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Role of convergence behaviour for superior recovery of thick coal seams in underground mines by blasting gallery

Indian coal mining industry is starving for want of a technology which can extract deep seated thick coal seams. Blasting gallery (BG) method is applied for thick coal seam in underground. This technology ensures better percentage of extraction, ease of management, more safety and cost efficient. Though, it has limited applications in gassy coal seams still it yields an excellent result in a few Indian underground coal mines. Caving characteristics of overlying roof strata during liquidation of a coal seam vary from place to place depending upon the depositional condition of the site. Coal mining with caving has always an edge over partial extraction or a stowing face due to technical simplicity, favourable economics and high production and productivity. Unfortunately, Indian geo-mining conditions make it very difficult for a mine planner to opt for a caving coal mining face mainly due to the presence of massive overlying strata. In this paper prerequisites, development conditions, detailed extraction procedure and study of convergence of strata as the working progresses considering all the operational variables to designing a site-specific model of relevance to current days mining have been discussed thoroughly. Having control on strata by such scientific approach, the extraction of thick seam mining by blasting gallery method will yield highest percentage of recovery with utmost safety.

Key words: Gassiness, thick seam extraction, ring-hole blasting and induced blasting, convergence behaviour.

Introduction

Around 75% of the total coal reserves of India are workable by underground mining methods only. But underground extraction of coal could not achieve significant importance due to the difficult geo-mining conditions of the coal deposits and unavailability of adequate engineering support to meet the required level of safety and rate of production. Although underground winning of coal is considered as a part of clean coal technology, the share of coal production in the country by opencast mining has been continuously increasing during the last 45 years. The scope of fast mechanization, short set-up gestation period, and high production and productivity are the main reasons behind the growth of coal production by opencast mining [8-12]. As the coal reserves suitable for extraction by opencast mining are dwindling, mining methods for safe and effective underground winning of coal are going to play an important role in future coal production.

Coal seams of 4.8m thickness or higher are called thick. Nearly 60% of the total coal reserves that are workable by underground mining methods in the country are thick coal seams. To meet the increasing demand of coal, most of these thick coal seams have been developed extensively in single or multiple slices/sections. Around 30% of the developed thick seams are underneath a protected surface, while the remaining 70% are available for caving subject to the availability of a suitable mining method to extract coal under the existing challenges of the difficult geo-mining conditions [2,13,15]. In fact, underground coal production is maintained by way of formation of pillars due to the suitability of the available technical support and knowhow to maintain the required level of safety and low capital investment. Most of the thick coal seams of the country have been developed and, now, the industry is contemplating to depillar the developed thick coal seams to meet the production target as the coal production target of India is being increased every year to meet the growing demand of energy [9,14].

Brief description of blasting gallery (BG) method

Conventional depillaring with a system of drilling, blasting and manual loading is struggling to survive in the country-mainly due to its poor productivity. However, the socio-economic conditions of the country hardly allow the industry to adopt large-scale mechanization/automation for the pillar

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extraction. Intermediate mechanization (drilling, blasting and loading by machine) is, probably, the best-fit system within the backdrop of the country. Accordingly, increasing number of depillaring faces are adopting machines for coal evacuation from the face in conjunction with conventional drilling and blasting [16-18].

Blasting gallery (BG) method has found application in extraction of coal where the seam thickness is more than 6m. The system has been very successful with significant higher production from the panels. It is not possible to extract the full thickness of the seam in a single slice in case of bord and pillar, longwall or continuous mining method. The limitation of the shearer height in longwall system and continuous miner is limited up to 4.8 to 6m whereas the thick seam available is of about 8-10m in many of cases. So, the BG method is introduced for safe and speedy liquidification of such developed pillars with maximum possible percentage recovery [3]. BG method of wining coal was originally developed by French scientists and proposed in practical field conditions by Charbonnage de France (CdF). In the year 1989 Singareni Collieries Company Limited (SCCL) first adopted this technology in India and successfully implementation was done in GDK-10, GDK-8 and VK-7 mines. This method has been practically successful in chora seam (RVI) of Chora 10 Pit colliery of ECL and X-seam of East Katras colliery of BCCL due to some geological constraints of the area. In Chora colliery of ECL coal recovery was found to be about 70% from the BG panel which was substantially higher than conventional bord and pillar system and output per manshift (OMS) was quite higher at 2 tonnes. In case of GDK-8 and GDK-10 mines of SCCL production in the medium thickness seams 850tpd and OMS over 5 tonnes. The recovery of coal from the seam is 85% [4].

Prerequisite of BG method

1. Thick seam: Thickness of the coal seam ranging 6 m-15 m
2. Gassiness of the seam: Preferably free from gas or very low emission rate.
3. Gradient of the seam: Flat or mild steep gradient not steeper than 1 in 6 (9º).
4. Immediate roof: Carbonaceous shale and soft sandstone roofs are preferable (i.e. easily cavable).

Description of BG method

It is basically bord and pillar method and capital investment is not much. It can extract the entire seam in a single slice. The basic principle of this method is to recover coal from a thick seam by long hole drilling and blasting around the galleries i.e. side and roofs of the galleries in a single operation located at the bottom of the seam and placed at regular interval. The width of the pillar left between two adjacent galleries is 8-13m.

Conditions before commencement of extraction

- Working shall be resurveyed and verified for accuracy.
- Division into subpanels in accordance with the incubation period to avoid mine fires due to spontaneous heating problem.
- Independent ventilation circuit for each panel.
- Overlying goaf shall be free from water to avoid inundation.

