Deployment of Continuous Miner in Under Ground Coal Mine – A Case Study of Sarpi Mine.

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Abstract:

The continuous miner technology (CMT) is being adopted extensively in underground coal mines of India as Mass Production Technology (MPT). This technology potentially eliminates the two-unit operating, namely the drilling and blasting. This elimination helps for better strata control and avoids the drillers working in unsafe conditions, maybe under the loose coal roof. This CMT improves the quality of the coal extracted and increases the output per man shift (OMS) by reducing the deployment of face crew. It also reduces the accident as it is operated by remote and workforce exposure to faces is limited. The method also helps for better roof and side control, thus preventing side and roof fall danger. With the changing time now, continuous miners of different heights are available, which helps for optimum use of technology to mine out varying insitu height of coal seam. This paper discusses the performance of the CMT in the Sarpi mine and compares the technology available globally.

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

1. Introduction

India is the second-largest coal producer globally, where 93.7 percent of coal is produced from opencast mining[1], and the rest of the coal is produced from underground coal mining. With the high rate of extraction from opencast mining and the increase in the number of new open cast mining fields, it is essential to depend on underground coal in the future. The reason for shifting to Mass Production Technology for underground coal for some companies may be the high stripping ratio, shortage of free land, and severe quality issues. Underground mining can only bridge the demand and supply gap with decent quality and quantity, provided proper technique is used for mass production from underground mines. 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.

Moreover, it is a proven method practised in different fields which can even produce 2000 tonnes to 2500 tonnes of coal [1] daily with an extraction ratio of 65-70% [2] during the depillaring. A comparison of production in CMT and conventional method 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 insitu pillars and continuous production rate. Therefore, an in-depth study has been taken up in this research for this deployment of a continuous miner. CMT was commissioned for the first time in India[3] in May 2002 at Anjan Hill [4] 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.

Fig.1. Comparison of production in CMT and conventional method using LHD and SDL.

After developing the underground transport system in underground mining, the mining engineers tried to find out the solution of extracting coal by mechanical means. Primarily the continuous miners were introduced in late 1940, and CM 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 insitu coal. Continuous miners are generally suitable for a room and pillar mining system. The CMT can develop a virgin seam for coal extraction by the bord and pillar method. The size of pillars left for withstanding the roof load is guided by the coal mine regulations [5]. 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 or columns of coal left standing to help support the roof. The fundamental concept of bord and pillar methods by a continuous miner(CM) 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 during the first workings as the bords are driven. They may or may not be extracted systematically on subsequent second workings, depending on the scheme adopted. 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 18-38m centre to centre square pillars depending upon the working depth as per CMR 2017[5].

2. Condition favourable for the deployment of continuous miner

The deployment of CM is dictated by a host of factors such as (i) gallery width (not less than 5.5m), height (not less than 3m) for the standard height CM, (ii) ground condition (minimum can withstand 184 kPa ground pressure) (iii) power (1.1KVA) (iv) adequate ventilation system (sufficient to remove the coal dust and other noxious gases) (v) transport system -preferably belt conveyor (vi) pumping arrangements (vii) adequate filtered water for dust suppression and roof bolting. According to the incubation period of the coal and the production rate, the panel size is designed. After that, one has to calculate the daily production by CM, and then one can easily calculate the daily advancement. Therefore, can create the panel, and the number of headings should not exceed six because there is some limitation for the cable. As the cable from the load centre, we only get 200m as per IER 2010[6]. A typical plan view of the continuous miner district of five headings is given in Fig. 2.

Fig. 2. A plan view of the CMT section.

A comparison of the various infrastructural requirements vital for mechanisation for any mine is shown in Table 1. It can be seen that it is easier to convert an SDL/LHD operated mine to CM operated mine with minimal adjustments in the underground infrastructure (Table 1). However, to handle the mass production of coal, it must make necessary arrangements at the surface and bunkering.

Table 1. Infrastructure requirements for mechanised workings.

