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Caveability Assessment of a Hanging Overlying Massive Deccan Trap and its Effect on Underground Working

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Abstract

Efficient and safe extraction of coal from underground mines require regular/smooth caving of the hanging overlying strata in goaf which is intended to fall. Sometimes presence of extremely difficult to cave massive strata (EDTCMS) having higher strength and thickness as immediate roof delays the natural caving and affect adversely the depillaring operation in underground mines. Such EDTCMS are found globally (India, China, United States, Czech Republic) with thickness varying to hundreds of meters characterised as igneous/sedimentary formations. It is found to be lying either just immediately above or after a certain parting from the coal seam. The latter is found more frequent to the former in coalfields of the world including India. Bulking factor plays a major role in filling the void by the falling of the partition between coal seam and EDTCMS. When a large overhang of EDTCMS is created in the void then their sudden breakage may generate issues like dynamic weighting, floor heaving, pillar spalling, coal bump/rock burst, goaf encroachment/pillar failure and air blast in and around the face. Dynamic weighting by a dolerite sill in the roof destroyed the integrity of almost half of the chock shields in less than 4 second at Churcha West Colliery, India. Various techniques have been adopted worldwide to deal with the issues due to EDTCMS like their pre-fracturing, induced blasting, leaving wider barrier pillars at the face, back filling and injection of grouting material into the mining-induced overburden. This paper presents a case study discussing issues of spontaneous heating and pre-mature collapse of pillars due to EDTCMS at Mathani Underground Mine.

Keywords : EDTCMS; Depillaring; Immediate Roof; Caving; Dynamic Weighting

Introduction

Usually, it is found that the immediate roof in underground coal mines mostly consists of shale, clay, sandstone and their intercalation with thickness varying from 0.1-10m. When coal is extracted below such roof then it keeps hanging in the void space (goaf) created. Such strata caves easily and regularly without creating high induced stresses after a certain exposure as experienced in Pinoura underground mine in India [1]. Initially, the hanging roof in goaf is supported from all the sides and acts as a strong beam, inhibits caving. After a certain exposure, the strong beam fails/caves in goaf to become cantilever which keeps caving regularly. It is the story when working under easily to moderate caveable strata where roof fall takes place regularly on certain exposure of roof span. Sometimes extremely difficult to cave massive strata (EDTCMS) of sedimentary/igneous rock type is present in the roof having higher strength and thickness in hundreds of metres, delays the natural caving and affect adversely the depillaring operation in underground mines. Such strata keep extending their span without caving in the void space created and leads to a major accident in the mine. It is found to be lying either just immediately above or after a certain parting from the coal seam (Figure 1). EDTCMS located after a parting from coal seam have lesser chances to affect towards the working due to the filling of the void by caving of the partition (Figure 1a). When EDTCMS is found just immediate of the coal seam then it keeps hanging over a large span in the void without any failure and transfers load towards the working resulting into issues of coal bump/rock burst (Figure 1b). Mostly it is found after a parting from the coal seam. When a large overhang of EDTCMS is created in the void then their sudden breakage may generate issues like dynamic weighting, floor heaving, pillar spalling, coal bump/rock burst, goaf encroachment/pillar failure and air blast in and around the face. There is an incident of dynamic weighting by a dolerite sill in the roof which destroyed the integrity of almost half of the longwall chock shields supports in less than 4 second at Churcha West Colliery, India (Table 1). Another incident of water inrush occurred followed by a coal and gas outburst during the drivages of the gate roads at the Haizi Coal Mine in China (Table 1). Load of the EDTCMS is mostly shared by the coal pillars and the parting between it and the coal seam keeps falling regularly. EDTCMS starts building high abutment load towards the working causing the premature collapse of coal pillars. Goodrich et al. [2] has studied the load transfer distance by EDTCMS in United States coal mines. Less studies are available on measurement of mining induced stress under EDTCMS in Indian coal mines.

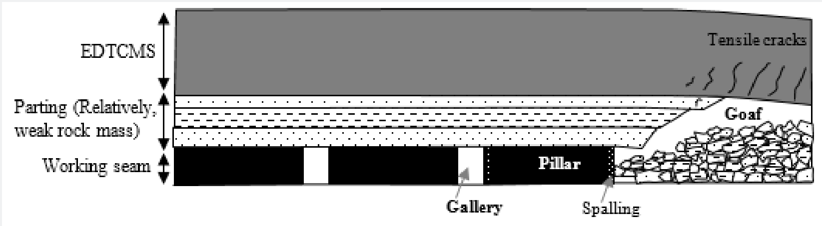

Figure 1a: EDTCMS Located after a Parting from the Coal Seam.

