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A Global Overview of the Schemes of Extraction of Pillars in Major Coal Producing Countries

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Abstract

Seams amenable to opencast mining is on the verge of exhaustion globally and to meet the future demand of coal, underground mining method is the only viable technique left. In India, also quite a large number of coal seams have been extensively developed and standing on pillars for a long time. Extraction of these standing pillars with reasonable safety has been a challenge to mining engineers for most of reasons. Presently, depillaring in Indian mines is mostly carried out through cyclic unit operations involving drilling, blasting, loading with either a Side Discharge Loader (SDL) or a Load Haul Dumper (LHD), transport and hauling. Fully mechanized depillaring panels are limited in number. Mechanized depillaring using continuous miner and shuttle car is being used in a few mines in India with a view to achieving bulk production and high productivity. Still we are far behind with our Output per Man Shift (OMS), to a tune of 2.01 compared to the global OMS of 12 tonnes per man-shift in depillaring districts. Different strata, along with hostile geo-mining factors, are considered to be this prime case of low productivity. This paper seeks to highlight the existing depillaring practices in India and other major coal-producing countries namely USA, Australia and South Africa. The authors also present a case study on conventional depillaring practice in the Indian context and a few methods being practiced in major coal-producing countries.

Keywords: *Bord and Pillar, Coal Pillar, Depillaring, Underground Mining*

1.0 Introduction

The share of underground production of coal around the globe is about 60% and the rest is from surface mines. The share of underground production of coal in major coal producing countries such as China, USA, India, South Africa and Australia stands at 95%, 33%, 10%, 50% and 20% respectively[1]. India has decades of history to produce coal from underground to cater to the ever increasing demand for energy. The extraction of coal through underground mining methods is considered a part of clean coal technology. About 70% of the total reserve of the coal in India is amenable to underground mining methods[2]. However, the extraction of coal by underground mining methods could not be carried out at its full potential owing to difficult geo-mining conditions and a lack of adequate mechanization, resulting in low production and productivity. Currently, fully mechanized opencast workings in India have proved to be highly productive, with much higher productivity. It has become a cheaper option for producing coal up to a depth of 300 musing draglines. Seams lying at shallow depths are preferred for opencast mining but such seams are going to exhaust in a few years. Thereafter, coal extraction through

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underground methods will play a pivotal role in future in meeting the increasing demand for energy in India[1]. More than 60% of coal resources fall under the category of thick seams of 4.8 m and more[3,4]. Most of the thick seams are developed with an average gallery height of 2.5-3.0 m[5]. Coal recovery from the thick seams can be maximised by increasing the extraction height during coal liquidation keeping in view the availability of suitable machines and geo-mining conditions. Geo-mining conditions do at times make it difficult to handle strata control problems[6] due to incomplete knowledge of geological anomalies[1,7]. In many cases, presence of a hard roof results in difficult caving subsequent to pillar extraction, which may further lead to an air blast problem causing loss of life and property[8]. Many times the seams are developed forming rhombus pillars to facilitate maneuverability of face machinery[9].

In India, the extraction of coal by underground mining[10] is predominantly carried out by indigenously developed methods of board and pillar mining, while others are of foreign origin. One of the foreign methods, for thick seam mining, which showed promising production potential through the extraction of full height in a single lift, is the Blasting Gallery method. This method has been tried in a couple of mines in Indian coalfields. The most challenging task while practicing the Blasting Gallery method is to provide high-capacity support to the roof during depillaring operation. This method is capable of winning the roof coal during depillaring of thick seams[6,11].

