Deployment of Continuous Miner in underground 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. 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 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 in situ 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

Introduction

India is the second-largest coal producer globally, where 93.7% 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 [2] daily with an extraction ratio of 65–70% [3] during the depillaring. A comparison of production in CMT and conventional method of Sarpi mines is given in Fig. 1. Data have been taken from the monthly report of Sarpi mine, Bankola area. 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. 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 [4] in May 2002 at Anjan Hill [5] 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. 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 in situ 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 [6]. 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 5.5–6.5 m 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 as the bords are driven during the first workings. Depending on the scheme adopted, they may or may not be extracted systematically on subsequent second workings. In the current case study, the development consists of five road entries. The three entries are utilised as the intake airways. The formed pillars are mined at 18–38 m centre to centre square pillars depending upon the working depth as per CMR 2017 [6].

**Coal Extraction by a Continuous Miner**

Bord and pillar’s mining is one of the widely preferred methods of coal extraction in India. Before developing continuous mining technology, the mining cycle was composed of undercutting/middle cutting/side cutting the coal (required as per gassiness of the seam), drilling, blasting and loading. Continuous miners consist of rotating steel drums with tungsten carbide teeth that scrape coal from the seam. Continuous miners are generally combined with shuttle cars or ram cars to transport the extracted coal from the face to the feeder breaker. The coal is transported by the underground conveyor system and taken to the surface. After developing pillars in the bord and pillar method, consideration is given for the extraction of coal pillars, known as pillar extraction or depillaring. The extraction line should be arranged to facilitate roof control in pillar extraction. A diagonal line or step diagonal line of extraction is commonly followed. In exceptional cases, a steep diagonal line or straight line of extraction has been followed due to the machines movement and rapid advancement of the faces.
Condition Favourable for the Deployment of Continuous Miner

The deployment of standard height CM is dictated by a host of factors such as (1) gallery width (not less than 5.5 m), height (not less than 3 m) for the standard height CM, (2) ground pressure in the range 184–200 kPa [7]; however, the ground pressure of higher value can also be considered in hard floor condition depending upon the bearing strength of the floor. (3) Power (1.1 kVA), (4) adequate ventilation system (sufficient to remove the coal dust constraints of visibility and other noxious gases), (5) transport system -preferably belt conveyor, (6) pumping arrangements, and (7) 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 one can create the panel, and the number of headings for optimum use or efficient use may be limited 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 200 m as per IER 2010 [8], an ideal layout of the continuous miner district with five headings is given in Fig. 2.

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).

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 picks 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 scarping unit, methane sensor, water spraying arrangements which are very useful considering the health environment and safety. 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.

Continuous Miner

A host of manufacturers of the continuous miner is Joy Global Inc, model no 12CM15 having around 11.03 m length and height minimum 1.05 m [7] and width 2.77 m. JA Engineering, South Africa, Sandvik, Caterpillar, Chines CM. Performance and acceptance-wise in India, Joy and
Table 1  Infrastructure requirements for mechanised workings were modified [9]

| Infrastructure requirements                                                                 | High potential mine characteristics (For CM) | Moderate potential mine characteristics (LHD or SDL) | Low potential mine characteristics |
|-------------------------------------------------------------------------------------------|----------------------------------------------|-----------------------------------------------------|----------------------------------|
| Roadway size                                                                             | 4.8 m (as restricted by Indian Legislation) [6] | 4 to 4.8 m. Access at least 4.5 m                     | Less than 4.5 m                  |
| Incline gradient                                                                         | The gradient of the incline is not more than 1in 6 | The gradient of the incline is not more than 1in 6    | Not necessary any specified gradient |
| Water supply                                                                             | Clean filtered water, neutral pH, 250 lit/min, and 2000 kPa (15Bar) [7] | Clean filtered water, neutral pH, 250 lit/min, and 2000 kPa | Filtered water not required |
| Conveyors                                                                                | 500 te/h min, 1200 mm belt                      | 450 te/h with 1000 mm wide belt                       | Less than 400 te/h 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 m³/s for the CM district required         | 10–15 m³/s for the JHD and SDL district required      | Under 10 m³/s 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            |

Caterpillar CM have been top-rated. A brief comparison of the global CM is presented in Table 2.

