Convergence monitoring stations including arrangement for measurment of bed sepation due to stowed goaf of no – 4 seam in the BG Panel-K1 are shown in **Fig 5**. Set of convergence and load cell instruments shall be installed at 10 m interval at all levels and split levels and regularly monitored from the goaf edge along the line of extraction. Convergence stations are also proposed in 4 seam at all junctions to understand the tendency of any roof/parting movement. Strain bars grouted up to about 1.5 m inside the stooks at 1 m vertical interval shall be installed near the middle of the panel to understand the behavior of pillar/stook at various stages of extraction of pillars.

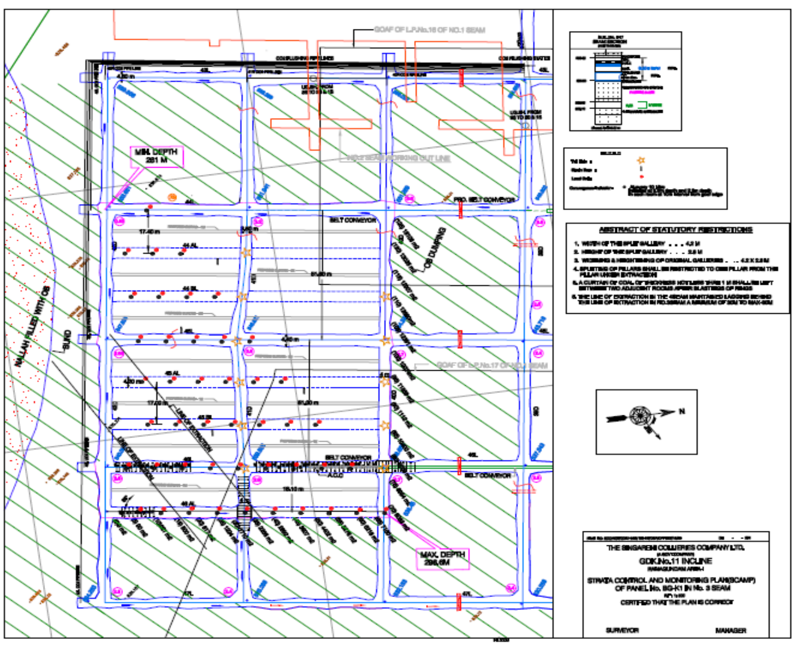

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Fig.5: Status of working and instrumentation of BG K1 panel in seam # 3, GDK11 incline

Convergence

Maximum Roof to floor convergence recorded up to 25.2.18 was 7 mm near the goaf edges. Convergence of workings during extraction of Panel No.BG-K1 of Block-B in No.3 seam up to 25.2.18 is presented in **Table 2**. And **Table 2** represents observation of load on hydraulic supports indicating maximum variation of load up to2.7 tons. Table 3 shows record of Dual height tell tales with maximum of 10 mm separation below the anchor at 4 m inside the roof. Table 4 shows maximum of 3 mm deformation in 1 m length indicating strain of 3mm/m as per the strain bar readings..

Table 2: Observation of convergence of workings during extraction of thick seam by BG method

Level	Station No.	Date of		Cumulative	Remarks
46AL	A2	04.01.2018	1	7	**Went into the Goaf on 20.02.2018**
	A3	04.01.2018	1	5	
	A4	04.01.2018	1	5	
	A5	19.02.2018	Nil	Nil	
46L	B1	10.01.2018	**1**	**5**	
	B2	10.01.2018	1	2	
	B3	10.01.2018	Nil	Nil	
45BL	C1	13.01.2018	**1**	**3**	**Went into the Goaf on 06.02.2018**
	C2	05.02.2018	**1**	**5**	**Went into the Goaf on 20.02.2018**
	C3	05.02.2018	**1**	**7**	
	C4	05.02.2018	**1**	**2**	
45AL	D1	16.02.2018	**1**	**5**	
	D2	16.02.2018	**1**	**2**	
45L	E1	16.02.2018	**1**	**4**	

Load on supports

Maximum setting load of about 10 Tons and Maximum variation of 2 tons increase and also upto 3 tons decrease int eh load on support was observed during extraction of the panel (Table 3) .Load cell installed at 44LS/41 D1 on 23.4.18 showed maximum load of 3.1 Ton upto 5.5.18 with maximum variation of 0.23 T/day when the station reached to about 2.5 m from the goaf edge. Load cell installed at 44LS/41 D2 on 5.5.18 showed maximum load of 5.5 Ton. Load on the support increased and decreased with irregular trend, which may be due to disturbance of the support by moving machinery.