Development and preparatory works

The proposed BG panels consists development of multi headings with different pillar sizes with a view to optimize resource utilization in achieving higher production. Initially the development is similar with bord and pillar method as shown in Figs.1 and 2. Formation of pillar of suitable dimension is done according to the size of galleries as per statutory provision i.e. according to CMR-99(4). Galleries are to be developed along the floor of the seam and the prepared coal is to be loaded at face by load haul dumper (LHD). Before blasting of the roof coal the pillars are split along the face line to increase the number of loading points and to reduce

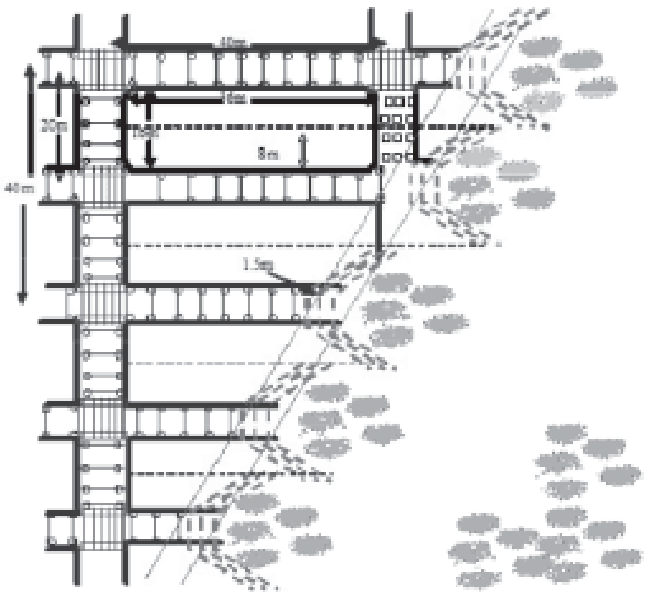

Fig.1 Operation procedure

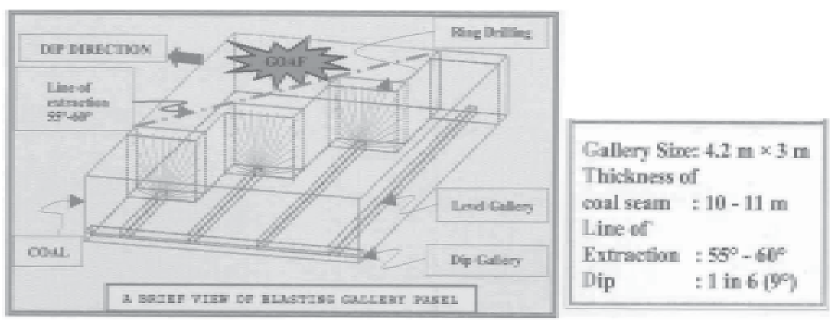

Fig.2 A brief view of BG panel

the length of the ring holes to be drilled to win the roof and side coal. During the extraction of pillars in the steep seam the advancement is done along the apparent dip direction to avoid the overloading on the pillars.

Manner of extraction in BG method

1. Level galleries/splits shall be driven with a width of not more than 4.2 m and height of not more than 3m, at an interval of 15.75 m to 22 m from center to center along bottom section.
2. The full thickness of the seam will be extracted by blasting a ring of shot holes having about 34 shots of depth not exceeding 13.6 m.
3. Each shot hole shall be drilled by a Jumbo drill machine.
4. The shot holes shall be drilled in a ring pattern sloping at an angle of about 30 degrees to 40 degrees from the vertical towards goaf.
5. The spacing between consecutive rings shall be 1.5 m.
6. The pattern of the rings in level galleries adjacent to the barrier shall be so designed that the thickness of the barrier is not reduced in any way in the seam (Fig.3).
7. A curtain of coal not less than 1.5 m. Thickness shall be left between two adjacent rooms after blasting of rings.
8. Extraction in level galleries shall be from in-bye to out-bye and extraction in the panel from dip to rise forming a diagonal line of extraction at an angle of about degrees to the direction of levels.
9. Drilling shall be carried out under protection of supports.
10. In order to ensure safety of the drilling crew from the falling of rolling pieces of coal and stone from the goaf, hydraulic props shall be erected at the edge of the goaf at 0.5 m. Interval.
11. Template shall be provided and used for proper pattern of drilling while using approved explosive and ring cord (Table 1), etc., for ring hole blasting.

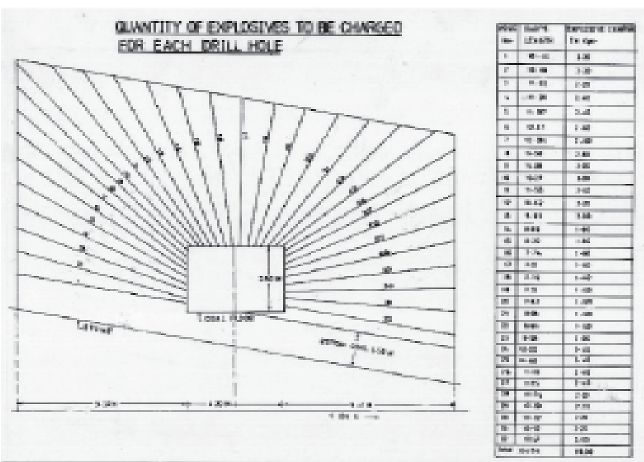

Fig.3 Ring hole pattern

TABLE 1: EXPLOSIVE USED IN BG PANEL

	Power ring	
	Description	
1	Density	1.15 g/cc
2	Relative weight strength	0.67
3	Relative bulk strength compared to ANFO @ 0.8 g/c	0.92
4	Velocity of detonation range (VOD)	3200 +/- 400 m/s
	Power cord	
	Description	
1	Colour	Red
2	PETN	8 to 9 g/m
3	Diameter	4 to 4.5 mm
4	VOD	6000 m/s

Roof support

- 200 mm × 200 mm steel roof girders placed at 1.0 m apart.
- Supported both ends by 40t open circuit hydraulic props.
- Successive girders are braced with steel bracers.
- Supports are made in all galleries upto 40 m. from face. This is maintained throughout extraction of the panel.
- Junctions are supported by 6 nos. of 5.5 m. long girders which are held in position with 4 nos. girders which in turn supported by 8 nos. of OC props.