Frequent strata control problems are encountered in conventional depillaring method, which results in low productivity. A fully mechanized depillaring scheme with a continuous miner and shuttle car combination has been adopted recently in some of the Indian mines to increase productivity with improved safety. One of the success stories relates to the Anjan Hill mine of South Eastern Coalfield Limited (SECL) in Chhattisgarh, India[12], where mechanized depillaring with a Continuous Miner (CM) and shuttle car combination[13] along with roof bolting technology for mass production, was adopted, which conveyed a positive message across the country to counter the productivity problems that conventional depillaring faces. Only roof bolts were used to support all working areas, along with breaker line support at the goaf edges. This scheme was implemented in collaboration with Joy Mining Machinery and Rock Mechanics Technology, UK[14]. A second successful trial of the Continuous Miner technology was carried out in the Tandsi mine of Western Coalfields Limited (WCL) in Madhya Pradesh, India. This mine had difficult roof conditions as well as problems with high horizontal stress[15–17] calling for the use of high-density, resin-grouted, stiff, and pre-tensioned roof bolts as roof supports[18–20]. The above combination of mechanization and support system proved to be helpful for the Tandsi mine of WCL. After these two successful cases, several mines in India adopted this technology fully, but with mixed results. Presently, conventional methods of depillaring with blasting and loading of face coal with SDLs continue to be widely used, but efforts are also being made to deploy machines for face cutting. Schemes of pillar extraction as practiced in India.

The underground coal mining in India is highly regulated. Regulation number 111 of the Coal Mines Regulations (CMR) 2017 states that the dimensions of pillars and galleries and the shape of pillars formed in any seam or section shall be such as to ensure stability during the formation and extraction of pillars, and during the period between such formation and extraction. It further stipulates the maximum width and height of development galleries and prescribes the minimum size of pillars for combinations of gallery width and seam depth. Further regulation 112 states that the extraction and reduction of pillars shall be conducted in such a way as to prevent collapse or subsidence of the goaf over pillars which have not been extracted.

Pillar extraction methods can be broadly divided into two categories namely: (1) full extraction with caving and (2) full extraction with stowing.

1.1 Pillar Extraction with Caving

When the full height of coal is extracted and supports from the working area are withdrawn, the resulting void is known as goaf. When the goaf becomes large, the overlaying strata fall. This method of extraction is usually referred to as depillaring with caving. Some overlying strata are weak and cave in easily, thereby reducing the load on the adjacent outbye pillars. However, when the immediate overlying roof is strong and remains hanging in the goaf, it gives rise to a significantly high abutment load on the adjacent standing outbye pillars which is a potentially dangerous situation. Under such circumstances, the sudden collapse of a large area in the goaf results in an air blast[21] causing damage to people, material and property. Strong and massive roof is tackled by induced blasting[22] before it hangs and creates a potentially hazards situation.

During depillaring, the dip-most side of pillars in a panel is split by driving split galleries, and slices are taken along the dip following a diagonal line of extraction. The working area is fully supported, and the half pillars formed during pillar splitting are extracted slice by slice judiciously leaving sufficient thickness of rib pillar to act as temporary support. Splitting of two pillars ahead is permitted in accordance with Regulation 112(5) of CMR-2017 and pillar extraction greater than 4 m in height is usually not permitted by the regulatory authorities due to difficulties in support installation unless remote-controlled equipment is used. After extracting slices in vicinity of the goaf edge, the supports other than roof bolting are removed and re-installed at new sites to enable further extraction in other pillars. During depillaring a certain line of extraction is followed depending upon the geological conditions of overlying strata and the transportation schemes deployed underground. This method of pillar extraction is also referred to as the 'slice and rib' method (shown in Figure 1) of pillar extraction[23]. This split gallery is supported only by roof bolts or by a combination of roof bolts and props, leaving sufficient space for face-loading machines like SDLs and LHDs to move. Junctions formed by driving splits and slices are supported by cogs, roof bolting or W-strap. Because the abutment load is greatest at the goaf edge, it is usually supported by cogs placed skin to skin. Breaker line support is set closely near the goaf and rows of props

