Geotechnical Investigations and Numerical Modeling Vis-À-Vis Extraction of Pillars by Blasting Gallery Method

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ABSTRACT: This paper presents various sensors/instruments useful for understanding stability of workings in underground mines with specific reference to the geotechnical investigations in typical coal mines of Southern India. Convergence indicators, load cells, auto warning electronic extensometers etc were installed in different Levels in the working panel. Maximum load on support, and convergence of workings up to January 2012 in the BG panel are 9.7 Tons, and 51 mm, respectively. Finite difference code - FLAC (Fast Lagrangian Analysis of Continua) was used for simulation of the strata behaviour at different stages of extraction of a thick seam. Numerical modeling results indicated absolute roof deformation of about 6 mm in development gallery. Simulation results for extraction of five stooks representing the condition of main fall indicated roof deformation of 55 mm in the gallery, whereas 51 mm convergence was measured in the field. In view of loss of coal in this type of thick seam mining, it is also suggested to formulate guidelines for designing innovative methods of thick seam mining with meticulous evaluation of performance of BG method through a technical committee involving experts from industry, research, academic and regulatory agencies.

1 INTRODUCTION

At GDK 10 Incline of Adriyala project area SCCL, Blasting Gallery method was adopted in panel # 3A of III Seam in Block C. Average depth cover and thickness of the seam in the proposed panel are about 350 m and 11 m, respectively. About 30 nos of BG panels were extracted till now in GDK-10 incline producing about 7 Million tons of coal. Some of the particulars about the mine GDK-10 Incline are presented in Table 1. 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.

Table 1 Particulars about the mine GDK-10 Incline

Extractable Reserve in the mines	13 Million Tons.
Area Of Lease Hold	40 Ha
Gassiness	I Degree
Grade Of Coal	D
Men On Roll	1342
Annual Target(10-11)	7,30,000T
Introduction of BG Tech.	1989
Total no. Of panels extracted	30
Production From BG Panels	70 Lakh Tons

The coal formations of Ramagundam area is of Kamthi and Barakar series. Five workable coal seams occur in the Barakar stage – II, IIIB, IIIA, III and IV seams. The top most seam I is being worked by GDK 10A Incline. Seams IA and IIIB are inconsistent, and therefore could not be worked. The lower most seams IIIA, III and IV are being worked by GDK 10 Incline. Two major faults are running through the property. One of that has up throw of about 53 m while the another is a down throw fault with a throw of about 24 m. The mine property is divided into three blocks : Block A, Block B and Block C, demarcated by the fault running across the property.

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^{o} 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 (NIRM, 1999), 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. Details of performance of BG Panels in the mine including dimensions of the panels, period of extraction, total reserves, recovery from the panel etc are presented in Table 2 to 4. 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. Minimum and Maximum period of extraction of a panel is about 5 months to 1 year 4 months. Minimum and maximum depth covers of the BG panels worked so far are in the range of 11 to 199 in Block A and Block B.

Table 2 Information about BG Panels of 3 Seam Block-A at GDK.N0.10inc

Panel No.	Dimensions and Area m2	Depth of Panels		Period of Extraction	Total Reserve (Tons)	Extracted Coal (Tons)	Main Fall (m^2)
		Min	Max				
1A*	140 x 155 (21700)	120	140	1 year 4 months 22 days	341775	280454	3100
1B	200 x 155 (31000)	127	145	1 year 9 months 18 days	488250	299338	3450
1C	190 x 155 (29450)	135	148	1 year 5 months 3 days	463837.5	387552	3831
1D	125 x 155 (19375)	135	148	11 months 27 days	305156	230464	3467
2A	250 x 155 (38750)	100	122	1 year 5 months 4 days	610000	415509	6800
2B	227 x 155 (35185)	111	125	1 year 4 months 15 days	554160	413829	3118
2C	231 x 155 (35805)	112	128	1 year 4 months	563928	395834	4456
2D	193 x 155 (29915)	114	130	1 year 4 months 1 day	471160	338254	1282
3A	155 x 170 (26350)	144	163	8 months 1 day	395250	152000	4200
3B	165 x 150 (24750)	151	166	9 months 20 days	198450	1346627	2500

Many of the above panels were sealed off/closed prematurely due to occurrence of fire. Minimum and maximum width/length of the panels was about 125 m and 250 m. Main fall area was in the range of 1282 to 6800 m^2. Depth of Panels varied from 111 to 166 m in this block.