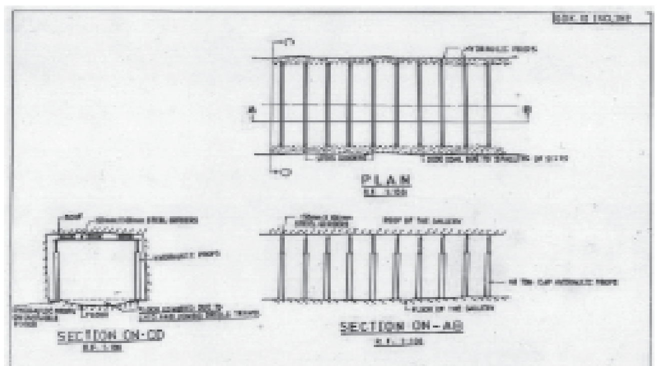

Fig.4 Roof support plan and section of a BG panel

Systematic support designing in BG panel

In this case support system of a mine of south India is being discussed. Mainly roof bolts, pit props are used for support galleries, junction and goaf edge.

Roof load at gallery: 4.4 t/m^2

Roof load at junction: 5.32 t/m^2

Roof load at slices and goaf- edge: 7.79 t/m^2

Support for splits and galleries

Galleries (4.2-4.5 m wide) are supported by 1.5 m long full column cement grouted rock bolts (2 bolts at 1.2 m distance in the middle) and pit prop should be placed at 1.2 m in each side near the side of pillars. The rows will be 1.2 m apart from each other. If the gallery width increases due to side spalling (up to 5.5-6 m) two additional roof bolts are needed to be installed in a row.

Support resistance offered by 2 bolts and 2 pit props.

Support resistance = [(2×8) + (2×10)]/(4.5×1.2) = 10.37 t/m^2

Factor of safety (FOS) = 10.37/4.41 = 2.35

Support at junction

The junction is to be supported by 4 bolts at 1.2 m interval in a row and spacing between rows is 1 m. Props are placed at corners. So total; 20 bolts and 4 props are used in a junction. For side spalling or cracks in roof 2 additional roof bolts is used in a row.

Support resistance = [(2×8) + (4×20)]/(4.5×4.5) = 11.85 t/m^2

Factor of safety = 11.85/5.32 = 2.23

Support at slices

Slices (4.5 m wide) supported by 2 full column grouted cement rock bolts and 2 props in a row and spacing between two rows is 1 m at the junction 2 props are removed split gallery and placed towards the goaf edge.

Support resistance = [(2×8) + (2×20)]/(4.5 ×4.5) = 12.44 t/m^2

Factor of safety = 12.44/ 6.19 = 2.0

Support at goaf edge

Goaf edges are supported with pit props in a row and spacing between the 2 rows 0.6m. Alternatively 3 square chocks (1.2 m × 1.2 m) of round cogs can be used to set a distance not more than 30 cm from the goaf edge. In some cases open circuit hydraulic props are used with arrangement of power pack to control the flow of hydraulic fluid. The spacing interval in this case is maintained 1.3 m.

Support resistance = (8 ×20)/(4.5 × 12) = 29.63

Factor of safety = 29.63/7.79 = 3.8

Loading and transportation

- Coal is lifted by means of LHDs which are having a bucket of 3 cu.m capacity.
- These LHDs are fitted with remote control facility to load coal from the goaf. About 50% - 60% of the coal will be lifted with remote control operation.
- The LHDs unload coal in to chain conveyors installed in the raises. The chain conveyors will be unloading the coal on to belt conveyors located in the top levels.
- Transportation of materials into the district is by means of endless haulers installed in the panel.

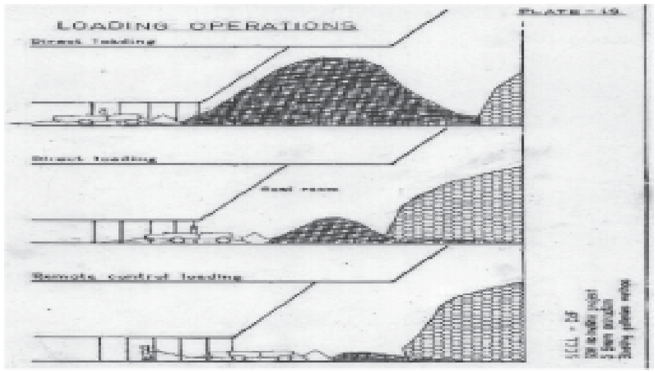

Fig.5 Loading operation of a BG panel

Advantages of BG method

- Entire thickness of seam can be extracted in single lift.
- Percentage of extraction - 80%.
- Highly flexible.
- Most of the equipment and spares are indigenously available.
- Loss of production is minimum while shifting the equipment.
- Low investment.

Problems of thick seam depillaring

Selection of a suitable mining method for extraction of a thick coal seam with optimal recovery and safety is an extremely delicate process. Recent advancements in mining technology have provided quite a few options to select a suitable mining method for underground winning of thick and virgin coal seams. Generally two types of approaches, multi-slice working or single-lift extraction of full thickness, are adopted to reduce operational constraints during underground extraction of a thick coal seam. Single-lift working of the full thickness of a thick coal seam has always an edge over the multi-slice working due to favorable economics and high production and productivity.

