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.

EVALUATION OF STRATA BEHAVIOUR – CASE STUDIES

CASE STUDY-1 MINE

About 30 nos of BG panelswere extracted in GDK-10 incline producing about 7 Million tons of coal. First Blasting Gallery method of extraction was introduced in SCCL in 1989 at GDK No.10 Incline and being worked successfully. Although, first BG in India was introduced in East Katras Colliery of Jharia Coal Fields, BCCL and Chora Colliery of Raniganj Coal Fields, ECL in 1987, the workings were abandoned in East Katras Colliery due to Strata Control Problem, and were discontinued in Chora Colliery due to premature Spontaneous heating problem. GDK-10 Incline mine falls in Godavari Valley Coal Fields of Singareni Collieries Company Limited and is situated in

Andhra Pradesh. It was opened on 25-11-1976 with three workable seams viz., 3A Seam, 3 Seam and 4 Seam. The parting between No. 3A Seam and No.3 Seam is 40m and between No.3 Seam and No.4 Seam is 4.5 m to 5.5 m.

The coal measure formations observed in borehole # 637 within GDK 10 Incline area indicated that the thickness of III seam is about 11 m with an average gradient of 1 in 7 towards N 23½° E. The strata overlying the coal seam are composed of coarse to medium grained sandstone with carbonaceous shale bands. Cavability studies of roof of III seam at GDK 10 incline and the underground observations in the previous panels, indicated a Maximum cavability index of the roof of about 2915 in the overlying rock mass in the BG panel-I of Block-C. First major fall conditions are anticipated at about 50 to 60 m clear span in the goaf without presence of any ribs. Induced caving of immediate roof up to 8 m (i.e., bed with cavability index of 1616) allows the overlying roof with low cavability index to fall on its own at about 21 m clear span in the goaf. It will also give cushioning effect during first major fall with no perceptible dynamic loading.As per the records submitted by the management, the maximum area of extraction at the time of major fall was about 6,800 m^2. Total area extracted in the BG panels of above block are in the range of 7345 to 22080 m^2. Percentage of coal extraction in the panels are in the range of 35 to 89. In the Panel no 2E of the above block , out of total reserve of 2,50,000 tons, 2,22,812 tons. The percentage of extraction was 89%, which may be considered as efficiently worked panel in the above block. Panel size in these workings is 150 x 128.5 m, and worked during 06-07-2005 to 08-02-2006 for a period of 7 months 2 days. Thickness of #3 seam is about 11 m with an average gradient of 1 in 5.5. The strata overlying the coal seam are composed of white sandstone with carbonaceous clay bands. Coal face mechanization in the panel consists of jumbo drills and remote controlled Load Haul Dumpers (LHD) loading on to chain conveyors in the levels.

Instrumentation was carried out in the galleries - 59A to 56A levels, 40 to 43 dips, for monitoring various parameters of strata behaviour. The following instruments were used to monitor the strata behaviour in BG Panel #1A:

a) Convergence stations	- Telescopic rod type
b) Load cells	- Vibrating wire type
	- Mechanical type
c) Stress meters	- Vibrating wire type
d) Extensometers	- Tell-tale (four-point) type
	- Magnetic ring type

The **telescopic rod convergence indicator** is a simple instrument consisting of a graduated rod fitted in a pipe. It has a least count of 0.5 to 1 mm, and the telescopic movement is for a length of 2 to 4 m. The measuring points ("reference stations") are metal rods grouted in the roof and floor. Measurements are taken by simply stretching the telescopic rod between the reference points, and reading the graduations on the rod. Convergence stations were installed at every 20 m interval in the levels of the panel. These indicators are useful for understanding the roof to floor closure in the advance galleries at various stages of extraction. Rate of the closure may give some indication of the impending roof falls.

The **electronic load cells** work on the principle of vibrating wire gauge. The v-w gauge consists of a stretched wire, which is plucked by a pulse of high energy. Changes in the load exerted on the cell cause changes in the length of this wire, resulting in variations of frequency of vibration. This frequency is measured by a digital read-out unit, and is converted into load using calibration charts. The load cells were installed under the hydraulic props using specially prepared steel seating arrangement.