Table 3 Information about BG Panels of 3 Seam Block-B At GDK.N0.10inc

Panel No.	Dimensions And Area m2	Depth of Panels		Local	Panel sealed on	Period of Extraction	Total Reserve (Tons)	Extracted Coal (Tons)	Main Fall (m^2)
		Min	Max						
1A*	180x103.5 (18630)	169	197	26-11-93	05-11-94	11 months 9 days	298000	251789	4100
1B	180 X 123 (22140)	188	217	14-09-94	24-07-95	9 moths 10 days	348000	168603	3860
2A	75 X 130 (9750)	134	149	11-01-96	30-07-96	6 months 21 days	201600	114533	6092
2B	80 X 160 (12800)	141	159	26-07-96	12-03-97	7 months 16 days	255937	145598	5818
2C	125 X 130 (16250)	151	170	16-02-97	17-07-97	5 months	177502	90693	2885

						1 day			
2D	98 X 115 (11270)	160	180	22-08-97	21-03-98	6 moths 29days	179556	147660	3106
2E	95 X 120 (11400)	168	199	22-02-98	20-09-98	6months 28 days	354375	121923	3400

In the above Block B, many of the above panels were sealed off/closed prematurely due to occurrence of fire/spontaneous heating. Minimum and maximum width/length of the panels was about 75 m and 180 m. Main fall area was in the range of 2885 to 6092$m^{2.}$ Percentage of extraction varied from 50 to 90 in the above block.In the Panel no 2D of the above block out of total reserve of 2,50,000 tons, 2,22,812 tons with percentage of extraction of 89, which may be considered as efficiently worked panel in the above block.

Table 4 Information about BG Panels of 3 Seam Block-C at GDK.N0.10 inc

Panel No.	Dimensions and Area m2	Panel Started on	Panel Sealed on	Period of extraction	Total Reserves (Tons)	Extracted Coal (Tons)	% of Coal Extraction	Area Extracted (m2)
1A	150 X 175 (26,250)	08-03-2000	22-12-2000	08M 14D	3,24,000	1,31,288	41	13,354
1B	150 X 160 (24,000)	12-02-2001	16-07-2001	05M 04D	2,26,575	80,242	35	7,345
2A	103 X 154 (15,862)	09-12-2001	29-06-2002	06M 20D	2,10,125	184,680	88	15,862
2B	113.5 x 150 (17,025)	29-07-2002	18-01-2003	06M 20D	2,30,850	1,43,542	62	12,987
2C	123 x 150 (18,450)	10-03-2003	30-09-2003	06M 20D	2,35,000	1,87,694	80	17,478
2D	125 x 150 (18,750)	06-02-2004	25-07-2004	05M 19D	2,27,772	1,41,634	62	11,704
2E	150 x 128.5 (19,275)	06-07-2005	08-02-2006	07M 02D	2,50,000	2,22,812	89	19,030
2F	121 x 150 (18,150)	16-02-2006	27-08-2006	06M 11D	2,36,000	1,77,000	73	15,537
1C-1	12387	11-10-2006	26-05-2007	06M17D		1,65,384		12,450
1C-2	13095	08-05-2007	02-11-2007	06M08D	5,94,484	1,79,889	84	12,042
1C-3	9816	05-07-2008	12-05-2008	06M29D		1,47,630		8,740
1D	120 X 150 (18892)	01-12-2008	21-07-2009	07M21D	3,05,156	2,30,464	76	18,800
1E	150X79 (11049)	17-07-2009	05-10-2010	012M22D	1,98,214	1,67,994	84	22,080

Minimum and maximum width/length of the panels was about 103 m and 150 m in the above Block C. 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.

2 GEO-MINING CONDITIONS OF THE PANEL -3A

Thickness of #3 seam is about 11 m with an average gradient of 1 in 5.5 (Table 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. Average size of pillars is 60 X 50 m , and Gradient of the seam is 1 in 5.5 at a depth of 323 m to 352 m.