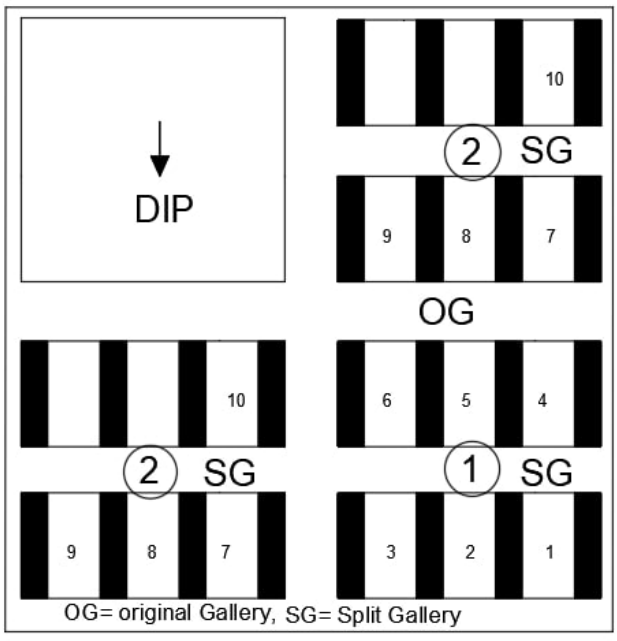

Figure 1. Conventional slice and rib method.

are installed at an interval of 0.3 m or less. Breaker line support is supposed to facilitate caving of roof in goaf and arrest the fall of roof into the working areas[24]. Slice and rib method demands heavy supports in adjoining areas including junctions and goaf edge[19,25]. Shifting of goaf edge supports requires more time, and the next slice cannot be started until a heavily supported goaf edge is prepared.

To solve the aforementioned problems, it is suggested that the goaf edge should be supported with hydraulic or hydro-mechanical supports of high capacity but less in number, which can be shifted swiftly as a whole and not piece by piece. Except for the goaf edge, other support systems should consist only of roof bolts; no cog support should be used anywhere except at junctions having weak roof rock.

1.2 Pillar Extraction with Stowing

In many mines in India as well as in other countries, depillaring is associated with hydraulic sand stowing. Stowing is adopted to keep the overlying strata and surface features intact. Stowing helps to achieve better results in terms of productivity and safety.

This method is adopted only when alternative methods do not meet the safety requirement as far as strata control is concerned. Conventional slice and rib with sand stowing is the most common method in India to meet the required production with a high level of safety. In this method, after the slice is driven to its full length, the support system is withdrawn and the sand are filled after judiciously thinning the ribs[24]. This judicious extraction of ribs is also known as 'robbing of ribs'.

India is now moving toward mechanized depillaring operations with a combination of continuous miners and shuttle cars. It ensures a faster rate of production with desirable standards of safety. The Christmas tree (Figure 2) and Pocket-and-Fender methods (Figure 4) are being followed in Indian mines. Some of the mines adopting this mechanized depillaring scheme, as listed below in Table 1, have successfully concluded the mining operation.

2.0 Coal Extraction Practices in China

China is the world's largest coal producer, accounting for 3.23 billion metric tonnes of coal in 2016[26,27]. The country has a total proven coal reserve of 997 billion metric

Table 1. Details of some of mechanized and semi-mechanized depillaring mines in India

Company	Name of mine	Depth of cover, m	Pillar size, c to c, m	Bord width, m	Average working height	Method of extraction
SCCL	GDK 11	325	48 × 46	6.0	4.6-6.0	Pocket and fender
	VK 7	377	40 × 40	5.0	4.6	Pocket and fender
	Anjan Hill	85	28.2 × 28.2	6.6	4.5	Pocket and fender
SECL	Pinoura mine	60	18.5 × 9.5	6.5	3.0	Fish Tail
	Churcha mine	375	50 × 50	6.6	3.5	Split and fender
	Jhanjra 1 and 2 Incline	64.3	22.5 × 22.5	4.2	2.78	Slice and rib with caving
ECL	Jhanjra CM Panel	125	26 × 26	6.0	4.2	Pocket and fender
	Khottadih colliery	90	30 × 30	4.9	2.87	Slice and rib with caving
	Central Kajora	140	22.5 × 22.5	4.8	2.8	Slice and rib with caving
BCCL	Maheshpur Colliery Sinidih section	59	14 × 14 to 28 × 23	4.2	2.46-3.51	Slice and rib with caving
TATA STEEL	Digwadih Colliery	339	45 × 45	4.2	2.4	Slice and rib with stowing
	Jamadoba Colliery	538	50 × 50	4.8	2.4	Slice and rib with stowing

tonnes, mostly located in the west and north-eastern parts of China. The majority of coal reserves are deep-seated at an average depth of 400 m[28] and they are only amenable to underground mining[29,30].

