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Amelioration of production and safety in bord and pillar work through the deployment of continuous miner technology

The nation's standard of living depends on its quantum of production and use of natural resources, including coal. Coal plays a major role in the development of a country like India. India has great potential of producing coal economically. Unfortunately, even after the nationalisation of 50 years of major Indian coal mines, we still have lower productivity than other coal-producing countries. The Indian mining industry has improved productivity in the opencast sector, but unfortunately, the industry still has to improve productivity in the underground sector. The underground coal is more free from any dirt, which is more acceptable for the user. If the underground productivity of the Indian coal industry is seen, it is the lowest compared to the countries producing coal. Initially, the industry thought of using the longwall technology but could not succeed of its limitations. For the last 20 years, the underground coal mines have been experiencing continuous miner who is not very expensive (as in the case of Longwall), not requiring the major restructuring of the old structures, having good productivity and more safety in operation. This paper deals with continuous miners and their success in the bord and pillar method.

Keywords: Underground coal mine; depillaring; numerical modelling; continuous miner; strata monitoring; instrumentation.

1.0 Introduction

Coal in India has two means of working for extraction, opencast and underground, depending on the depth of coal seam/seams. Growth in opencast production with high productive machines has helped the industry improve productivity, resulting in a higher growth rate, whereas growth in underground production continues to be dismal. The present scenario demands the future strategy towards mechanisation of underground technology. Over 80% of current underground production in India is by the bord and pillar method. Introducing the partial mechanisation with LHD'S, SDL'S, shuttle cars, etc., provides moderately success in improving the productivity in underground coal mines. However, present scenario, there is considerable awareness of the capacity of fully mechanised bord and pillar system using mass production technology with continuous miner and shuttle cars. In conventional mining and semi mechanised manual or loading by LHDs/SDLs, the workforce's engagement increased the production cost and threatened the workforce's safety. As the demand was for more production with more safety, the thought was given for introducing the continuous miner technology (CMT) by using continuous miner, which has the number of success stories in other countries.

Moreover, it is a proven method practised in different fields which can even produce 2000 tonnes to 2500 tonnes of coal (Modi and Bharti 2017) daily with an extraction ratio of 65-70% (Das et al. 2018) during the depillaring. A comparison of production in CMT and conventional method (SDL and LHD) of Sarpi mines are given in Fig.1. The state-of-the-art technology of the continuous miner (CM) deployment is a unique method to extract coal seam lying at greater depth with higher seam thickness, minimising the loss of coal in terms of in situ pillars and continuous production rate. CMT was commissioned for the first time in India (Mandal et al. 2018) in May 2002 at Anjan Hill (Leeming 2003) mine in Chirimiri, SECL. Later the success of this technology prompted other coal companies in India to adopt the CMT. Now 15-17 CMT projects are under operation in India. After developing the underground transport system in underground mining, the mining engineers tried to find the solution of extracting coal by mechanical means.

1.1 Origin of Continuous Miner

Primarily the continuous miners (CM) were introduced in late 1940 in the mines in the United Kingdom, and CM

Blind peer reviews carried out

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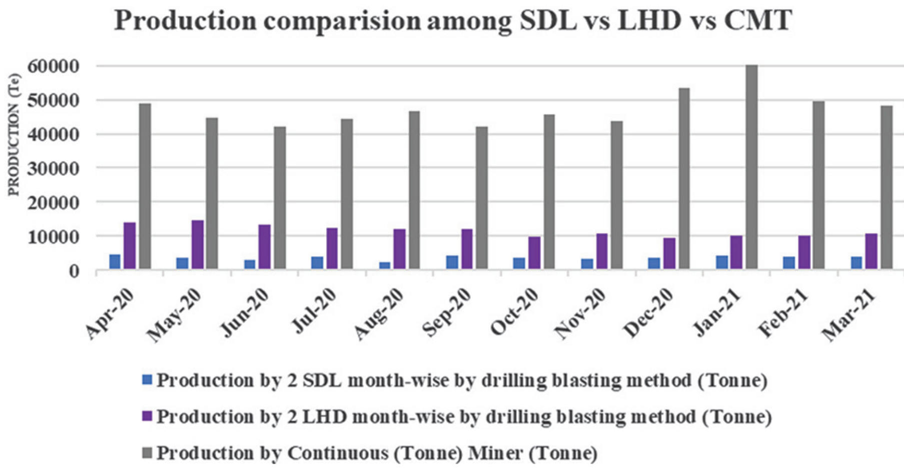

Fig.1: Comparison of production among CM, LHD and SDL

Fig.2: Continuous miner (12CM15 model)

provided a quantum leap in the speed and efficiency of coal extraction. The continuous miner uses the principle in which a large rotating steel drum equipped with tungsten carbide steel 'teeth' or cutting bits cut the in situ coal. This machine simultaneously cuts and loads the coal without any disturbances. This machine is a modification of the concepts of coal plough and the road header. Continuous miners are generally suitable for a room and pillar mining system. The size of pillars left for withstanding the roof load is guided by the coal mine regulations (CMR 2017). Introducing CM in virgin seam depends on the mining method; once the entire specified block of 5-6 pillars is formed, one can plan for depillaring. Accordingly, a series of 5.5m to 6.5m wide rooms are driven in the coal pillars. The fundamental concept of bord and pillar methods by a CM (Fig.2) is divided into a regular block-like array by driving through its primary galleries, which are intersected at regular intervals by connecting galleries. The galleries are called "bords". The blocks of coal bounded by them are called the "pillars". The pillars support the overlying strata as the bords are driven during the first workings. In the current case study, the development consists of five road entries. The three entries are utilised for intake ventilation whilst the other is used for return airway. All travelling and conveyor belt roads of 6 m width developed by CM are utilised as the intake airways. The formed pillars are mined at 36m centre to centre square pillars depending upon the working depth as per CMR 2017(CMR 2017).