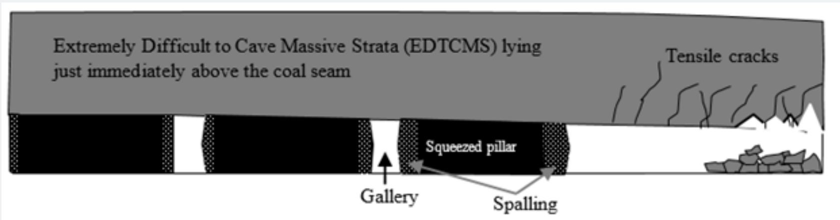

Figure 1b: EDTCMS Located just Immediate of the Coal Seam.

Figure 1: EDTCMS Location from the Coal Seam and their effects on the Working

Table 1: Characteristics of EDTCMS in some Coalfields with corresponding Mining Conditions and Dynamic phenomena.

Name and Location of the Mine	Depth of Coal Seam	EDTCMS Rock Type	Thickness of EDTCMS (m)	Uniaxial Compressive Strength of EDTCMS (MPa)	Young's Modulus of EDTCMS (GPa)	Parting Thickness between Coal and EDTCMS (m)	Parting Lithology	Mining Height (m)	Mining Induced Phenomena
Churcha West Colliery, India [7]	216-223	Dolerite sill	125-132	80-145	16-27	80-133	Medium to coarse grained sandstone	3-3.4	Dynamic weighting
Mathani underground coal mine, India	60 - 168	Basaltic Deccan Trap	40-150	80-90	8-11	2-60	Clay/coarse grained sandstone	4.5-6	Premature collapse of pillar and goaf encroachment
Ostrava-Karvina Coalfield, Czech Republic [4]	650-720	Sandstone conglomerate	51-63	70-120	22-40	Absent	---	3.1-5.2	Rock bursts and high stress conditions
Deer Creek Mine, Energy West Mining Company, USA [2]	610	Sandstone conglomerate	70	169	40.7	229.0–290.0	Shale	2.1–2.7	Pillar burst, rib spalling
Haizi Coal Mine, Huaibei mining district, China [8]	587-737	Igneous sill	140	140	32.4	170	Sandstone/ mudstone/ loose bed	2.5	Water inrush, coal and gas outburst

The parting between the coal seam and EDTCMS caves in the void by the stress-induced fracturing or goaf blasting technique or fall under gravity. Further, when the hanging rock fragments' separate from the overlying rock mass, there are likely chances of rotating these irregular sized and shaped fragments' in the void space. As a result of falling on to the ground there is pos-

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sibility of reduction in size of rock fragments. It results into an increase in volume as broken rock fragments do not lock with each other perfectly causing inefficient packing due to air gaps between them. This increase in volume of rock mass to the actual volume is called bulking factor (BF). Height of caved zone is mostly dependent upon the BF of overlying strata during depillaring of coal pillars. Bulking of rock by blasting is completely different phenomenon from the natural caving of rock. As per previous studies, BF of different rock mass is found to be ranging between 1.05 and 1.84. Thus, if the parting is enough to fill the void created by coal extraction then there is least effect of EDTCMS towards the working. Sometimes, bulking of the parting is not enough or thickness parting is not enough to fill the void after their caving in the goaf. In this case, EDTCMS keeps hanging over a large span creating several issues towards the working. Various techniques have been adopted worldwide to deal with issues due to EDTCMS like their pre-fracturing by high pressure water injection [3] or induced blasting [4] (Figures 2 and 3), leaving wider barrier pillars at the face, back filling and injection of grouting material into the mining-induced overburden [5] (Figure 2).

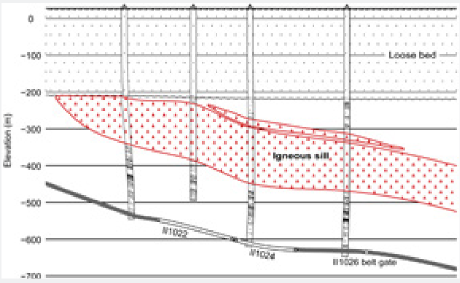

Figure 2(a): Grouting the overburden [5].

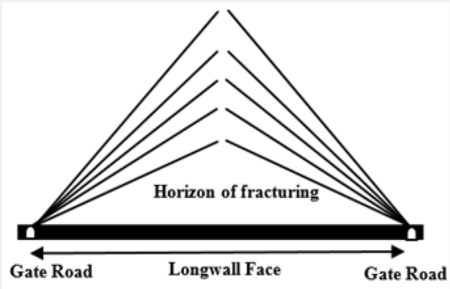

Figure 2(b): Destressing by Induced Blasting Longwall.

Figure 2: Various Methods to Deal with the EDTCMS.

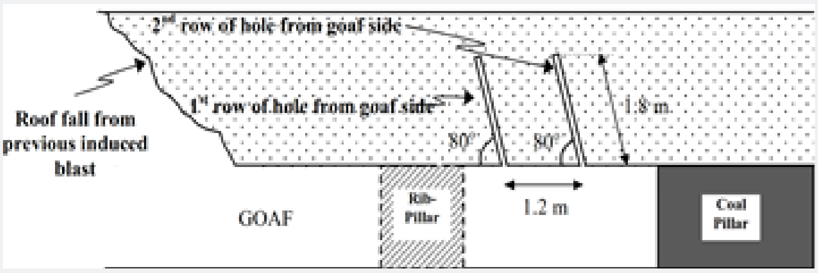

Figure 3: Induced Blasting Practised during Blasting Gallery Method to Break the Hanging Overlying Strata.