In 2008, the share of underground production in China accounted for 85.9% of the total production, the opencast share was only 6% and the rest was from other types of mining. For underground production, longwall and its derivatives are very popular in China. In general, they are classified into three major categories based on seam thickness. Seam thickness varying from 0.4 m to 1.3 m, utilize shearers as cutting machines, armored face conveyors and chock shields for production. Seams of medium thickness ranging from 1.4 m to 3.5 m and a low gradient are considered suitable for the mechanized longwall method. Lastly, in seams of thickness greater than 5 m with a mild gradient, the multi-slicing long wall method is deployed in Chinese mine.

In addition to the popular longwall method, the room and pillar method of working is also practiced in some of the Chinese mines such as Dongsheng, Yanzhou, Da Liuzuang in Shanxi and Nantun in Huangling[31].

3.0 Methods of Pillar Extraction in the United States of America

Room and pillar mining, a modified version of bord and pillar is a predominent method of mining practiced in the United States. In this method, the developed pillars are recovered by mechanized operation using continuous miners and shuttle cars. As compared to Indian coalfields, the strata problems in the coalfields of the USA are minimal, which is due to strong overlying strata. In the USA, the galleries are wider, up to 6.0 m, as compared to 4.5 m in India. For pillar extraction, the following methods are used: (a) Christmas tree (b) Outside lift (c) Split and Fender and (d) Pocket and fender method[32]. Christmas tree method of extraction is the most widely used method because of its inherent capacity to deliver a high level of safety and productivity[33].

3.1 Christmas Tree (Left-Right) Method

The Christmas tree method, also known as "twinning" is generally adopted under shallow depths of cover for pillar sizes ranging from 18 m to 24 m center to center[33]

and the dimension of the pillars in such cases suits the operational limits of continuous mining[26]. Liquidation of such small pillars does not require splitting, and the coal is won by continuous mining with a combination of shuttle cars by driving cuts or slices on both sides of the entry. This ensures a high extraction ratio. In addition, there is no need to leave small ribs to support the overlying strata between the slices; however, a small thickness of snook is essentially required to minimize the strata problems arising in the immediate outby of the intersection[34]. The Christmas tree method is characterized by a fast rate of extraction. This method is mostly practiced for pillar recovery in the Kentucky coal basin of the USA. Figure 2 shows the common operational sequence of pillar recovery using Mobile Roof Supports (MRS).

Prior to recovery of lift 1, MRS units1 and 2 are installed at entry 1 and MRS units 3 and 4 are installed at crosscut of entry 1 for providing active support. MRS units 1 and 2 restrict the effects of goaf pressure. The mobile roof supports are re-installed at the nearest working zone to provide immediate support to the mining area as each slice is extracted. Firstly, slice 1A and 2A are extracted, and MRS are taken out at a new position. This process continues until the extraction of coal from all slice numbered 1 to 8 in lift 1 is completed. After the completion of lift 1, MRS units (1 and 2) and MRS units (3 and 4) are installed at lift 2 and another cycle of coal extraction starts from the next slice and continues until the last lift[29].

3.2 Outside Lift Method

The outside lift method of depillaring is generally applicable for mines with weak overlying strata. Many variations in the layout are possible depending upon strata conditions, pillar dimensions, working depth, etc. This method was initially developed for the application of MRS. The outside lift method has been designed in such a way that the cuts are taken from only one side of the stook of the pillar without compromising safety. The sequence of cuts starts near the goaf and moves toward the solid pillar by taking consecutive cuts (1, 2, 3, 4 and 5, shown in Figure 3) on one side of the stook, by leaving a snook of about 2.5 m width for providing support to the overlying strata. This method has many advantages. It provides better protection to the continuous miner operators because personnel are always adjacent to the solid coal pillars.

3.3 Pocket and Fender Method

The pocket and fender method is the most preferred method of pillar extraction in the US, India, Australia and South Africa. The depillaring is carried out in a retreating manner. It means the pillar near the goaf will be extracted first, retreating toward the solid coal pillar. Thereby, a wide roadway is driven at the center of the pillar in a direction perpendicular to the strike of the deposit, splitting the pillar into two halves, and the split gallery is supported by roof bolts. The first lift1 is made in the dip direction, and a continuous miner moves outby of the pillar. The width of the cut is decided based on the pillar size and strata conditions. While lift1 is being supported, the continuous miner keeps cutting lift 2. Other lifts or cuts follow the same sequence (Figure 4). In case of hard roof conditions the roof remains hanging in the goaf as a cantilever. This is a potentially dangerous situation for the operator and the cable handler of CM. Though the method is characterized by high production potential and improved recovery, the major limitation lies in the longer time taken for shifting of the CM and quadbolter from one cut to another.