1.2 Favourable condition to introduce continuous miner

For the successful operation of standard height, CM is required to maintain a few factors such as (i) gallery width (5.5-6.5m), height (3m-4.8m); (ii) ground pressure in the range 184 kPa-200 kPa (JOY 2022); (iii) power (1.1kVA); (iv) adequate ventilation system (sufficient to remove the coal dust constraints of visibility and other noxious gases); (v) transport system – preferably belt conveyor (1000mm-1500mm dia); (vi) pumping arrangements; (vii) adequate filtered water for dust suppression and roof bolting.Therefore, the number of headings for optimum use or efficient use may be limited to five to six, considering the limitation of the length of cable attached to the continuous miner and the shuttle cars/ram cars. As the cable from the load centre, permitted by the Director-General of Mines Safety, is only 200m as per CEA 2010, an ideal layout of the continuous miner district with five headings is given in Fig.3.

1.3 Infrastructure requirements for introduction of continuous miner

In Indian coal mines are gradually improving safety and productivity from time to time. Now, most underground mines are operated by the SDL, and some of the mines have been operated by LHD. Very few mines adopted the longwall mining and the road header for the non-favourable geological parameters of the seams. In 2002, CM was adopted in the

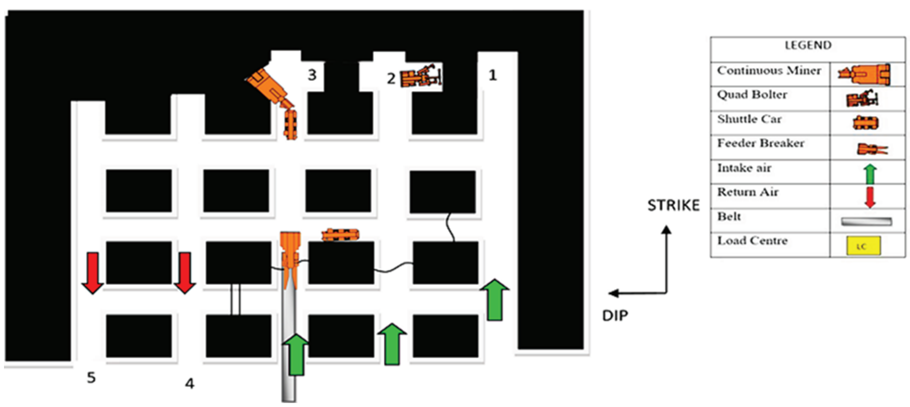

Fig.3: Five heading development layout by continuous miner

Table 1: Infrastructure requirement to adopt CMT, modified after (Murthy et al. 2013)

Roadway size	Not less than 3m height 4.8m width(as restricted by Indian Legislation) (Director general of mining safety 2017)
Incline gradient	The gradient of the incline should not be more than 1in 6.
Water supply	Clean filtered water, neutral pH, 250 lit/min, and 2000 kPa (15Bar)(Corp. Group 2022)
Conveyors	500 te/hr min, 1000m-1500mm belt dia.
Electrical	1.5MVA capacity for CM district and min 5MVA for total mine. 1100 Volts $^{+}$/- 10%
Ventilation	10-20 m^3/sec inside the CM district
Surface man-riding haulage	The man riding in and out of the mine required (If the travel distance is more than 3 KM)
Ground pressure	140kPA-227kPA
Fan size	AF 65 to more having minimum 2000m^3/min, pressure 25 mm water gauze
Workshop	An extensive workshop with an overhead crane near the entry with all the latest workshop machinery.
Degree of gassiness	Preferable degree I, II
Surveying instruments	Modern survey Instruments like total station, theodolite with the experienced team
Shaft	The shaft may not require compulsory it can be used for ventilation purposes.
Bunker/CHP	Underground bunker, a surface bunker minimum 5000Te to 15,000Te capacity highly recommended. It may be connected by rail or truck, or SILO.
Consumable storage room	To store the spare, consumable, support materials and strata monitoring instruments particular room with computer and air conditioning is recommended.
Haulage line/utility vehicle	To transport the machines spare, either haulage line up to face or the utility vehicle facility is required to reduce the breakdown time.
Others services required	Mechanisation culture among all workmen; establishing coal evacuation system by belt conveyors; making underground bunkers, if possible; creating workshop- facilities for repair, maintenance of equipment; essential strata management plan in a scientific way; statutory environmental monitoring; commissioning filter plant; Code of practices for all operations and training centre; establishing contingency plan in case CM is buried in goaf; enforcing regular caving of hanging goaf by induced blasting.

Indian mines, and now 15-18 mines are operated by the continuous miner. Many mines authorities want to convert semi-mechanised mines to mechanised. Some essential requirements and benefits of deployment of CM are given in Table 1.

1.4 Advanced safety features associated with a continuous miner

A continuous miner is associated with safety devices for better services. They are: 1. Emergency switch, 2. Water interlocking system – without sufficient water pressure, the cutter will not start, 3. Overload protection, 4. Methane sensor, 5. Oil level trip, 6. Water spraying with a scrubber to collect the dust and make it slurry, 7. Remote operation with high frequency (50m operating distances). Tram switch in the remote controls additional safety by pressing it with the tramming bottom, 8. Main's isolations switch. The modern machine has the indicator that if any person is staying in a radius of 3m, it starts to blink. Also, some machines have one more core in the cable, which monitor the machines from the surface.

2.0 Benefits of continuous miner technology

India is the second-largest coal producer globally, where 93.7 per cent of coal is produced from opencast mining (IBM 2019), and the rest of the coal is produced from underground coal mining. CMT is one of the best underground coal mining methods over conventional or partial mechanised ones with a high rate of safe extraction. Its high productivity, the highest level of safety, eliminating blasting vibration, eliminating the occurrence of noxious gases generated after blasting and restricting the deployment of the workforce directly under the exposed roof attracts the operator to choose the method. The method provides optimum extraction in a given coal seam and satisfies the following performance and safety aspects elimination of blast vibrations, prevention of noxious gases generation, better strata control. CMT increased the production rate as well as reduced the face crew. This CMT recovered the optimum height of coal and produced the continuity of the production. It also eliminates the manual loading at faces and can operate remotely from a distance—moderate capital investment with a higher production rate.

Developing bords using continuous miner with regular support and high mechanisation and advanced strata monitoring instruments increased safety. Fig.1 shows the production comparison among SDL, LHD and continuous miner.

