SHYAM SUNDAR PRASAD
RABINDRA KUMAR SINHA
and
KATLA SUDHEER

Application of continuous miner technology for extraction of deep seated coal seam under hard roof conditions – a case study of Churcha mine

India is the second-largest leading coal-producing country in the world. One of the main reasons for this feat is attributed to the adoption of the latest technologies of mining. In the case of underground (UG) coal mining, one such technology is continuous miner (CM), a mass production technology. After the introduction of CM technology in UG coal mines, production, productivity and safety have improved drastically. This technology has performed well in most of the mines where they are deployed, as it provides great flexibility to orient mining layout and strategy in changing geo-mining conditions. However, there have been experiences of challenges in maintaining production, productivity and safety standards in the cases of mines practicing depillaring operations with CM under adverse and difficult strata conditions. One such unique experience is the case of achieving an outstanding performance of CM technology at Churcha mine (RO) of South Eastern Coalfields Limited (SECL), hereinafter referred to as Churcha mine, where two sets of caterpillar make CM package are deployed under a strata condition which is not favourable due to the coal seam being deep-seated under hard roof conditions overlain by a hilly terrain surface topography. Even the powered support longwall (LW) face with shearer and powered supports got collapsed in the past due to heavy weighting on the supports in this mine. This paper discusses the difficulties faced in operating CMs in this mine with a deep-seated coal seam under a hard sandstone roof and the corrective measures adopted to overcome those challenges to set a unique example of achieving an appreciable level of production, productivity and safety in the UG coal mining history of India.

Keywords: Continuous miner, technology, strata control, strata management, depillaring, breaker line supports.

Messrs. Shyam Sundar Prasad, Rabindra Kumar Sinha, Department of Mining Engineering, Indian Institute of Technology (Indian School of Mines) Dhanbad, Jharkhand 826004 and Katla Sudheer, General Manager (Mining), GMMCO Ltd. (CK Birla Group), Email: rksinha@iitism.ac.in

1.0 Introduction

Underground coal mining in India has reached greater heights by overcoming the technological vacuum in the exploitation of seams. As the productivity competition is now global, the implementation of new technologies became necessary. These new technologies faced serious techno-economical challenges and strata control problems after their deployment in Indian mines (Mandal et al, November-December 2004). SECL, a subsidiary of Coal India Limited (CIL) is the first company to deploy CM in India. It deployed its first CM in Anjan Hill, Chirimiri followed by Sheetaldhara - Kurja, Khairaha, NCPH, Rani Atari, Haldibari, Bangwar, Vijay West and Churcha mine. All the projects are outsourced to Joy Global UK except for the Churcha (RO) project, which was handed over to GMMCO Ltd., the authorized dealer of CAT products in India. SECL and GMMCO together, have been handling the Churcha CM project for the last 6 years in an effective way by deploying two sets of continuous miner package, where each package comprises a load center, continuous miner, feeder breaker, diesel coal haulers (2 nos), twin bolter and a diesel multi utility vehicle (MUV).

The project has shown tremendous growth last year (Fig.1). By proper planning of mining activities coupled with good equipment maintenance practices has improved the equipment availability to 85% which resulted in the best production performance of 10.8 lakh tonnes in the financial year 2020-21 and is expected to improve further. But the only constrain in achieving improved availability is the pre-existing geo-mining condition which makes it difficult for the technology to achieve maximum production. Hence various scientific agencies were engaged to investigate the strata behaviour of the mine. Celtis Geotechnical cc was the first scientific agency to do research on the behaviour of superincumbent strata followed by SRK Mining Services (India) Pvt. Ltd and CSIR- Central Institute of Mining and Fuel Research (CIMFR). With the advice and guidance of scientists from these three agencies, the mine management has successfully completed four Annual Production Programmemes (APPs), and now with the scientific assistance of CSIR-CIMFR on strata behaviour, SECL and GMMCO have stepped into the final APP of the 5 years contract.

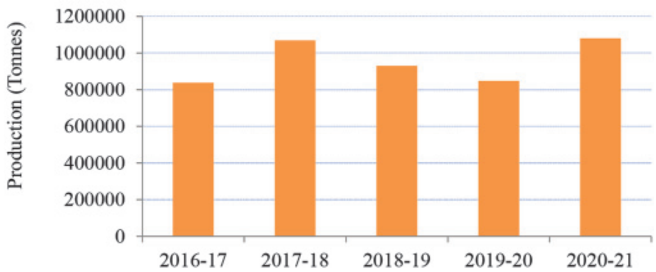

Fig.1: Financial yearwise production (tonnes)