	High Potential Mine Characteristics (For CM)	Moderate Potential Mine Characteristics (LHD or SDL)	Low Potential Mine Characteristics
Roadway Size	4.8m (as restricted by Indian Legislation)	4 to 4.8m. Access at least 4.5m	Less than 4.5m

Incline gradient	The gradient of the incline is not more than 1 in 4.	The gradient of the incline is not more than 1 in 4.	Not necessary any specified gradient.
Water Supply	Clean filtered water, neutral pH, 250 lit/min, and 2000 kPa (15Bar)	Clean filtered water, neutral pH, 250 lit/min, and 2000 kPa	Filtered water not required
Conveyors	500 te/hr min, 1200mm belt	450 te/hr with 1000mm wide belt	Less than 400 te/hr belts or Tub
Electrical	1.5MVA capacity for CM district and min 5MVA for total mine. 1100 Volts +/- 10%	1.5MVA capacity for CM district and min 2.5MVA for total mine with 1100 Volts +/- 10%	Under 2.5 MVA capacity
Ventilation	10-20 m ³ /sec for the CM district required	10-15 m ³ /sec for the JHD and SDL district required	Under 10 m ³ /sec available
Surface Man-riding Haulage	The man riding in and out of the mine required (If the travel distance is more than 3 KM)	The man riding in and out of the mine required (If the travel distance is more than 3 KM)	No man riding required.

3. Continuous miner and the allied machinery

There are various CM manufacturers in the world, and they supply almost the same outfit of machines. The primary difference is the capacity and operational output and its size. In the CMT, continuous miner, shuttle car, load centre, feeder breaker, quadbolter, LHD is generally used. LHD is used for miscellaneous purposes. The continuous miner has a cutter drum where pics are mounted. It has two gathering arms to collect and gather the cutting coal (**Fig. 3**). Next, the coal is transported to the shuttle car with the help of the conveyor. CM has a scrubbing unit, methane sensor, water spraying arrangements which are very useful. Shuttle car is used for carrying the cutting coal from CM to feeder breaker. Quadbolter is used for the roof and side support after cutting is completed. The feeder breaker receives the coal from the shuttle car, sizes it into a regular shape, and then conveys it to the central belt.

3.1 Continuous miner

There is a host of manufacturers of the continuous miner they are Joy Global Inc, model no 12CM15 having around 11.03 m length and height minimum 1.05m. and width 2.77m. JA Engineering, South Africa, Sandvik, Caterpillar, Chines CM. Performance and acceptance-wise in India, Joy and Caterpillar CM have been top-rated. A brief comparison of the global CM is presented in **Table. 2**.

Table. 2. Global survey of the continuous miner of low height and standard height.

Continuous Miner	Joy Mining	JAE	Caterpillar	Sandvik	Chinese
Model No	12CM15	Wildcat JAE42 CM	CM345M	ALPINE MINER ACM 10	ML300/492
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	11.45 × 2.85 × 2.1
Ground Clearance (mm)	305	280	356	220	185
Weight (Te)	58	110	74.8	43	60
Cutting width (m)	3.3	3.65	3.58	2.9	3.3
Cutter Diameter (m)	1.12	1.32	1.12	0.95	1.02
Cutting Height Min-Max-(m)	2.16 4.6	2.2 4.7	2.06 4.62	1.8 3.6	1.9 4.6
Cuttable rock strength UCS in MPa.	60	70	65	15-30	40
Loading Capacity (Te/min)	15-27	50	15-39	15	25
Conveyor width (mm)	762	960	762	600	800
Tram Speed (m/min)	0-19.8	0-20	0-20	0-26	0-8.5
Ground pressure (kPa)	184	220	227	140	220
Total installed power (kW)	746	828	727	296	492

Fig. 3. Continuous miner in use at Sarpi mine.

The safety features incorporated with the continuous miner are the tram safety switch, which has to be pressed throughout the tramming unless CM will be stopped, besides the other safety devices such as the main isolation switch, dust controller, emergency stop, water interlocking, methane sensors. The methane sensor is fixed on the cutter frame, and this sensor can directly monitor the methane concentration and display it to the video display unit (VDU) and trip the machine if it crosses the set limit.

3.2 Shuttle car

The shuttle car (**Fig. 4**) can take the load from CM and unload it to the feeder breaker. As the cable length is fixed as per the IER 2010 [6], there may be some limitations. However, one can also have an option for the diesel-operated machines (called ram car), which could be plying in any direction with unlimited distance. However, its deployment depends upon the degree of gassiness of the coal seam. The vital specification of an electrically operated shuttle car is given in **Table 3**.

Table. 3. Specification of the shuttle car used at Sarpi mine.