Mine Details

Mathani underground mine lies in the Thesgora block 'A' between the latitude 78054'37" to 78057'36" and longitudes 22013'17" to 22014'55", located at Chhindwara district of Madhya Pradesh, India. This underground mine was explored during 1992 and mining activity started in 1994. It is situated about 27 km east of Parasia town in the Pench valley. The area exhibits a rugged terrain comprising hills and valleys. Seasonal nallah runs in the block and drains to either Gunar or Pench river. Mathani village has a population around 350 persons, which lies in the middle of the Mathani underground mine's property in the northern boundary. The seam of Mathani underground mine has Degree II gassiness level with an incubation period of 3 months.

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A total of 11 coal seams/section viz seam/sections-IA, I(B+C), IIA, II/IIB, IIIB, IVA, VA, VB1, VB2, VB and VC in descending order at different depths of cover are present in Mathani underground mine. Among these coal seams only three coal seams i.e. I(B+C), IIIB and VA are workable, and rest are unworkable due to their poor thickness and less span. Seam VA is present throughout the property and found in almost every borehole, whereas seams I(B+C) and IIIB are absent or having unmineable thickness in few boreholes. Depth of cover for seam I(B+C) is found to be varying between 60-168m and seam IIIB is between 69-162m. The parting between seam I(B+C) and IIIB is less than 9m (varying between 2-7m) and is being worked contiguously with superimposition. The parting between the Deccan Trap and Seam I(B+C) is varying from 2-60m and thickness of the Deccan Trap is varying from 40-150m as per the various available boreholes data. Seams I(B+C) and IIIB are contiguously developed into various panels with pillar size 21.30m x 25.50m and gallery size 4.2m x 3.0m. Depillaring with caving approach by conventional drilling and blasting method is being carried out in contiguous section at the Mathani underground mine, leaving a rib of 2.3m width in both the seams which is further reduced judiciously during retreat. Around 9 panels (1A, 1B, 1C, 1G, 1H, 1I, 1J, 1K, 1L) of seam I(B+C) (Figure 4) and 9 panels (3A, 3B, 3C, 3G, 3H, 3I, 3J, 3K, 3L) of seam IIIB (Figure 5) are depillared successfully. Deccan Trap (basaltic sill) having thickness varying between 40-150m (Figure 6), lying as overhanging roof in the caved goaves of seam I(B+C). Problem of goaf encroachment causing overriding of pillars, faced while caving of Panel 1M of seam I(B+C) which further caused pre-mature closure of this panel and subsequently 3M Panel of seam IIIB also. Further, it kept affecting the barrier pillars by inducing fracture from corners and subsequently working pillars in the Panel 1N. Barrier and working pillars are under continuous deformation (from the dip most side) due to the incidences happened in previous Panel 1M. It has encroached up to two rows of barrier pillars in Panel 1N creating issue of reserve loss and strata control. It is guesstimated that the Deccan Trap is almost unbreakable to cave for the formed void and the mining induced stress created by the depillaring of previous 9 panels of the seam I(B+C) is causing the instability issues of natural supports during the working in Panel 1N. Accordingly, it is planned to study the caveability of hanging overlying massive Deccan Trap in the goaf of seam I(B+C) and its effect at this mine. It is found during the working in seam I(B+C) is difficult due to the mining induced disturbance in the Deccan Trap. It is diluting the strength of the working and barrier pillars and encroaching and affecting the working area. This encountered problem of the mine forced to leave two rows of barrier pillars between the depillared Panel 1M and working Panel 1N. Further, it is also found that the working in Panel 3M of seam III B is becoming difficult due to failure of the parting between seam I(B+C) and IIIB but the pillars are still intact. Geo-mining details and required information are collected for assessment of caveability of hanging overlying massive Deccan trap in the inbye goaves and its effect at Mathani underground mine. Details of the studied problem is mentioned in this report.

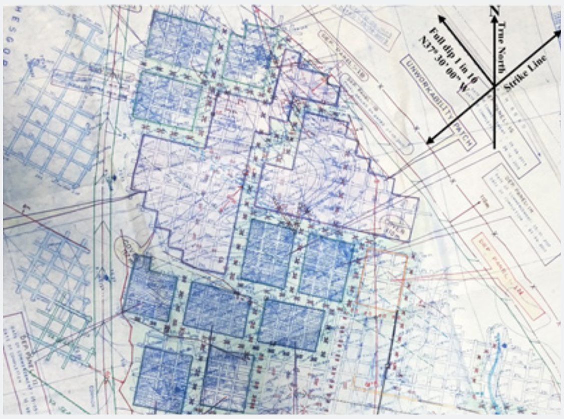

Figure 4: Plan of Coal Seam I (B+C) and Different Panels Extracted.