Table 5 Details of working BG Panel No.3Aof No.3 Seam, Block-C

Incubation period	9 months
Overlying Seam	1 Seam goaf by 10A Longwall
Underlying Seam	4Seam virgin
Thickness of seam	11 m
Width of the development gallery	4.2 m
Height of the development gallery	3.0 m
Size of the Panel	150m x 120m
Area of the Panel	16000 m^2
No. of Pillars	6
No. of Rooms	9

2.1 Support system in the BG-3A 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 (Fig 1) . 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 1 Support system with I-section MS cross girders on hydraulic props

3 INSTRUMENTATION

Convergence indicators and, load cells were installed in 66 AL, 66 BL, 67L, 67AL, 67 BL, 68L, 68AL, 68BL, and 70 Level in the 41 to 43 dips at an interval of 10 m along the levels. In addition to the above, instrumentation for observation of bed separation with anchors at 0.5 m and 2.5 m was done in all the above levels. All necessary records were maintained from starting of extraction of the panel (Jayanthu, 2011). The data was analyzed regularly and necessary steps were taken for better strata control. The observations were carried out manually every day. Tell tales extensometers were also installed in the panel.

4 STRATA BEHAVIOUR OBSERVATIONS

4.1 Convergence

Convergence stations are installed at about 10 m interval along the levels and sublevels; 70L, 68BL, 68AL, 68L, 67BL, 67AL,67L,66BL and 66AL in the BG panel 3A. Convergence observations at C9-70L indicated no perceptible roof movement. About 4 mm cumulative convergence was noticed at this station. Less convergence at this station maybe attributed to the barrier effect. Comparatively more convergence of workings was observed at C9-68BL. About 18 mm cumulative convergence was noticed at this station up to the end of 31st August'2011.Sounds were observed in 68BL

followed by stone fall in pre-shift on 10th August 2011, with convergence of 1 mm only at the station C9 – 68BL.At 68AL, it is observed that station C-7 has the cumulative convergence of 22 mm. Maximum rate of convergence of about 2 mm/day was observed when the station was nearer to the goaf edge i.e., 4 m. Sounds observed and followed by stone fall in pre-shift on 10th August 2011.

At station C6 in 68L about 38 mm cumulative convergence was noticed up to the end of 31st August'2011. Maximum convergence about 3 mm was observed when the station was nearer to the goaf edge i.e., 3 m. Stone fall has took place on 20th August 2011 in third shift. The station C5-67AL was installed on 05thAugust'2011 at a distance of about 16 m from the goaf edge and maintained up to 31st August 2011. Maximum of 13 mm cumulative convergence was observed for the last five days as it is very nearer to the goaf edge. Total cumulative convergence at this station is 23 mm. A fall took place after indicating 3 mm convergence on 27th August 2011 in first shift.

The station C6-67AL was installed on 1st October'2011 at a distance of about 4 m from the goaf edge and it is observed that maximum daily convergence recorded when the goaf edge is 16 m from the station. Total cumulative convergence at this station is 32 mm. Maximum convergence observed when station nearer to goaf edge. Total cumulative convergence at C11-67L is 36 mm (Table-6). Total cumulative convergence at C10-66AL is 15 mm.

Table 6 Convergence Observation Up to the End of the Month of December –11

Sl No	Location	Cumulative convergence-mm (Monitoring Station)	Max. rate of convergence/day Mm (Date of observation)
1	67BL	33 (C10)	2 mm (1 and 2/12/11)
2	67AL	25 (C11)	3mm (2 and 10/12/11)
3	67L	36 (C11)	4mm (17/12/11)
4	66BL	38 (C10)	3mm (4 and 17/12/11)
5	66AL	36 (C9)	3mm (17/12/11)

Before the occurrence of main fall on 2nd September, 2011, rate of convergence at a distance of about 10, 15m and 20 m was 2-3 mm/day for five days, 1 mm/ day for four days, 1 mm/ day for three days, respectively. Convergence observations at Station C10 in 66BL during 26th November 2011 to 20th December 2011 are shown in Fig 2. Goaf Edge Distance (GED) was about 21 m at the time of installation of the convergence station C-10 in 66 B Level. Maximum convergence of 38 mm was recorded when the station reached goaf edge i.e at a distance of about 3 m from the goaf edge, beyond which the monitoring of convergence with manually is not possible.