2.1 Array of continuous miners and their technical specifications

There is various continuous miner manufacturers globally almost; they produced two categories of CM: a. low height 1.2m to 3.0m and standard height CM capable of extracting 2.8 to 5m height. A comparison of various CM with their important specification is tabulated in Table 2.

However, CM can be used in various coal seam thicknesses depending upon the expertise of the miners and proper planning. Manufacturers are always trying to modify the model according to the requirements.

TABLE 2: GLOBAL COMPARISON OF CONTINUOUS MINER (JOY2022) (CAT 21) (JAE2006) (SANDVIK 2022).

Continuous miner	Joy mining	JAE	Caterpillar	Sandvik
Model No	12CM15	Wildcat JAE42 CM	CM345M	ALPINE MINER ACM 10
Dimension ($L \times W \times H$) in meter	11.02×1.85×3.3	12.1×1.9×3.32	11.25×1.7×3.6	9.6×1.7×2.9
Ground clearance (mm)	305	280	356	220
Weight (Te)	58	110	74.8	43
Cutting width (m)	3.3	3.65	3.58	2.9
Cutter diameter (m)	1.12	1.32	1.12	0.95
Cutting height min-max-(m)	2.164.6	2.24.7	2.064.62	1.83.6
Cuttable rock strength (UCS in MPa)	60	70	65	15-30
Loading capacity (Te/min)	15-27	50	15-39	15
Conveyor width (mm)	762	960	762	600
Tram speed (m/min)	0-19.8	0-20	0-20	0-26
Ground pressure (kPa)	200	220	227	140
Total installed power (kW)	746	828	727	296

2.2 DEVELOPMENT BY A CONTINUOUS MINER

Generally, the bord and pillar section uses one continuous miner and two electric/diesel/battery-operated shuttle cars travelling between the CM and the feeder breaker. One quad bolter equipped with a temporary roof support system for facilitating the roof support can drill four holes for erecting roof bolts at a time in the roof and side. The feeder breaker receives coal from shuttle cars and crushes the coal to -200 mm before being fed to the main belt. The entire equipment is supported with power through the load centre, a step-down transformer (3.3 kV/1.1kV), placed in a suitable centrally located place. The load centre is capable of supplying power to different face equipment, including the face pumps and the LHD (generally used for cleaning the route of the shuttle cars) apart from the CM, shuttle cars, feeder breaker and quad bolter. The use of LHD in the continuous miner section is also for the transportation of daily use materials to maintain production. A continuous miner with bord and pillar is now prevalent and economical. The gallery's width is usually kept between 5.5m and 6.5m, for which special permission is required from DGMS (CMR2017). With the development of the continuous miner, the CMs are available to extract 1.5mt to 6m height coal seams. The feeder breaker is installed in the middle so that the shuttle car covers the maximum distance from both sides. After completing one level cutting, all the machines and belts shifted to the next pillar.

2.3 DEPILLARING USING CONTINUOUS MINER

After the formation of bord, a continuous miner can carry coal pillar extraction. Continuous miners typically have a cutting head that is 3.3m wide. The machine is usually "sumped in" between 0.5m and 0.75m at roof level, with the rear stab jack on the machine lowered if required, and then the head is sheared down to floor level. The cutter head usually loads around 8 tonnes per 500mm sump in a 3.5m seam (1.4m^3/tonne). When the miner opens the gallery width to 6m, the second cut width is only 2.7m after the first cut of 3.3 meters. In depillaring, the continuous miner is supported by the equipment used in development. There are various methods for working a coal seam using continuous miner depending on the depth of working, strata condition of the immediate roof, and pre-mining state of stress and pillar size. To determine the proper methods for the depillaring, all the above conditions are considered. From the field experience, it is seen that a continuous miner can cut a slice of 14 m length in one go without any support. Therefore, in any depillaring method, the slice length is restricted to 14m. The split and fender method, which has been very popular in India, is used in Sarpi mines, where the extraction involves splitting the pillar in strike direction, and subsequently, fenders are extracted. Further, fenders are also extracted by taking slices, leaving adequate ribs to provide temporary support (Mangal 2021). Slices are driven at an angle of about to enable safe movement of the machine and to operate the machine from a distance allowing maximum visibility.

2.4 VARIOUS DEPILLARING METHODS BY A CONTINUOUS MINER

There are many methods for working a coal seam using continuous miner according to the depth of working, strata condition of the immediate roof, and pre-mining state of stress.

Fig.4 shows a few depillaring methods by a continuous miner, which are further elaborated (Fig.4).

2.4.1 Split and fender method

In the Indian coalfield, the most popular split and fender method account for 73% of the global CM production (Mark and Zelanko 2001). Here at the level, the pillar is split into two half. After that dip, the most fender is splitted, leaving 5m rib at a 60-degree angle from the split gallery. Subsequently, after taking two to three slices again, one rib should be left, and the process will continue. In the second fender, the process is the same, but more rib is left at the last 8%, called snook. This is the most popular method in India, suitable for 30-38 m pillar sizes.