2.0 Strata conditions – the main bolltleneck in coal exploitation at Churcha mine

The Churcha mine is located in Sonhat coalfield in the Rewa Gondwana basin having 7 coal seams, of which seam V is the only workable seam of thickness ranging from 3 to 4m. The seam is dipping in the direction N40^{o}W with a variable gradient of 1 in 18. The surface topography of the mine block is hilly terrain, which makes it difficult to extract coal by conventional mining methods having a limited rate of extraction, as the load acting on the pillars is more. An important geological feature of the deposit is the presence of a 75m to 163m thick dolerite sill occurring between 38m to 190m above the seam V. Except for a small patch on the rise side, almost the whole mine is covered by the sill. In 1990, the LW method of mining was introduced in Churcha West mine, which is part of the present Churcha mine (RO). Due to the presence of dolerite sill in the overlying strata and deployment of underrated powered supports, the LW face collapsed during dynamic loading after the face advancement of 220 m. Fig. 2 shows the borehole section MESC-17 drilled at the dip most point of the seam, showing seam V and position of the dolerite sill above (not to scale). The physico-mechanical properties of the roof rocks of seam V are summarised in Table 1 (Data source: SECL).

The mine is presently working at a depth of 300 to 380m. A small layer of shale having a thickness of 0.1m to 1m is present in the immediate roof, which gets separated from the roof on exposure. Above which a massive competent sandstone roof exists up to the dolerite sill. This massive sandstone in the roof does not favour natural caving, which in turn increases the area of exposure while depillaring. Due to this large hanging area, the pillars in the front abutment zone are being pressurized extensively. As the coal formation in the middle portion of the seam is vertical or angularly cleated the propensity of side spalling and floor heaving during abutment pressures is high, resulting in heaping of coal lumps on both sides of the roadway. This increases the gallery width but narrows down the roadway width. The increase in gallery width causes further expansion of the pressure arch, which in turn increases the height of the immediate roof. On the other hand, the narrowing of roadway width by coal lumps restricts the passages for machinery. So, compulsory sweeping by multi-utility vehicles is required

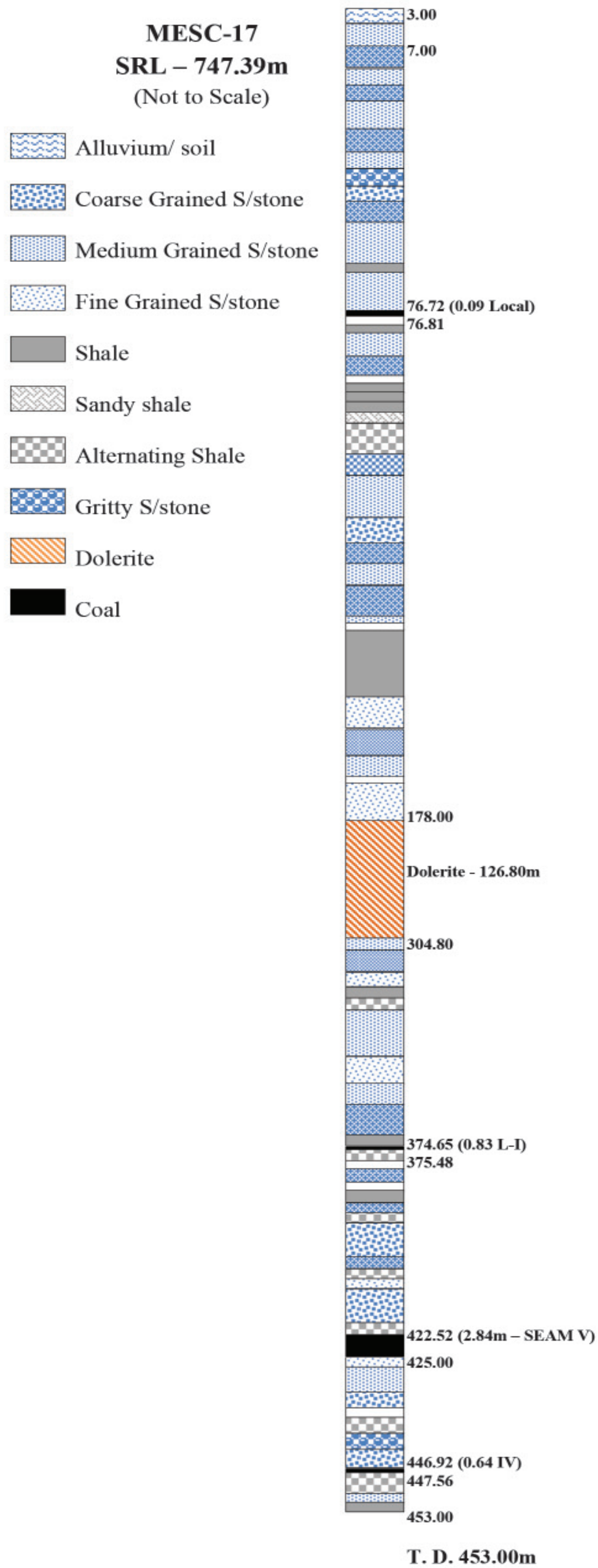

Fig.2: Borehole section MESC-17 showing seam V and position of dolerite sill above seam V (Not to Scale)