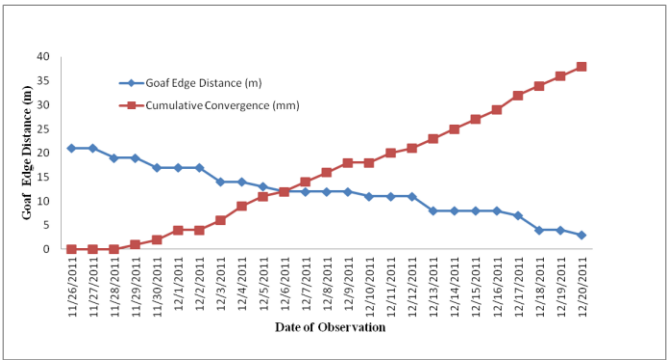

Figure 2 Convergence observations at Station C10 in 66BL

4.2 Load on supports

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 load was 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 from the goaf edge.

Load cells in the panel were installed with a setting load of about 2 to 5 T. Maximum daily variation of load observed was 1.715 T when it was about 10 m from the goaf edge. At station in 67BL the cumulative load has reached up to 9.7686 T when it was about 10 m from the goaf edge. At Load cell in 66AL, the cumulative load has reached up to 10.161 Tons when it was near the goaf edge. Maximum daily variation observed was 1.13 Ton when it was 15 m from the goaf edge. At station in 67L the cumulative load has reached up to 8.313T when it was nearly 10 m from the goaf

edge. Maximum daily variation observed was 1.715 T near the goaf edge. At station in 67L the cumulative load has reached up to 4.183T when it was near the goaf edge. Maximum daily variation observed was 8.107 T when it was 9 m from the goaf edge. At station in 66AL the cumulative load has reached up to 3.44 T when it was nearly 8 m from the goaf edge. Maximum daily variation observed was 0.807 T when it was 10m from the goaf edge.

Maximum load on hydraulic support was about 9.76 Ton during Spetmeber'11 in 67 BL in the working of the panel #3A. Maximum cumulative load on support before the major fall in the panel was 4.9 T, 1.9 T, 6.1 T up to the end of June, July, and August'11, respectively. During the Main fall conditions occurred on 2nd September'11, load increased to 9.7 T on the Hydraulic prop. Later the props experienced comparatively less load up to 6.1 T, 8.3 T, 4.2 and 3.4 T, respectively during October, November, December'11, and January, 2012. Although, there is a regular trend of increase in load in the stations, quantitatively significant trend could not be noticed, and hence observation of load on support may not be considered as a guideline for warning an impending main fall. This may also be attributed to the fact that the load on support depends not only on the roof sag but also on the extent of area of bad roof, type of roof, damage to the roof by blasting, many a time also influenced by disturbance due to moving machinery (Jayanthu, 2011; Jayanthu et al 1998; NIRM, 1997).

4.3 Bed separation

Bed separation was observed with anchors at a distance of 2.5 m and 0.5 m in the roof in the present panel. Maximum bed separation recorded at 70 Level was about 7 mm during 21.6.11 to 20.7.2011 till the station reached goaf edge. In 67 Level bed separation of about 16 mm was observed within 0.5 to 2.5 m horizon in the overlying roof near the convergence station C3. 1 mm bed separation was noticed in the horizon of 0.5 to 2.5 m in the overlying strata during 21st to 27th July,2011. It can be inferred that 3 mm bed separation took place in the immediate roof beds overlying 2.5 m probably at about 7.9 m due to weak clay and carbonaceous shale bands as intercalation between sandstone and coal seam.

Maximum bed separation of about 7 mm was observed within 0.5 to 2.5 m horizon in the overlying roof near the convergence station in 68 L during august'11. 6mm bed separation was noticed in the horizon of 0.5 to 2.5 m in the overlying strata during September'11 at C5 station in 67 level. Maximum bed separation of about 9 mm. 3 mm, 10 mm was observed within 0.5 to 2.5 m horizon in the overlying roof near the convergence stations during October, November, December'11, respectively. During January 2012, 2 mm bed separation within 0.5 to 2.5 m horizon in the overlying roof near the convergence station in 66AL.

5 INDUCED BLASTING/ROOF FALLS

Induced blasting practices for effecting filling of roof are conducted at frequent intervals as the area gets exposed. Location of goaf falls including major roof fall is shown in Fig 3. Major roof fall occurred on 9/2/2011 at a span of 85 m & 99 m in strike and dip direction with total area of extraction of 9034 m^2 associated with complete filling of goaf. The details of the induced blasting and roof falls are given below in Table 7.