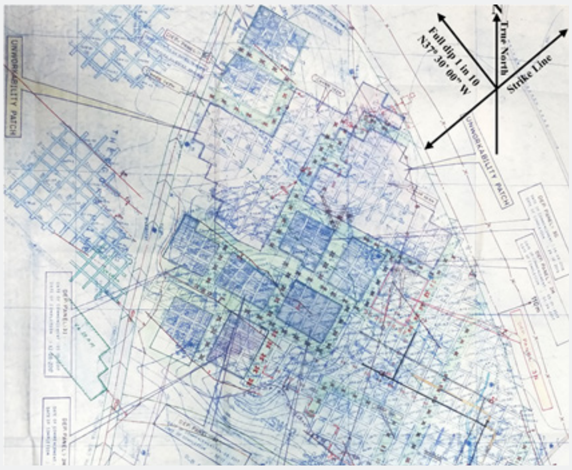

Figure 5: Plan of Coal Seam III B and Different Panels Extracted.

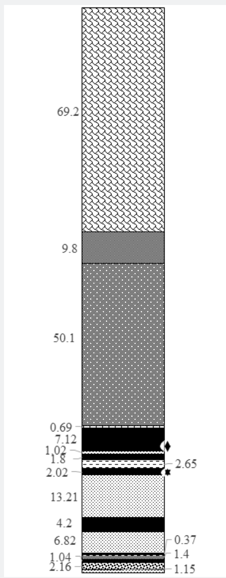

Figure 6a: TG-16.

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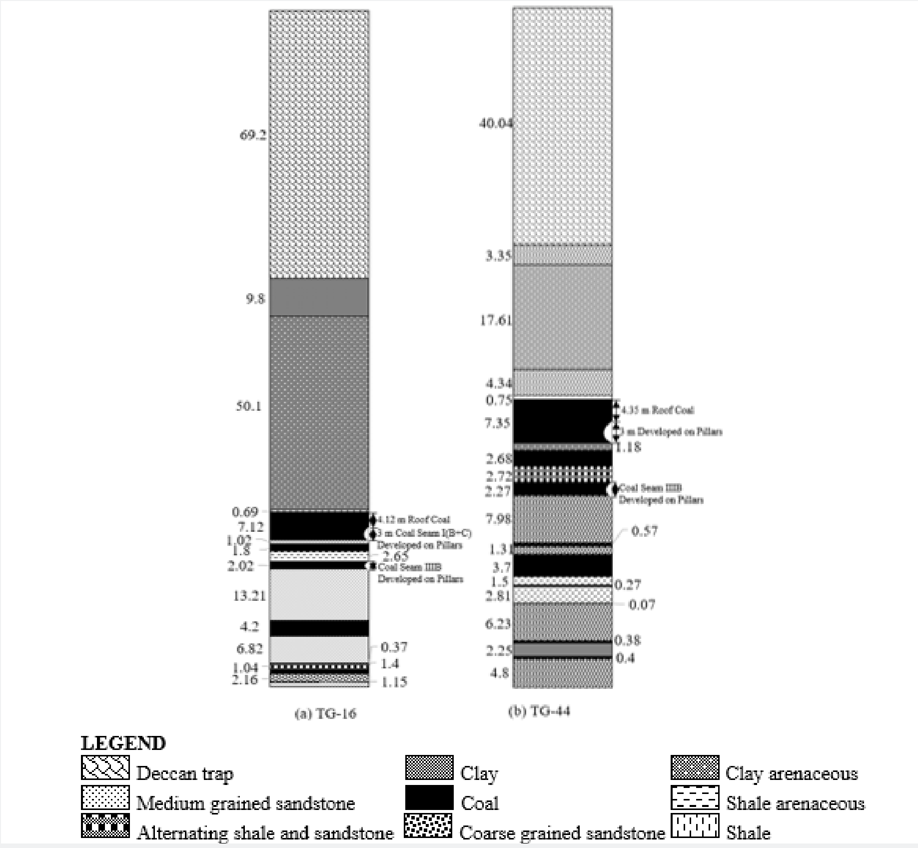

Figure 6: Borehole Sections TG-16 and TG-44.

Details of the Problem

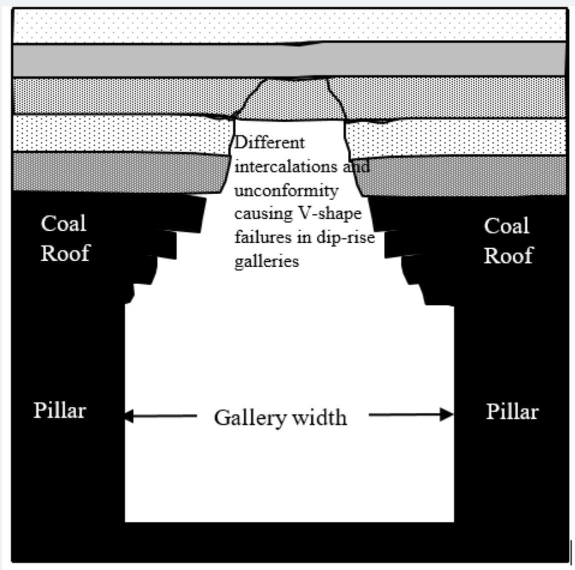

Figure 7: V-type instability in Galleries in Dip-rise side of Seam I(B+C) due to Different Unconformity.