TABLE 1 : PHYSICO-MECHANICAL PROPERTIES OF ROOF ROCKS OF SEAM V AT CHURCHA MINE

Strata*	Young's modulus (GPa)	Poisson's ratio	Density (Kg/m^3)	Uniaxial compressive strength (MPa)	Uniaxial tensile strength (MPa)	Bieniawski's RMR	Source
Alluvium			2000				Assumed data
Cgsst	3.2	0.25	2198	18.63	1.86	64	
Mgsst	8.26	0.25	2240	44.63	4.46	71	
Fgsst	4.51	0.25	2332	29.90	4.43	71	
Shale	4.76	0.25	2410	37.69	6.88	66	
Sandy shale	5.13	0.25	2441	34.39	5.25	66	CIMFR (2015)
Alternating shale	6.51	0.25	2325	41.16	5.67	68.5	
Carbonaceous shale	3.565	0.25	1905	29.245	4.48	60.5	
Shaly coal	3.565	0.25	1905	29.245	4.48	60.5	
Coal seam (V)	2.37	0.25	1400	20.08	2.0	55	
Dolerite	18.606	0.172	3006.6	124.1	9.116	85	From different sources of data available at CSIR-CIMFR. RMR data assumed.
Mgsst (just below the dolerite sill)	9.97	1.933	2997	94.8	12.629	85	Provided by GMMCO Ltd.

*Fgsst: Fine-grained sandstone, Mgsst: medium-grained sandstone, Cgsst: coarse-grained sandstone

TABLE 2: PHYSICO-MECHANICAL PROPERTIES OF 40.23M ROCK CORE SAMPLES OF AN UPWARD BOREHOLE DRILLED IN ROOF OF SEAM V, CHURCHA MINE (PROVIDED BY GMMCO LTD.)

	Rock type*	Density (Kg/m^3)	Uniaxial compressive strength (MPa)	Tensile strength (MPa)	Young's Modulus (GPa)	Poisson ratio (v)
1	Mgsst	2188.8	34.54	2.03	6.82	0.32
2	Mgsst with Carbonaceous band	2171.5	29.19	1.94	6.26	0.20
3	Mgsst to Cgsst	2160.2	23.14	1.73	6.79	0.29
4	Mgsst to Fgsst with carbonaceous band	2274.4	41.77	2.94	8.28	0.33
5	Fgsst to Mgsst	2281	42.96	2.89	7.63	0.19
6	Shale	2426	-	4.31	-	-
7	ShalySst	2334.2	45.53	4.32	7.02	0.10
8	Fgsst	2241.6	34.02	4.24	7.55	0.10
9	Fgsst	2358	-	6.30	-	-
10	Shale	2415	53.64	4.16	7.00	0.10
11	Fgsst to Mgsst	2272	39.85	3.45	7.91	0.19
12	Shale	2358	69.50	6.83	7.31	0.26
13	Shaly Sst	2221.5	-	4.35	-	-
14	Mgsst to Cgsst	2202.2	36.62	2.94	8.50	0.18
15	Fgsst	2199.3	24.49	4.22	5.92	0.18

*Sst: Sandstone, Fgsst: Fine-grained sandstone, Mgsst: Medium-grained sandstone, Cgsst: Coarse-grained sandstone

during depillaring operation. In addition to that, there are various major and minor faults available in the seam, which makes it difficult for the free steered vehicle to march from one face to another.

3.0 Measures taken to overcome the adverse strata behaviour

Churcha mine is known for competent immediate roof strata and presence of dolerite sill above the seam V. The RMR (unadjusted) of the mine is 71. To assess the physico-mechanical properties of roof strata, core drilling was done in coal measure strata up to 40.23m at 125 LE of 7 dip junction. The core samples were sent for testing to CSIR-CIMFR and the results are given in Table 2 (Source: GMMCO Ltd.). Based on those physico-mechanical properties the caving nature of the overlying strata is determined. Fig.3 shows the cavability index and RQD of different roof strata. From this figure, cavability index of 10462.78 and an RQD of more than 80%