Table 7 Summary of Induced blasting and roof falls in the BG panel #3A Block -C

Sl.No	Location	Date	Span	Area Of Extraction (M2)	Areaof Hanging Goaf	Area Of Fall	Cum.Fall Area
1	70LN/42D	23-05-2011	31	1299	1299	40	40
2	68BLN/42D	27-05-2011	29	1510	1245	225	265
3	68BLN/42D	03-06-2011	36	1903	1268	370	635
4	70L&68BL	07-06-2011	38&39	2119	1134	350	985
5	70L&68BL	17-06-2011	45	2648	1243	420	1405
6	68LN/42D	26-06-2011	47	3187	1322	460	1865
7	67BL&68L	27-06-2011	51&47	3271	1126	280	2145
8	67BLN/42D	29-06-2011	51	3381	986	250	2395
9	68LN&70LN	30-06-2011	52&51	3491	646	450	2845
10	68LN&68BLN	30-06-2011	52&51	3491	396	250	3095
11	68ALN&68BLN	03-07-2011	51&55	3857	482	280	3375
12	67BL&68L	08-07-2011	55&55	4059	424	260	3635
13	68LN&70LN	18-07-2011	61&65	4899	972	292	3927

14	68ALN&68BLN	18-07-2011	59&59	4899	712	260	4187
15	68BLN	19-07-2011	65&70	5098	616	295	4482
16	68ALN/42D	26-07-2011	63	5530	928	120	4602
17	68BLN	28-07-2011	76	5670	1018	50	4652
18	68LN/42D	29-07-2011	66	5742	890	200	4852
19	67AL&67BL	01-08-2011	64&66	5900	823	225	5077
20	67AL&68BL	03-08-2011	64&78	6073	646	350	5427
21	68ALN&70LN	10-08-2011	77&80	6733	856	450	5877
22	67LN	12-08-2011	70&73	6815	638	300	6177
23	66BL&67L	17-08-2011	74&73	7588	861	550	6727
24	68LN/42D	20-08-2011	81	7773	836	210	6937
25	67AL&68L	27-08-2011	82&85	8453	1066	450	7387
26	66BL&67L	30-08-2011	81&83	8716	1119	210	7597
27	67AL&68L	9/1/2011	85&87	8915	508	450	8407
28	67LN&70L	9/2/2011	85&99	9034	0	627	9034
29	68L&68AL	9/7/2011	91&99	9711	397	280	9314
30	67L&70L	9/8/2011		9932	18	600	9914
31	67L&67BL	10/27/2011	102	11121	457	750	10664
32	68L	10/28/2011	105	11261	447	150	10814
33	68L	10/31/2011	107	11639	475	350	11164
34	66AL&66BL	11/3/2011	104&112	11881	317	400	11564
35	68L	11/5/2011	110	11989	75	350	11914
36	67AL&68L	11/13/2011	119	12450	36	500	12414
37	66AL & 68L	11/23/2011	133	13933	319	1200	13614
38	67L	11/28/2011	142	14210	46	550	14164
39	66AL	12/10/2011		15074	460	450	14614
40	66AL	12/23/2011		15693	529	550	15164