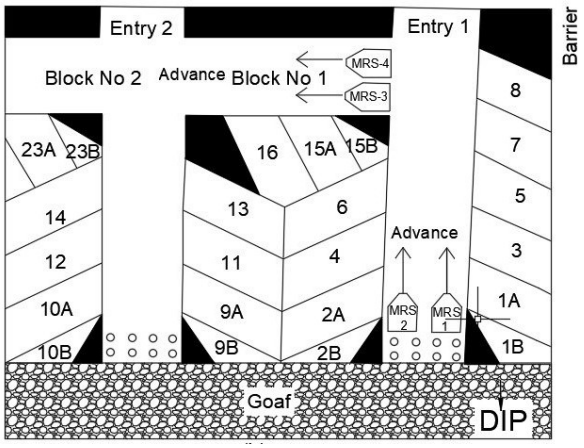

Figure 2. Extraction sequence in Christmas tree method.

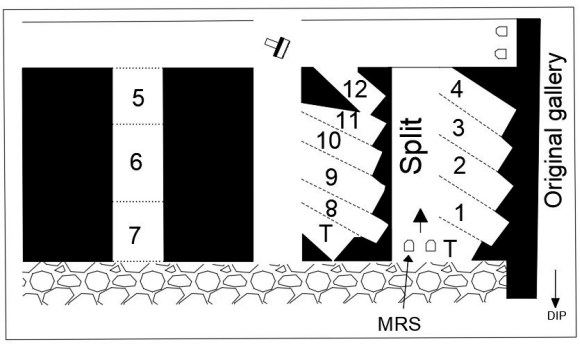

Figure 3. Cutting sequence of outside lift method.

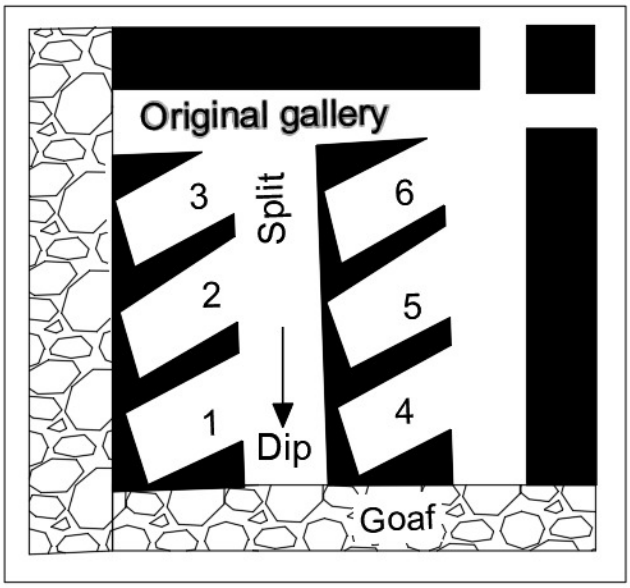

Figure 4. Cutting sequence of pocket and fender method.

3.4 Split and Fender Method

The split and fender method is a commonly used pillar extraction method in the US and in India. This method is more suitable where small pillars are to be extracted and the mine encounters strata problems. The Split and Fender method can also be used to extract a large pillar with multiple splits in the pillar. The process of extraction of the pillar is almost similar to the Pocket and fender method, which is described in the above section (3.3). The only difference is that a small thickness of rib is left out on the outby of the pillar to support the overlying strata. The cutting sequence of Split and Fender method is shown in Figure 5.

4.0 Pillar Extraction Practices in Australia and South Africa

The manner of depillaring practices in Australia ranges from conventional Bord and Pillar depillaring method to the recent pillar striping technique such as Christmas tree and outside lift as followed in US[35].