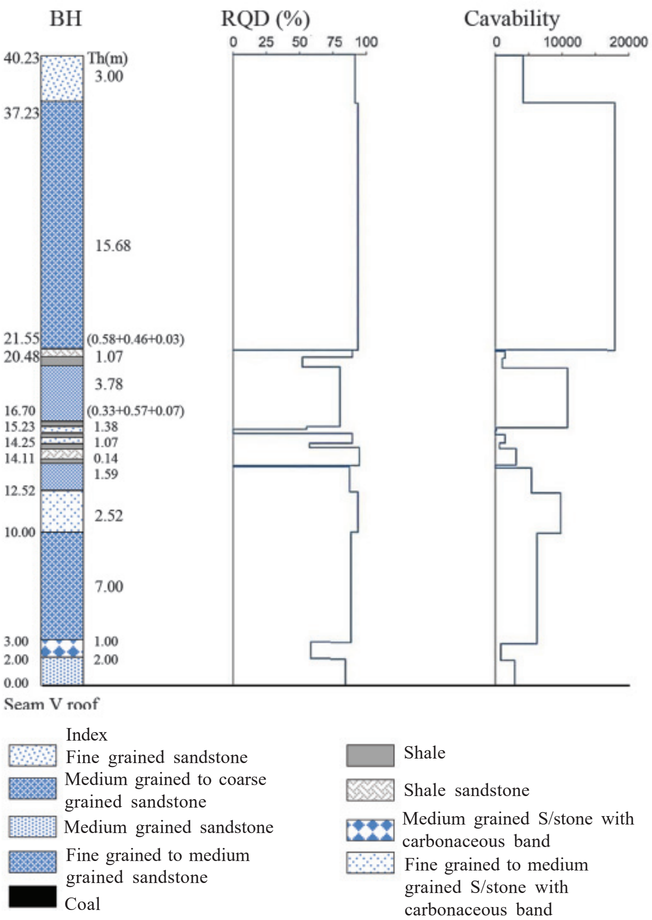

Fig.3: Plot showing RQD and cavability index of roof rock strata of various layers at Churcha mine (RO)

are obtained. Such higher RQD of the immediate roof favours the extraction of seam V with a stable cut-out distance (COD) up to the length of CM, which is 12m. But the resulted cavability index of the roof is categorized as cavable with substantial difficulty.

3.1 Strata Management

As the cavability index of the roof is categorized as cavable with substantial difficulty, regular caving of roof strata is possible only with the practice of induced caving by blasting up to a height of 7.5m in 2 sections considering the safe working condition. A jumbo drill machine was deployed specially for long-hole drilling for induced blasting which can drill holes up to a maximum length of 35m. After practicing induced blasting, the caving of strata took place at every 2000 to 3000 m^3. Further, to arrest goaf encroachment during roof fall, high capacity (25 tonnes) pre-tensioned resin roof bolts (2.4m length) were used as breaker line of support, which are proved to be effective.

3.2 Instrumentation in CM panels

The dilation in the immediate roof strata is monitored by installing Auto Warning Tell-Tale (AWTT) with anchor point at 10m in immediate roof strata and Rotary Tell-Tale (RTT) anchored at 5m depth in the roof and such AWTT and RTT are installed at four-way junctions, three-way junctions, mid of split galleries, mid of original galleries and near geological disturbances.

The mining induced stress on the pillars is monitored by installing vibrating wire stress cells up to 7m depth in the pillars as per the design provided by the scientific agency.

Instrumented rock bolts are installed in the breaker-line support (2.4m length bolts) at goaf edges, to monitor the axial loading on the breaker line support at different horizons of the bolting zone, exerted due to the dynamic loading at the time of roof falls.

Data logger is used to capture the realistic data of stress changes, by connecting wires of vibrating wire stress cells and instrumented rock bolts to the data logger.

Based on the experience gained from the past, a Trigger Action Response Plan (TARP) is framed and after cumulative dilation of immediate roof strata by 7mm, all personnel is made alert and vigilant during mining operations and when a cumulative dilation reaches 10mm observed in AWTT or RTT, operations are stopped and men and machinery are withdrawn to safe locations. Also in the event of sudden rate of change of dilation in AWTT or RTT observed more than 3mm at any working place, operations stopped immediately and men and machinery withdrawn to safe locations and thus safe mining operations are ensured.

Short encapsulation pull tests (SEPT) are conducted, whenever there are new lots of resin capsules or roof bolts supplied to CM panels and also in the event of a change of strata conditions, to ensure the efficacy of roof bolting.

For preventing spalling of sides due to abutment pressure on pillars, supporting of sides is done with the combination of cuttable plastic tensile mesh and glass reinforced polymer (GRP) bolts of length 1.5m. Hence the sidewalls of pillars are secured and ensured the safety of men and machinery deployed in the CM panels.