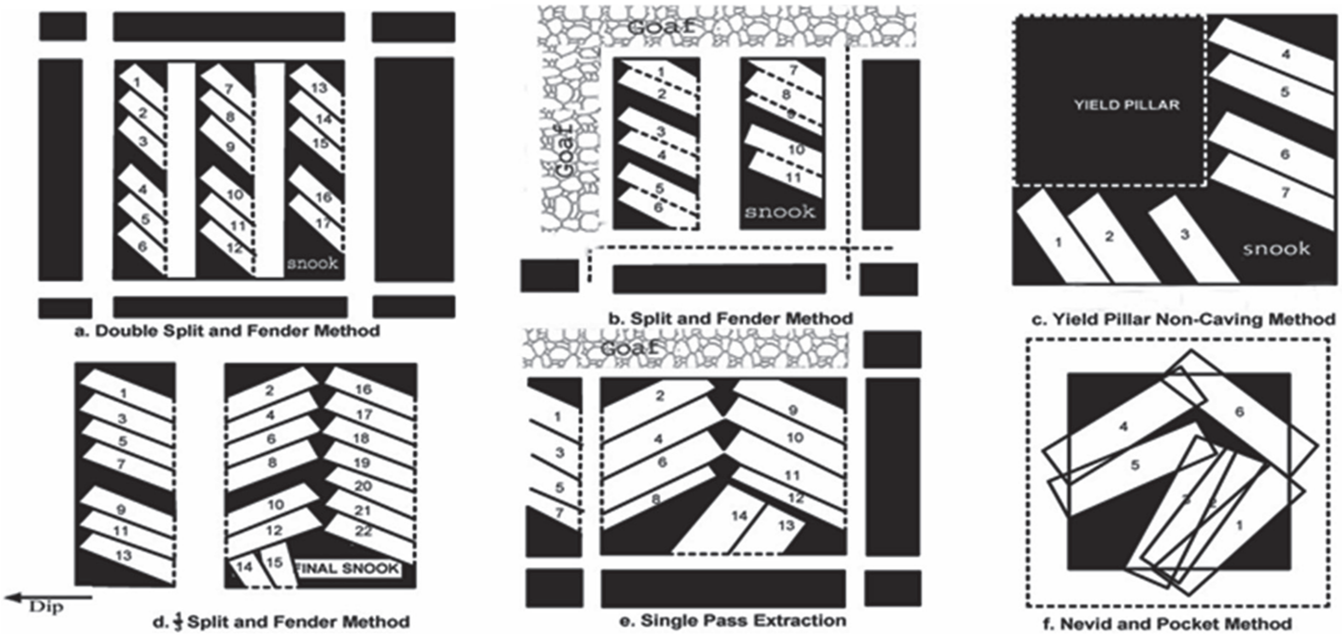

Fig.4: Various methods of pillar extraction by continuous miner

2.4.2 Yield pillar non-caving method

Yield pillar non-caving method is not so popular; significantly less production of about 1.5% of the global total. This method of depillaring is practised in the VK7 colliery (Andrew 2009) of SCCL. This is suitable for partial extraction where high stress is acting over the pillar, particularly in the depth mines more than 250m.

2.4.3 Modified nevid system of extraction

In this method, the pillars are mined by a continuous miner from the original level and dip galleries continuous miner cuts on either side of pillars from the original gallery. Thus a solid stump of mid-portion of the pillar leaves by cutting around it. A modified Nevid and pocket system is chosen for smaller pillars (18-20m). Modified Nevid system of extraction is being followed under hard and massive roof cover amounting to 10.6% of the global coal production by CMT.

2.4.4 Fish and tail method

The method involves the extraction of coal by cutting slices using continuous miner in the level direction first and then driving a push out in the dip direction. A straight line of pillar extraction is maintained during coal extraction, and sequence is adopted to allow the caving of the roof in the dip direction.

2.4.5 Double split and fender method

Pillar sizes within the range of 25.5–34.5 m are generally worked by the split and fender method without being supported. Therefore, the double split and fender method becomes the most suitable choice for the panels whose pillar size is more than 38m. Here, the pillar is splitted into three halves, and slices are taken from the dip side to the rise side. Leaving 5m rib, slices are taken, and again rib left after taken 2-3 slices. After completing the first lift, the second fender is taken in the same manner.

2.4.6 One-third split and fender method of extraction

Pillar size more than 35m may be extracted by the one-third split and fender method. The split and fender method of extraction involves splitting the pillar in strike direction, and subsequently, fenders (Chawla et al. 2017) are extracted. Further, fenders are extracted by taking slices, leaving adequate ribs to provide temporary support. Slices are driven at an angle of about, for the safe movement of the machine. Furthermore, allow to operation of the machine from a distance allowing maximum visibility. The one-third split and fender method splits the pilar in one-third position and takes slices both left and right side from the split gallery. Again slices are taken from the outer gallery.

2.4.7 Christmas tree method

The Christmas tree method is the most comprehensive pillar extraction method, followed by continuous miner depillaring panels. It is also known as the left-right, fishbone, or tree topping method of pillar extraction. The layout of the method is suitable for pillar widths varying from 18 to 24 m centres. The size and shape of the pillar remnants, back wing, and push out stumps can vary from pillar to pillar.

2.4.8 Outside lift method

The primary advantage of the outside lift plan is that the operators always have a solid pillar at their back. It also has some disadvantages, and it cannot be used to recover wide pillars without leaving large remnant fenders of coal (wide pillars may be required to meet global stability requirements in thick seams and under deep cover), and; it usually employs deeper cuts, making the CM more challenging to extract if it is trapped while extracting a lift by a roof fall or rib roll.

2.4.9 Pocket and wing method

Deep cover operators practice both full and partial production and barrier pillar recovery during panel retreat. An operator's rationale for electing one extraction method over another is usually based on factors including equipment and timber availability and cost, pillar size, coalbed thickness, roof competency, and local custom. Approximately two-thirds of the panels in the database were extracted using either the Christmas tree or split and fender extraction methods. Of the two techniques, the Christmas tree is usually the one most favoured by operators because it does not require place changing and bolting. Another extraction method practised to recover large pillars entirely is the pocket and wing procedure, which requires changing the operating place and bolting. Some operators indicated that if large pillars require splitting, the split and fender method is preferred because it minimises gob exposure compared to the pocket and wing technique.

3.0. Ventilation in CM district

The planning of ventilation in any CM section is a major factor for achieving success. In this work system, as, more or less, all the galleries adjacent to the working faces are used for the movement of the shuttle car and the quad bolter, the quantity of air is more than generally required for conventional mines. For face ventilation, the use of auxiliary fans is essential. It is not advisable to use continuous miners where inadequacy of ventilation exists. It is required to clear the considerable quantity of gases before being restored. Following basics are needed to be implemented strictly in CM panels.The recommended ventilation layout is with the 'single split' system where the air is brought up one side of the entries and exhausted from the other side. Returns are separated from the intake by brick plastered stoppings. Air is directed around the section using plastic curtains, often called 'brattice' and used as line curtains to direct air to the face. Coal Mines Regulations require six cubic metres per minute of air per person employed in the most significant shift or 2.5 cubic metres per minute of air per daily tonne of output (CMR 2017), whichever is the more. Although the face advancement is fast, around 80-90m, adequate brattice and stopping are required. In the bord and pillar working as already having 5-6 faces, it is quite challenging to ventilate and remove the gases. Therefore, it is highly recommended to use atleast 2-3 auxiliary fans to ventilate the faces. In Fig.5, a typical ventilation layout is shown to understand the circuit. The blue arrow indicates the intake airflow, and the red arrow is indicated the return airflow.