Most of the thick coal seams in India are developed along the floor with 2.5 m average gallery height. The height of extraction can be increased by winning roof or floor coal to optimize coal recovery from the seam. Increased extraction height for better recovery from a thick coal seam severely affects the design and rating of roof support, movement of overlying roof strata, stability of pillars and, in fact, dilutes almost every safety norm of underground mining. These inherited geo-technical problems for underground exploitation of a developed thick coal seam become even worse under Indian geo-mining conditions mainly due to the massiveness of the coal seam, as well as the overlying roof strata, and shallow depth of cover. The increase in the height of extraction may not be suitable for the length of the available conventional roof support systems. High values of mining-induced stresses in and around a depillaring face under a massive roof, generally, create a threat of pillar overriding. The chance of these threat further increases for depillaring of a thick coal seam, as the height of extraction is inversely proportional to pillars/supports strength [5]. The most critical problem for depillaring of a thick coal seam is under thinly laminated immediate roof strata. In this situation, reinforcement of the immediate roof strata was necessary to improve the safe span of overhanging beam/ cantilever even for a remotely operated LHD to transport/load the blasted roof coal lying on floor inside the goaf edge. The problems of the blasting gallery method during winning of roof and side coal have been shown in Fig. 6a. Solutions of most of these problems were considered in terms of reinforcement of the coal band of the immediate roof and main roof well in advance by a full column grouted cable bolt. Application of cable bolting (Fig.6) [6] during depillaring of a thick and developed coal seam provided encouraging results with a considerable amount of success in improving overall productivity and safety during extraction of a thick coal seam supported by pillars.

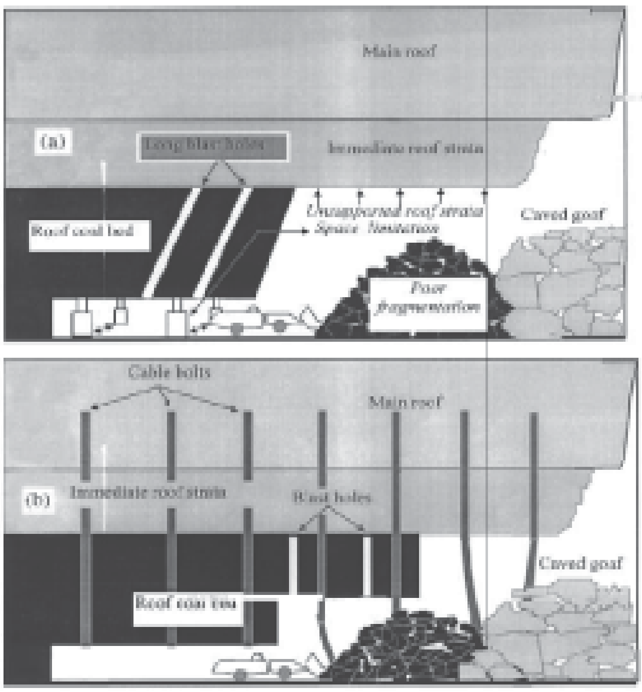

Fig.6 Problems of the blasting gallery method

INSTRUMENTATION

There are several number of instruments are used to measure the load on roof near the excavation point in the coal mine, bed separation and convergence. Instruments are following below:

Vibrating wire type roof support load cell

APPLICATION

The roof support load cells are used to measure the load of roof near the excavation point in the coal mine.

- These are used to monitor load under roof bed in mines and underground excavation.
- To monitor load at rib supports in roadways.
- To monitor load at crown of rib supports in tunnel.
- These are used to monitor the compression load in pile foundation.

INSTALLATION

- In coal mine we recommend that the load cell should be installed under the steel prop.
- Hydraulic prop or wood prop are also used as shown in the figure.
- However in some cases where floor is full of mud, water etc. It can be installed over the prop also.
- Before installation the surface should be made plane and load cell position should be vertical.
- The steel/hydraulic/wood prop should be installed vertically over the load cell to avoid the eccentric loading on the load cell.
- Give the initial load of about 2/3 te.

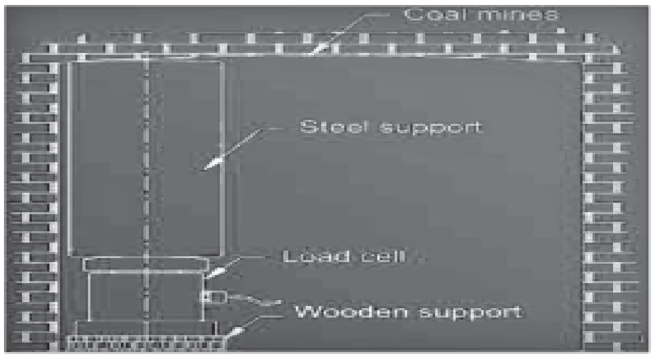

Fig.7 Vibrating wire type roof support load cell

DATA MONITORING

- After proper vertical installation of load cell take the initial frequency reading of each wire with the help of readout unit.
- Programme the readout unit as per the procedure and data asked by the readout unit.
- Measure the individual readings of each wire in tonnes add it and divide by three to get the average load of that load cell.

Remote convergence indicator

APPLICATION

- Convergence meter Model SME 2540 is a device for measurement of convergence in mines and underground convergence between roof and floor of the cavity.
- System is available with different types of sensors like linear potentiometer type displacement sensor or vibrating wire type displacement sensor for accurate remote measurement.