4.0 Successful extraction of coal in 14 panels with CM technology

The pre-existing mining condition has often been a deterrent for the CM technology to achieve the target production, but the technology never stopped proving its success. It overcame all the difficulties and completed depillaring in 13 panels within the incubation period. The details of the panels worked by CM technology are enumerated in Table 3.

The faster rate of extraction was possible only through the proper designing of extraction methods that suit the pre-existing geo-mining condition. Even a new extraction methodology was invented in few panels, where the strata condition and the pillar dimension were not favouring the routine “split and slices” caving method. Especially in the

Table 3: Details of panels worked by continuous miner

	Panel name	No of pillars	Size of pillars (m) Center to center	Depth of cover (m)	Panel length (m)	Panel width (m)	Percentage of recovery
1	124LW	30	50×50	340-385	300	250	55%
2	124LE	47	50×50	330-380	500	250	70%
3	115LE	55	50×50	321-352	550	250	57%
4	122LW (A) DIP	15	50×50	368-388	250	150	25%
5	122LW (B)	56	50×50	373-383	550	250	63%
6	110LE	85	45×45	319-343	765	225	68%
7	119LW	Due to the presence of surface feature (water dam) only development was done					
8	124LW	87	48×50	412-426	1250	100-250	65%
9	C2 DIP	50	50×50	384-415	560	230	61%
10	117LW	24	45×50	360-370	300	180	66%
11	16E	32	45×40/40×40	338-364	500	250	68%
12	15E	50	36×36/44×44	315-355	205	395	74%
13	7 DIP	15	50×50	368-388	250	150	76%
14	97LE	37	48×50	304-322	320	182	75%

124LW panel, the recovery of coal in the single split and two fender slicing method was less than 50%, as the width of the resulting fenders was 19 meters and the cut-out distance was limited to 12 meters. In the case of the double split and three fender slicing method, the factor of safety of snook formed was not up to the norms. Also, the fishbone method of slicing with single split was eliminated, as the extraction span in the slice junction will favour more number of local falls. This is due to the presence of shale in just above 15cm thick sandstone roof above coal seam of 124LW panel which gets separated easily in the event of water seepage in between roof layers. So, an innovative 'T-split' extraction methodology was designed especially for the said panel and also found success after its implementation.

5.0 Experience in depillaring panels with CM technology

After the commencement of depillaring operation, domed GRP bearing plates used in side support turned flat due to the load acting on pillars and were able to hold the coal lumps along with the mesh for few days. After reaching an extraction span of 36000m², the GRP bolts and the plastic tensile mesh got sheared due to excessive spalling of sides. Even spalling up to 1.5m from the last column roof bolt was observed in the main galleries.

At the 3/4th portion of panel extraction, heavy bumps were experienced frequently which resulted in huge spalling of sides up to a distance of 100-150 meters outbye, due to dynamic loading on pillars. Also while driving of split galleries, side spalling occurred from both dip and rise sides of the split. After a goaf span of about 1 lakh m², cracks were noticed along the roof, which was extended from dip to rise along the panel width and a few of them were noticed in the level galleries also. Some cracks were of 15 mm -20 mm size.

While depillaring the dip side panel (sub panel 122L A), which was surrounded by goved out panels on three sides, abnormal bumps and abnormal spalling of sides were experienced. Due to frequent bumps and high loading on pillars, the floor got heaved and resulted in the formation of cracks of width 2-3 inches in the sandstone floor. Stress cells in the panel have given indication of high loading (279 Kg/cm^2) on the pillars. So, the exploitation of pillars was stopped

