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Extraction of Locked-Up Coal in Standing Pillars in Indian Underground Coal Mines

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ABSTRACT

Ensuring energy security for the growing population with rising per-capita energy demand has emerged as one of the greatest challenges before India. The developing nation like India will continue to rely heavily on thermal power plants for meeting energy demands against restricted access to nuclear technology and mixed success of non-conventional energy sources. Since inception of mining industry till now, bord and pillar (room and pillar) method of mining is still the predominant method of working in India. In most cases only the development workings have been done due to various complex mining conditions. As a result, huge amount of coal reserves are locked as standing on pillar (SOP) in these mines. Therefore, the adoption of effective mining technologies for the fast liquidation of these standing pillars is the need of the time to meet energy demands of India up to some extent. This paper presents a brief review and successes of different mass production technologies like continuous miner technology, shortwall mining and blasting gallery method of mining adopted for fast liquidation of SOP reserves in some of the Indian coal mines.

Keywords: Mass production technology; SOP; Continuous miner; Shortwall; Blasting gallery

1. INTRODUCTION

Energy needs of the Nation are growing at a faster pace than ever. Driven by the rising population, expanding economy and quest for improved quality of life, per-capita energy demand in India is expected to rise sharply. Coal is the major contributor for energy generation in India. India depends heavily on thermal power plants for meeting energy demands against restricted access to nuclear technology and mixed success of non-conventional energy sources. The power sector continues to report capacity losses from coal shortages. The demand tends to outstrip domestic supply. Power capacity addition in existing and upcoming coal based power projects has hardly been commensurate with the present coal production. The coal reserves amenable for opencast mining are depleting fast and this call for introduction of appropriate technologies in underground mining operations to augment production levels.

In India about 400 mines are being operated by underground method. About 93% of underground production is achieved by bord and pillar method. In most cases only the development workings have been done due to various constraints and complex mining conditions. As a result, huge reserves of coal of around 2500 million tonnes are locked up in underground as standing pillars (SOP). Conventional depillaring using SDL's/LHD's of these standing pillars is slow and uneconomical. With widening gap in production and demand of coal, production has to be ramped up from existing mines to keep the shortfall within limit. Hence, the coal pillars in underground need to be rightly exploited to meet the country's present coal requirement. Under such circumstances, the only option is to innovate and improve the available technological scenario. Therefore, the adoption of effective mining technologies for the fast liquidation of these standing pillars is the need of the time to meet energy demands of India up to some extent.

This paper presents a brief review and successes of different mass production technologies like continuous miner technology, shortwall mining and blasting gallery method of mining adopted for fast liquidation of SOP reserves in some of the Indian coal mines. The paper deals with basic design parameters, support assessment, strata monitoring and safety issues which are to be studied in detail for planning and execution of pillar extraction/depillaring. Adoption of these technologies in other mines will ensure higher production, improved productivity and enhanced safety standard.

2. MASS PRODUCTION TECHNOLGY FOR UNDERGROUND DEVELOPED COAL PILLARS

Underground production has remained stagnant over the decade in Indian coal mining industry in spite of large area of the coal seam has been developed and standing on coal pillars. The main reason is that there is a lack of suitable underground fast liquidation mining technology for these developed pillars, although the overall coal production has considerably increased. The increase in overall production contributed mainly due to opencast mines. Trends of production of coal in India from opencast and underground mines in last 10 years (Provisional Coal Statistics, 2013-14) are shown in the plot below in Fig. 1.