Convergence

Convergence station C3-59L near the junction of 59L/42D recorded a total convergence of 6 mm by the end of June'2000 (Fig 1). Rate of convergence increased to about 2 mm/day upto 30th July'2000, with the total convergence of about 42.5 mm, indicating initiation of active movement of the roof. C5-57AL station was installed on 22nd Aug'2000 at about 30 m from the goaf edge. Rate of convergence increased to about 2 mm/shift on 21st Nov'2000 may be due to induced blasting in the adjacent level. The total convergence at the station reached to 64.5 mm on 9th Dec'2000 when it was about 2.5 m from the goaf edge

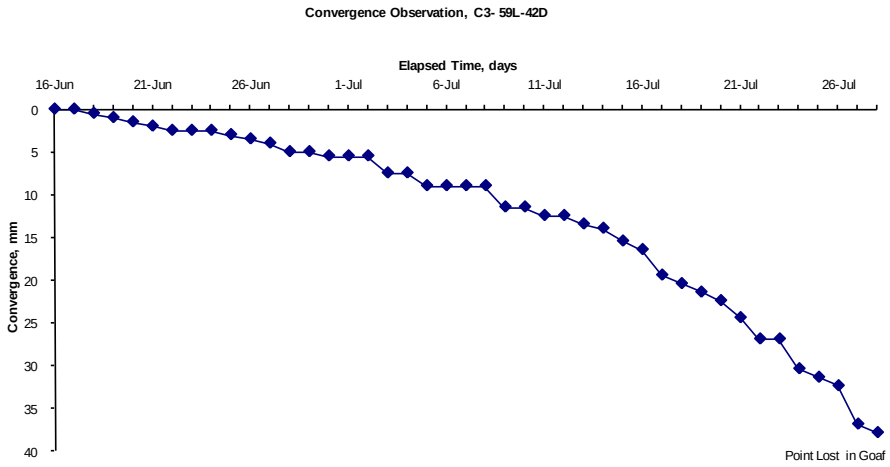

Fig. 1 Convergence observations at C3-59AL

The support system in the district consists of I-section MS cross girders of 200 x 200 mm, set on 40 ton hydraulic props at each end. In each row there are two props and a girder, with a row spacing of 1.0 m. Additional supports including chocks and props are being provided wherever required. The split galleries are supported with 1.8 m long roof bolts with 1m spacing and row is 1.2m apart.Advance supports are installed up to 40m in all the rooms. Junctions are supported by two sets of skin to skin MS girders of 150mm x 150mm and supported by two No. of 40T hydraulic props on each side. In addition to the above cable bolting was done at 1.5m interval in grid pattern anchored upto a length of 1.0 m above the coal seam into sand stone roof. Corners and Sides supporting is being done with 1.5 m length bolts with 1m grid pattern whenever required. Hydraulic props of 40 Tons capacity are set at about 6 to 8 T in majority of the supports in the panel. At station L3-66AL the cumulative load has reached up to 6 T when it was nearly 8 m from the goaf edge, it was installed with a setting load of 5.35 T at about 19 m from the goaf edge. Maximum daily variation observed was 1 T on 24-08-11 when it was 13 m from the goaf edge.Load cell at station L4-66BL the maximum variation of loadwas recorded about 6 Tons.When it was nearly 13 m from the goaf edge.Maximum daily variation observed was 2.3 T on 29-08-11 when it was 15 m.At station L5-67BL about 4.5 Tons variation of load was recorded when it was nearly 3 m from the goafedge, it was installed with a setting load of 9.8 T at about 18 m from the goaf edge. Maximum daily variation observed was 1 T on 02-08-11 when it was 15 m from the goaf edge of Max. load was observed when station was within 10 meters from goaf.