4.0 Case study of sarpi mine

Sarpi continuous miner project belongs to Shyam Sundarpur colliery of Bankola area of Eastern Coalfields Ltd. Before the nationalisation of the coal industry, Sarpi and Shaym Sudarpur colliery were two different collieries. Since nationalisation in 1973, Sarpi merged with Shaym Sundarpur colliery and became part of it. The first pit opened at Shaym Sundarpur colliery on 05.12.1946 and Sarpi (Fig.6) on 23.12.1950. The Sarpi mine is located in the north-eastern part of Raniganj coalfield in West Bengal, India, at about 30 km north-west of Durgapur railway station in the Burdwan district. The mine is located between the latitudes N2337'45" to 23°39'20" and longitude E87°14'30" to 87°16'30". The present area of Shaym Sundarpur colliery spreads over 533 Ha. of land. The mine plan and the mine location are shown in Fig.7. This mine has adopted the mass production technology using CMT in 2012. Sarpi mine from a part of the Bankola area of Eastern Coalfields Limited has eight working seams from R-IX to R-II in descending order. The coal-bearing measures of the Raniganj formation are unconformably overlain by poorly consolidated quaternary laterites, sands and gravels and weathered Gondwana sediments. This region commonly encounters water-bearing horizons, which varies in thickness from 2 to 10 m across the area. Within the Sarpi block, the upper seam R-IX is mined out, and coal production is now being done from

Seams R-VIII and R-VII. The depth of cover in this sector varies from 120m in the north to approximately 210 m in the south, with a mean dip of 4 degrees.

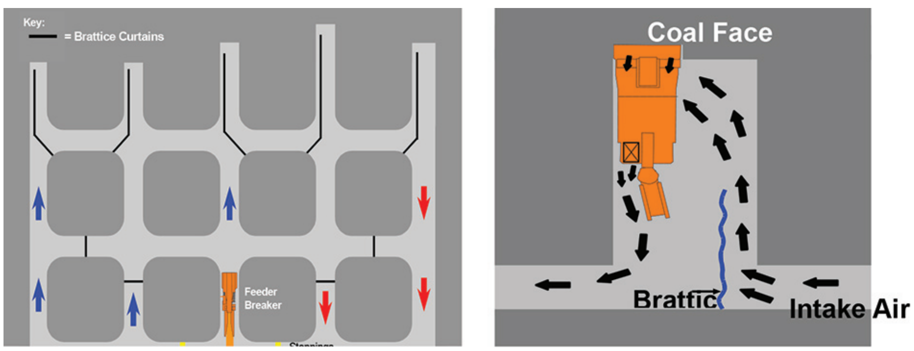

Fig.5: Ventilation system in CM district

5.0 Support system in CM panel of Sarpi Mines

Typically, in a continuous miner panel, 1.8m to 2.4m long steel bolts are inserted into holes to bind the strata together. The systematic roof support in all development districts of Sarpi mine consists of 1.8m full column resin roof bolts per row spaced at 1.5m from each bolt and 0.75m from the side and 1.2m row intervals. Breaker lines bolts are also installed consisting of 2.4m

