AN OVERVIEW OF BORD AND PILLAR MINING METHOD

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Abstract: The significance of mining to human civilization is undeniable. Mining, being one of the earliest human endeavors, and its evolution are inextricably linked to cultural advancement. Mining is the cradle of all other businesses. Different strategies have been approached for mining effectiveness while keeping output and safety in mind. The Bord and Pillar method of mining is one among them. One of the earliest methods of mining is the Bord and Pillar method. The most important aspect of successful Bord and Pillar mining is choosing the right pillar size. The mine will collapse if the pillars are too small. If the pillars are excessively huge, significant amounts of precious material will be lost. Now-a-days, difficulties connected to pillar stability and effective extraction from it is a serious concern. The safety factor is the most critical criterion to consider while building a pillar. The major goal of this present work is to raise the extraction ratio of Bord and Pillar workings while maintaining a high level of safety.

Index Terms **- Civilization, pillars, safety factor, Bord and Pillar.**

I. INTRODUCTION

Mining is that the process of extracting natural resource from the earth, usually from an ore body, vein, or seam (of coal). During a broader sense, mining refers to the extraction of any non-renewable resource (e.g., petroleum, fossil fuel, or perhaps water). Prospecting for ore bodies, analysing the economic potential of a last reclamation, restoration, rehabilitation of the land to organize it for other purposes once the mine is closed are all a part of modern mining processes. The growing needs are pushing the boundaries, to which the mining industry must reach to lift itself to fulfil the demand. The effect may be seen from the methods of mining that have evolved over the years. One among the oldest methods of mining is that the Bord and Pillar. It's a way within which the mined material is extracted across a horizontal plane while leaving "pillars" of untouched material to support the overburden leaving open areas or "rooms" underground. It's usually used for relatively flat-lying deposits, like those who follow a specific stratum.

The key element in Bord and Pillar mining is selecting the optimum pillar size. If the pillars are too small the mine will collapse. If the pillars are large then significant quantities of valuable material are going to be left behind reducing the profitability of the mine.

OBJECTIVES

The main objective of this present work is to review the overall Bord & Pillar working used in coal mines.

3. METHODOLOGY

Steps involved in Bord and Pillar Mining System

Develop the entire area into pillars and then extract the pillars starting from the boundary.
Develop the area into panels and extract pillars subsequently panel wise. This is called panel system of mining.
"Whole" followed by "broken" working in which the mine is opened out by a few headings only and thereafter development and depillaring go on simultaneously.

3.1 Development:

In case of Bord and Pillar, two sets of galleries, one normally perpendicular to the other, are driven forming pillars between them of size that currently depends on depth and size (width(B)) of the gallery. The Centre-to-Centre distance is denoted by 'C' and width of the pillar is denoted by 'W' in the following figure width of the pillar is denoted by 'W' in the following figure.

Panel: A group of such pillars form what is known as a 'panel' and one panel is separated from another panel by having solid coal barrier in between in the form of long rectangular pillars. Connections between one panel and another should be as few as possible.

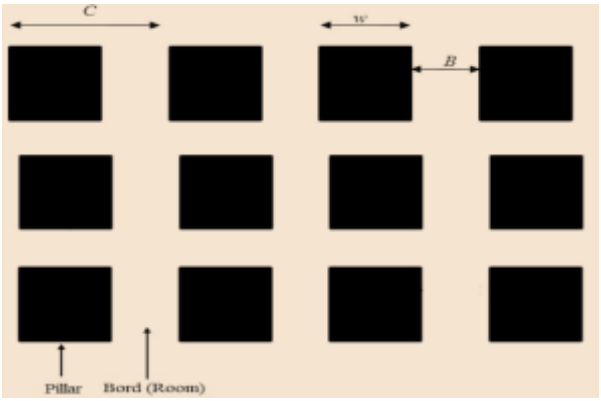

Fig.1: Extraction of Pillars.

3.2 Design of Bord and Pillar Workings

The main elements of Bord and Pillar workings are:

- **Size of the Panel**

The main consideration in deciding the size of the panel is the incubation period of the coal seam. The size is so fixed that the entire panel can be extracted within the incubation period without the occurrence of spontaneous fire. The period in Indian coalfields generally varies between 6 to 12 months.