Load on Supports

Hydraulic props of 40 T capacity were set at about 7to 10 T in majority of the supports in the panel. At station L3-59L the change in load has reached upto 11 T when it was nearly 10 m from the goaf edge, it was installed with a setting load of 9.36 T at about 12 m from the goaf edge (Fig. 2). Maximum load on prop was about 28 T at the station L2-58AL when it was nearly 1.5 m from the goaf edge. It was installed on 15th November'2000 with a setting load of about 12.7 T at a distance of 3 m from the goaf edge . At station L1-58AL, maximum change of load on the prop up to 14th Nov'2000 was about 20 T, when it was at a distance of about 3 m from the line of goaf. The maximum load on prop at station L1-56AL reached upto 20.5 T on 3rd Dec'2000 as it was at a distance of about 15 m from the goaf edge, initially it was set at 11.98 T at about 31 m from the goaf edge.

CASE STUDY-2 MINE

Thickness of Queen Seam is about 9.5 m with an average gradient of 1 in 12 towards S 39W with F grade of coal. Coal face mechanization in the panel consists of jumbo drills and remote controlled Load Haul Dumpers (LHD) loading on to chain conveyors in the levels. Geo-mining details of the panel are summarized below:

Depth of cover (minimum)	-	176 m
Depth of cover (maximum)	-	196 m

Thickness of seam	-	9.5 m
Width of the development gallery	-	4.2 m
Height of the development gallery	-	3.0 m
Length of the panel	-	960 m
Width of the panel	-	870 m

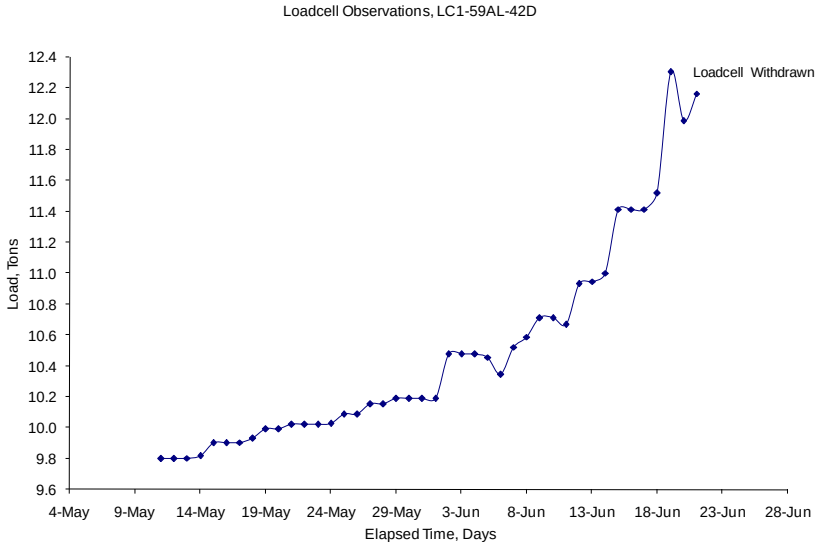

Fig. 2 Load cell observations at LC1-59A L-42D

BG 3E panel was started on 23/02/2012 and was sealed during the month of April 2013. Earlier 30 pillars were extracted but later another 3 pillars were permitted for extraction . The total area of the panel was 30,107m^2 with 32m*29m size of panel.The support system in the district consists of I-section MS cross girders of 200 x 200 mm, set on 40 ton hydraulic props at each end. In each row there are two props and a girder, with a row spacing of 1.0 m . Additional supports including chocks and props are being provided wherever required. W straps are used with 2.4m long roof bolts, Resin capsules arealso used for providing better support to the roof. Hydraulic props of 40 T capacity were set at about 6 to 10 T in majority of the supports in the panel. Summary of observations of load on Hydraulic props are presented in Table 1. At station 67AL-(D1) the cumulative load has reached up to 10.15 T when it was nearly 10 m from the goaf edge, it was installed on 12th March 12 at about 20 m from the goaf edge. Maximum daily variation observed was 4.21T on 18th March 12 when it was 15 m from the goaf edge. Goaf sounds were heard when the cumulative load reached up to 10.15 Tons. Maximum daily variation of load observed at station 66AL- (F2) was 5.48 T when it was about 4 m from the goaf edge. At Load cell in 66AL-(F2), sounds were observed when the cumulative load reached up to 10.24 followed by stone fall on 25th April 12.Up to the end of August 2012, cumulative load reached up to 27.53 at station 65AL-(H4) when it was 3m from the goaf edge after which it was removed.On October 28 2012 after a natural fall on 21st October goaf sounds were heard when the cumulative load was 14.92 T, the maximum day load observation was also recorded on that day which was 4.33T at 13m GED. Up to the end of February 2013 maximum day load was observed to be 4.77 T with a cumulative load of 21.48 when it was 4m from the goaf.