Table 3: load cell observations during extraction of thick seam by BG method at GDK 11 mine

Level	Location	Date of Installation	Setting load (Tones)	Observed Load (Tones)	Cumulative load (Tones)	Remarks
46AL	46ALS/41D	25.01.2018	7.00	9.17	**2.17**	Went into the Goaf on 20.02.2018
	46ALS/41D	25.01.2018	10.28	12.40	**2.12**	
	46ALJ/41D	19.02.2018	8.48	6.77	**-1.71**	
46L	46LS/41D	25.01.2018	9.86	6.65	**-3.21**	Went into the Goaf on 08.02.2018
	46LS/41D	25.01.2018	9.04	11.73	**2.69**	

	46Ls/41D	08.02.2018	9.22	9.51	**0.29**	
45BL	45BLS/41D	19.02.2018	8.61	9.00	**0.39**	
	45BLS/41D	19.02.2018	7.35	6.30	**-1.05**	

Dual height tell tales were installed at 46ALJn/41D, and 46LJn/41D locations during extraction of thick seam by BG method at GDK 11 mine. Maximum Cumulative deformation of about 10 mm, 5 mm was observed below 4 m anchor in the corresponding locations. Dual height tell tails were also installed in the Stowing panel for observation of tendency of bed separation in the parting between 3 and 4 seams (Fig 6). No ostensible change in the reading of Telltales was noticed indicating no perceptible bed separation in the parting between seam # 3 and #4 and also adequate filling /packing of goaf by sand.

Fig 6: Dual height tell tail instrument in the Stowing panel for observation of tendency of bed separation in the parting between 3 and 4 seams at GDK 11 mine

ASSESSMENT OF GOAF ATMPSPHERE

At GDK 11 mine, Nitrogen and CO_2flushing in the goaf by pipelines from the storage tank installed at the surface was practiced to control the spontaneous heating susceptibility. Conventional system of sample collection by water displacement method and tube bundle method was followed to evaluate the percentage of gases regularly. The need to perform a complete analysis by Gas Chromatography of atmospheres generated during coal fires or heating's is not only critical but the only option to obtain an accurate assessment of the flammability status of the underground environment. Failure to do so can lead to wrongly assessing the atmosphere to be inert, when in fact it could be explosive or fuel rich, due to the generation of percent levels of carbon monoxide and hydrogen during mine fires. The presence of percent levels of these gases not only adds to the percentage of combustible gases present but also has a major influence in the lowering of the oxygen nose point (the lowest oxygen concentration at which an explosion can occur). Co and CH_4 sensors and tele-monitorinfg system was also used for contionuous monitoring of goaf atmosphere in the BG K1 panel (Fig 7). Efforts are also being made for introduction of wireless communication systems including various types of gas sensors in the mine on experimental basis (Fig 8) . An attempt is made to investigate the presence of toxic gases in critical regions and their effects on miners which can be extended for monitoring of health of the equipment. A real time monitoring system using wireless sensor network, which includes multiple sensors, is developed. This system monitors surrounding environmental parameters such as temperature, humidity and multiple toxic gases. This system also provides an early warning, which will be helpful to all miners present inside the mine to save their life and the equipment before any casualty occurs. The system uses Zigbee technology to establish wireless sensor network. It is wireless networking standard IEEE 802.15.4, which is suitable for operation in harsh environment.