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.

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 (210 m) as per the IER 2010 [8], 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.

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 supports the green roof after cutting the coal by CM. The quad bolter 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.

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).

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).
In a load centre, the following safety devices are merged.

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

| Application data                                      | Specification               |
|-------------------------------------------------------|----------------------------|
| Supply voltage                                        | 1100 V AC 50 Hz 3 phase    |
| Maximum recommended material hardness to be           | 70 MPa                     |
| rotary drilled                                        |                            |
| 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/h (Depending on bolt density, meshing, chemical, strapping, and operator skill level) |

| Machine dimensions                                    |                             |
|-------------------------------------------------------|-----------------------------|
| Minimum tram height (ATRS)                            | 2150 mm                     |
| Minimum operating height                              | 2400 mm                     |
| Maximum bolting height                                | 4775 mm                     |
| Minimum operating width                               | 3160 mm                     |
| Length overall                                        | 7780 mm                     |
| Ground clearance                                       | 295 mm                      |
| Gross vehicle mass                                     | 29,800 kg                   |

| TRS (Temporary roof support):                         |                             |
|-------------------------------------------------------|-----------------------------|
| Height                                                | 2150–5000 mm                |
| Max load holding capacity                             | 215 kN                      |

| Electrics                                             |                             |
|-------------------------------------------------------|-----------------------------|
| Electric motor vac/50 Hz/3ph                           | Morley 112 kW/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                 | Trolex 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 |

Fig. 5 Quad bolter used in Sarpi mine

**Case Study**

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 Shyam Sundarpur colliery were two different collieries. Since nationalisation in 1973, Sarpi merged with Shyam Sundarpur colliery and became part of it. The first pit opened at Shyam Sundarpur colliery on 05.12.1946 and
Sarpi (Fig. 8) on 23.12.1950. On 12.05.2004 eastern part of Bankola colliery became a part of it through mine boundary adjustment (215 Ha land). 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 120 m in the north to approximately 210 m in the south, with a mean dip of 4 degrees. Current production is about 48,000 te/month. The CMT section is developed using a gallery dimension of 6 m width and 4–4.5 m height. During depillaring, the rib dimension varies from 36.39 to 85.9 m², and the snook left in the pillar varies from 64.39 to 99.2 m².

**Location**

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 N 23° 37' 45" to 23° 39' 20" and longitude E 87° 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. 8.

**Seam Details**

There are multi-seams workings within the mine boundary. The top R-IX seam was available only in a small patch and

Table 5 Specification of the feeder breaker

| General | Machine type: BF—14B-3-7C |
|---------|---------------------------|
| Breaker motor | 112 kW |
| Controller | From gate end box |
| Remote start/stop | Push buttons |
| Panic bar | |
| Conveyor and drive | |
| Width | 1270 mm |
| Chains (covered) | 76 and 101 mm pitch, 86000 kg |
| Flight p-u77 | 44 mm × 101 mm solid alloy steel |
| Head shaft | 101 mm dia with 89 mm bearings |
| Tail shaft | 87 mm dia with 87 mm bearings |
| Speed | 2 speeds |
| Breaker pick diameter | 711 mm |
| Dimensions | |
| Length | 10.18 m × Width 3.81 m × Height 2.01 m |
| Ground clearance | Intake 203 mm to 406 mm |
| Discharge with positive lock | 203 to 584 mm |

Table 6 Specifications of cables

| Qty | Cable duty | Cable type | Core size (mm²) | Length (m) |
|-----|------------|------------|----------------|------------|
| 1   | Continuous miner | 7 m to BS6708 | 95 | 210 |
| 3   | Shuttle car | 11 to BS6708 | 16 | 200 |
| 1   | Feeder breaker | 11 to BS6708 | 16 | 60 |
| 1   | Quad bolt | 7 m to BS6708 | 35 | 225 |
exhausted. Seam R-VIII Top and R-VIII Bottom are contiguous, and most areas standing on pillars, some parts depillared. The next seam is R-VII which is partly developed and partly virgin, and CM is deployed in this seam. R-VIIA seam is partly developed and most parts virgin. The bottom R-VI to R-II is virgin and presently has no access.