South Africa has rich experience in coal extraction by a conventional methods. The country has now adopted continuous miner technology to meet the desired production. Some of the mechanized depillaring techniques followed in South Africa are (a) Open end (b) Usutu method (c) Rib pillar and (d) NEVID method[35].

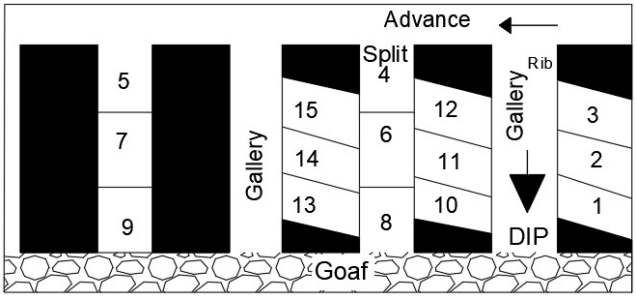

Figure 5. Cutting sequence of Split and Fender method.

Amongst the said methods most popular one is the rib and pillar and the NEVID techniques.

4.1 NEVID Method

The NEVID method was first introduced in the Highveld coalfield in the Mpumalanga province of South Africa. The reserve of the mine lies between 170 m to 220 m below the surface and is overlain by a laminated competent sandstone, above which there exists a massive dolerite sill. The massie dolerite sill hangs and finally breaks violently after a critical span is achieved resulting in casualties and buriad of CM. The mine has a sad history of burial of CMs due to violent failures. For every three panels mined out, on an average, one CM was buried in the goaf in South Africa. In 1996 twelve CM were buried in that mine and its neighboring collieries[36]. Such incidents motivated the mining community in South Africa to adopt the NEVID method of extraction. The cutting sequence of the same is shown in Figure 6. This method has been successful as the length of the cut in the pillar made by CM is significantly reduced as compared to other methods. In addition, the thick ribs left in the goaf yield slowly with the increase in load, thereby eliminating violent roof failure.

5.0 Case Study of a Depillaring Scheme Followed in India

India has a rich history of extraction of underground coal by bord and pillar technique. Amongst all the techniques deployed in India for underground extraction of coal, bord and pillar have a share of 84.4%[1]. One of reason for the popularity of the bord and pillar method of mining is probably due to the faster rate of return on capital as compared to other mining methods. The other reason is the complicated geology of the Indian coalfields dominated by a large number of faults making it less

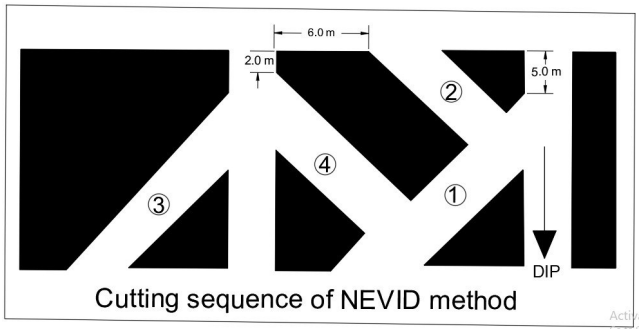

Figure 6. Cutting sequence of NEVID method.

suitable for the adoption of mass production technology. A few coal mines of Coal India Limited (CIL) and SCCL have been practicing the aforementioned methods, such as rib and slice, Christmas tree, pocket and fender, and, split and fender, to extract coal from underground. Prominent mines of ECL namely, Khottadih, Madhusudanpur, Central Kajora, Mahespur, Madhwpur, Jhanjara colliery have adopted the slice and rib method. A case from Jhanjra colliery is discussed in next the section.

5.1 Incline 1 and 2 Mine of Jhanjra Project

Jhanjra Project has three units namely, Incline 1 and 2, Continuous Mining (CM) working and Longwall workings. Working Incline 1 and 2 units constitute in major part of the R-VIIA seam (Figure 7). Coal is extracted from this unit using the conventional bord and pillar method by deploying LHD for loading of broken coal. Presently panels AE-S13 to AE-S17 are being depillared in the Incline 1 and 2 mines (Figure 8). The CM workings lie on the south-western part of the leasehold being worked in the R-VIIA seam using the combination of a continuous miner and shuttle cars.