- **Size of the Barrier**

The width of the barrier depends on the load which it has to carry and its strength. Greater the depth of working, wider is the barrier and also softer the coal, the more, the width of the barrier.

- **Size of Pillars**

The size of the pillars is influenced by the following:

- Depth from the surface and percentage extraction.
- Strength of the coal
- The nature of the roof and floor
- Geological Considerations
- Time dependent strain

Table-1: Pillar and gallery dimensions **(CMR 2017)**

Depth of the seam from the surface	Where the width of galleries does not exceed			
	3m	3.6m	4.2m	4.8m
	The distance between centers of adjacent pillars shall not be less than (in m)			
Not exceeding 60 m	12	15	18	19.5
Between 60-90 m	13.5	16.5	19.5	21
Between 90-150 m	16.5	19.5	22.5	25.5
Between 150-240 m	22.5	25.5	30.5	34.5
Between 240-360 m	28.5	34	39.5	45
Exceeding 360 m	39	42	45	45

3.3 Principles of Pillar extraction techniques

The principles of the designing pillar extraction techniques are:

1. Roof exposure at just one occasion should be minimal. within the Indian coalfields, where caving is practiced, 60-90 m^2 exposure is often allowed. But in stowing districts the exposure could also be increases up to 90-100sq.mts.
2. The dimension of the pillar should be like depillaring is completed within the incubation period. This period commonly varies between 6-12 months.

3. The extraction line should be so arranged on facilitate roof control. In practice of diagonal line, or step diagonal line of face is common.
4. The one lift extraction is proscribed to height of 4.8 m or less. If the thickness of the seam is quite 4.8 m, the extraction is finished in multi-lifts.
5. Regardless of the method of extraction, the working area is systematically supported by the cogs and props.
6.

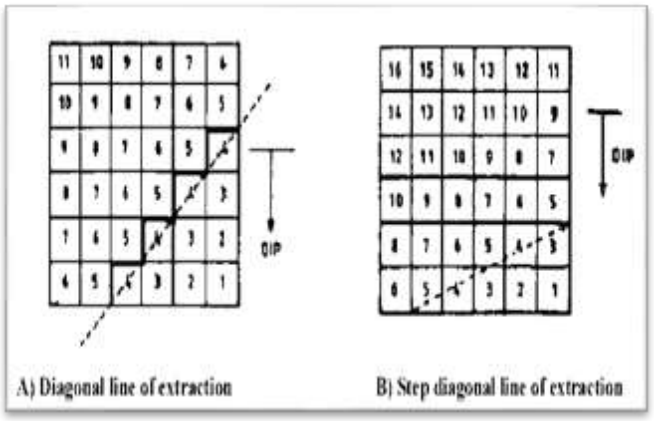

Fig. 2: Extraction of Pillars sequence. **(RD Singh)**

3.4 Depillaring by caving:

In a method of depillaring, stated because the caving method, the coal of the pillars is extracted and also the roof is allowed to interrupt and collapse into the voids or the de-coaled area, called goaf. because the roof strata about the bed break, the underside surface develops cracks and subsides, the extent of harm depending upon depth, thickness of the seam extracted, the character of strata, thickness of the subsoil and effect of drag by faults.

The pillars formed during development are split into small pillars called "stooks" which are then extracted one by one. A gallery driven within the pillar for this purpose is termed a "split". one split within the Centre of the pillar along the strike and another split of comparable width within the Centre of the pillar along the dip, are driven so as that the pillar is split into 4 stooks. The splitting may start from 4 middle points of the pillar simultaneously. In Fig.3, the circles indicate the pillars which is in a position to be attached at a time. The plain numbers (un-circled) indicate the stooks which might be extracted simultaneously to require care of a diagonal line of extraction.