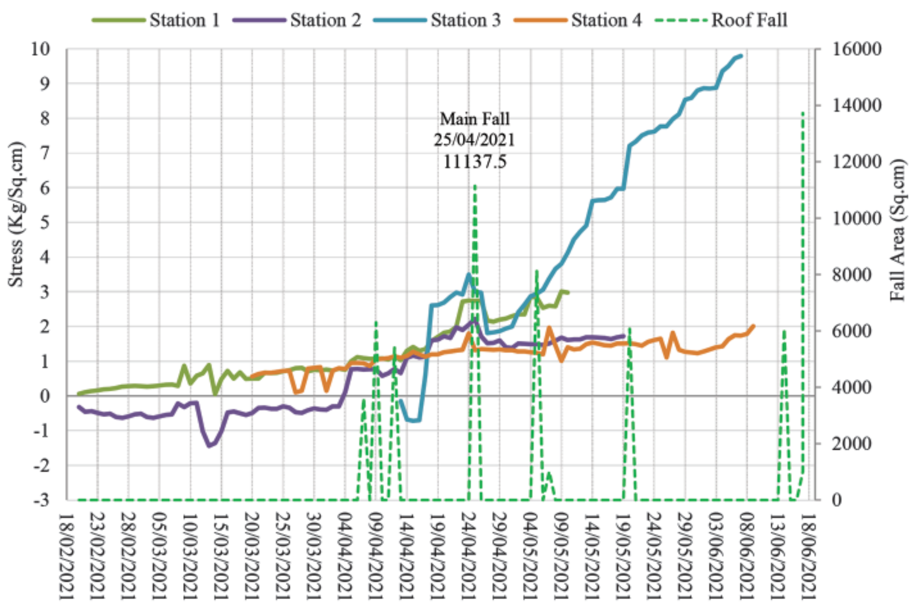

Fig.4 Interpretation between stress and roof fall of 97LE panel

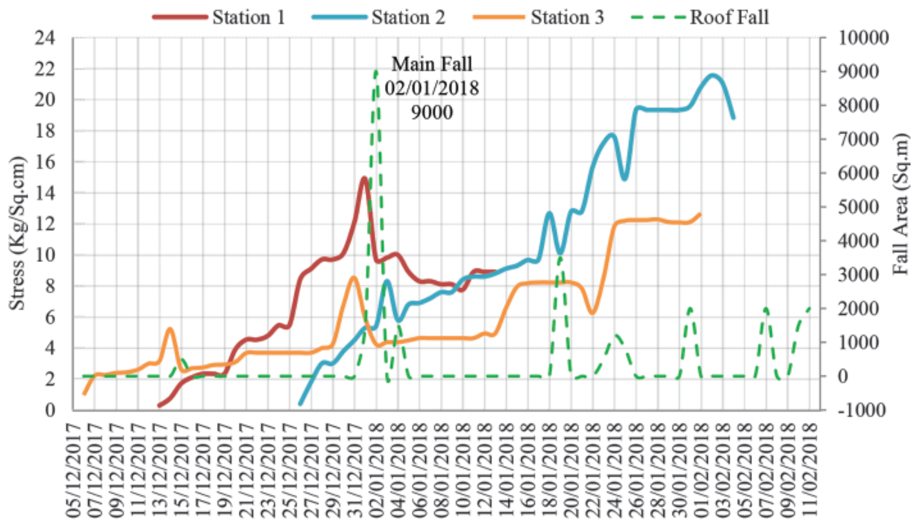

Fig.5: Interpretation between Stress and roof fall of 110LE panel

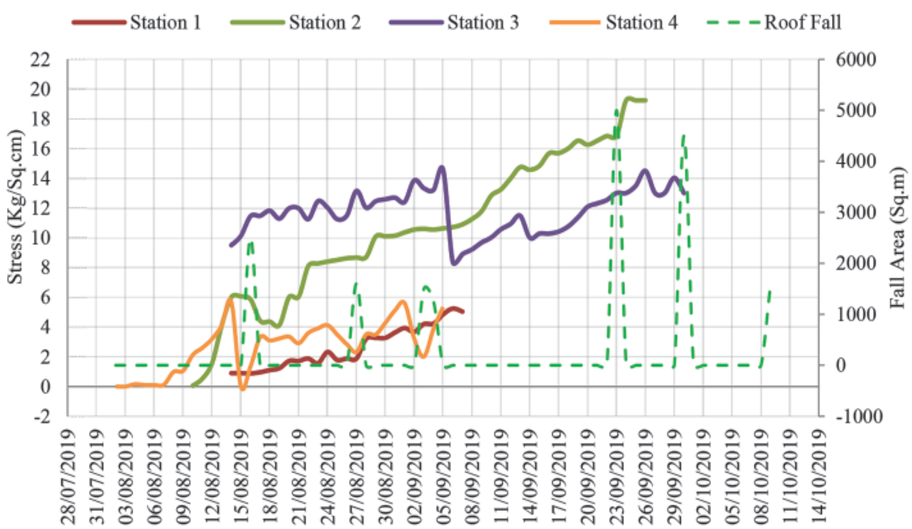

Fig.6: Interpretation between stress and roof fall of C2 Dip panel

Table 4: Experiences of main fall in earlier CM panels

Panel	Depth of cover	Area of extraction before the first fall	Area of extraction before Main fall
124LW	340-385	5000	37500
124LE	330-380	6900	36000
115LE	321-352	2700	38500
122LW(A)	368-388	-	Not identified
122LW(B)	373-383	5500	38500
110LE	319-343	5500	42000
C2 DIP	384-415	3000	38500
117LW	360-370	3500	38000
16E	338-364	3800	36000
15E	315-355	19000	37000
7 DIP	368-388	5740	38690
97LE	304-322	14400	18250

immediately and the panel was sealed after marching CM to the next panel. After that incident, the numbers of instrumentation in the succeeding panels were increased and the readings were interpreted. From the interpretation, it was observed that before every fall only the stress readings of the nearest station show an elevation in the value, but before the main fall, stress readings of all the stations show an increase in their value. The same was observed in all the depillared panels.