The longwall unit of the project is situated in R-VII Top seam which is among a few large longwall mines in the country. The project lies in the Ranijanj coalfield in the State of West Bengal which is one of the important coalfields in India. Block-I in this coalfield is located in the Burdwan district of West Bengal state extending from latitudes 23°40' to 23°41' and longitude 87° 17' to 87° 20'. This coalfield is the first in the country to adopt scientific mining started by M/s J. Sumner and S. G. Heatly of East India Company in 1775.

A schematic diagram of depillaring scheme is shown in Figure 8. Each half of the pillar so formed is extracted by driving a dip slice not exceeding 4.5 m in width and maintaining a rib of coal not less than 2.25 m in thickness

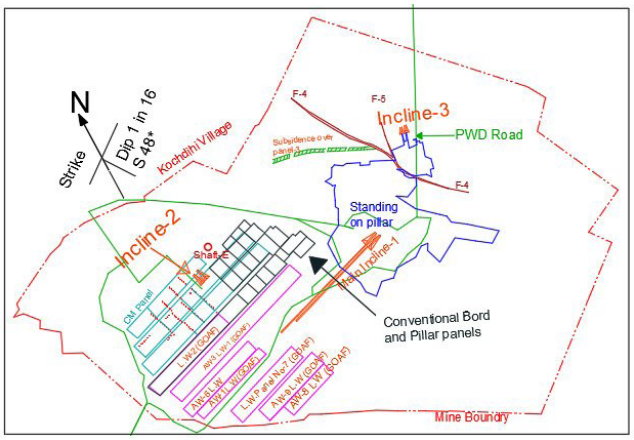

Figure 7. Key plan of Seam VIIA of Jhanjra project showing only main features.

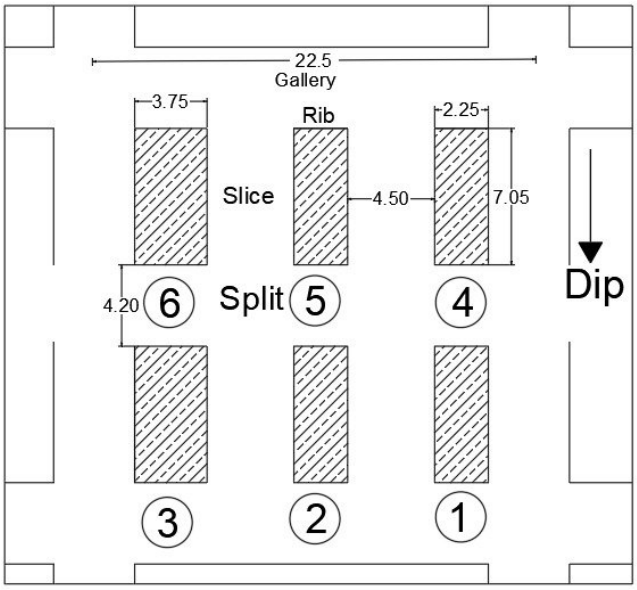

Figure 8. Schematic diagram showing the depillaring scheme with dimension (in m) at 1 and 2 Incline, Jhanjara Project colliery (ECL).

against the adjoining goaf. The rib of the coal is reduced judiciously while retreating from the slice.

Keeping in view the restriction imposed by the Regulation under CMR-2017, the splitting of the pillar is restricted up to two pillars ahead of the pillar under actual extraction and the line of splitting should not be parallel to any fault plane or dykes.

6.0 Conclusion

A wide variety of pillar extraction techniques are being followed in different parts of the globe. The choice of

such a method is largely dictated by the concerns for high production and productivity with safety. The rib and slice method is still popular in India because of its simple layout requiring not much of technical skill and acumen, though the extraction ratio is low as compared to other mechanized methods. Pillar extraction techniques such as Christmas tree is characterized by a higher production, better safety, ensures high extraction ratio. They are highly popular in the USA and Australia. The pocket and fender method is the most preferred method of pillar extraction in the USA, India, Australia and South Africa. The depillaring is carried out by this method in a retreating manner. South Africa has a rich experience of coal extraction by conventional methods, but the country has now adopted the continuous miner technique to meet the targeted production and productivity levels with a high standard of safety.

7.0 Acknowledgement

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