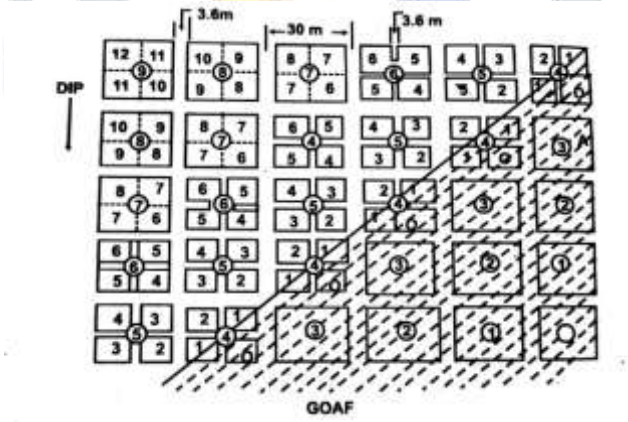

Fig. 3: Pillar extraction with diagonal line of face.

At one time, 3 to 4 such stooks are under extraction and the other miners are employed on splitting and gallery heightening jobs. During extraction of coal a rib about 1 meter thick is left against the goaf.

3.5 Depillaring with stowing:

When mineral is extracted from a coal mine the goaf is packed with sand or other incombustible material wherever it is conveniently and cheaply available in sufficient quantities. The process is known as "goaf stowing". The material used for stowing may be stone or shale obtained from bands of stone or shale if they are present in the coal seam under extraction. They may be used for erecting pack wall or for stowing in the goaf, in the crushed form. Other material used for stowing are sand, earth, boiler ash, crushed material available from quarry overburden, shale pickings at the screening plant, washery refuse, mill railings, or slag from blast furnace for iron ore smelting. The material should be free from carbonaceous matter.

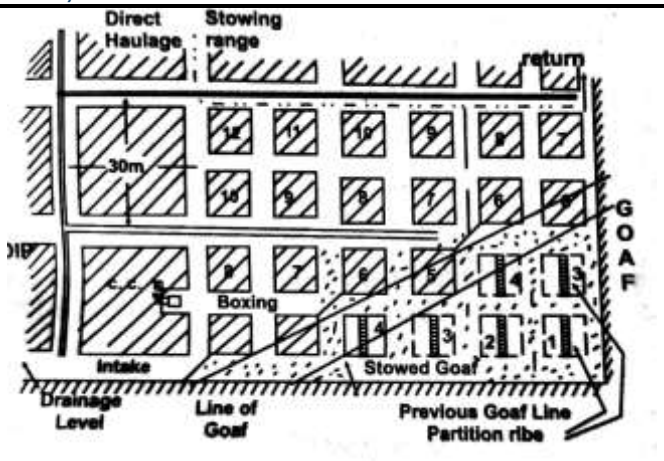

Fig. 4: Depillaring with hydraulic stowing. (**DJ Deshmukh**, **vol.1**)

Hydraulic Profile and H: L Ratio: It is essential that the pipe layout in a hydraulic stowing installation should conform to a correct hydraulic profile. Incorrect profile will cause cavitation and then the full available head cannot be pressured to use. The ratio H/L. (height/length) indicates stowing range efficiency. Generally, this ratio is 1/7 for reasonably good slowing rate**.**

3.6 Face Machinery:

Side Discharge Loader (SDL):

Fig.5: Side discharge loader

It is a coal loading machine of UG mines which can unload coal to the right or left of machine. SDL carries the coal that is blasted with the help of bucket mounted at the front of machine, transports and dumps it on the onto chain conveyor, belt conveyor, tub or mine car. As it is a crawler mounted, SDL can be used in gradients upto 1 in 4. Height of machine over canopy is 2.1 m. Special models for working seams as thin as 1.3 m are also available. The machine is powered by 550 V electric motor and all movements of bucket are done hydraulically for which hydraulic pack is mounted on machine itself. Some SDL's have cable reel for trailing cable. Most SDLS are used without cable reel.

Load Haul Dumper (LHD):

LHD is a tyre mounted loading machine which takes blasted coal from the face in its bucket, transports it over a distance and dumps it on the district chain or belt conveyor. Being tyre mounted, it can move faster than SDL. LHD can work in gradient upto 1 in 7. LHD is made in two parts which are joined by a flexible joint and can turn upto 100°, enabling it to take turn at a narrow gallery junction also.