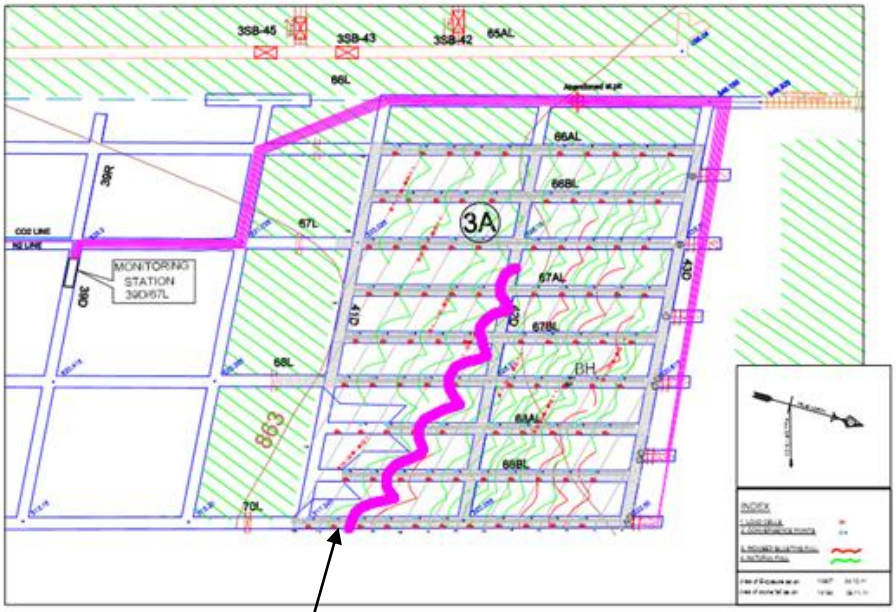

Fig 3 Location of goaf falls including major roof fall in BG Panel

6 COMPUTER SIMULATION

Extensive application of numerical models was demonstrated for understanding the stability of workings for extraction of pillars in thick coal seams. Depillaring process in the BG panel include different stages of division of pillars into stooks and extraction of stooks with ring drilling or blasting up to full seam thickness. For two dimensional representation of full seam extraction in a11 m thick seam, vertical section with four galleries G_1, G_2, G_3, and G_4 in an idealized panel was selected. A few parameters were kept constant for the models, e. g., width of pillar, development gallery, split gallery as 50 m, 4.2 m, and 4.2 m, respectively. Pillar size was kept constant at 50 m in accordance with the average size in the field experimental trials. In the first stage of extraction, splits of 4.2 m width are provided with symbols, S_1, S_2, and S_3. Second, third and fourth stages of extraction include high openings up to full seam thickness represented as E_1, E_2, and E_3.

Finite difference code - FLAC (Fast Lagrangian Analysis of Continua) was used for understanding the coal seams on stress distribution over pillars or stooks at different stages of depillaring (FLAC, 2005). Numerical models with different configuration of openings in the field are used. The following sequence of pillar extraction was simulated for all the above parameters:

Development of pillars

- Splitting of pillars
- Extraction of a row of pillars
- Extraction of two rows of pillars
- Extraction of three rows of pillars

The coal elements in the panel are small 0.5m in the ribs and 1m in the pillar. Each represents $2m^2$ area of the seam as maximum size. The model has plate elements with nodes. The problem domain consists of appropriate boundary conditions and grid pattern with development into three pillars of 50 m and 4.2 m wide galleries. These models simulate pillar extraction in plain strain conditions with Mohr Coulomb material. The model has its outer boundary located 150 m away from the mine panel i.e., three times the width of the final excavation. The top is free to move in any direction, and the bottom edge of the model is restricted from moving vertically and horizontally. Roller type boundary conditions for all the models are placed along two edges of the models. In the absence of the in situ stress measurements in the coal field, the following norms were adopted for estimation of in situ stress field prior to the excavation of the area.

$$\text{Vertical stress} = \gamma.H \quad (1)$$

$$\text{Horizontal stress} = 3.75 + 0.015H \quad (2)$$

Where,

γ = specific weight of the overlying rock mass, and

H = Depth cover

The model has a graduated internal stress that simulates gravity loading. To generate pre-mining conditions prior to adding the mine openings to the input, the model goes through an initial analysis to generate the in situ stresses. Gravitational and horizontal loading are imposed on the other two surfaces in order to account for in situ stresses. The displacements are then reset to zero and mine openings are added. The model is then reanalyzed to obtain the final stress distribution and deformation in the simulated geomining conditions. The numerical model results in the BG panel 3A panel are comparable to the filed observations. Comparatively low stress levels in the models as compared to the field observations may be attributed to idealization of depillaring to two dimensional domains. Stress distribution through the models showed the trend of asymmetrical loading around the galleries with high stress concentration towards the goaf side and comparatively low stress levels on the other side.

7 ANALYSIS OF STRATA BEHAVIOUR

Maximum roof deformation indicated in the model was 6 mm after development of the gallery (Table 8). After splitting a pillar, the maximum deformation in galleries and splits are indicated to be 7 mm and 6 mm respectively. Fig 4 shows the result of roof deformation in development galleries with 6 mm roof deformation.

Table 8 Deformation in various stages of depillaring through Numerical Modelling

Stage	Location (Deformation in mm)										
	Goaf	G1	S1	S2	G2	S3	S4	G3	S5	S6	G4
Development		6			6			6			6
2 Splits		7	6	6	7			7			7
4splits, 1stook	30			15	10	10	10	10			10

extraction											
6splits, 2stooks extraction	75					30	20	20	20	20	20
3 Stooks extraction	50				20	15	15	15	10	10	10
4 Stooks extraction	100						45	30	25	25	25
5 Stooks extraction	125							55	40	35	35
6 Stooks extraction	150								70	50	50
7 Stooks extraction	180									90	60
8 Stooks extraction	230										110