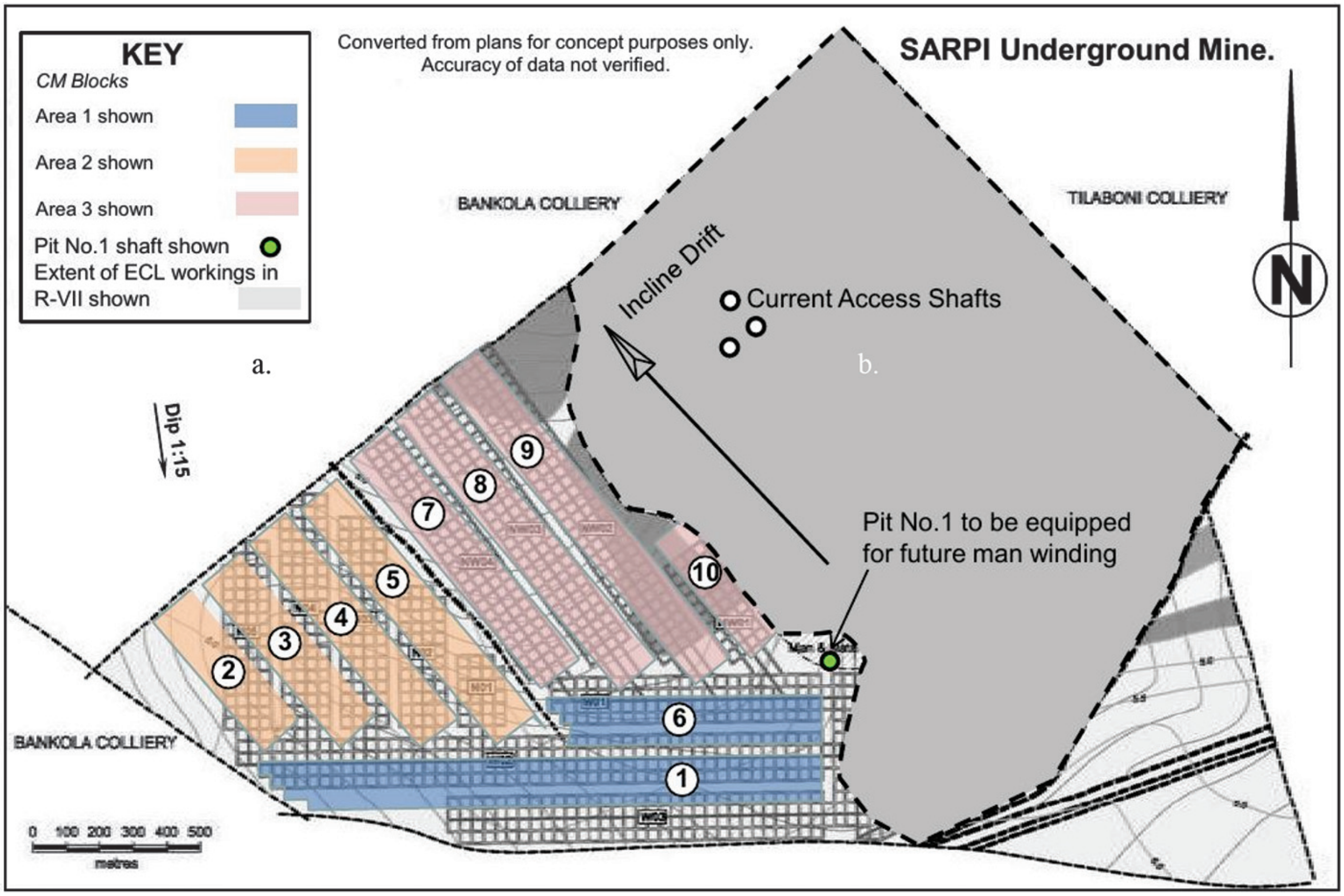

Fig.6: Mine plan of Sarpi underground mine

long, full column resin roof bolts per row spaced at the interval. Each breaker line consists of 2 rows of bolts of at the spacing of 0.6m. Glass-reinforced plastic (GRP) bolts are installed at the side to stabilise the side due to 4.5 m height and which can easily be cut by continuous miners during pillar extraction. The side bolt patterns are given in Fig.7.

5.1 Support efficiency verifications

One of the most effective processes to verify the efficiency of the support is the short encapsulation pull test called SEPT (Pile et al. 2003) which indicates the resin and rock bolt behaviours. A small length of roof bolt (Bond length -300mm) is being tested by partial encapsulation. All the load-bearing readings with the displacement are plotted with a graphical presentation. That graphical presentation reflects the performance of every roof bolt chosen for such a test. This test is widely practised to check the resin capsules' quality supplied as consumable. In the SEPT, one inner pack is used for applying the load, and a dial indicator, a monopod, is used to take the reading. All the applying load with the displacement is recorded and input to the software for analysis. Fig.8 presented the above test procedure and the load vs displacement graph.

In the same manner, after installing the roof bolt, some Indian mines use the anchorage testing process. The roof bolt is pulled out by the inner pack and shows the load-bearing capacity only.

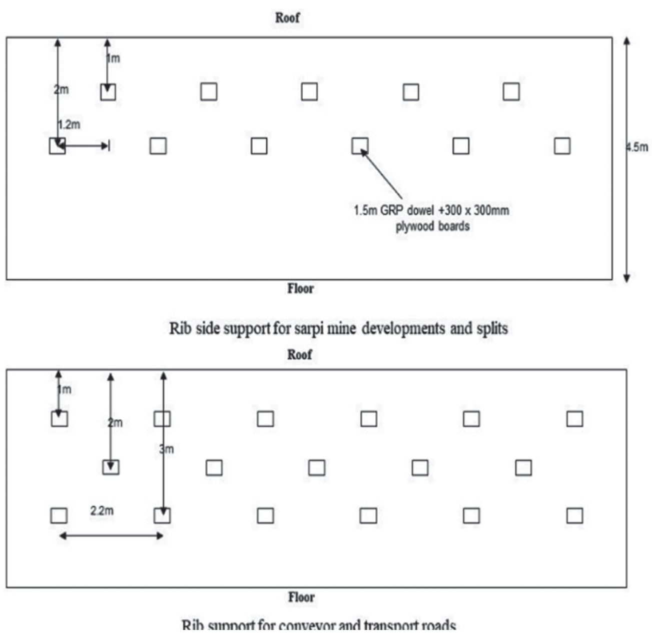

Fig.7: Side support system of Sarpi mines

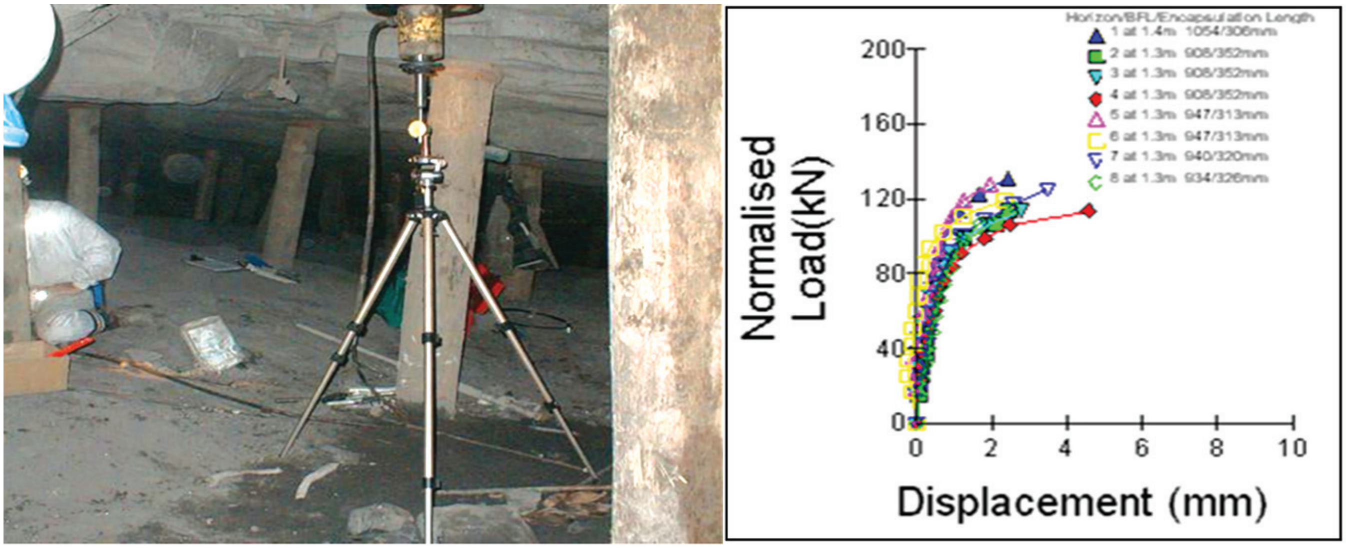

Fig.8: Short encapsulation pull test (SEPT) procedure

5.2 Strata monitoring in CM district (P5 panel) of sarpi mine

The strata monitoring plan of Sarpi mines was prepared jointly by Rock Mechanics Technology (RMT) and the Central Institute of Mining and Fuel Research (CIMFR) team and categorised into design and safety monitoring. The instrument (Andrew 2009) used in the mines are auto warning tell-tale, dual height tell-tale, extensometer, strain gauze. All the strata monitoring instruments details are given below:

Auto warning tell-tale

It is an instrument used during depillaring in a single anchor with 7.5-10m height. Deformation can be customised according to requirements. When load arises automatically, it blinks until the roof fall. This instrument provides information about the movement of roof strata within the horizons, where these instruments are fixed. If any movement of roof strata occurs within 10m of the gallery's roof, it starts flushing automatically. As this instrument has three stages of warning, it is required to be determined and fixed or set in the instrument. It indicates the required precautions to be taken for the safety of man and machinery after the warning Fig.9.

Fig.9: Auto warning tell-tale

Dual height tell-tale

This instrument is used for determining roof convergence. It gives the reading of the vertical strata movement by two different anchors. The length of the one anchor is usually above the bolted height, and another is below bolted height Fig.10. This instrument provides a visual indication of the movement of roof strata in the opening of a coal seam. The cut-off values are also designated on the instruments, warning of possible roof failure. Remedial actions may be taken if the observed value exceeds the cut-off value. These instruments are proposed to be installed at all the junctions and in the middle of all dip-rise galleries.

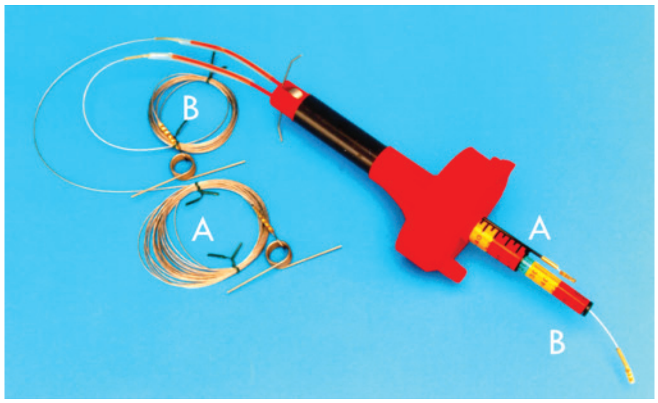

Fig.10: Dual height tale-tell

Strain gauged rock bolt

It is a simple roof bolt where a narrow rib is cut, and the opposing pairs of resistance strain gauges are inserted throughout its length (Fig.11). Individual 120Ω strain gauges are mounted in radially different longitudinal slots machined throughout the bolt length. It carries nine gauges scattered along with each slot, depending on the bolt length. This data can be recoded using RMT's EXBOLT software (Andrew 2009), presenting axial and bending load profiles throughout the bolt. The gauges are electrically connected to an external flying lead and socket via cable (ribbon) fixed in the gauge slot and protected from damage during installation and transport by an uneven sealant. Each standard supplied strain gauge bolt has a 10m electrical cable, which can be permanently connected to the lead after the installation. The individual strain gauges are bound in a quarter bridge

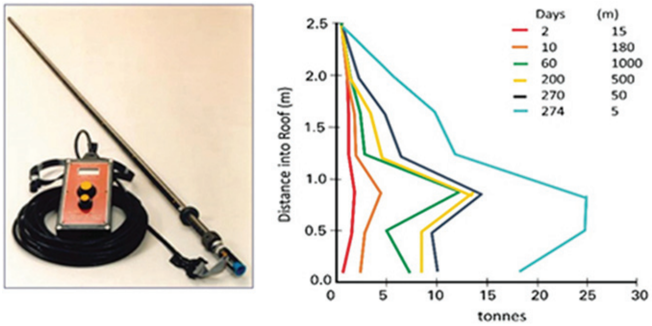

Fig.11: Strain gauge bolt with read-out unit and recoded graphs

configuration by double common along the 10m cable to offer temperature compensation. The strain gauge read-out unit incorporates the necessary bridge completion with the bolt.

Stress cell monitoring

The stress cell consists of a high-strength steel proving ring wedged tightly across one diameter inside a borehole drilled into the rock. The distortion of the proving ring, caused by changing rock stresses, is measured utilising a vibrating wire that is tensioned across another diameter. Changes in rock stress cause changes in the resonant frequency of vibration of the tensioned wire, and the two are related using calibration data supplied with each stress meter. The gauge has been given a high initial sensitivity coupled with a virtually unlimited stress range by reorienting the vibrating wire concerning the loading platens. A thermistor can be incorporated into the stress meter if temperatures are measured. Diamond drill holes EX size is preferable. Boreholes drilled percussively should have their walls smoothed by incorporating a reaming shell in the bit. A vibrating wire-type stress cell (Fig.12) is used to monitor the mining-induced vertical stress developed over the pillars/stooks/fenders. It is a reliable and preferred instrument for long-term monitoring because it provides frequency as an output signal. The stress cellis installed into the horizontally drilled boreholes in the pillars by setting tool and tightened with the help of wedge and platen assembly (Mandal and Das 2017). The stress meter is read out using the GK-401 read-out box to take the reading automatically.

Instrumented rock bolt

Instrumented rock bolt (Fig.13) is generally used during the depillaring operation. Sometimes, performance has not been measured or not adequately assessed at the breaker line, which is the vital point for the operator. In that portion, instrumented rock bolts are generally used. It is standard types roof bolt 22mm dia and 1.8-2.4m length. For installation, 28-32mm holes are required, regular resin capsules are used for grouting the bolt, as used of a regular roof bolt. On the head or tip of it, a microprocessor is fitted, connected through the cable, enabling the miner to have continuous reading showing the roof's status through a read-out unit for taking the reading. It gives the result of the load that comes to the point. In the Sarpi mine, this bolt is being used quite extensively with full satisfaction.