Operating voltage (volt)	1050 volt
Voltage rating	+/- 10%
Total rated power (kW)	202.6
Weight (kg)	20,500
Cubic capacity (with 305mm sideboard) (m ³)	10.19
Dimensions ($L \times W \times H$) in meters	$8.99 \times 3.05 \times 1.31$
Ground clearance (mm) nominal	290 mm
Ground bearing pressure (kPa)	520 (empty), 830 (loaded).
Gradient	Below 6 degrees
Cross gradient	Not greater than 5 degrees
Brakes	Service brake and parking brake

Fig. 4. Shuttle car used in Jhanjra mine.

3.3 Quad bolter

This machine is used for vertical and side bolting up to 90 degrees in the sidewall, as four rigs for the bolt are attached to the machine called quadbolter. The detailed specification of this machine is given in **Table 4**. Quad bolter is used to support the green roof after cutting the coal by CM. The quadbolter has a temporary roof support unit (TRS), which can be quickly erected and removed (**Fig.5**) on the green roof. The load-bearing capacity of the TRS is approximately 215 kN.

Fig. 5. Quadbolter used in Sarpi mine.

Table. 4 Specification of Quadbolter.

Application Data	
Supply voltage	1100V AC 50Hz 3 Phase
Maximum recommended material hardness to be rotary drilled	70 MPa
Water consumption (2 roof bolters operating)	40-50 L/min (21- 26.4 US gal/min)
Recommended water pressure range	0.7- 1.2 MPa (100-175 psi)
Bolting rate	Up to 25 bolts/hour (Depending on bolt density, meshing, chemical, strapping, and operator skill level)
Machine Dimensions:	
Minimum tram height (ATRS)	2150mm
Minimum operating height	2400mm
Maximum bolting height	4775mm
Minimum operating width	3160mm
Length overall	7780mm
Ground clearance	295mm
Gross Vehicle Mass	29800kg
TRS (Temporary roof support):	
Height	2150-5000mm
Max load holding capacity	215 kN
ELECTRICS:	
Electric Motor vac/50hz/3ph	Morley 112kW/4 pole / 1100
Lighting: Area light	4 Nos, Victor Fluorescent 110vac-20w
Head Light	2 Nos, Rear lights –2 off (MEDC 24vac)
Emergency Stop	5 Nos (2 front +2 rear +1 tram station)
Low/High Oil Level / High Temp. Cut- off	Troxex Insertion Switch -1 off
METHANE SENSOR	This sensor is attached to the platform, and if it crosses the setting point, the machine will be trip.

3.4 Feeder breaker

A feeder breaker is used to receive the coal from the shuttle car or ram car and send it to the central belt after crushing in the desired size. It is a crawler-mounted machine having a belt conveyor in the middle of the machine (**Fig.6**). A crusher is fitted with a water spraying system that breaks the coal lumps to - 200 mm (**Table**

5).

Fig. 6 Feeder breaker used in Sarpi mine

Table. 5 Specification of the Feeder Breaker.

General:	Machine Type: BF – 14B-3-7C
Electrical:	
Breaker Motor	112kW
Controller	From gate end box
Remote Start /Stop Panic Bar	Push Buttons
Conveyor and Drive:	
Width	1270mm
Chains (covered)	76 and 101 mm pitch, 86000kg
Flight p-u77	44 mm x 101 mm solid alloy steel
Head Shaft	101mm dia with 89 mm bearings
Tail Shaft	87mm dia with 87 mm bearings
Speed	2 speeds
Breaker Pick Diameter	711mm
Dimensions:	
Length	10.18m x Width 3.81 m x Height 2.01m
Ground Clearance	Intake 203mm to 406 mm
Discharge with positive lock	203 to 584mm

3.5 Load centre

The load centre is a type of step-down transformer. The incoming voltage in the machine is 3.3 kV, and it can reduce the voltage to 1.1 kV. This machine has ten drives for a separate power supply to the individual machine (**Fig.7**).

Fig. 7. Load centre use in Sarpi mine.

In a load centre, the following safety devices are merged

1. Transformer secondary 1100V earth fault protection
2. 1100V, 1200A circuit breaker with short circuit tripping function
3. 1100V test switch
4. 5KVA, 120V lighting transformer with four switched outlets
5. Individual pilot circuit control all outgoing motor drive sockets
6. Individual overload protection, all 1100V motor drive

The load centre where all the cables are connected to supply the power to all machines. The specifications of the cable are given in **Table 6**.

Table 6: Specifications of cables.