* G – Gallery
* S – Stook

After splitting of 2 pillars and extraction of first stook, the maximum deformation in goaf, split 2, and gallery are 30 mm, 15 mm and 10mm respectively. After extraction of first row of pillars and splitting in subsequent row of pillars, the maximum deformation in goaf, gallery and splits was found to be 125 mm, 55 mm and 40 mm respectively. After extraction of 3 pillars, the maximum deformation so indicated includes 230 mm in goaf and 110 mm in G4 respectively. From the numerical modeling, the maximum deformation of 110 mm is indicated over G 4. Increasing trend in convergence with decreasing distance from goaf edge was observed in the panel. During major fall conditions, at the stage of extraction of 5 stooks with opening of E1, E2 and E3 in two dimensional model up to a height of 11 m , maximum deformation in the adjoining gallery in the model is 55 mm, while 51 mm was recorded in the field. On the whole, the two dimensional model results are comparable with the field conditions with a variance of $\pm$ 10% for the geomining conditions mentioned in this case study.

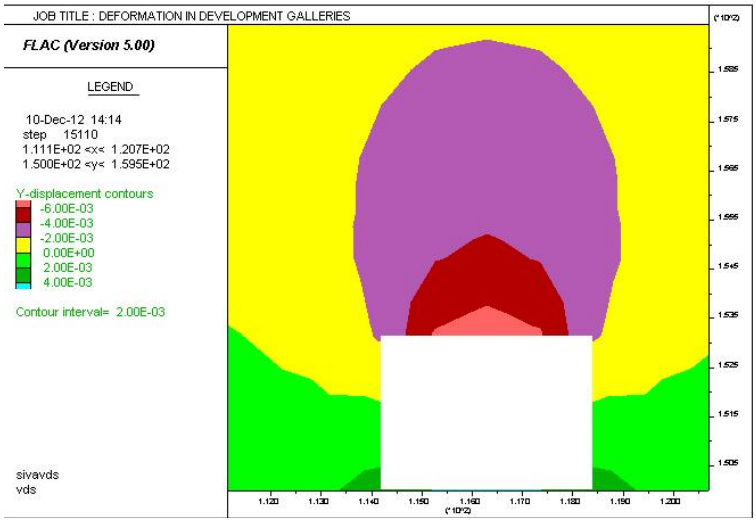

Figure 4 Deformation in vertical direction in development galleries

8 CONCLUSIONS

All the pillars in the BG panel 3A could be extracted with fair goaf settlement and without any adverse strata control problems unlike many other previously worked and prematurely closed BG panels in the mine. Maximum load on support, and convergence of workings up to January 2012 in BG panel #3A are 9.7 Tons, and 51 mm, respectively. Maximum rate of convergence and load on support recorded was about 4mm/day, and 2 Tons/day, respectively in the panel. Maximum bed separation of about 16 mm was observed within 0.5 to 2.5 m horizon in the overlying roof. Goaf falls were regular with induced caving up to 1.5 m in Sandstone roof and natural falls occurred with complete filling of goaf during Main fall. Overview of performance of previous BG panels, 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 help in premature sealing/closure of panels reducing chances of fires/spontaneous heating in subsequent BG panels.

Cavability studies of roof of III seam at GDK 10 incline and the underground observations in the previous panels (NIRM, 1997), indicated a Maximum cavability index of the roof of about 2915 in the overlying rock mass in the BG panel-I of Block-C. However, severity factor indicating intensity of dynamic weighting during major falls was found to

be within 1.6 only exhibiting no likelihood of any significant dynamic loading. In the panel, First major fall conditions occurred at about 60 m clear span in the goaf. Induced caving of immediate roof (i.e., bed with cavability index of about 1616) gave cushioning effect during first major fall with no perceptible dynamic loading. Before the occurrence of main fall, rate of convergence at a distance of about 10 m was 2-3 mm/day for five days. For the similar conditions of this panel, continuously increasing trend of convergence for five days may be considered as guideline warning for impending main fall. Other available norms based on ratio of convergence or cumulative convergence or trend in load on support could not indicate any impending major fall, and hence not recommended in similar conditions of this panel as a guideline. In view of loss of coal in this type of thick seam mining, it is also suggested to formulate guidelines for designing innovative methods of thick seam mining with meticulous evaluation of performance of BG method through a technical committee involving experts from industry, research, academic and regulatory agencies.

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