Fig.4 shows the interpretation between stress and roof fall in a recently depillared 97LE panel, where the trend in stress readings shows a variation before each fall. Especially on 24/04/2021, before the main fall (25/04/2021) occurred, the trend in all the four stations shows an elevation. Similarly, Figs.5 and 6 show the interpretation between stress and roof fall in earlier depillared panels 110LE and C2 dip respectively.

Previous experience of the first fall and main fall of roof in different extracted panels using CM technology in seam V is given in Table 4. From the table, it is found that the main fall generally occurs after an area of extraction of 36,000 m² to 42,000m².

Since the area of goaf at the time of main fall is around 42,000m², 128LW/6FXof 124LW panel was chosen for installing an instrumented rock bolt for determination of vertical load acting on roof bolts during main fall. The resulted trend is shown in Fig.7.

Figs. 8 and 9 shows the convergence observations in the C2 dip panel obtained from AWTT and RTT dilations respectively. The sudden increase of convergence near the zero line is mainly due to the huge abutment pressures during roof fall. At zero line, there is no effective natural support so the convergence shoots up just before the fall.

6.0 Inferences drawn from strata monitoring in depillared CM panels of Churcha mine

The experience shows that the first local roof fall in panels takes place after an extraction area of 5500 m² as commonly found in previously extracted panels. After extraction of the first row of pillars (i.e. 12,500 m² area), loading on abutments

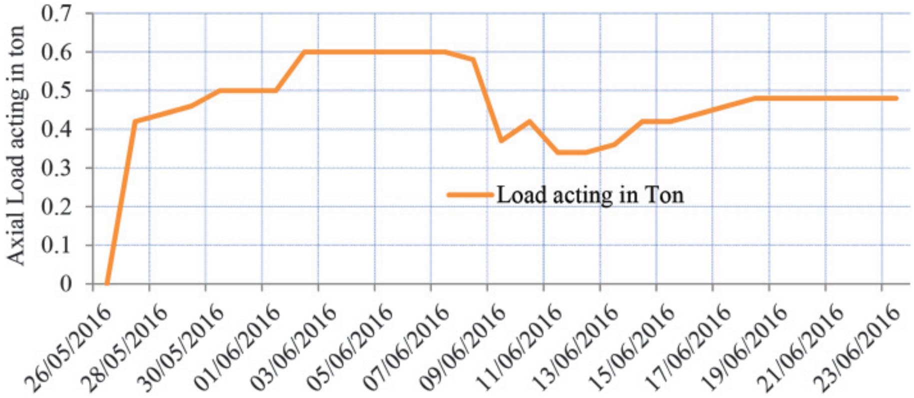

Fig. 7: Interpretation of axial load using Instrumented rock bolt in 124LW panel

There were a few instances of overriding of goaf due to partial extraction of fenders, as coal was left intact for protection against geological disturbances/faults. The caving of immediate roof and packing of galleries up to roof height at regular intervals reduced the roof overhang and prevented the occurrence of air blasts. The caved strata material is blocky in nature due to massiveness, measuring about 1-3m (length)x 2-3m(width) × 0.6-1.2m (thick), which is found towards the eastern side of the property.

increases, and huge spalling of coal from sides up to a distance of one and a half pillar out-bye occurs. After an area of extraction of around 36,000 m² (3 rows), caving of strata takes place naturally, at every 2000-3000 m² of extraction.GRP bolts of 1.5m length and plastic tensile mesh got sheared due to lateral dilation of pillars owing to significant vertical loading on outbye pillars (up to 100m distance), which is observed after extraction of 4 rows of pillars. Drilling of holes for installation of GRP bolts in the sides of split galleries was difficult on most of the occasions, as drill rods got struck up as crushing of holes occurring due to loading on fenders and also due to soft nature of coal which is managed by a faster rate of extraction safely.