Qty	Cable duty	Cable type	Core size (mm ²)	Length
1	Continuous miner	7m to BS6708	95	210m
3	Shuttle car	11 to BS6708	16	200m
1	Feeder Breaker	11 to BS6708	16	60m
1	Quad bolter	7m to BS6708	35	225m

4. Development and depillaring by a continuous miner

4.1 Development

Development by a continuous miner with room and pillar is now prevalent and economical. The gallery's width is usually kept between 5.5m and 6.5m, for which a permit is required from DGMS. With the development of the continuous miner, the CMs are available for 1.5-meter height to 6-meter height. The deployment of CM in any coal seam is possible for a height ranging between 1.5 to 6 meters, provided the permission is obtained from DGMS [5]. The feeder breaker is installed in the middle so that the shuttle car covers the maximum distance from both sides. After completion of one level cutting, all the machines and belts shifted to the next pillar. A typical layout is given in **Fig.2**, which shows the development work of Sarpi mines.

4.2 Depillaring

There are various 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 and pillar size, which decide the proper methods for the depillaring. Field experience states that a continuous miner can cut a slice of 14 m length in one go without being supported. Beyond this length, it is not advisable to extract a slice, as the shuttle car or the ram car, which is not a remotely operated vehicle (ROV), enters the unsupported roof. Thus, the length of the slice should not be more than 14 m. Therefore, in any depillaring method, the slice length should not exceed 14m in any case. 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[7]. Slices are driven at an angle of about 120° to enable safe movement of the machine and to operate the machine from a distance allowing maximum visibility.

4.3 Cutting sequence

The cutting sequence by the continuous miner in the bord and pillar development system is shown in **Fig. 8**. In this method, the straight-line extraction method contradicts the diagonal line of extraction in the conventional

method. In this method, a faster extraction rate, especially from the pillars that had been split through a straight line of extraction, is more suitable. Splitting is done from the level gallery. In this method, pillars 1, 2, and 3 have been split into two halves. Then from the dip most side, the extraction sequence is followed by using the CM. This manner of extraction (straight line of extraction) is followed only to accomplish the machinery's easy maneuvering.

Fig. 8 Cutting sequence

4.4 Various depillaring methods

In the Indian coalfield, the most popular method is the split and fender method Fig.9(b). Some of the other methods being practised throughout the world are - double split and fender method Fig.9 (a) [8], yield pillar non-caving method, as shown in Fig.9 (c), One-third split and fender extraction method Fig.9(d) single-pass extraction Fig.9(e) modified Nevid system of extraction Fig.9 (f). If the pillar sizes within the range of 25.5–34.5m are usually worked by the split and fender method. Therefore, the double split and fender method becomes the most suitable choice for the panels whose pillar size is more than 38m. A modified NEVID and pocket [9] system is chosen for smaller pillars (18-20m). Pillar size more than 35m may be extracted by the one-third split and fender method, as shown in Fig.9(d).

Fig. 9. Various methods of pillar extraction.

5. Support system

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 consists of 2.4m long, full column resin roof bolts per row spaced at interval each

breaker line consist of 2 rows of bolts of 5×2 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 pattern of the side bolt and roof bolt is given in **Fig. 10,11**.

Fig. 10 Plan view of support system

Fig.11 Side view of side support system

6. Strata monitoring

The strata monitoring plan of Sarpi mines was prepared jointly by RMT[10] and CIMFR and categorised into design and safety monitoring. The details of the instrument used and its position of instruments are shown in **Fig. 12**. The red colour indicates the dual height tale-tell used in the junction and the middle of the pillar. Blue stars denoted the strain gauge bolt, and the red triangle shows the stress cells. The red lines show the breaker line. The other strata monitoring instruments details are bellowed.

Fig.12. Plan view of strata monitoring plan of Sarpi mine.

6.1 Sonic extensometer.

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 readout 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 output graph is given in **Fig. 13**.

Fig. 13 Output data of the sonic extensometer of Sarpi mines at 23D/26L (junction).

6.2 Strain gauged 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 15**). Individual 120 Ω 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[10], 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 configuration by double common along the 10m cable to offer temperature compensation. The strain gauge readout unit incorporates the necessary bridge completion with the bolt. The standard 10m cables are concluded with a 25 pin D connector compatible with the SG 1041 and SM01 meters installed with this bolt.