| Name of the seam | RVII |
|------------------|------|
| Thickness        | 4–7 mts |
| Gradient         | 1 in 15 |
| Gassiness        | Degree II |
| Grade            | B |
| Roof             | Shale and intercalation of mud and sandstone |
| Floor            | Shale and sandstone |
| Reserve          | Mineable about 9MTe |
| Extractable Reserve | about 5.043MTe |
| Development      | 2.817MTe |
| Depillaring      | 2.226MTe |

Regional Geology of Sarpi Mines, ECL

The proposed area for mechanised mining in seam R-VII at Sarpi colliery lies to the south and west of the current production area. The seam in this area varies in depth from 120 to 210 m dipping gently at 1 in 15 ($\frac{4}{15}$) to the south. The R-VII seam is predicted from surface boreholes to vary in thickness from the north to south from 4 m to greater than 5.5 m. The proposed CM R-VII block has been extended overworked in the R-VIII(T2)/(B1) seams approximately 60 m above. The roof overlying core’s immediate roof above the R-VII seam indicates that weak grey carbonaceous mudstones overlie the seam up to 0.6 m thick. This, in turn, is overlain by interbedded weak mud and sandstones and coal bands that can be significant up to the lower leaf of the R-VIII(B1) seam approximately 60 m above. In addition to this, the CM R-VII block has also been underworked in a localised area in the north east of the reserves by the R-VIIA seam approximately 25 m below. The remaining reserves below R-VIIA are reportedly virgin.

Development and Depillaring by a Continuous Miner

Development

Development by a continuous miner with room and pillar is now prevalent and economical. The gallery’s width is usually kept between 5.5 and 6.5 m, for which a permit is required from DGMS. With the development of the continuous miner, the CMs are available for 1.5-m height to 6-m height. The deployment of CM in any coal seam is possible for a height ranging between 1.5 and 6 m, provided the permission is obtained from DGMS [6]. 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. A typical layout is given in Fig. 2, which shows the development work of Sarpi mines.

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

![Fig. 8 Mine plan and location of Sarpi underground mine](image)
14 m. Therefore, in any depillaring method, the slice length should not exceed 14 m 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 [10]. 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.

Cutting Sequence

The cutting sequence by the continuous miner in the bord and pillar development system is shown in Fig. 9. 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, the extraction sequence is followed from the dip most side by using the CM. This manner of extraction (straight line of extraction) is followed only to accomplish the machinery’s easy manoeuvring.

Various Depillaring Methods

In the Indian coalfield, the most popular method is the split and fender method Fig. 10b. Some of the other methods being practised throughout the world are—double split and fender method Fig. 10a [11], yield pillar non-caving method, as shown in Fig. 10c, One-third split and fender extraction method Fig. 10d single-pass extraction Fig. 10e modified Nevvid system of extraction Fig. 10f. If the pillar sizes within the range of 25.5–34.5 m 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 38 m. A modified NEVID and pocket [12] system is chosen for smaller pillars (18–20 m). Pillar size more than 35 m may be extracted by the one-third split and fender method, as shown in Fig. 10d.

Support System

Typically, in a continuous miner panel, 1.8 m- to 2.4 m-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 1.8 m full column resin roof bolts per row spaced at the interval. Each breaker line consists of 2 rows of bolts of 5 × 2 at the spacing of 0.6 m. 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 and roof bolt patterns are given in Fig. 11.

Strata Monitoring

The strata monitoring plan of Sarpi mines was prepared jointly by Rock Mechanics Technology (RMT) [10] and the Central Institute of Mining and Fuel Research (CIMFR) team and categorised into design and safety monitoring. The details of the instrument [13] 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.

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 7.5 m 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 are given in Fig. 13.
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. 14). 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 [13], presenting axial and bending load profiles throughout the bolt. The strain gauge read-out unit incorporates the necessary bridge completion with the bolt. The standard 10 m cables are concluded with a 25 pin D connector compatible with the SG 1041 and SM01 metres installed with this bolt.