Fig.6: Load haul dumper

3.7 Supporting System in Bord and Pillar Mining Method:

Roof Bolt: Bolts support the roof in 3 ways

(i) The immediate layers of roof are held by suspension from a stronger bed above. (Suspension effect)
(ii) Bolts clamp several thin layers of roof rocks into a thick beam, which is stronger than the individual layers. If beam is 5 times thicker, strength increases by 32 or 25 times. (Beam effect)
(iii) Sometimes in fractured or jointed blocks in the roof, a piece of stone is so located that if it is withdrawn, other stones will fall. Bolt prevents such key stone from falling. (Key stone effect).

Fig.7: Roof bolting

Cog, Chock or Chock mate: Cogs are used for supporting at goaf edges, at junctions of splits and galleries, in depillaring areas. Only rectangular sleepers, or sleepers having their two opposite sides chopped flat, should be used. The length of the sleepers of cog should be a minimum of 1.2 m to support roof at a height of upto 3m and for roof height of more than 3m is may be 1.5m. The sleepers should have a minimum cross section of 100mm×100mm.

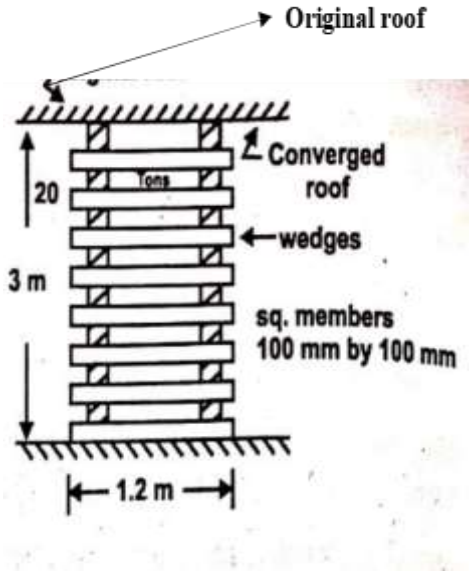

Fig. 8: Cog supports (**DJ Deshmukh, vol.1**)

Prop: A timber prop when erected in a mine to support the roof. The timber prop is strongest when the load act parallel to its length.

Fig.9: Wooden prop

3.8 VENTILATION

Standard of Ventilation:

1**.** Quantity: Air passing along the last ventilation connection, in every ventilating district, shall be not less than 6m³/min/person employed in the district in the largest 2.5m³/min/tonne of daily production shift, or whichever is more.

a. **Quality:** At every place where persons are required to work or pass, air shall contain O_2, not less than 19% CO_2 not more than 0.5% no noxious gas likely to affect health of persons. METHANE shall be not more than 0.75% in the return of ventilating district and not more than 1.25% at any place in the mine.
b. **Temperature:** At any working place not to exceed 33.5°C (wet bulb). If it exceeds 30.5°C (wet bulb), velocity of air shall be not less than 1m/sec.

2. To ensure compliance with the above standards, air samples and temperature readings shall be taken atleast once in 30 days and the results recorded.

3. Respirable air borne dust at any working place shall not exceed 3mg/m³ air.

4. Air velocity shall not be less than that prescribed in Reg. 136A.

DEVICES USED FOR MEASURING OF AIR

Anemometer:

Anemometer instrument is which determines the distance travelled by air in a given time, and is used to find out velocity of air in a mine road way. Velocity multiplied by area of cross section of roadway gives the quantity of air flowing.

Hygrometer:

Hygrometer is an instrument for measuring relative humidity of air. on a wooden frame and fitted with a loose handle so that it can be whirled (rotated 360^0) in the atmosphere to be tested.

4. CASE STUDY

4.1 LOCATION & COMMUNICATION:

SCCL has four coalfields Bellampalli in Adilabad, Ramagundam in Karimnagar, Bhoopalpalli in Warangal and Kothagudem in Khammam Districts. Padmavathi Khani No.5 Incline is existing Bhadradri Kothagudem District. Padmavathikhani-No.5 Incline is located approximately between North Latitude 17^O 29'13" to 17^O 30'35" and East longitude 80^O 39'28"to 80^O 41'00" and is covered under survey of India Topo sheet No.65-C/11. It falls in Bhadradri Kothagudem district of Telangana state.