Table-1:Summary of observations of load on hydraulic props-- 21 Incline-SCCL

Location	Date of Installation with GED	Final Cum load (Tons)
67AL-(D1)	12-03-2012 at 20m GED	7.92 T, GED 2m on 03-04-12
67AL-(D2)	04-04-2012 at 29m GED	5.7 T, GED 5m on 13-05-12
67AL-(D3)	14-05-2012 at 28m GED	4.97 at 2m GED on 21-06-12
65AL-(H3)	14-05-2012 at 26m GED	6.69 T, GED 1m on 15-07-12
65AL-(H4)	26-07-2012 at 27m GED	26.33 T, GED 3m on 27-08-12

64AL-(J4)	22-08-2012 at 34m GED	13.02 T, GED 3m on 25-09-12
65AL-(H7)	12-09-2012 at 22m GED	7.04 T, GED 4m on 01-10-12
65AL-(H9)	01-10-2012 at 34m GED	23.4 T, GED 4m on 13-10-12
64AL-(J9)	03-12-2012 at 24m GED	4.1 T, GED 2m on 34-12-12
67AL-(D11)	30-12-2012 at 16m GED	35.51 T, GED 2m on 23-01-13
64AL-(J11)	19-01-2013 at 23m GED	21.48 T, GED 4m on 14-02-13
65L-(I2)	25-02-2013 at 16m GED	2.62 T, GED 3m on 06-03-13

CASE STUDY-3 MINE

Godavarikhani No.8 Incline, existing in the southern extension of – South Godavari Mining Lease. It falls in RamagundamTaluq of Karimnagar District of Andhra Pradesh State. It lies between Latitude: 18 –50 and Longitude: 79^0 –28' & 79^0-35'.The 5.60 Sq.K.m of the leasehold is a strip of 68.48 Sq.KM leased area of South Godavari Coal Field, belonging to Singareni Collieries Company Limited. The Mine is approximately 20 KM from Ramagundam Railway station, 10 km from Central screening plant & Railway siding of GDK.No.1incline. It is 60 KM from Karimnagar and about 220 KM from Hyderabad by Road. South side GDK 10 & 10 A Inclines. North side Identified for OCP 2 Mine extension Block, Dip side part of OCP 2 & part of OCM 1-Extension Phase-II. The Gondwana series slightly dipping in North-Easterly consists here in the property the Barker and Talchirformation. The production was started on 1974 with the life time about 38 years and extractable reserves of 36 MT. The average daily production was consistently more than 1400 t, with good production records. Till now 24 B G panels were successfully. The gradient of mine is 1 in 8. The grade of coal is 'D' grade. Total number of seams encountered the area are seven namely – 1A,1,2,3B,3A,3 and 4seams, of which No.1,2,3 and 4 seams are considered to be workable. The strata within the boundaries are gently anticlerical in structure. The support system in the district consists of I-section MS cross girders of 200 x 200 mm, set on 40 ton hydraulic props at each end . In each row there are two props and a girder, with a row spacing of 1.0 m. Additional supports including chocks and props are being provided wherever required. The split galleries are supported with 1.8 m long roof bolts with 1m spacing and row is 1.2m apart. Advance supports are installed up to 40m in all the rooms.Junctions are supported by two sets of skin to skin MS girders of 150mm x 150mm and supported by two No. of 40T hydraulic props on each side. In addition to the above cable bolting was done at 1.5m interval in grid pattern anchored up to a length of 1.0 m above the coal seam into sand stone roof. Corners and Sides supporting is being done with 1.5 m length bolts with 1m grid pattern whenever required. Fig 3 shows variation of about 22.8 ton load on hydraulic support in a typical working place of Blasting gallery panel at GDK-8 incline –SCCL.