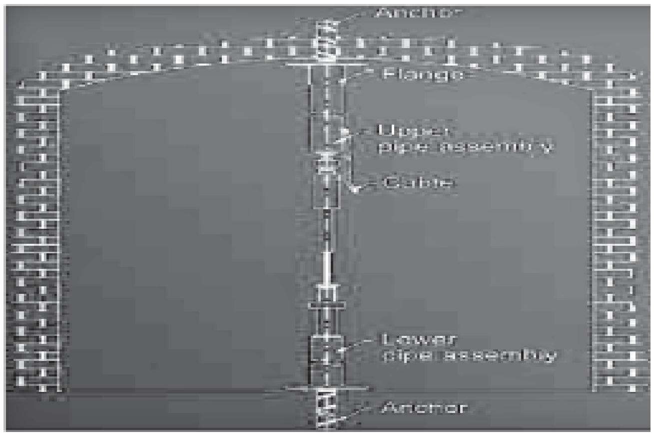

Fig.8 Remote convergence indicator

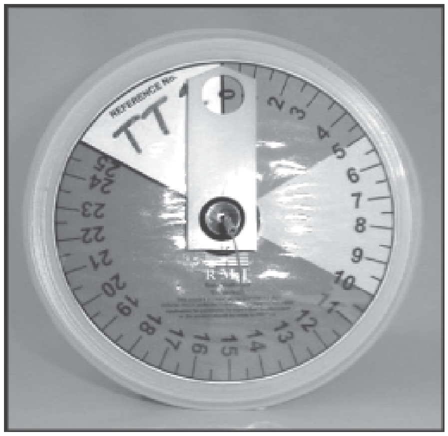
Fig.9 Rotary tell tale

- Remote type system is generally used where access is not always.

INSTALLATION

- The remote convergence indicator should be installed vertically by measuring the roof height where it is to be installed.
- Drill two holes of 42mm dia. of 1 feet depth in roof and floor. Grout the upper and lower pipe with flange and anchor with the help of quick setting cement.
- The installation height can be adjusted by adding/ removing the pipe and adjusting the pipe length.
- Fix the sensor in between two pipes as shown in the figure by taking out sensor rod of about 80 to 90% of its capacity.

Wire type extensometer or tell tale

Tell tales are safety devices which provide a continuous visual indication of the level of roof deformation that has taken place within the monitored height following installation. It is a very sophisticated instrument and which is very necessary for continuous monitoring of the roof in the underground coal mines. The rotary tell tale design has been developed to give a resolution of 1mm. This accuracy is important at sites where roof deformation levels are generally low. It is generally placed in the junctions of the galleries.

- Monitoring height is generally decided basing on the method of extraction, height of extraction, lithology and geotechnical parameters of the strata.
- Movement between adjacent anchors is calculated by subtracting the movement of the lower anchor from the movement of upper anchor.
- Analysis of the data obtained from instruments gives an idea of the horizon of the weak planes along which bed separation or fracture is taking place and
  - Immediate roof convergence
  - Bed separation between layers
  - Progressive failure height of the strata
  - Ensure efficacy of bolting and influence of extraction or development

It should be the responsibility of the miner each shift to record the tell tales by colour for all active areas in the section. A book should be kept at the section waiting place in which each shifts tell tale readings are recorded.

Where a colour change takes place this should be reported on the shift in-charge's statutory shift report, together with comment on any remedial actions taken. In addition the miner records the millimeter reading of the relevant tell tales.

So, we can measure the convergence from the colour in tell tale instrument. Colour incorporate with the convergence and actions should be taken by the officials are given below:-

ACTION LEVELS

We can indentify convergence from the colour in rotary tell tale.

TABLE 2: CHANGING OF COLOUR WITH THE CONVERGENCE IN TELL TALE

Colour	Convergence
Green	0 - 5 mm
Yellow	5 - 10 mm
Red	10 mm+

ACTIONS

From the upper table, we have to determine the convergence. Then suitable steps should be taken by the management are given below (Table 3):

TABLE 3: NECESSARY ACTIONS TAKEN DUE TO COLOUR CHANGES

Colour	Action
Green	No action required, continue routine monitoring
Yellow	Install additional reinforcement. Length and type of support to be determined by investigations co-ordinate by shift in-charge mine overman/roof control officer
Red	Restrict access. Consult shift in-charge/ mine overman / roof control officer

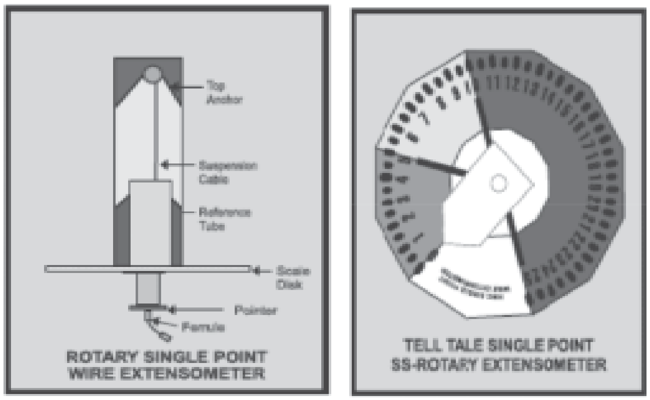

Fig.10 Single point rotary tell tale extensometer

Single point rotary tell tale extensometer

FEATURES

- It is useful where the conventional method of roof support testing is not convenient or possible.
- Movement of strata is indicated on the scale with a magnification 1:15
- It gives visual indication to workmen regarding the status of roof stability.
- Rapid and simple to install.
- Rotary types are useful for variable depth.

Auto warning tell tale

Fig.11 Auto warning telltale

- RMT's auto-warning tell tale has been designed to provide additional instantaneous warning of movement occurring in a rockbolted excavation.
- This is of particular value in dynamic mining situations, such as pillar extraction operations, where workman and equipment are operating close to a developing goaf.
- The LED is configured to flash when the B indicator shows greater than 25mm of roof deformation.
- The trigger level on the B indicator is factory set and cannot be adjusted by the user, but alternative trigger levels can be factory set on request.