This Mine is situated about 8Kms. of Bhadrachalam Road Railway Station of south-central railway. By road it is about 90Kms.from the district headquarters and 295Kms. from Hyderabad, the state capital. On the rise side of this mine abandoned mine 5A is existing adjacent to the North side boundary of PVK-No. 5 Incline and South side VK-7 Incline is existing. On the dip side about 240 mtrs vertical partition to King seam No.1 Seam workings of 5B Incline is existing. The vertical parting from Top Seam to No.1 Seam is 190mtrs, which is above the Top Seam. On the West side of Mine Boundary 3 & 4 Incline workings are existing which are likely filled with water.

4.2 DETAILS OF THE MINE

Mine started in: 1952
Mine Area: 9.25Sq.Km.

4.3 MINE WORKINGS:

The mine was opened on 19.03.1952. As the mine progressed to a distance of 3.20 Kms from the incline, 6.09 mtrs dia and 212 mtrs, vertical shaft was sunk in the year 1972-73 for man winding.

4.4 METHOD OF WORKING:

Top Seam:

Initially top seam development was done by conventional method before the shaft was sunk. With the introduction of man winding shaft up to King Seam, two entries were made namely North Tunnel Rise and South Tunnel Rise from King seam to Top seam and there from the development was made in both Rise and dip directions. Subsequently, when there was a demand for poor grade of coal, Padmavathi khani project was initiated with a view to increase the production and to liquidate the top seam at a faster rate by introducing Longwall technology in the year 1995.

King seam:

King seam is of high quality of coal has been extensively developed in two sections up to 64L along floor and roof with a parting of 4.00m in the middle by Bord and Pillar technology. Majority of the panels above shaft level have been extracted in both sections; Bottom section by stowing and top section by caving, where there is only one section, the seam extracted by caving only.

Bottom seam:

Bottom Seam, which is of high quality of coal, has been developed up to 43L. Further development was stopped due to thinning of seam. A few panels have been extracted by Bord and Pillar technology with hydraulic sand stowing and some panels were extracted by caving.

4.5 MINE VENTILATION:

As the mine is very extensive and has long air circuits. The water gauge of two fans is more because of collapses in the return air ways. In the month of Oct- 2005 Prof. D C. Panigrahi has made ventilation pressure quantity survey and computer simulation is taken up. As per the recommendations, it is proposed complete the major ventilation reorganization works in two phases.

In the Phase - I,

1. Closing of total bottom seam and King Seam above 59L by closing 4 Inclines and one Air shaft of Incline Section.
2. Shifting of winder from the existing 5 shaft to the new shaft.

3. Converting the existing 5 shaft as up cast shaft.

In the Phase - II

1. Total closing of top Seam by closing entire seam tunnels between top and king seam and 2 Inclines and one air shaft.
2. Drivage of new tunnel from surface to king seam. After completion of Phase - II operations there will be only three entries i.e., two Shafts and one incline.

4.6 PRESENT MINE DEVELOPMENT:

At present the mining activity is only in king seam where LHD's 912 model (5 No's) are working in one district i.e., N-58 by hydraulic Sand Stowing the required permission was already obtained. The present workings of King Seam are below the No.1 Seam workings of 5B Incline. To dewater the goaf water of No.1 Seam workings, two boreholes were drilled and submersible pumps of 350 HP, 1000 GPM are lowered

5. CALCULATIONS

Percentage of Extraction: Percentage of extraction is the ratio of volume coal extraction during development to total in-situ volume of coal

$$R=(((a_1 + b_1) * (a_2 + b_2)) – (a_1 *a_2))/((a_1+b_1) *(a_2+b_2))$$

Where, a_1 & a_2 are length and breadth of the pillar, b_1 & b_2 are the size of galleries in dip and rise direction

For a square pillar and same gallery size,

$a_1 = a_2 = a$ & $b_1 = b_2 = b$

$R= [1- (a^2/ (a+ b)^2]$

Tributary Area: It is the area of development gallery.