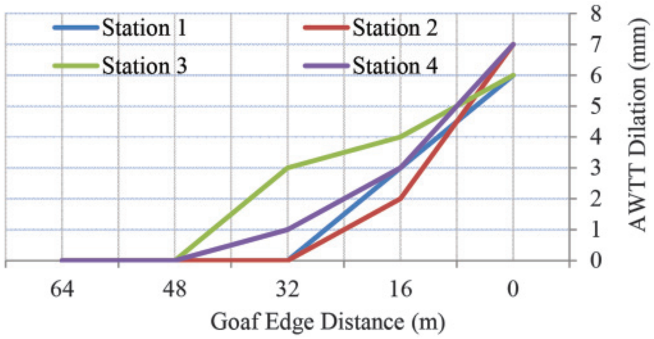

Fig.8: Interpretation of roof convergence with AWTT dilation in C2 Dip panel

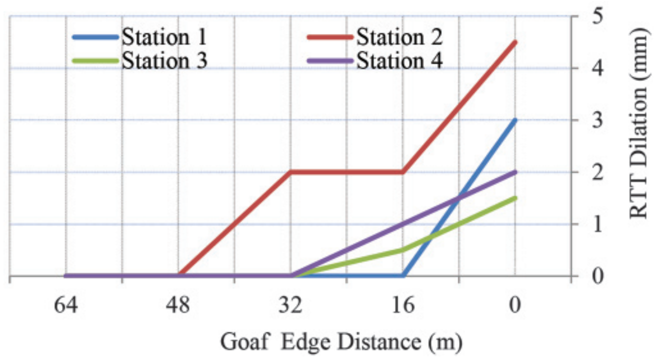

Fig. 9: Interpretation of roof convergence with RTT dilation in C2 Dip panel

After extraction reached the middle of the panels, tremendous loading on pillars is happening, which results in bump events in split galleries and original galleries up to 100m outbye distance, causing huge spalling of coal from sides and also roof contact of the corners of the pillars is getting lost which is observed while depillaring panels beyond 380m depth. After every event of 10mm of the roof dilation, in AWTT and Rotary TT, the roof fall usually takes place within 1-2 shifts duration. When there is a sudden rate of change in roof dilation by 3-4mm during a shift in AWTT/RTT (beyond 7mm of the existing dilation), noticed that roof fall occurs within two hours duration. Also, the indicator/policeman prop gives timely indication and warning of the sagging of immediate strata towards the goaf side, which helps in alertness and in decision making for timely withdrawal of men and machinery.

Breaker line supports of 2.4 m length roof bolts with 1m × 1m grid (12 bolts) are observed working effectively in preventing goaf encroachment. On few occasions, found roof cracks up to 2-3 m outbye side of the breaker lines, particularly where fenders or big size snooks are left in goaf due to the presence of geological disturbances. Before impending roof falls, enough indications of shearing of bearing plates, strata separation with huge sound, and indicator props bending in the goaf were noticed, which alerted mine personnel to take timely shelter in safe locations. In two panels (122LW and 15E), after extraction of three-fourth portion in the panel, tensile cracks were developed in the roof along the level and dip-rise original galleries in the outbye pillars which was managed by the practice of providing additional support with W-straps in the original galleries.

7.0 Conclusions

After the introduction of CM technology in Churcha mine, there were difficulties faced in achieving good production and safety results, but at the same time, the difficulties became the reason for gaining more knowledge about the technology. It changed the way of approaching the adverse geo-mining conditions in a more scientific way, where the safety of the personnel was ensured to a maximum level. Many strata management tools have emerged. With the help of instrumentation data, it became easier to do predictive analytics of the strata behaviour enabling more accurate timely decision making, which led to the safer extraction of coal even in difficult strata conditions.

Based on the experiences gained in various depillaring panels with CM in the mine, many interpretations about the strata behaviour were standardised, which helped in safer extraction of subsequent panels even in the case of deep-seated deposit with the difficult roof conditions. It was observed that after every event of 10 mm of the roof dilation in AWTT and Rotary TT, the roof fall takes place within 1-2 shifts duration and in case of sudden rate of change in roof dilation by 3-4mm in AWTT/RTT (beyond 7mm of existing dilation), the roof fall occurs within 2 hours duration. The development of understandings and standardised interpretations regarding the area of exposure for first local fall and main fall of roof, as elaborated under para 6 above, were extremely helpful in being extra watchful and vigilant by frequent observation of instrumentation data for timely withdrawal of persons during such impending events. Likewise, a practice of restricting the splitting operations not beyond one pillar of the pillar under extraction, supporting the pillar sides with cuttable GRP bolts in combination with plastic tensile mesh, and faster extraction of pillars were adopted to overcome the lateral dilation of pillar sides due to significant vertical loading. Thus, systematic monitoring of strata behaviour coupled with standardisation of few important indicators not only helped in evolving an improved goaf management technique but also in achieving a high level of production, productivity and safety standards under the given difficult roof conditions in Churcha mine.

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