Stress Cell

The stress metre (Fig. 15a) consists of 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 metre. The gauge has been given a high initial sensitivity coupled with a virtually unlimited stress range along the 10 m cable to offer temperature compensation.

Fig. 10 Various methods of pillar extraction

Fig. 11 Roof and side support system of Sarpi mines
by reorienting the vibrating wire concerning the loading platens. The stress metre 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 metre 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. Designed of underground structures and excavation patterns is greatly influenced by the value and range of mining-induced stress. A vibrating wire-type stress cell (Fig. 15b) 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 metres are installed into the horizontally drilled boreholes in the pillars by setting tool and tightened with the help of wedge and platen assembly [14]. The stress metre is read out using the GK-401 Read-out Box to take the reading automatically.

**Remote Reading Tell-Tale**

Remote reading tell-tale (Fig. 16) 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 are noted in a book and analysed using 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 tell-tale transducers are available in single height, dual height, or triple height versions. These are easy to instal wire extensometers designed to fit into 35–45 mm 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 [10]. 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.

**Multiwire Extensometer**

This instrument monitors the separation of different roof strata 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 (Fig. 17). 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. This panel proposes the installation of two-way and four-way type roof extensometers.

**Auto Warning Tell-Tale**

It is an instrument used during depillaring in a single anchor with 7.5–10 m 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. 18a.

**Rotary Tell-Tale**

This type of tell-tale is fixed up to the length of 5–7.5 m 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 Figs. 16, 18b, ordinary people can quickly check the rotary tell-tale and handle any problem. Only one drawback to taking the reading has to be reached beneath the device, which is difficult during high-stress conditions.

**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. 18c. 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.

**Rock Tale**

The rock-tale is a unique mechanical and electronic device that provides early warning of roof instability in underground mines. This instrument is used in an underground mine with 2 or 3 trigger points variety of different horizons, and it blinks with different colours when a load arises on any horizon. The best thing about this instrument is that it indicates the particular horizon where the deformation has occurred. The device consists of two LED lights (blue and red), and maybe in other models with three LEDs (blue, red and green) to provide advance warning of a roof or sidewall separation. Generally, this instrument requires 22–51 mm hole dia. It is entirely water and dustproof. The installation of this rock tale for the bottom anchor indicates the blue, which is installed less than 2 m in height in the roof (Fig. 19). The middle anchor is denoted by the red colour installed up to 2–3 m. In the other model where three anchors are available, the extra anchor point is denoted by green and installed more than 3 m. The lower trigger anchor moves downwards once the lower roof once separated from the strata. The inner piston with the blue reflective tape snaps outward once the lower trigger anchor moves downward, then it starts to blink and sound (optional).

Similarly, if the other anchor crosses, the trigger values also blink with a different colour. These trigger values can be customised, and a minimum 1–3 mm deformation can be measured. Other advantages include light blinking and additional fluorescent tape also pasted with the body of.
various triggers for easy visibility. These instruments are widely used in the country like South Africa. Very easy to install and easy to receive alarm by even any unskilled miner.

**Instrumented Rock Bolt**

Instrumented rock bolt (Fig. 20) 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 22 mm dia and 1.8–2.4 m length. For installation, 28–32 mm holes are required, and 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 mines, this bolt is being used quite extensively with full satisfaction.

**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 are 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, determining 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 are tested at the IIT (ISM), Dhanbad Rock mechanics laboratory. Using the laboratory determining strength and the RMR value [15], the corresponding rock mass strength parameters are scaled down from Eqs. (1) to (7).