The pillars are found to be spalling up to 1-1.5m from all the sides and it is more visible in the dip most side, when compared to that of rise side in the pillar. Further, it is increasing gradually, causing the gallery width to increase from 4.2m to more than 6m. The parting between Deccan Trap of thickness 40-150m and Coal Seam I(B+C) is varying between 2-60m. However, the thickness of this parting at the present working is around 10m only and the height of the working is 3m. This parting is mostly con-

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sisting of arenaceous (sandy) clay and coarse to medium grain sandstone with less bulking factor (BF). There is no evidence of goaf packing by caving of fragmented overlying strata. Usually, BF for coal measure formation is 1.1. Field investigation noticed in Panel 1N of coal seam I(B+C) that the roof deterioration is in V-shape form along dip-rise galleries (Figure 7) and is found to be a simple manifestation of instability in the gallery. Extraction of coal by conventional drilling and blasting further deteriorates and dilutes the competency of roof and pillar. There is no observation of any mining induced movement in the Deccan Trap but overriding of pillar and goaf encroachment has been experienced in Panel 1M after extraction of 5 pillars in a panel of 12 pillars. It is guesstimated that the observed dilution of barrier pillar strength in Panel 1N has happened due to the load transferred by the Trap. Further the same incident continued and caused to leave two rows of barrier pillars between Panel 1M and 1N. Local fall regularly occurred up to a height of 3 m after a goaf exposure varying from 77-87m2 and the goaf is found to be filled partially. Panel 1M started on 18-06-2018 and the working discontinued due to pillar crushing and then panel was sealed on 23-08-2018 (Figure 8). Only local fall was observed during working in this panel. No monitoring is being carried out by any instrument, which makes the study incomplete for understanding of the strata mechanics. Seam IIIB is a low height seam at a parting varying from 2-7m between seam I(B+C) and IIIB. It is being worked in contiguous section. This parting mostly contains coal seam II with alternating bands of shale sandstone. This parting is not stable due to its poor competency, mainly due to poor thickness of laminated formation (shaly sandstone and coal seam II). During the mine visit it is found that the roof (parting between the two seams) of seam IIIB is getting detached even around the intact pillar. The working in Panel 3M (Figure 8) is abandoned due to the encountered problems in Panel 1M of seam I(B+C).

Figure 8(a): Panel 1 M.

Figure 8(b): Panel 3 M.

Figure 8: A Plan View of Workings During Goaf Encroachment and Overriding in Panel 1M of Seam I (B+C) And Subsequently in Panel 3M Of Seam III B.

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Geology of the Area

Table 2: Geological Succession of Coal Seam Formation in Area.

Age	Formation	Lithology	Thickness Range (m)	
1	2	3	4	5
			Minimum	Maximum
Sub-Recent	Soil Residual	Sandy and clayey soils	Nil	3.4
Upper Cretaceous to Eocene	Deccan traps with intertrappeans dolerite dyke	Flows of basalt with beds of clay/claystone of variagated colours	38.23	149.4
Unconformity				
Jurassic	Jabalpurs	Gritty sandstone and clays with red Jasper pebbles	2.9	19.6
Unconformity				
Permians	Moturs	Clay/claystone of brick-red, purple and grey colours with sandstone lenses/bands at places	9.42	50.16
Permians	Barakars	Sandstone with Kaolinised feldspars inter banded with shale and coal seams	20	90
Permians	Talchirs	Fine grained argillaceous sandstone and green shale	5.67	9.3

The geology of the area is based on the geological report on exploration for coal in Thesgora Block 'A' P.K. Valley Coalfield, District Chhindwara Madhya Pradesh prepared by MECL in January 1989. The entire area is covered by basalt, Jabalpur moturs and barakars are concealed under the cover of basalt flows. The area exhibits a rugged terrain comprising many hills and valleys. The maximum and minimum elevation being 791.22 m to 727.61m respectively above MSL. The general geological succession has been proved by sub-surface details as obtained by boreholes drilled from time to time. Based on borehole data, the lithological formations present in the area under consideration have been summarised in Table 2. The exploration in Thesgora Block 'A' has confirmed existence of a total of 11 coal seams/sections viz seam/sections-IA, I(B+C), IIA, II/IIB, IIIB, IVA, VA, VB1, VB2, VB and VC in descending order. The general sequence, thickness of coal seams and parting ranges are given in Table 3.

Table 3: General Sequence of Coal Seam with their Workability.