Fig 7: Gas sensors installed in the BG panel for continuous monitoring of goaf atmosphere at GDK 11 mine

Several of the fire ratios commonly calculated from results use Oxygen deficiency. It is the amount of oxygen consumed/ removed by any activity and is often determined using the following equation:

Oxygen deficiency = 0.268* N2 – O2

This equation is based on the assumption that nitrogen, being an inert gas, will not be consumed nor will it be created. If the initial gas entering the area under investigation had a fresh air ratio of 20.95 % oxygen to 79.02 % nitrogen and Argon 0.9 % (20.95/(79.02-0.9)= 0.268), then the initial oxygen concentration can be determined using the amount of nitrogen determined to be present in the sample. Ratios incorporating oxygen deficiency will underestimate if there is more than one source of oxygen deficiency

There are well documented ratios and indices that are used for monitoring the progression of heating, the following are as follows:

6.1.1. Graham's Ratio
6.1.2. CO/CO2 Ratio
6.1.3. Young's Ratio
6.1.4. Jones and Trickett's Ratio
6.1.5. Willett's Ratio
6.1.6. H2 /CO Ratio
6.17. C/H Ratio

Graham's ratio (GR)

Graham's Ratio (GR) is useful in low oxygen environments such as goaves, and is also applicable in ventilated roadways. This ratio generally expressed as percentage, represents the fraction of the oxygen absorbed as a result of heating or fire which appears as carbon monoxide.

$$\mathbf{GR} = \frac{\mathbf{100 \times co}}{(\mathbf{0.268 \times N2}) - \mathbf{O2}}$$

Values of GR quoted in a number of technical references are:-

- ≤ 0.4 per cent indicates normal value
- 0.5 per cent indicates necessity for a through checkup
- 1 per cent indicates existence of heating
- 2 per cent indicates serious heating approaches active fire
- 3 per cent and above indicates active fire with certainty
- Values of GR ≥ 7 may occur for blazing fire

Young's ratio

Young's ratio is same as Graham's ratio except that CO is replaced by CO2 as the indicator of oxidation. Because of the size of the CO2 concentration it is not usually multiplied by 100 and thus is a fraction not a percentage as in Graham's Ratio. Carbon Dioxide produced as a percentage of oxygen absorbed is considered as Young's Ratio or CO2 /O2 deficiency ratio.

$$\mathbf{YR} = \frac{100\times CO2}{(0.265\times N2)-O2}$$

- If the value of this **ratio** is **below 25** it is considered to be indicative of **superficial heating**. If it is **more than 50** it should be corroborated with other fire indices to rule out or confirm **a high intensity fire (Active Fire).**

Jones and trickett ratio (JTR)

This ratio serves as an indicator of the type of fuel involved in any fire or explosion. Jones and Trickett developed this ratio for determining whether methane or coal dust has been involved in a mine explosion.

$$\mathbf{JTR} = \frac{(CO2)+0.75\times(CO)-0.25\times H2}{(0.265\times N2)-O2}$$

- JTR <0.4 normal
- JTR <0.5 methane fire possible
- JTR < 1.0 coal fire possible
- JTR >1.6 impossible

CO/CO2 Ratio

It is suitable for both sealed and fresh air heating. It is generally expressed in percentage. This ratio is independent of oxygen deficiency and so overcomes a lot of problems associated with other ratios that are dependent on that deficiency. It indicates the completeness of the combustion or oxidation. This ratio has a significant advantage that it is unaffected by inflow of air, methane or injected nitrogen. The index increases rapidly during early stages of heating, but the rate of increase slows at high temperature. This index can be used only when no carbon dioxide occurs naturally in the strata.

- 2 per cent indicates active fire in the adjacent zone.
- ≥ 13 per cent indicates blazing fire

C/H Ratio

$$\frac{C}{H} = \frac{3(CO2 + CO + CH4 + 2C2H4)}{(0.2468 \times N2 - O2 - CO2 - 0.5H2 + CH4 + C2H4) + H2 - CO}$$

- Upto 3 indicate Superficial heating.
- 5< $\frac{C}{H}$ <20 indicate Active Fire.
- $>$ 20 indicate blazing Fire.

Table 4 shows typical goaf atmosphere sample results with tube bundle and gas chromatograph. Typical results of analysis of gaof atmosphere through various approaches indicates that there is no sign of heating as per the Grahams ratio (Table 5). Results of Young's ratio (YR), Jones and trickett ratio (JTR) and CO/CO2 Ratio are presented in Table 6 to 8, respectively. Different ratios related to evaluation of goaf atmosphere shows different status in which Graham's ratio (GR),Young's ratio (YR), Jones and trickett ratio (JTR) and CO/CO2 Ratio shows no sign of heating, Active Fire, coal dust Explosion and no sign of heating respectively indicating the need of further evaluation of the ratios with meticulous monitoring of goaf atmosphere through various continuous gas real time monitoring systems including Wireless sensor communication systems for understanding the status of fire.