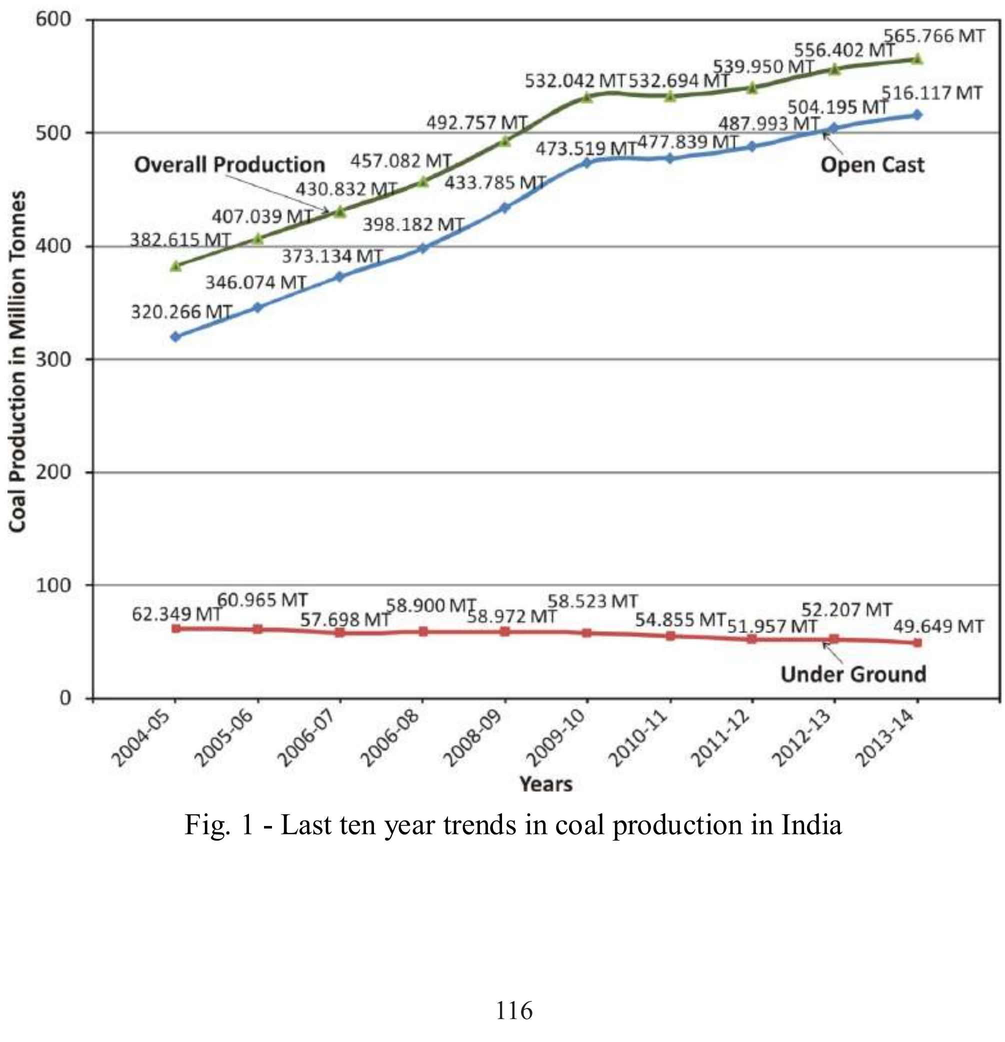

Fig. 1 - Last ten year trends in coal production in India

The plot in Figure 1 shows that in general open pit mining accounts for 90% of the total coal output whereas only 10% is being produced from underground. Due to increasing demand of coal and the fast depletion of opencastable reserves at shallow depth cover, the mining of coal by underground methods in mass scale is inevitable. With the implementation of mass production technology, coal production in the Asia Pacific region has grown tremendously. Advances in mass production technology have made coal mining today more productive than it has ever been. Fortunately, Coal India Limited (CIL) and Singareni Collieries Company Limited (SCCL) both have started inducting gradually mass production technology in their underground coal mines through international competitive bidding and direct negotiations to cope up with coal demand and future necessity. Foreign companies with technical capability and proven experience are encouraged. Presently, foreign companies like Bucyrus, Sandvik, Joy Mining are working in India in CIL and SCCL mines. To enhance underground production, the following mass production technologies have been introduced to extract SOP reserves in some of the Indian coal mines:

(i) Continuous miner (CM) technology
(ii) Shortwall mining technology
(iii) Blasting gallery method of mining

These mass production technologies are beginning to be adopted and there is enormous scope for improvement. New mining technology initiatives are needed to be addressed properly to achieve improved production performance and extraction percentage.

3. IMPORTANT PARAMETERS GOVERNING THE SUCCESS OF MASS PRODUCTION TECHNOLOGY

Favourable conditions for adoption of mass production technology in underground mines are as follows:

- Adequate seam thickness; ideally 4 to 5m for continuous miner, around 9m for BG and average 3m for shortwall
- Depth of working ranging from 100m to 400m for CM and BG and 40m to 200m for shortwall. The major issues with increasing depths are Ground control, Stability of Pillars and Ventilation
- Coal seam with gradient less than 1 in 7
- Competent roof and floor rock
- Infrastructure facilities like belt conveyors, storage bunkers and water supply etc. should match with production rate.

All the above mentioned mass production technologies are vastly different from other mechanized Bord & Pillar mining methods, mainly due to extraction of developed pillars at high rate which resulted quick variation in stress re-distribution pattern at the face and in surrounding rocks in the working areas. For successful implementation of these technologies in any mining field, the important strata characteristics and approaches for design of method of extraction and support system which are to be studied are dealt below:

3.1 Cavability Characteristics of the Roof Rock Strata

The success of any mass production technology depends on cavability of roof rock. Caving should be regular in goaf for smooth operation in face. Induced blasting is to be adopted where caving is not regular so as to reduce the pressure on working face and achieving better recovery with safety. CSIR-CIMFR Dhanbad has developed its own method for assessing the cavability of roof rocks strata. The following empirical relationship expresses the relation between caving index 'I' (Sarkar and Singh, 1985) with the influencing factors as mentioned below:

$$I = \sigma_c \frac{t^{0.5}}{5} L^n \tag{1}$$

where I = cavability index; σ_c = intact rock compressive strength (kg/cm^2); t =Bed thickness (m); L = average core length (cm); n = 1.0 for RQD < 80 and 1.2 for RQD > 80.

For estimating the cavability index of the roof rock strata of any seam, rock samples of at least two borehole sections of the proposed area have to be studied properly in the laboratory. The measuring parameters are length of the core samples, its thickness and RQD. Putting these values in above Eq. 1, cavability index of the roof rock strata can be estimated. Based on field observations and caving behaviour, the roof rock has been categorized as given in below Table 1.

Table 1 - CSIR-CIMFR characterization of roof rock strata

Sl. No.	Category of the roof	Range of cavability index	Roof rock strata characteristics
1	Category – I	Up to 2000	Easily cavable
2	Category – II	>2000 and up to 5000	Moderate cavable roof
3	Category – III	>5000 to 10000	Roof strata cavable with difficulties
4	Category – IV	>10000 to 14000	Cavable with substantial difficulty
5	Category – V	>14000	Cavable with extreme difficulty

3.2 Possibility of Air Blast during Caving

Twenty four Goodman jack tests were conducted inside two NX size drill-holes one each on left and right abutments. Tests were conducted during drilling of drill-holes. Pressure was applied in such a way so that transferred stress is comparable with those applied in plate loading tests. The volume of rock affected by the jack is about 0.028 m3 (1cft.) and extends to about 114 mm into rock away from the borehole wall.