Section	Variation in Thickness (m)		Variation in Parting (m)		Workability
	Minimum	Maximum	Minimum	Maximum	
IA	0.13	0.66	0.5	1.36	Unworkable
I(B+C)	3.54	7.43	1.01	1.68	Workable
IIA	0.1	0.35	0.19	0.36	Unworkable
II/IIB	1.18	3.69	1.2	3.71	Workable
IIIB	0.76	3.19	3.61	11.79	Workable
IVA	0.19	0.47	1.07	8.65	Unworkable
VA	2.33	7.1	2.78	10.84	Workable
VB1	0.06	0.95	0.18	3.05	Unworkable
VB2/B	0.11	2.6	3.22	11.75	Unworkable
VC	0.19	1.67	-	-	Unworkable

Description of coal seams

Seam I(B+C) is the youngest seam in the area. The depth range of the floor of this seam varies between 60.45-139.91m with thickness varying between 5.17-7.31m (most prevalent range being 6-7 m). Immediate roof contains dominantly shale and immediate floor contains sandstone mostly. Dirt bands varying from 0-0.3m is present in this coal seam. Seam II/IIB underlies seam I(B+C), at a parting range between 0.47-2.47m consisting mostly of sandstone with shale band. The parting of seam II/II B with underlying seam III B varies from 1.20-3.71m.

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The depth of cover varies between 66.04-142.79m with seam thickness ranging between 1.50-3.50m (mostly 1.50-2.50 prevalent). Immediate roof and floor contain shale mostly. This seam is generally devoid of any dirt bands. Seam IIIB underlies seam I (B+C) at a parting ranging between 5-7m consisting mostly of shale with sandstone bands and coal seam-II/IIB. The parting of seam IIIB with overlying seam II/IIB is varying from 1.20-3.71m, which is dominantly consists of shale. Its depth range varies between 67.86-147.4m with seam thickness variation 1.74-2.28m (most prevalent 1.5-2.0m). Immediate roof and floor contain shale and sandstone respectively. No dirt band is present in this coal seam. Seam VA underlies seam IIIB at a parting ranging between 10-20 m generally. The parting in the considered area varies between 13-16m and is mostly consist of sandstone with thin shale bands. This coal seam lies below depth of cover ranging between 83.02-164.81 m with seam thickness varying from 2.37-6.82 m (most prevalent is 4-6 m). Immediate roof and floor of this seam are sandstone and shale respectively. No dirt band is present in this coal seam. From the above Table, it can be seen that out of these 11 coal seams/sections only four I(B+C), II/IIB, IIIB and VA attain workable thickness.

Method of Working

Based on geo-mining and financial considerations, the mine management has decided that all seams would be extracted by Bord and Pillar method, seam I (B+C) and III B would be worked contiguously and seam II is being left out due to low inter-seam parting. Parting between floor of seam VA and IIIB is about 16m and that of between seam IIIB and I(B+C) is about 8 m. This brings out a drift length of 60m up to III B and 90 m up to seam I(B+C). Upper seam I(B+C) is approached by two intakes drifts and two return drifts from the main dips via III B seam. Main dips are driven in seam V A from the surface. The working panels in both the seams are opened from these drifts and dips. Seam I(B+C) and IIIB are being worked contiguously as the parting between these two seams is less than 9m and thus the workings are developed as per Coal Mines Regulation 104 (CMR 1957) by prior permission from DGMS. Pillars in upper seam I(B+C) are coinciding vertically with the pillars of lower seam III B. Size of the pillars and galleries in these panels are developed as per Regulation 99 of CMR 1957. The length of a panel is kept around 600-800m, but the panel is divided into different sub-panels of around 100 m length and 75 m width based on the estimated production and incubation period. Seam III B is around 2.0m (a low height) thickness and is being extracted by B&P method. Seam I(B+C) is having thickness from 5-7m with relatively inferior coal in roof. The method of extraction adopted here in this seam is to split the pillar in two halves by a level split of 4.8m x 3.0m dimension. Dip slice of 3m height and 4.5m width is to be driven leaving a rib of 1.8m against the goaf. Coal in roof is blasted by drilling of holes on retreat with an interval of 1.2-1.5m spacing similar like Blasting Gallery method. Rib is also being reduced judiciously on retreat along with the roof coal.

Rock Mass Rating

As per the available documents with the mine management, the RMR of immediate roof for seam VA is 30.60 belongs to poor roof category and seam II is 31.5 belongs to poor roof category. RMR of immediate roof for seam I(B+C) is 37.26 belongs to poor roof category and seam IIIB is 34.02 belongs to poor roof category. The compressive strength of shaly sandstone present in immediate roof of seam I(B+C) is 12.00 MPa. The compressive strength of moist coarse-grained sandstone present in immediate roof of seam VA is 0.80 MPa. The compressive strength of shaly sandstone present in immediate roof of seam II is 2.70 MPa. The compressive strength of shaly sandstone present in immediate roof of seam II is 7.22 MPa.