STRATA CONTROL PROBLEMS

- Thick seam extraction results into formation of lot of voids in the goaf.
- If massive sand stone is allowed to fall on its own, there are two dangers
  1. Air blast
  2. Due to overhanging goaf , the abutment pressures shifts towards the working rooms and create overriding of pillars
- To overcome these problems Induced caving by blasting is practiced at regular intervals. To bring down the goaf stone to fill the goaf immediately and thereafter remaining portion of stone falls on its own.

INDUCED BLASTING

- If overhanging goaf does not cave by its own weight, Induced blasting is carried out at regular intervals when the roof span is about 120-190 m^2.
- Induced blasting can be carried out from surface or underground
- Generally induced blasting is carried out from underground only.

INDUCED BLASTING FROM U/G

- Drilling holes by Jumbo from 3.5 m to 4.5 m from goaf edge at 400-450 angle from the horizontal
- Hole is in coal top by the time it reaches stone roof, later on the hole is continued to drill in stone roof up to predetermined point 5-11 m in stone
- Erection of extra supports from the induced blast holes portion to the goaf edge
- Charging of stone drilled portion by leaving 1m in stone and stemming the remaining part of the drill hole
- Examination for presence of inflammable gas
- Firing of shots

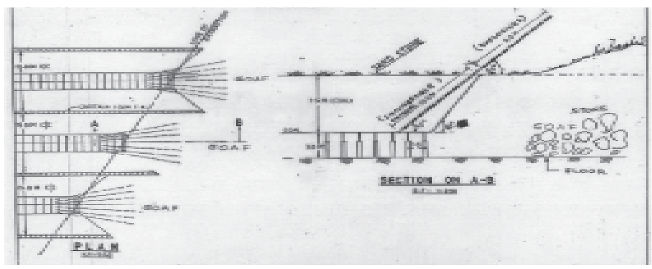

Fig.12 Induced blasting technique

Case study

To form the database, the information of blasting gallery method of work have been collected and processed through some stages. The respective mines are visited number of times while working as in charge of strata monitoring cell of that region and experience is gained on the system of operation. Data have been collected from instruments installed in the BG panels and through log books and registers of the mine concerned. The data has been checked and authenticated by the strata control officers of those mines.

Convergence observation in a panel

For safe operation of depillaring by blasting gallery method, it is mandatory to record convergence at each room daily. It is major indicative of the movement of strata and gives well in advance indication of impending fall in goaf or weighting on pillars. Telescopic convergence indicator is used to observe the convergence behaviour.

Mathematical interpretation of convergence and their behaviour

In order to understand the strata behaviour with respect to goaf edge distance, a number of observations are made in various stations in panel. Convergence behaviour in different stations is critically observed and their deformation pattern characteristics are mathematically interpreted with the help Microsoft excel.

The mathematical relationship between two variables namely goaf edge distance (GED) and cumulative convergence (cumulative convergence) are shown and mathematical equation is developed to describe their inter-relations so as to find out the best fit curve after being converges to a limit of number of iterations without using any weighting for this purpose. In order to draw the mathematical relationship the values of two variables (GED and cumulative convergence) are used predominantly as the guiding norms for this exercise.

The mathematical relation between GED and cumulative convergence of station 1 is represented in Fig.13 where the nature of graph is found to be 3rd degree polynomial and the mathematical equation that can satisfy their relationship has been given as $y = -0.247x^3 + 5.832x^2 - 45.26x + 120.7$.

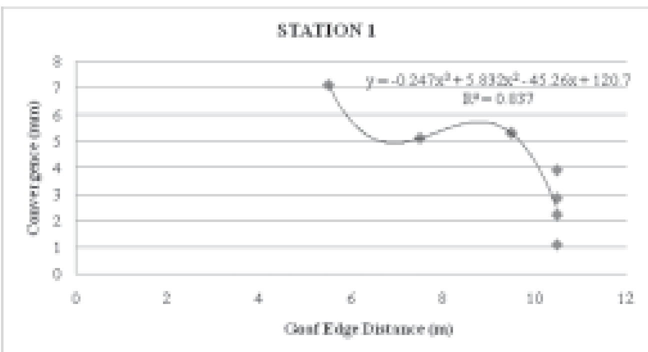

Fig.13 Cumulative convergence vs goaf edge distance (station 1)

The mathematical relation between GED and cumulative convergence of station 2 is represented in Fig.14 where the nature of graph is found to be 3rd degree polynomial and the mathematical equation that can satisfy their relationship has been given as $y = -0.002x^3 + 0.127x^2 - 2.569x + 25.53$.

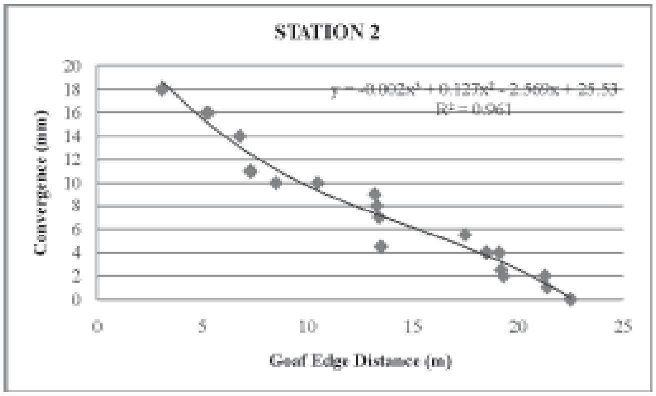

Fig.14 Cumulative convergence vs goaf edge distance (station 2)

The mathematical relation between GED and cumulative convergence of station 3 is represented in Fig.15 where the nature of graph is found to be quadratic and the mathematical equation that can satisfy their relationship has been given as $y = 0.072\,x^2 - 2.449x + 20.76$.