The chances of air blast during extraction of any seam are dependent on roof rock strata characteristics. If the cavability index of the majority of the roof rock strata is less than 5000, chances of air blast will be minimal and the roof rock failure in the goaf will be in periodic manner. If this index is between 5000 and 10000, the roof rock failure in the goaf will delay, but there is a little chance of air blast at the face. In case of cavability index more than 10,000 chances of air blast at the face will always be there if area of exposure will increase more than a certain limit (Sarkar and Singh, 1985).

CSIR-CIMFR Dhanbad has developed a correlation between the equivalent face advances or ultimate stable span a_{eq} with RQD as given below (CMRS, 1987):

$$a_{eq} = 0.59 \text{ RQD} + 5.2 \quad , \text{ m} \tag{2}$$

$$\text{Expected area of main fall} = (1.55 \text{ x } a_{eq})^2 \quad , \text{ m}^2 \tag{3}$$

In case of depillaring of developed pillars from any mine, if the area of expected main fall increased more than the calculated value using above Eqs. 2 and 3, the chances of the air blast cannot be ruled out (CMRS, 1987). Under such condition, induced caving of the goaf roof at the face from underground using jumbo drill machine is needed. Therefore, it is recommended that, if the cavability index of the roof rock strata is more than 10000, there must be proper arrangement of Induced Caving and Jumbo Drilling Machine to run the face smoothly without facing air blast problem at the face.

3.3 Design of Method of Extraction and Support System

To design a suitable method of extraction and support system in and around the face numerical modelling technique has to be used to assess the stability of the surrounding rock strata and required support density at the face. CSIR-CIMFR uses FLAC^{3D} software (ITASC, 1997) for simulation which is based on explicit Finite Difference method. For the modelling purposes, the following rock properties (Floor rock, Coal and Roof rock) have to be estimated in the laboratory as per ISRM Standard: (i) Young's modulus, (ii) Poisson's ratio, (iii) compressive strength, (iv) tensile strength and (v) rock density.

Rock mass ratings (RMR) of the roof rock strata (Venkateshwarlu et al., 1989) along with RQD of the borehole rock samples are also needed at the time of designing of method of extraction, support system and induced caving pattern to achieve successful extraction of developed pillars with high production and productivity with Mass Production Technology. Support design using numerical modelling technique requires special attention for stable intersection and goaf edge breaker line support to prevent the encroachment of fall into working areas and to maintain safe conditions in working areas. Numerical modelling is envisaged in the following stages:

- Grid generation;
- Selection of appropriate material behaviour model;
- Incorporation of elastic constants, rock-mass properties, in situ stresses and boundary conditions;
- Solution to the equilibrium of elastic model;
- Development of roadway excavations in the model;
- Various stages of depillaring are simulated;
- Post-processing of the principal stresses obtained from the above models to evaluate safety factors of the rock mass. CIMFR failure criterion (Sheorey, 1997) is used to obtain the average safety factors of the rock mass.

The aim of this numerical modelling exercise is to come up with an optimum and safest scheme of depillaring taking the combined effect of adjacent goaves.

3.4 Strata Monitoring

Strata management of the proposed depillaring panel is carried out by number of geotechnical instruments. Instruments are installed at the strategic locations as planned in the Instrumentation plan like level, dip and split galleries and at 3 way and 4 way junctions. Some instruments are also installed near geological disturbances. Additional instruments are installed in the barrier pillars and the pillars which are under extraction during the time of main fall. Strata monitoring is done in two stages for routine monitoring and design monitoring with the help of instruments such as Remote convergence indicator, Rotary tell-tale, Auto warning tell-tale, 4 way roof/rib extensometer, Load cell and Vibrating wire stress cells. Data generated by the instruments are helpful in fixing the warning limits and withdrawal limits for the working face. Decisions with respect to timely withdrawal of machines and workforce are the result of strata monitoring carried out in the panel.

4. CASE STUDIES

4.1 Continuous Miner Technology: VK7 Incline, SCCL Mine

This is a case study of VK7 Incline of Singareni Colliery Company Limited (SCCL), India, where continuous miner (CM) technology was adopted for the extraction of 6.5m thick King Seam. The seam is dipping at 1 in 7.5 and occurs at an average 337m depth of cover. The complete system, supplied by Joy Mining Machinery Ltd, included a 12CM15 continuous miner, two shuttle cars for coal loading, a feeder breaker, a mobile roof bolting machine and electrical distribution system. The King seam was already developed with a height of about 3m along the roof, almost 20 years back. CSIR-CIMFR Dhanbad has conducted detailed scientific study for its first two caving panels such as CMP-5A and 5B to design the extraction pattern (CSIR-CIMFR, 2011; Kushwaha, et al., 2013). CMP-5 was sectionalized into two sub panels as CMP-5A and CMP-5B keeping in view of incubation period and rate of extraction. The cavability index of the proposed seam was determined which came to category I & II of the Table 1. Therefore, chances of air blast during extraction of King seam with caving is very less as the overlying strata are not very difficult to cave. However, it has been tried to quantify the extent of the area of roof exposure after which the induced blasting is required to initiate the roof fall in the goaf areas of King seam using CIMFR formula Eq. (2) & (3). The average RQD up to 23m for the immediate roof was found to be 72. Putting this value into above Eqs. 2 & 3, the ultimate stable span (a_{eq}) has been obtained as 48m and the expected first main fall would be in an area of about 5535 m^2.