Support System

In addition to the basic purpose of the support system, it is supposed to give sufficient free space for the movement of machineries. Accordingly, all development galleries are being supported by roof bolts with or without roof stitching. Few hydraulic props of 10t capacity are provided to cater the urgent need supports at the faces. All the galleries lying within 3 pillars from the pillar under extraction are kept supported by 1.5m long full column grouted roof bolts at spacing of 1.0 m between the bolts in a row and 1.0 m between the rows of bolts and strengthened with W-straps at a matrix 1.0m x 1.0m. The junction is supported by 25 % extra bolting along with four numbers of W-straps. Also, one wooden/steel chock at a suitable location without hindering in movement of LHDs is provided at the junction. To prevent side spalling the sides of 3 pillars from pillar under extraction including split and slices are supported with fixing of bolts of 1.5m length in the side wall at a grid spacing of 0.75m x 2.0m in three horizons all along. Whole pillar is strengthened with rope stitching and kept tightened with wooden laggings from the side. All the split and slice galleries are kept supported by 1.5m long full column grouted roof bolts strengthened with W-strap at a matrix 1.0m x 1.0m. In addition to the above supports, wooden chock or steel chocks topped with at least 30% wooden slippers are set alongside of the rib side at an interval of 2.4 m and one rows of props are provided in between the chocks in each slice. Ledges (V-shaped deformation) formed are supported by three bolts of 1.5m length with W-straps.

Caveability Index

Assessment of caveability of overlying strata is vital for the method of extraction and design of underground structures during pillar extraction. The caving nature of overlying roof strata during depillaring of a coal seam depends on their thickness and the uniaxial compressive strength. Previous experiences of working in underground mines have revealed that a thick, strong and massive stratum caves after a large suspension inside the goaf and develops large mining induced stress transfer distance towards the working. Whereas, a weak/laminated roof stratum caves regularly and smoothly without their much overhang.

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Based on different field studies, the caving characteristics of overlying strata are quantified in terms of Caveability Index (I) [6], which is defined as:

$$I = \frac{\sigma l^{n} T^{0.5}}{5} \quad (1)$$

Where, σ = Uniaxial compressive strength in kg/cm^2, l = Average length of core in cm and T = Thickness of the strong bed in m and the factor n has a value of 1.2 in the case of uniformly massive rocks with a weighted average of RQD of 80% and above. In all other cases n = 1. This value of I is to be calculated for roof thickness equal to 10 times of the height of extraction and the corresponding values are matched with the indices provided in Table 4 to decide the nature of caveability of a stratum. Generally, fresh core samples of the roof strata are procured and subjected to laboratory testing for an assessment of I to understand the caving nature of overlying strata. However, an assessment of I at different depillaring panels of mine is undertaken to judge the caveability of roof on the basis of the data provided by the mine management. Provided values of the physico-mechanical properties of overlying formations indicate that the strata between seam I(B+C) and Deccan Trap is easily caveable. However, Deccan Trap is difficult to cave due to their inherent strength and thickness.

Table 4: Caveability index of different nature of strata for longwall mining method

Roof Category	Caveability Index	Caving Nature
I	I ≤ 2000	Easily caveable roof
II	2000 < I ≤ 5000	Moderately caveable roof
III	5000 < I ≤ 10,000	Roof caveable with difficulty
IV	10,000 < I ≤ 14,000	Caveable with substantial difficulty
V	I > 14,000	Caveable with extreme difficulty

Caveability of massive deccan trap and bulking factor

Based on the above-mentioned formulation, the Caveability of massive Deccan Trap comes to be around 5400, which is under category III (Roof caveable with difficulty). Further, looking at the thickness of the Trap, a considerable section of the overlying strata is found to be caveable with difficulty, which makes the final extraction under the shadow of dynamic loading too. In fact, if sufficient dimension of the void is provided to break the Trap under the condition then there is a strong possibility of dynamic loading, otherwise the pillar extraction in the seam going to constantly encounter excessive loading and an impending threat of global instability. The caveability of roof i.e. parting between seam I(B+C) and Deccan Trap comes to be around 1800 falls under category I (Easily caveable roof). Usually, bulking factor for Indian coal measure formations are taken around 1.1. The average thickness of coal seam extracted during depillaring is 6m including the extraction at the time of retreat in slices. The parting between seam I(B+C) and Deccan Trap varies between 2-60m. Generally, the thickness of parting between the coal seam and the Trap over the present working is estimated to around 10m only. However, as per the bulking factor estimation, the upper limit of the parting thickness is not away from the influence zone. Thus, it can be said that there is an effect of the Deccan Trap during depillaring with caving on the working for the existing parting thickness between seam I(B+C) and Trap. Such a geo-mining condition can be dealt by effective management of the Trap. This can be achieved either through its caving or through adoption of narrow panel extraction with a good design of the natural support. It is important to note here that the indirect increase in height of the pillars (especially pillar at the goaf edge and barrier pillar) during retreat for full height working is also a point to be considered during the design [7].