Fig.13: Instrumented rock bolt

Remote reading tel-tale

Remote reading tell-tale (Fig.14) offers a range of compatible transducers designed for measuring rock displacement in the roof of mine roadways and other tunnels and can be read in various ways. The most straightforward configuration comprises individual transducers, which are read by connecting each, in turn, to a portable read-out unit. The data is noted in a book and analysed using a purpose-written Excel spreadsheet. The system has the advantage that up to 100 dual height or 50^{th} four-height transducers can be

Fig.12: Stress cell

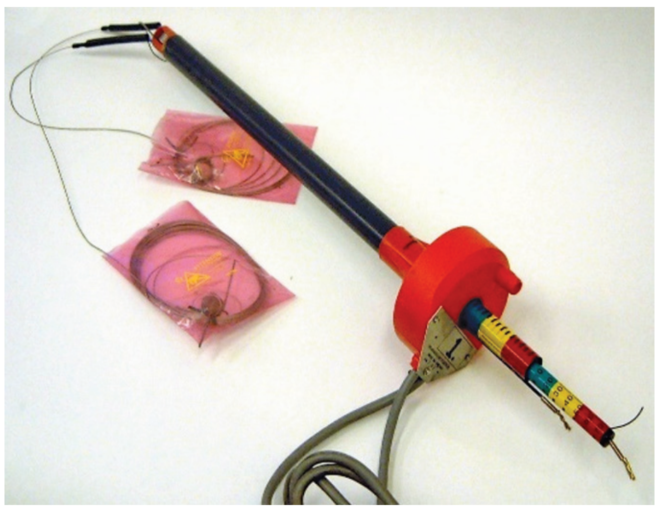

Fig.14: Remote reading tell-tale

connected using a twin-core cable and read from a single location. The tell-tale transducers are available in single height, dual height, or triple height versions. These are easy to install wire extensometers designed to fit into 35-45mm diameter boreholes with a stainless-steel wire attached to each borehole horizon using a simple spring anchor. It has been designed and engineered for coal mining applications (Mangal 2021). The principle employed is that the inductance of a coil will vary depending on the position of a ferrite rod moving within it. The onboard electronics convert the inductance to a frequency transmitted down the line when the transducer is addressed.

Magnesonic extensometer monitoring

A sonic extensometer is designed to provide detailed ground movement measurements in mining excavations. The instrument can measure the positions of up to 15-20 magnetic anchors in a 7.5m long borehole relative to a magnetic anchor located within the mouth of the borehole. It consists of a flexible probe and transponder head connected to a portable battery-powered read-out unit with a liquid crystal display (LCD). A single system can measure strata movement at multiple locations as the probe is only inserted into the borehole when a reading is taken. Hole furnishings, supplied separately, are low cost and simple to install. The anchor and read-out unit is given in Fig.15.

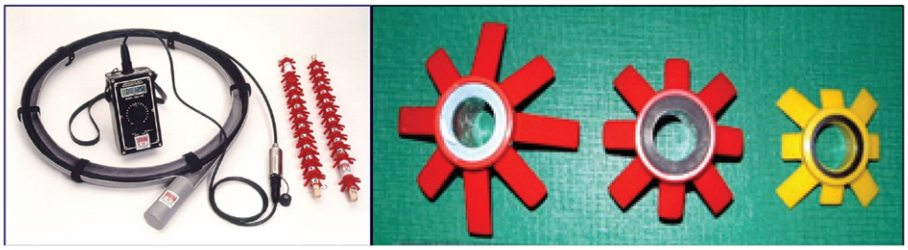

Fig.15: Magnesonic extensometer and its magnetic anchor

8.0 Problems encountered during CMT deployment

In any continuous miner, the weakest part is its crawler unit. To avoid any damage to crawler chains, moving the machine in preferably in a straigth line is practised. It is experienced that any attempt to change the direction of movement of the CM, the damage in chain had led to a serious problem, especially in the case of depillaring. In the case of depillaring, within 30 minutes or so, the movement in the roof is noticed after the formation of goaf. In such a case, if the crawler fails, it may cause serious damage. The continuous miner drum used to be suitable only for cutting the coal by its picks attached. In case of any intrusion is encountered, the CM either will not cut, or its cutter drum will have serious damage. The CM and its supporting equipment need to be maintained regularly for three to four hrs and need a highly skilled maintenance gang for its regular check-up. The continuous miner also limits working gradients (up to 1 in 4) in case of change in gradient of the coal seam effect the movement of the machine. The floor strength needs to be assessed beforehand to carry the load of these heavy machines. These CMT require face preparation in advance like widening and heightening, draining out the water, supporting the green roof, etc. The percentage of pillar extraction as compared to longwall technology is low. As limited cable length of CM, shuttle car, the long tramming distance may reduce the production.

9.0 Discussion and summary

The present study is an effort to throw light on the successful deployment of CM in the coal seam whose parameters are suitable for its use. With the change of technology and continuous research process, this technology is now being used for extraction for coal seam having thickness more or equal to 4mtrs with an equally high rate of extraction, which may not be economically feasible with the conventional method. Even on the date, the CMT is prefered for the seam of 1.2 meters. The method provides optimum extraction with safety. Elimination of blast vibrations and prevention of generation of noxious gases with better strata control increased production. The continuous miner has the advantage of reducing the face crew with better roof and side control. It helps keep the continuity of production with the recovery of the optimum height of coal. In today's scenario, where we need coal with the highest degree of safety, Economically profitable and with higher productivity, the mass production technology CMT plays a more significant role than the other underground conventional method regarding safety and productivity. In this paper, we discussed the use and method of continuous miners for development and depillaring in the bord and pillar method. To improve the production of coal and meet the nation's demand, introducing new technologies is essential. For a country like India, whose geological status does not permit the extensive use of longwall, switching over to the use of continuous miner technology is essential.

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