Considering the maximum 3 pillars wide extraction at VK-7 incline in CMP-5A sub panel, this area will be achieved just within 1st row of pillar extraction. Regular controlled caving of overlying roof rocks of King Seam will obviate the risk of air-blast, stress abutments in working areas and goaf encroachment. Therefore, seeing the characteristics of roof rock strata of King seam, it has been decided that the proposed sub panels CMP-5A and 5B shown in Figure 2 can be extracted with CM Technology with full caving using "Split & Slices" method of mining. Geometrical parameters of the development workings of CMP-5 Panel at VK-7 Incline were:

Pillars size	: 45m x 45m (centre to centre)
Development roadways	: 4.2m wide
Roadway height	: 2.8m to 3.0m along the roof
Depth of cover	: 330m to 345m

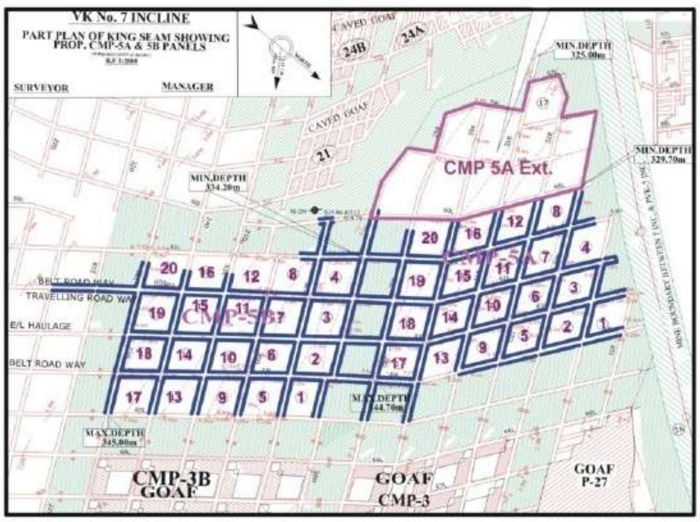

Fig. 2 - Part plan of sub panels CMP-5A and CMP-5B with sequence of extraction of pillars

To minimize the effect of adjacent worked out panel on this new panel, two rows of barrier pillars between this panel CMP-5 and already extracted panels were left. In the first step, all the developed roadways have been widened up to 6.5m from both sides of the pillars and height was left 3m only, so that shuttle car can move smoothly. Total widened roadways had been supported with resin encapsulated rock bolts of length 1.8m at an interval of 1.5m. For depillaring of these pillars, a single split of 6.5m wide and 3m height had been driven along level in such a way that it divided pillar in two stooks with dimension of one stook was 38.5m x 18.5m and of other stook was 38.5m x 13.5m. Similarly, one more experiment was done with double split of 5.5m over a pillar so that three stooks of size 38.5m x 9m can be formed. To estimate load coming over the stooks in both the cases, 3D numerical modelling using FLAC3D software was performed. Isometric view of model is shown in Fig. 3a.

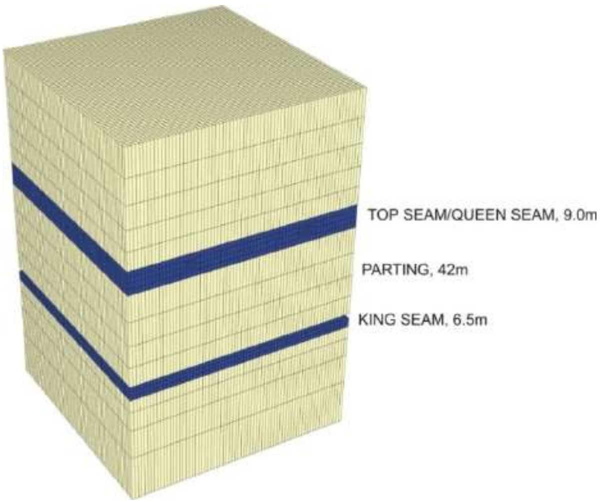

Fig. 3a - Isometric view of the model showing grid pattern

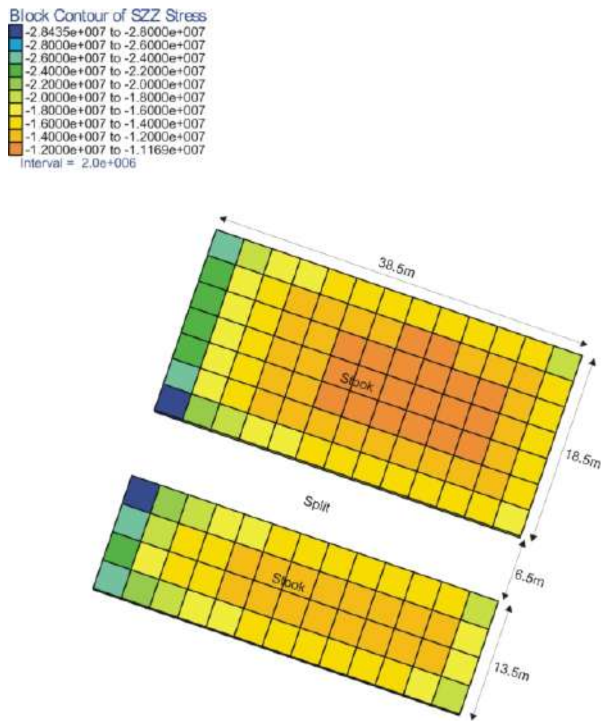

Fig. 3b - Block contours of vertical stresses over stooks with single split

The safety factor of stook with single split was found to be 1.35 and 1.04 for 18.5m wide and 13.5m wide stooks respectively (Fig. 3b). With double split it was 0.84. This study concludes that the safety factor of the stook with double split was less than 1, therefore; single split option with stook width of 18.5m and 13.5m was followed in panel CMP-5 during depillaring at VK7 incline mine of SCCL during application of CM Technology. The design (4 way roof and rib extensometers, VW stress cells) and routine monitoring (Auto warning Tell-tale, Rotary Tell-tale) instruments in the panel were found to be helpful in safer extraction of pillars and giving reliable data about the condition of the roof.