6.3 Stress cell

The stress meter (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 gage has been given a high initial sensitivity coupled with a virtually unlimited stress range by reorienting the vibrating wire concerning the loading platens. The stress meter behaves as a rigid inclusion in that the calibration varies by only a factor of two if the rock modulus varies by a factor of ten. A thermistor can be incorporated into the stress meter if temperatures are to be measured. Diamond drill holes EX size is preferable. Boreholes drilled percussively should have their walls smoothed by incorporating a reaming shell in the bit. Design of underground structures and excavation patterns is greatly influenced by the value and range of mining-induced stress. A vibrating wire-type stress cell 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 meters (**Fig.14**) are installed into the horizontally drilled boreholes in the pillars by setting tool and tightened with the help of wedge and platen assembly[11]. The stress meter is read out using the GK-401 Readout Box to take the reading automatically.

Fig. 14 Stress meter used at Sarpi Mine, ECL

4.2 Remote reading telltale

Remote reading telltale 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 readout unit. The data is noted in a book and analysed by subsequent input to a purpose-written Excel spreadsheet. The system has the advantage that up to 100 dual height or 50th four-height transducers can be connected using a twin-core cable and read from a single location. The telltale 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[7]. 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.

6.5 Multiwire extensometer

This instrument monitors the separation of different roof stratum during the drivage of an opening in the rock. Depending on the number of roof horizons of interest, it may be a single, double, or multi-point anchor type instrument. It is always good to place these instruments in a downward hole to understand the complete nature of bed separation because the instrument installed in an upward hole generally gets damaged with fall or significant movement of the immediate roof strata. Due to the high depth of coverage of the panel, these instruments are to be installed in upward holes. In this panel, two-way and four-way type roof extensometers are proposed to be installed.

6.6 Dual height telltale

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.16(c)**. 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, which gives a 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.15 Rock bolt

6.7 Rotary telltale

This type of Tell-tale is fixed up to the length of 5m -7.5m in a single horizon. Only a single anchor is observed in this instrument. It is a rotary type measurement device. By changing its colour red, green, and yellow Fig 16 (b), ordinary people can quickly check the rotary telltale and any problem they can handle. Only one drawback to taking the reading has to be reached beneath the device, which is difficult during high-stress conditions **Fig. 16(b).**

6.8 Auto warning telltale

It is an Instruments 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. Geo-mining conditions of the panel were considered, it is proposed to keep the length of this instrument equal to 10 m. If any movement of roof strata occurs below 10 m from the gallery's roof, it starts flushing automatically after achieving the set values in the instrument. It indicates the required precautions to be taken for the safety of man and machinery after the warning **Fig 16(a).**

6.9 Rock tale

It is an instrument used in an underground mine with 2-3 anchors with different horizons, and it blinks with different colours when a load arises on any horizon. Generally, it is installed during depillaring. The best thing about this instrument is that it indicates the particular horizon where the deformation has occurred.

Fig. 16 a) Auto warning Tale-tell, b) Rotary Tale-tell c) Dual height tale-tell.

7 Numerical modelling to determine the safe working

Numerical modelling is a scientific approach and an efficient tool to determine the safety of the working and verify the support system in the mines by CMT application, including Sarpi mines. The installed strata monitoring instrument of Sarpi mines (Stress cell, extensometer, Tale tell etc.) is verified by numerical modelling vis-à-vis model verification. The depillaring methods used in the Sarpi mine is split and fender method, which is very popular in Indian coal mines. The irregular sizes of the rib and snook are formed by the depillaring method by CMT, which is very difficult to calculate the factor of safety (FOS). Hence, the determination of the stability of rib/pillar by numerical modelling becomes very easy. A study of Sarpi mines is carried out to determine the actual stability of the area of rib and snook by numerical modelling. All the inputs geotechnical data is tested at the IIT (ISM), Dhanbad Rock mechanics laboratory. Using the laboratory determining strength and the RMR value [12], the corresponding rock mass strength parameters were scaled down from equations 1 through 7.

$$\sigma_1 = \sigma_{cm} \left(1 + \frac{\sigma_3}{\sigma_{tm}}\right)^{bm} \quad (1)$$

$$\sigma_{cm} = \sigma_c \exp\left(\frac{RMR-100}{20}\right) \quad (2)$$

$$\sigma_{tm} = \sigma_t \exp\left(\frac{RMR-100}{27}\right) \quad (3)$$

$$b_m = b^{RMR/100} \quad (4)$$

where, σ_1 is triaxial strength of rock mass (MPa), σ_c is compressive strength of intact rock (MPa), σ_{cm} is the compressive strength of rock mass (MPa), σ_{tm} is the tensile strength of rock mass (MPa) and b is the exponent in failure criteria. RMR is Bieniawski's rock mass rating.