Table 4: Typical goaf atmosphere sample results with tube bundle and gas chromatograph

Sl.no	Time	H2	O2	N2	CH4	CO2	CO	C2H4

1.	12:05	0.0000	20.8079	77.9472	0.0000	0.3445	0.0000	0.0000
2.	12:12	0.0037	4.1918	76.3159	0.5954	18.8376	0.0076	0.0016
3.	12:20	0.0016	4.3942	75.7087	0.5184	19.3295	0.0015	0.0060
4.	12:30	0.0022	3.3807	75.9734	0.6748	19.9180	0.0017	0.0064
5.	12:40	0.0018	4.9955	76.0765	0.5521	18.3272	0.0059	0.0059
6.	13:00	0.0021	4.1501	75.9325	0.6166	19.2497	0.0017	0.0061

Table 5:Graham's ratio (GR)

Sl.no	Time	GR	Status
1.	12:05	0.0000	No sign of heating (Normal)
2.	12:12	0.0467	No sign of heating (Normal)
3.	12:20	0.0094	No sign of heating (Normal)
4.	12:30	0.010	No sign of heating (Normal)
5.	12:40	0.0383	No sign of heating (Normal)
6.	13:00	0.0104	No sign of heating (Normal)

Table 6:Young's ratio (YR)

Sl.no	Time	YR	Status
1.	12:05	-226.80	No sign of heating
2.	12:12	117.5006	Active Fire
3.	12:20	123.3645	Active Fire
4.	12:30	117.3015	Active Fire
5.	12:40	120.8537	Active Fire
6.	13:00	120.5214	Active Fire

Table 7: Jones and trickett ratio (JTR)

Sl.no	Time	JTR	Status
1.	12:05	-2.2680	No sign of heating
2.	12:12	1.1753	Coal dust Explosion
3.	12:20	1.2336	Coal dust Explosion
4.	12:30	1.1730	Coal dust Explosion
5.	12:40	1.2087	Coal dust Explosion
6.	13:00	1.2052	Coal dust Explosion

Table 8:CO/CO2 Ratio

Sl.no	Time	Co/CO2	Status

1.	12:05	0.0000	No sign of heating (Normal)
2.	12:12	0.0403	No sign of heating (Normal)
3.	12:20	0.0077	No sign of heating (Normal)
4.	12:30	0.0085	No sign of heating (Normal)
5.	12:40	0.0321	No sign of heating (Normal)
6.	13:00	0.0088	No sign of heating (Normal)

CONCLUSIONS

Compilation of performance of all the BG workings in various mines of Godavari Valley coalfield would also be useful for understanding the caving behavior and strata mechanics at different stages of extraction with due regard to optimization of panel size, area of extraction etc. so as to minimize the chances of Fire and spontaneous heating of coal. Overview of performance of previous BG panels at GDK 10, and cavability of roof indicated that in near future, BG panels may be planned with panel sizes of about 120x120 m, so that the major fall with adequate span may occur at an area of about 8000 m^2. This size of panel may minimize the chances of premature sealing/closure of panels reducing chances of fires/spontaneous heating in subsequent BG panels besides goaf treatment with inert gas. In general, readings of load on supports in BG method are taken manually once in every one or two days. Carrying the readout unit which is of approx 1.5 kg to every load cell and taking reading out of it is a tough job taking lot of time as well as requires a skilled person who can operate the readout unit. If the load cells can be digitized, monitoring of the load can be much easier , and continuous load monitoring is also possible.

Maximum load on support, and convergence of the galleries in BG panel –K1 of GDK 11 mine are about 12.4 Tons, 7 mm respectively during extraction of pillars. This panel was sealed off on 18.6.18, and regular monitoring of goaf atmosphere although showed sign of heating in the initial days, but later indicated no sign of heating. Different ratios related to evaluation of goaf atmosphere shows different status in which Graham's ratio (GR),Young's ratio (YR), Jones and trickett ratio (JTR) and CO/CO2 Ratio shows no sign of heating, Active Fire, coal dust Explosion and no sign of heating respectively indicating the need of further evaluation of the ratios with meticulous monitoring of gaof atmosphere through various continuous gas real time monitoring systems including Wireless sensor communication systems for understanding the status of fire.

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