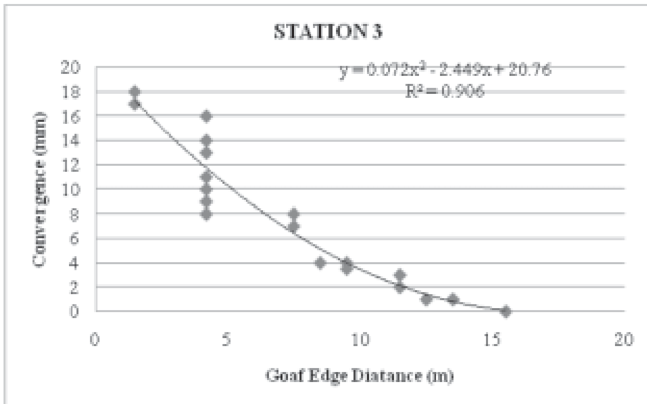

Fig.15 Cumulative convergence vs goaf edge distance (station 3)

The mathematical relation between GED and cumulative convergence of station 4 is represented in Fig.16 where the nature of graph is found to be 3rd degree polynomial and the mathematical equation that can satisfy their relationship has been given as $y = -0.007x^3 + 0.156x^2 - 1.580x + 13.89$.

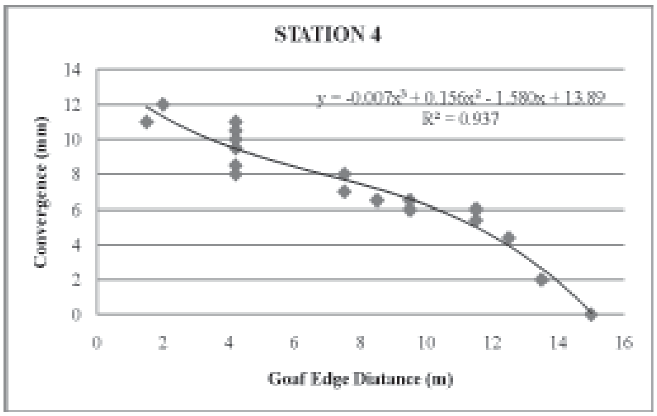

Fig.16 Cumulative convergence vs goaf edge distance (station 4)

The mathematical relation between GED and cumulative convergence of station 5 is represented in Fig.17 where the nature of graph is found to be linear and the mathematical equation that can satisfy their relationship has been given as y = -0.785x + 13.51

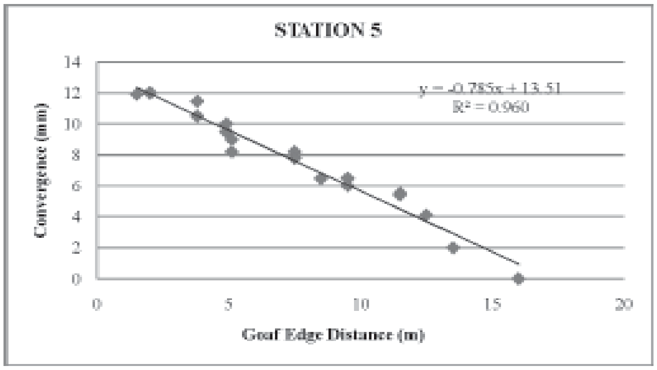

Fig.17 Cumulative convergence vs goaf edge distance (station 5)

The mathematical relation between GED and cumulative convergence of station 6 is represented in Fig.18 where the nature of graph is found to be 3rd degree polynomial and the mathematical equation that can satisfy their relationship has been given as $y = -0.007x^3 + 0.229x^2 - 2.571x + 16.15$.

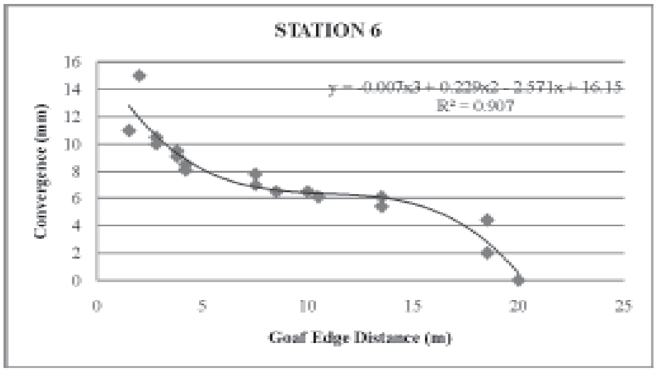

Fig.18 Cumulative convergence vs goaf edge distance (station 6)

The mathematical relation between GED and cumulative convergence of station 7 is represented in Fig.19 where the nature of graph is found to be linear and the mathematical equation that can satisfy their relationship has been given as y = -0.753x + 12.51.

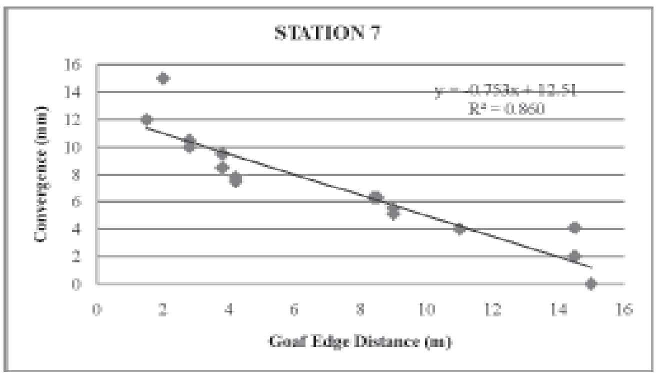

Fig.19 Cumulative convergence vs goaf edge distance (station 7)

The mathematical relation between GED and cumulative convergence of station 8 is represented in Fig.20 where the nature of graph is found to be logarithmic and the mathematical equation that can satisfy their relationship has been given as y = -6.09 ln(x) + 16.72.