Effect of Deccan Trap on Mathani Underground Mine

Deccan Trap is a major issue in this mine due to its inherent strength and thickness and remains overhanging inside the goaf after caving of the immediate roof of seam I(B+C). The observed caving does not fill the entire cavity generated due to extraction of the thick seam under the massive Deccan Trap. The overhang of Trap is generating considerable potential energy, which in turn is causing excessive stress over the natural supports like barrier pillars. As the trap is still intact over different voids of the previous depillaring panels, the ongoing system of depillaring at this mine will keep facing the problem of pillar instability. The approach to overcome such situation can be implemented through design of squat barrier pillars for the heightened goaf and induced caving of the overhang Trap inside the goaf through long hole drilling and blasting also called destress blasting. As the coal seams are extensively developed, the scope of design of pillars is limited and the requirement of the squat pillars can be achieved through packing/filling some of the selected galleries by incombustible material like sand. A proper design of manner and dimension of extraction along with an increase in the efficacy of the barrier pillars may prove to be an immediate solution for the mine. Experienced local instability of the parting requires to be dealt with appropriate design of support system as the quality of the inter-burden strata is poor. Around 6m thick coal seam has been extracted (full thickness) in the previous 9 panels of the seams, which has changed the nature of barrier pillars from squat to slender (reduced width to height ratio). In Panel 1N, the parting between seam I(B+C) and Deccan Trap comes to be around 10m, and thickness of Trap is around 90 m. Such a less parting can play major role in creating dangerous condition of overhanging Deccan Trap causing pillars to fail (due to abutment load) and encroachment of goaf. Overriding of pillar and goaf en-

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croachment has been experienced in Panel 1M after extraction of 5 pillars among 12. Further the same incident is repeated with two rows of barrier pillars of Panel 1N. Local fall occurred regularly up to a height of 3 m after a goaf exposure varying from 77-87 m2 and the goaf is found to be filled partially. Panel 1M started on 18-06-2018 and working discontinued due to pillar crushing then panel sealed on 23-08-2018, where the massive overlying Trap has played significant role [8].

Conclusion

Although underground coal mining requires site specific design from very beginning, the encountered geo-technical issues in depillaring at the Mathani underground mine is, mainly, two-fold:

(i) indirect increase in extraction height (heightened goaf) and

(ii) difficulties involved in destressing the mined-out area as the existing Deccan Trap keeps overhanging inside the goaf.

As the coal seams are extensively developed so the design of natural support has slim scope for any major improvement in their efficacy. Deccan Trap is a massive formation whose thickness varies from 40-150 m, lying in the roof of seam I(B+C) in the mine. The parting between seam I(B+C) and Deccan Trap is varying from place to place. In Panel 1N, the parting between seam I(B+C) and Deccan Trap comes to be around 10 m and thickness of Trap is around 90 m. Such a less parting plays major role in creating dangerous condition of overhang, which in turn is causing pillars to fail and encroachment of goaf inside working, Further, it is found that partial extraction (2-3 m of coal seam thickness) to control the height of caving would help in avoiding any movement to be induced in Trap when parting between seam I(B+C) and Deccan Trap is less than 60 m. However, in this situation, the excessive loading of the pillar will exist. The other approach would be destressing of the worked-out area by breaking the Trap for caving. This can be achieved by a suitably designed larger dimension of the void and adopting induced fracturing through long hole drilling and blasting. The blasting can be done from the existing underground openings but requires special equipment and effort to execute it. The attempt of caving/destressing should be practiced in presence of the competent natural supports, especially the barrier pillars. The competency of the existing natural support can be achieved through introducing a favourable tri-axial confinement condition as the discrete side support of pillars may not be effective. Reduction in the height of the final extraction (i.e. depillaring) is also an option to overcome the strata control issues of the depillaring.

Previously, Panel 1M of seam I(B+C) has been abandoned after extraction of 50% coal (from 12 pillars) due to overriding of pillar by goaf encroachment. Parting displacement in roof of seam IIIB can be restricted by proper installation of supports for which goal-post type support and/or W-straps with roof stitching may prove to be a better option. Further understanding about the goaf encroachment could be established through field instrumentation and strata monitoring. When the mine management planned to extract coal from Panel 1N of the same seam, they experienced failure of barrier pillars, which could have been avoided through the presence of a squat barrier pillars. It caused to leave one more row of barrier pillars in Panel 1N. Any induced movement in Deccan Trap may create apprehensive condition in the working leading to loss of men, coal and machinery but it is not confirmed yet whether movement in Deccan Trap has been considerably been initiated or not. It is required to install geo-technical instruments like stress meters, auto warning tell-tale, multi-point extensometers, load cells, instrumented roof bolts in the workings at selected locations to avoid any dangerous situation due to movement of the Deccan Trap. Further, a strata control team to look after the recordings of the installed instrument to give warning about any dangerous and risky condition in the mine would help in strata management. Depillaring with stowing is another option for the site but it will affect productivity along with associated operational and financial implications.

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