For Indian coal measure rocks, Sheorey's failure criterion [13] has been found suitable [14,15]. This criterion uses in the 1976 version of the RMR of Bieniawski. The basic CMRS- RMR value is used directly instead of Bieniawski's RMR since the failure criterion thus obtained has worked well in an Indian coal mine [16,17].

$$\tau_{sm} = \left(\sigma_{cm}\sigma_{tm} \frac{b_m^{b_m}}{(1+b_m)^{1+b_m}}\right)^{1/2} \quad (5)$$

$$\mu_{0m} = \frac{\tau_{sm}^2 (1+b_m)^2 - \sigma_{tm}^2}{2\tau_{sm}\sigma_{tm} (1+b_m)} \quad (6)$$

$$\phi_{0m} = \tan^{-1}(\mu_{0m}) \quad (7)$$

where, τ_{sm} is the shear strength of rock mass, ϕ_{0m} is the angle of internal friction.

For determination of the pre-mining stresses, the vertical stress (σ_v) and the horizontal stress (σ_h) are calculated by the formulae [18] given in equations no (8) and (9).

$$\sigma_v = 0.025 H \quad (8)$$

$$\sigma_h = 2.4 + .01 H \quad (9)$$

where H = depth of cover in meters

Table 7. Geotechnical data is used in the numerical model.

Sarpi mine, ECL, RMR- 46									
Layers	Layer thickness (m)	Bulk Modulus K (GPa)	Shear Modulus G (GPa)	Modulus of Elasticity E (GPa)	Poisson Ratio	Cohesion (MPa)	Friction Angle (deg)	Compressive strength of rock mass (MPa)	Density (Kg/M ³)
Roof1	5	6.49	11.96	4.80	0.25	0.67	36.52	53.50	2503
Roof 2	10	4.05	2.31	5.83	0.26	0.58	27.10	21.88	2376
Roof3	70	2.80	4.67	24.8	0.25	2.43	39.23	38.20	2467
Coal	4	1.42	0.93	2.29	0.23	0.61	29.56	12.16	1453
Floor	50	3.80	2.28	16.5	0.27	0.67	36.52	37.94	2604

The rib should have sufficient residual strength to carry the load, but it should not be strong enough to delay the caving. The factor of safety (SF) is defined as: -

$$SF = \frac{\sigma_{1m} - \sigma_{3mi}}{\sigma_{1mi} - \sigma_{3mi}} \quad \text{for } \sigma_{3mi} < \sigma_{tm} \quad (10)$$

$$SF = \frac{\sigma_{tm}}{\sigma_{3m}} \quad \text{for } \sigma_{3mi} > \sigma_{tm} \quad (11)$$

where σ_{1mi} = induced major principal stress (MPa) of the rock mass, σ_{3mi} = induced minor principal stress (MPa) of rock mass obtained from the numerical model. Subscript 'm' stands for the rock mass.

Figure 17 shows the safety factor of the pillar of panel P-5A of the Sarpi mine, and Figure 17 shows the max principal stress of the rib pillar.

Fig. 17. The factor of safety of the pillar at P5A panel of Sarpi Mines.

Fig. 18 Shows the Max Principal stress of the rib pillar at Sarpi mines.

The ARMPS software[19] was used to validate the numerical model (Table 8). The FOS from the numerical model was 3.8, and the ARMPS (USA) said 3.58, and their values match within a tolerable error.

Table. 8. A comparison of the factor of safety/Stability between ARMPS and Numerical model.

Sl. NO.	Name of the Mine	Parameters	Value in Meter	ARMPS (USA) FOS/ Stability Factor	FOS from the empirical relation	Avg. FOS from Numerical Modeling
1	Sarpi Mine. ECL	Depth of Cover (D)	146	3.58	3.65	3.8
2		Hight of extraction (h)	4			
3		Gallery width (W)	6			
4		Pillar Size (C to C)	34 x 34			

The study says the rib and snook left in panel P-5A of Sarpi mines is sufficient to take the load of the immediate roof and allow periodic caving.