4.1.1 Support system used in CMP-5A and 5B

For supporting the widened roadways and split level, resin encapsulated rock bolt of 1.8m length and 22mm dia was used as shown in Figs. 4a and 4c. For junctions 2.4m long roof bolt was used instead of 1.8m. These support patterns have been designed based on the modelling results. For side support, wire mesh with cuttable GRP bolts has been used to check the spalling of the pillar during depillaring process as shown in Fig. 4a. In case of slips and fault intersecting the roadways, 2.4m long resin encapsulated rock bolts was used as shown in Fig. 4b.

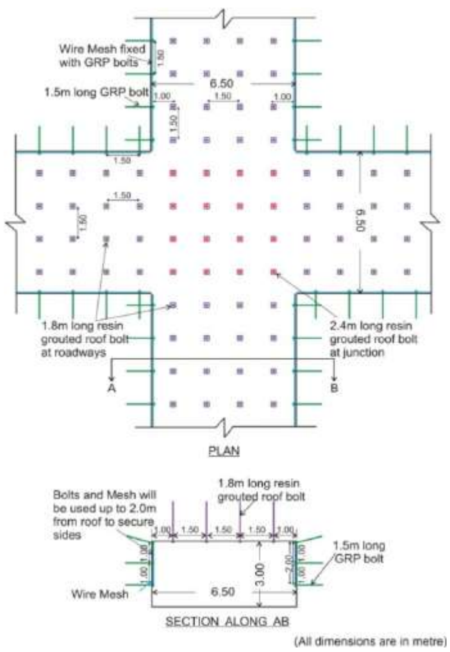

Fig. 4a - Support design for 6.5m wide gallery and junction

4.1.2 Pattern of extraction of pillars with CM technology in CMP-5A and 5B

In CM Technology during pillar splitting, two pillars are attacked at a time from stage 1 to 6 as shown in Fig. 5. The sequence of splitting and slicing of a pillar with CM technology in CMP-5A & 5B subpanels of VK7 Incline was as follows:

- Two pillars at a time was divided into two unequal parts by driving one level split keeping the working height and width 3.0m & 6.5m respectively.
- Roof & side supports and installation of breaker lines completed in splits in both pillars (Fig. 5).
- Made a ramp of 1 in 7 gradients along dip from the 2nd pillar junction as shown in Fig. 5 and deepen to full height of 4.6m.

- Deepen the 1st split; up to 4.6m full thickness by dinting. Slicing operation in dip side and around 5m incline in rise side up to 4.6m height was completed.
- The same slicing pattern was maintained leaving 2m thick ribs after each slicing till it reaches against last snook.

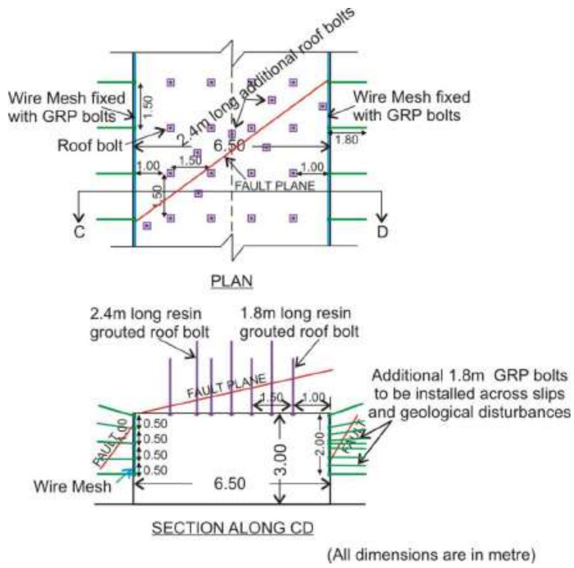

Fig. 4b - Support design for the area intersected with slips and faults

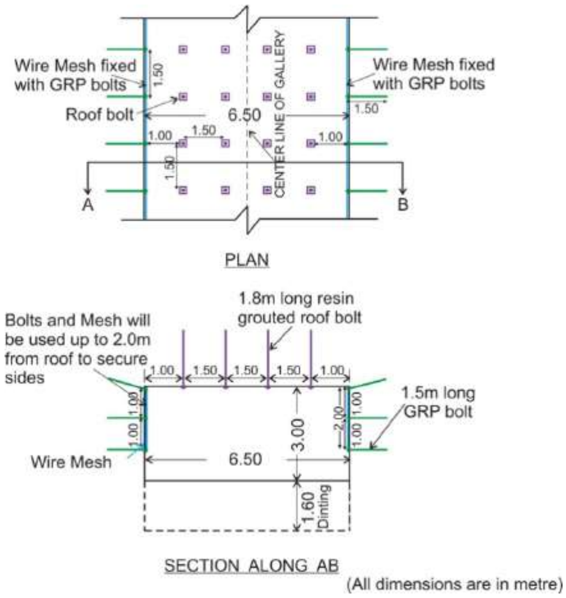

Fig. 4c - Support design for level splits and sides

- The dimension of the last snook was kept 7m x 13.5m x 15m x 14m. The estimated safety factor of this snook was 0.27, which can stand for few hours to withdraw the men and machine from face. Sometimes, this snook was not crushing, in that condition one slice of 3.3m was taken from this snook to weaken it, so that it fails and allows the roof to come down.
- After complete extraction of dip side stook (Fender A) of first pillar, deepening of original level (between pillar first and second) was completed. In the upper stook (Fender B), only dip side slice was taken up to the height of 4.6m in different leaving 2m ribs in between as shown in Fig. 5.