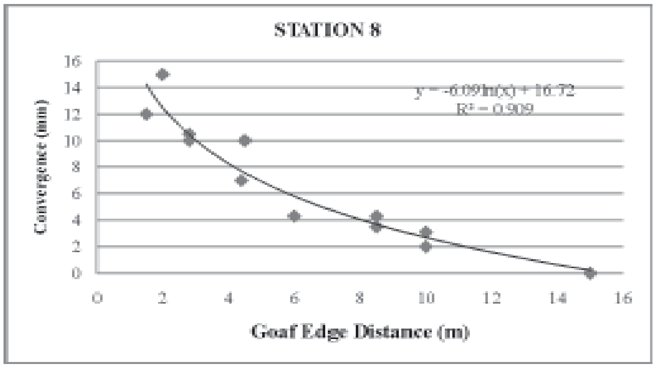

Fig.20 Cumulative convergence vs goaf edge distance (station 8)

The mathematical relation between GED and cumulative convergence of station 9 is represented in Fig.21 where the nature of graph is found to be linear and the mathematical equation that can satisfy their relationship has been given as y = -0.997x + 11.21.

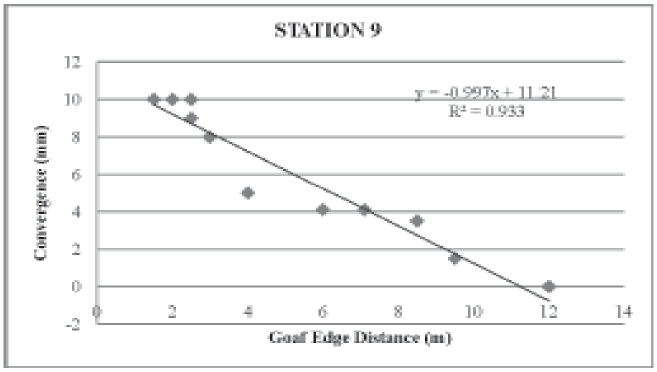

Fig.21 Cumulative convergence vs goaf edge distance (station 9)

The mathematical relation between GED and cumulative convergence of station 10 is represented in Fig.22 where the nature of graph is found to be logarithmic and the mathematical equation that can satisfy their relationship has been given as y = -41.5 ln(x) + 126.3.

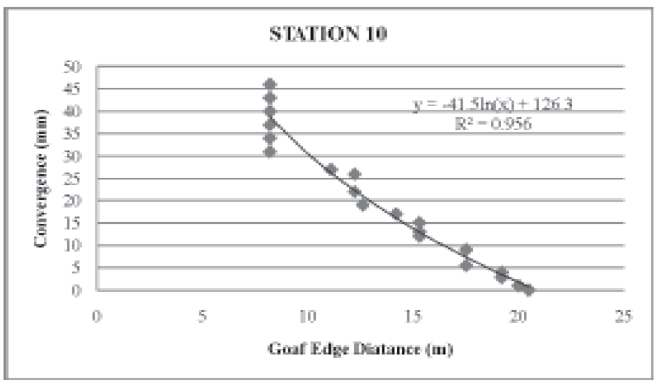

Fig.22 Cumulative convergence vs goaf edge distance (station 10)

Table 4: Observations of ten stations in BG panel and mathematical model analysis

	Best curve fit/model	Equation	No. of stations observed	Percentage
1	Polynomial fit (3rd degree)	$y = ax^3 + bx^2 + cx + d$	4	40
2	Quadratic fit	$y = ax^2 + bx + c$	1	10
3	Linear fit	$y = ax + b$	3	30
Linear regression models			8	80
4	Logarithm fit	$y = a \log x + b$	2	20
Non-linear regression models			2	20

Study on convergence against goaf edge distance

In order to study the behaviour of strata with regard to its convergence as the goaf edge advances, regression analysis is done. Total observations are 10 stations in BG panel and mathematical analysis is shown in Table 4.

Results and analysis

In order to find the relation of strata deformation due to mining coal in blasting gallery panel with respect to the advancing of goaf edge distance in panel, the best fit mathematical equations of the stations has followed linear regression models i.e. 3rd degree polynomial fit, linear fit and quadratic fit (80%). Where the goaf line velocity is uniform and faster the behaviour showed linear regression curve fit than non-linear regression curve fit.

Conclusions

About 65% of coal reserves in India are in seams thicker than 5.5 m. Blasting gallery method of thick seam extraction is a rib less method and does not have goaf edge support. This method enhances coal recovery and practiced, as it cannot be afforded loss of national resources in terms of poor recovery of coal from thick seam. Blasting gallery method of working can be practiced in virgin thick seam as well as developed pillars in thick seam achieving higher percentage of recovery (80-85%) by using LHDs.

Problems and issues associated with the final extraction of a thick coal seam are important factors during the selection of the horizon for pillar formation during development of the seam. Underground mining at full height in one lift becomes more difficult if the thick seam is already developed on pillars along the roof horizon. It may become more problematic during working below a competent roof stratum which caves with difficulty. The method of staggered development of the bottom section for under winning of roof coal is found to be effective for single lift working of a thick coal seam, already developed along the roof.

Winning of the overlying roof coal band during depillaring of a developed thick coal seam requires induced caving. Based on simple rock mechanics principles, the idea of using grouted steel rope under tension to support an overlying coal band (as well as a high roof and to improve the safe span of the overhanging beam/ cantilever near the goaf edge of semi mechanized depillaring of a developed thick coal seam standing on pillars). Abnormal strata loading should be overcome by adopting suitable line of operation. Besides depth, the geo-technical parameters including faults, folds and inherent weaknesses should be given due weightage prior to determining pillar and panel size and suitable line of operation.

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