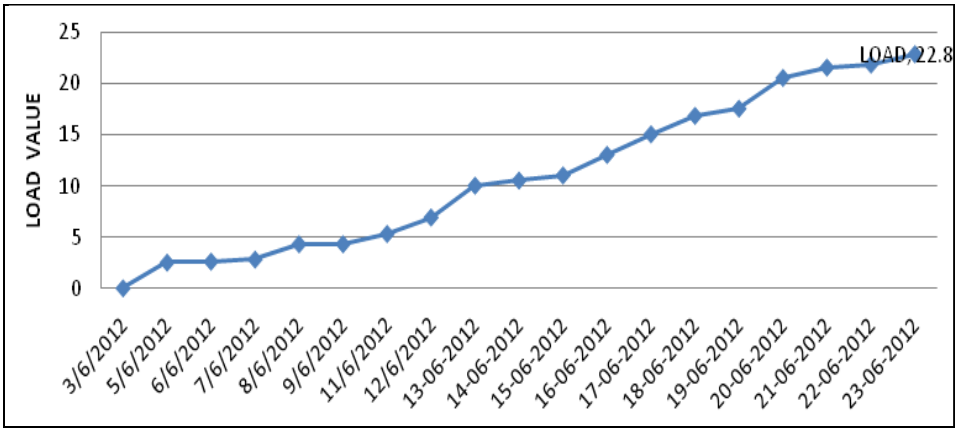

Fig 3: Variation of load on support in a Blasting gallery panel at GDK-8 Incline-SCCL

CASE STUDY - 4 MINE

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.

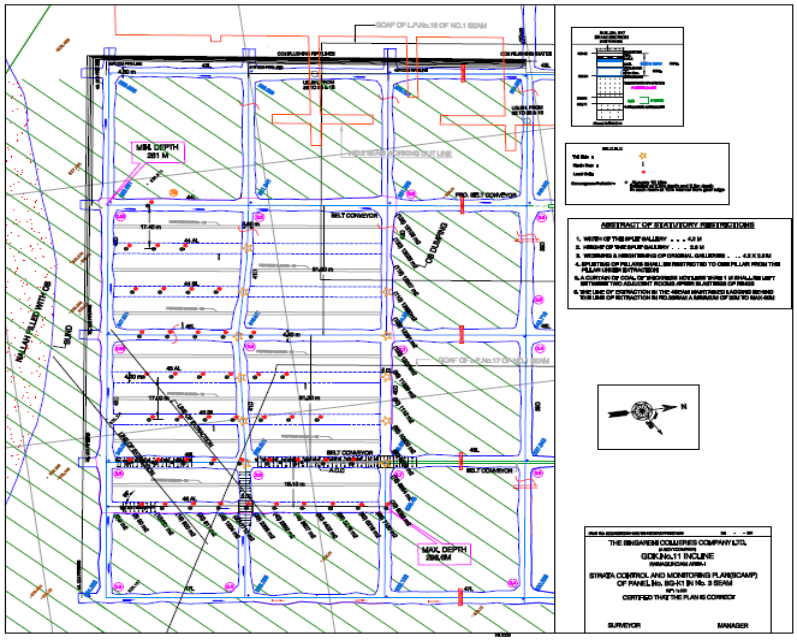

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Fig.5: Status of working and instrumentation of BG K1 panel in seam # 3, GDK11 incline

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.

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

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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