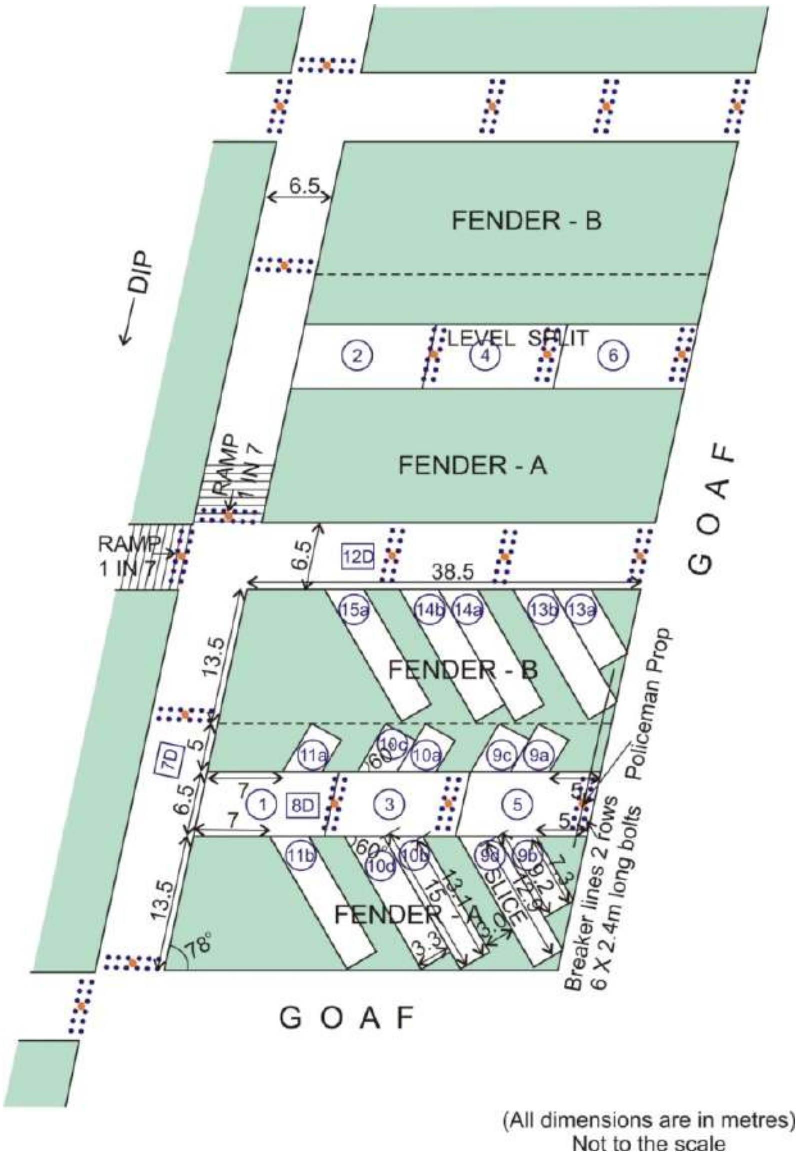

Fig. 5 - Pattern and sequence of extraction during splitting, slicing and dinting for sub-panels CMP-5A & 5B along with breaker line supports

4.1.3 Achievements

Average production with CM technology in CMP-5 panel at VK7 incline was around 1200 tpd and coal recovery within the panel was around 72%. Due to this technology, VK7 incline underground mine was running in profit.

4.2 Shortwall Mining

The shortwall mining technology is the method of extraction suitable for developed bord and pillar workings and is similar to longwall mining with shorter face lengths, ranging between 40 and 90m, The advantage of shortwall mining technology is that it helps in controlling the caving nature of the overlying upper strata, the load on support and the overall operation of the supports applied at the face. In shortwall mining technology, face is generally inclined 9° to 11° from pillar edge, shown in Fig. 6, so that stability at the face can be maintained (Kushwaha and Banerjee, 2005). This technology was firstly introduced in Balrampur mine of SECL with following mining geometry:

Depth of cover	: 50m
Developed pillar size	: 20m x 20m
Roadway width	: 4.2m
Seam Thickness	: 2.4m
Development height	: 2.4m

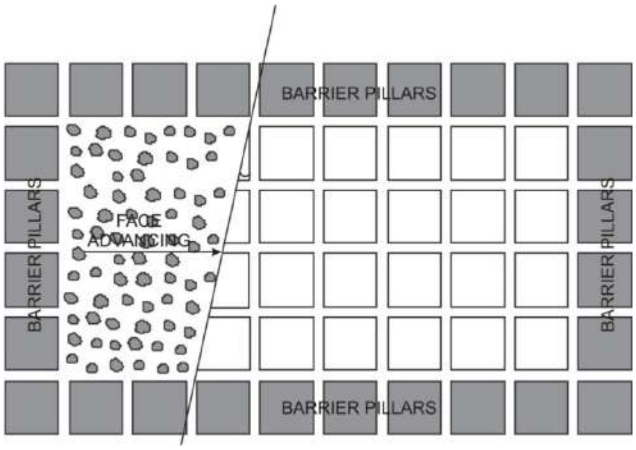

Fig. 6 - Face obliquity during shortwall mining

4.2.1 Mining pattern in shortwall mining

Orientation of the short longwall face was kept as oblique to avoid the formation of a thin long rib which could collapse suddenly. To overcome this problem, obliquity of the face minimized the exposed area and provides easier access to cross the advance gallery, from one end of the face to the other. Obliquity for Balrampur mine was kept as 9° to cross one advance gallery at a time.