\[
s_1 = s_{cm} \left( 1 + \frac{s_3}{s_{im}} \right)^{b_m} \quad (1)
\]

\[
s_{cm} = s_c \exp \left( \frac{\text{RMR} - 100}{20} \right) \quad (2)
\]

\[
s_{im} = s_t \exp \left( \frac{\text{RMR} - 100}{27} \right) \quad (3)
\]

\[
b_m = b^{\frac{\text{RMR}}{100}} \quad (4)
\]

where \( s_1 \) is triaxial strength of rock mass (MPa), \( s_c \) is compressive strength of intact rock (MPa), \( s_{cm} \) is the compressive strength of rock mass (MPa), \( s_{im} \) 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 [16] has been found suitable [17, 18]. 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 [19, 20].

\[\tau_{sm} = \left( \frac{\sigma_{cm}\sigma_{tm}}{b_m^{b_m}} \right)^{1/2} \]  
\[\mu_{0m} = \frac{\tau_{sm}^2 (1 + b_m)^2 - \sigma_{tm}^2}{2\tau_{sm}\sigma_{tm}(1 + b_m)} \]  
\[\phi_{0m} = \tan^{-1}(\mu_{0m}) \]

where \(\tau_{sm}\) is the shear strength of rock mass, and \(\phi_{0m}\) is the angle of internal friction.

For determination of the pre-mining stresses, the vertical stress \(\sigma_v\) and the horizontal stress \(\sigma_h\) are calculated by formulae [21] given in Eqs. (8) and (9).

\[\sigma_v = 0.025H \]  
\[\sigma_h = 2.4 + .01H \]

where \(H\) = depth of cover in metres. Various parameters used for numerical modelling are presented in Table 7.

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:

\[SF = \begin{cases} \frac{\sigma_{1m} - \sigma_{3mi}}{\sigma_{1mi} - \sigma_{3mi}} & \text{for } \sigma_{3mi} < \sigma_{1m} \\ \frac{\sigma_{3m}}{\sigma_{3m}} & \text{for } \sigma_{3mi} > \sigma_{1mi} \end{cases} \]  

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

Figure 21a shows the safety factor of the pillar of panel P-5A of the Sarpi mine, and Fig. 21b shows the max principal stress of the rib pillar.

The ARMPS software[22] validated 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.

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

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 Fig. 22. 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.

Short Encapsulation Pull Test (SEPT) to Determine the Bolting Performance

The short encapsulation pulls test (SEPT) [23] determines the resin and rock bolt behaviours. A small length of roof bolt (Bond length -300 mm) 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. 23.

Limitation of CM Deployment

A 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 min 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 h in a day to be checked and lubricated \[2\] result production being hampered. In the continuous miner technology, some 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.

![Fig. 21](image)

The factor of safety of the pillar at P5A panel of Sarpi Mines. Shows the max principal stress of the rib pillar at Sarpi mines.

| 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/M³) |
|---------|---------------|---------------------|-----------------------|-------------------------------|---------------|----------------|---------------------|----------------------------------------|----------------|
| Roof1   | 5             | 6.49                | 11.96                 | 4.80                          | 0.25          | 0.67           | 36.52               | 53.50                                  | 2503           |
| Roof2   | 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           |
4. These CMT requires 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.

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. 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.

1. The mine operator will also be responsible for fulfilling the statutory requirements of the mining regulations [6] 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

| S. no | Name of the mine | Parameters | Value in metre | ARMPS (USA) FOS/stability factor | FOS from the empirical relation | Avg. FOS from numerical modelling |
|-------|-----------------|------------|----------------|---------------------------------|-------------------------------|----------------------------------|
| 1     | Sarpi mine. ECL | Depth of cover (D) | 146             | 3.58                            | 3.65                          | 3.8                              |
| 2     |                  | Height of extraction (h) | 4               |                                 |                               |                                  |
| 3     |                  | Gallery width (W) | 6               |                                 |                               |                                  |
| 4     |                  | Pillar size (C to C) | 34 × 34         |                                 |                               |                                  |

Fig. 22 Comparison of the roof displacement using a numerical model (blue colour) and instrument data (orange)

Fig. 23 Short encapsulation pull test (SEPT) procedure

Fig. 24 Reinforcement stiff system of support:
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.

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 process of research, 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 continuous miner technology is preferred for the seam of 1.2 m. 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.

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.

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Declarations

Conflict of interest The author declares that he has no conflict of interest.

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