7.1 Support verification

In Sarpi mines, the roof displacement is taken from the auto warning Tale tell, and the displacement from the numerical model is compared in Table 9. Numerical modelling has been used to check the support (displacement) performance above the working. It also determines the ground pressure applied by the continuous miner while running at any underground mines.

Table 9. Compares the roof displacement using a numerical model (blue colour) and instrument data (orange).

7.2 Short encapsulation pull test (SEPT) to determine the bolting performance

The short encapsulation pulls test (SEPT) is to determine the resin and rock bolt behaviours. A small length of roof bolt (Bond length -300mm) is being tested by partial encapsulation. Take all the load-bearing reading with the displacement and plotted into the graph. That calculation is decided the individual performance of every roof bolt 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 the analysis **Fig 19**.

Fig. 19 Short encapsulation pull test (SEPT)

7. Limitation of CM deployment

Few problems encountered in pillar extraction are that the machine must move in a straight line. Sometimes cat-track(Crawler Chain) problems were seen when direction changes were attempted within the pillar in the steep gradient. A crawler chain break during the final stages of a pillar-extraction operation can cause serious problems. The first stage of goafing arises typically within 30 minutes after the timbers have been withdrawn. A breakdown, especially in the tramming mechanism, can be hazardous in pillar extraction. Scheduled maintenance is required for 3-4 hours in a day to be checked and lubricated [1] result production being hampered. In the continuous miner technology, some of the limitations are listed as under.

1. Not suitable to cut stone intrusions.
2. In poor strata conditions, the maximum utilisation of this mass production technology is not achievable.
3. The floor strength needs to be assessed beforehand to carry the load of these heavy machines.
4. These CMT require face preparation in advance like widening and heightening, draining out the water, supporting the green roof, etc.
5. The percentage of pillar extraction as compared to longwall technology is low.
6. As limited cable length of CM, Shuttle car, the long tramming distance may reduce the production.

8. Ventilation system

Ventilation in any Continuous miner district is a challenge. The reason is more or less; all the galleries are used for the movement of the machines. In such cases, the quantity required for the district increases. For face ventilation, the use of auxiliary fans is essential. For the inadequacy of ventilation where the methane exists, it is not advisable to use continuous miners. It is required to clear the emitted huge quantity of gases before being restored.

Following basics are required to be implemented strictly in CM panels.

1. The mine operator will also be responsible for fulfilling the statutory requirements of the mining regulations[5] in terms of ventilation measurements, plans, inspections, etc.
2. **Precautions against coal dust explosions:** Again, the mine operator has the responsibility to take the necessary precautions against coal dust explosions as required by the mining regulations. These include, but should not be limited to, the provision of stone dust barriers over the gate belt at both inbye and outbye ends and the treatment of the workings with stone dust.
3. **Gas:** There are three categories of gassiness for mines in India. In CMT, only mines of low or medium gassiness may be considered (Degree I, II).
4. **Spontaneous Combustion:** Many of the mines in India have varying degrees of spontaneous combustion of their coal resources. CMT is ideal for most mines due to its flexibility and speed of extraction. Usually, a complete panel of coal can be extracted before the incubation time for spontaneous combustion has expired. However, as a precaution, it is recommended that coal seams with less than a six-month incubation period should not be considered. If the size of the panels is to be designed, the extraction should be completed before six months, and the districts can be sealed.
5. **Coal quality:** Coal quality will not affect production or productivity; however, all projects in India are assessed on IRR, and the coal selling price does have a significant effect.
6. **Work culture:** The need of the hour is to change everyone from the concept of non-mechanisation to mechanisation. For such reason, it is advised that people must go for the training of developing the adaptability of mechanisation.

9. Conclusions and summary

The present study throws enough light for the deployment of CM to develop the coal seam and extract thick seams that may not be possible for a high extraction ratio using the conventional bord and pillar method of working. The method provides optimum extraction in a given coal seam and satisfies the following performance and safety aspects.

- a. Elimination of blast vibrations.
- b. Prevention of generation of noxious gases.
- c. Better strata control.
- d. It increased the production rate.
- e. Reduction of face crew.
- f. Better roof and side control.
- g. Continuity of production.
- h. Recover optimum height of coal.

Therefore, it can be concluded that the mass production technology CMT plays a more significant role than the other underground conventional method regarding safety and productivity.

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Conflict of Interest, the author declares that he has no conflict of interest.

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