With an oblique face crossing the advance gallery, a triangular rib was formed at last in every junction of the extracted pillar. In order to estimate the safety factor of the triangular rib, its strength was estimated using CIMFR strength formula and the load by using FLAC^{3D} numerical models. Factor of safety of ribs was ≥ 0.6 which stand stable for few days. Therefore, two travelling power support of 4.5m length was used in the advance gallery against rib which travelled from one end to other as the face progressed.

4.2.2 Support requirement at the face and in the advance gallery

The similar equipment used in longwall is utilized here too and open galleries ahead the face are well supported with longer roof bolts and cable bolts. Additionally, breaker line supports which are of normal power supports set in the open galleries with remote operation. Self-advancing, crawler mounted supports are also used as breaker line supports. Numerical models using FLAC^{2D} software was used for estimation of support requirement at the face and in the advance gallery. Support resistance on the powered support applied at the face was adequate to prevent failure of the immediate roof as the face approaches the advance gallery. This support system was designed with the safety factor more than 2.0.

4.2.3 Achievements

Average production with shortwall mining technology at Balrampur mine of SCCL was around 1200 tpd and coal recovery within the panel was around 95%. With shortwall mining technology, about 8 developed panels was extracted successfully. The geotechnical instruments installed in the panels have given timely indications during the monitoring period facilitating safe extraction of shortwall panels.

4.3 Blasting Gallery (BG) Method of Mining

Extraction of seams thicker than 4.8 meters has always been a technical problem for the mining industry. The problem is further aggravated by the presence of already developed pillars that are estimated to be of several million tons. Several methods had been tried in India for the extraction of thick coal seam but blasting gallery (BG) method of mining is considered to be the only economical and viable technology for thick seam extraction and it can be treated as mass production technology.

At Vakilpalli mine of RG-II area of Singareni Collieries Company Limited (SCCL), there are four seams viz., seam 1, 2, 3 and 4 in descending order which are dipping at an average gradient of 1 in 8.5. The upper most Seam 1 at a parting of 92m above 3 Seam was already extracted with longwall caving method and Seam 2 was not workable due to poor quality of the coal. Keeping in view of low gradient and seam thickness more than 9m of seam 3, blasting gallery method of mining was adopted in the south side property at Vakilpalli mine. Parting between seam 3 and seam 4 is 8m. Four seams were being worked by depillaring with sand stowing underneath the BG panels. During extraction of seam 4 and seam 3, number of experimentation with mining sequences was done in the field to minimize the strata control problem. It was found that when 4 seam is being worked first by depillaring with sand stowing followed by BG in 3 seam with a lag of around 30–60m (Fig. 7), the results were encouraging with significant improvement in roof rock strata condition (Kushwaha, 2014).

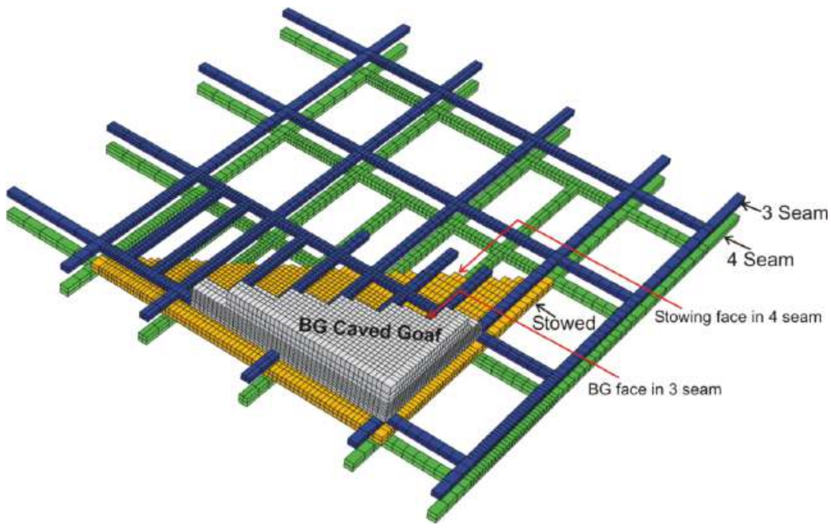

Fig. 7 - Simulated working face of seam 3 (BG method) against seam 4 stowing face

4.3.1 Extraction pattern in BG method at Vakilpalli mine, SCCL

The basic principle of Blasting Gallery Method as adopted in Seam 3 at Vakilpalli mine of SCCL was to recover coal from 9.6m thick seam by drilling and blasting the coal roof and sides of 4.2m wide and 2.7m height galleries developed along the floor of the seam at regular intervals. Ring holes up to 5-7m long are drilled in the roof and sides of galleries at regular distances varying between one to two meters by means of a Crawler mounted Jumbo drill (Fig. 8a & 8b). Blasting is done with explosive cartridges separated by inert spacers and detonating fuses so that the explosive is distributed uniformly. Special custom-made Permitted Explosive (P-3) is used for Ring Blasting. Loading is carried out by load haul dumpers (LHD) fitted with remote control system, which enables the operator to stand under the supported roof and operate the LHD to load the blasted coal from the goaf. The LHD bring coal from the faces and discharge onto armoured chain conveyor from there to belt conveyor network, which transport coal to the surface.

It has been observed that caving of the immediate strata in the goaf was taking place regularly; as a result abutment pressure at the face was nominal which caused low convergence of the gallery roof with face advancement. Geologically disturbed areas containing slips and fault planes, shown very high convergence values before goaf formation in comparison to other areas.

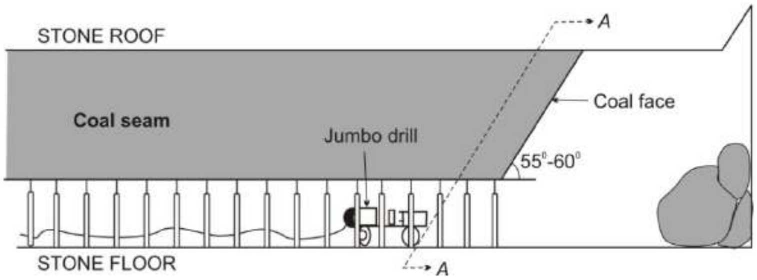

Fig. 8a - Drilling arrangement by Jumbo drill in BG pattern

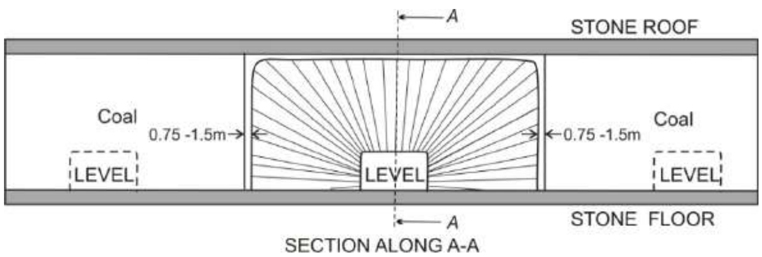

Fig. 8b - General drilling pattern of ringhole blasting in BG method

4.3.2 Design of support system for BG method in seam 3

For the design of suitable support system at the face and in the advance galleries, maximum required support or pressure at the face (obtained from the numerical models) has been taken into consideration, which came to 19.45 t/m^2. If two 40T capacity Open Circuit Hydraulic props are used as support system with 150 x 150 mm^2 cross sectional roof bars (girders) of 3.8–4m length, in a row at an interval of 1.0m between two consecutive rows all along the original and split level galleries along with four number of 2.4m long full column cement grouted bolts in a row and at an interval of 1m between two consecutive rows, then applied load was estimated using the Eq. 4 as given below:

$$Applied\ Support\ Load = \frac{n1 * Hp + n2 * G}{B * Sp1} + \frac{n3 * C}{B * Sp2} \tag{4}$$

where, $n1$ is the number of hydraulic props in a row, 2; n2 is the number of girder in each row, 1; H_p is the bearing capacity of hydraulic props, 40T; G is the bearing capacity of girder, 4T; B is the gallery width, 4.2m; Sp1 is the spacing between two consecutive rows of the hydraulic props, 1m; n3 is the number of bolts in a row, 4; C is the capacity of full column cement grouted bolts, 8T; $Sp2$ is the spacing between two consecutive rows of the bolts, 1m.

Putting all the above values in Eq. 4, the applied support or pressure will be 27.62 t/m^2. Therefore, safety factor of each support with single split of the pillars will be 27.62/19.45 = 1.42 > 1.0. A longitudinal sectional view of the original or split level galleries supported with the recommended support system for both the cases is shown in Fig. 9.

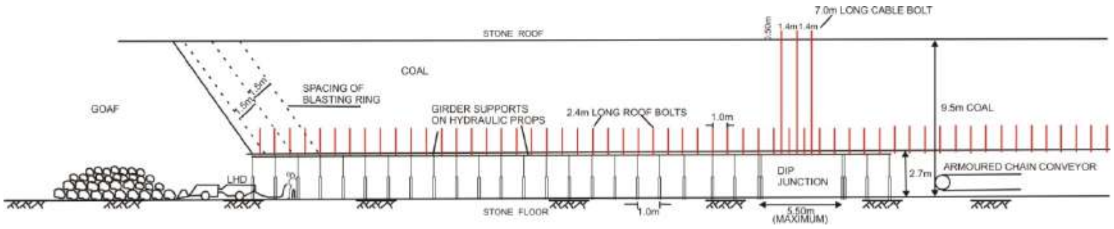

Fig. 9 - A longitudinal section of the roadway/split level with the recommended support system

4.3.3 Achievements

Average production with BG Method of mining at Vakilpalli mine of SCCL was around 1200 tpd and coal recovery within the panel was around 70%. Since the seam thickness was 9.6m, therefore, 70% recovery with indigenous support system was a very good achievement. This underground mine was also running in profit.

5. CONCLUSION

Coal has a dominant role to play in meeting the demand for a secure energy supply because it is affordable and in most circumstances cheaper per unit energy than other fuels. With the implementation of mass production technology, coal production in the Asia Pacific region has grown tremendously. Advances in mass production technology have made coal mining today more productive than it has ever been. In India about 400 mines are being operated by underground method. About 93% of underground production is achieved by bord & pillar method. In most cases only the development workings have been done due to various constraints and complex mining conditions. As a result, huge reserves of coal of around 2500 million tonnes are locked up in underground as standing on pillars (SOP). Extraction of these developed pillars by shortwall method, continuous miner technology and thick seam mining by blasting gallery method are the area where the Indian mining community should focus to liquidate the existing underground standing pillars. For successful implementation of these technologies, the important parameters described in the paper have to be taken into account carefully for design of method of extraction and support system.

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