Tributary Area (TA) = $((a_1 + b_1) * (a_2 + b_2)) – (a_1 *a_2)$

Load Acting on Pillar: Load acting on the pillar can be determined by

$P= y *D*(1/(1-R))= y *D*((a+ b)^2/a^2)$

Where,

R= percentage of extraction,

D = depth of the pillar from surface

a = length and breadth of the pillar

b = width of the galleries

y = weight per unit volume of the super-incumbent rock

Strength of Pillar: The strength of pillar can be determined by Salamon and Munro, 1967 as

$S=K*(W^{0.46} /h^{0.66})$ Salamon and Munro, 1967]

Where, S = Strength of the pillar in lb./in²

K = constant (1320 lb./in²)

W= Width of pillar in ft.

h= Length of pillar in ft.

Factor of Safety of Pillar: Factor of Safety of Pillar is given by

F.O. S= Strength of pillars (S) / Load acting on pillars (P)

As per assumption,

Depth of Workings=200 M (656.17ft)

Width of galleries =3 m (9.84 ft)

Height of galleries =3m (9.84 ft)

Width of square pillars

Between centres of bords=22.5 m (73.82 ft)

Find out (i) the strength, and (ii) the factor of safety of pillars.

From Salomon's formula

$S = 1320 (W^{0.46}/hssss^{0.66})$

S = Strength of pillars, lb./in^2.

W = Width of pillars, ft.

h = Height of galleries. ft.

$S = 1320*((73.82-9.84)^{0.46}/ (9.84)^{0.66}$

$=1320*((63.98)^{0.46}/ (9.84)^{0.66})$

= 1976.8672

= 1977 lb./in^2

= 138.97 kg/cm²

P= y* D*(1/(1-R))

P = density of strata

d = depth of working

R= percentage extraction

$R= [1- (a^2/ (a+ b)^2]$

a =width of pillars.

b = Width of bords

$R = 1 –((19.5)^2/(22.5)^2)$

= 0.249999

= 0.25

Average density of Indian coal measure strata may be assumed to be approximately = 2.306

Hence load on pillars,

P = (2.306*200*1000)/ (100*100) *(1/ (1-0.25)) Kg/cm^2

= 46.12/0.75

= 61.49 kg/cm²

Factor of Safety = Strength on the pillar / Load on pillar

=138.97/61.49

= 2.26

Calculation of powder factor

A coal heading 4 m wide and 2.5 m high has an advance of 1 m per cycle. The amount of explosive used in blasting is 6 kg. Taking specific gravity of coal as 1.5, the Powder Factor (PF) is

PF = (Weight of coal produced in te/ Explosive required in Kg)

= ((Vol. of coal produced* density of coal)/explosive required)

$$= \frac{\text{Vol. of coal produced* (specific gravity of coal* density of water)}}{\text{Explosive required in Kg}}$$

= ((((4*2.5*1) *(1.5*1000))/1000)/6)

=2.5 te/kg

6. CONCLUSION

After thorough observations and calculations done by using the data obtained from a Bord and Pillar working, it can be concluded that, the key to the successful Bord and Pillar mining is selecting the optimum pillar size. If the pillars are too small the mine will collapse. If the pillars are too large then significant quantities of valuable material will be left behind reducing the profitability of the mine. The most important parameter before designing a pillar is the Safety factor. From calculations, the data obtained is as follows:

- Percentage of extraction 25%
- Load acting on pillars 61.49 kg/cm^2
- Strength of pillars 138.97 kg/cm^2
- Factor of safety 2.26

REFERENCES

- Singh, R. D. (2005)., Principles and Practices of Modern Coal Mining. India: New Age Publishing.
- Elements of Mining Technology Vol. 1 (8th Edition). (2010)., India: Denett & Company
- Kaku L.C (2014), Mining Digest: India: lovely prakashan publishers.
- Gorai, A.K. (2018)., A Complete guide for mining engineers. India: lovely prakashan publishers.
- Kaku, L.C. (2018) Coal mine regulations 2017, lovely prakashan publishers.
- Bieniawski, Z. T., 1984, Rock Mechanics Design in Mining and Tunnelling, A. A. Balkema.
- Madden, B J, 1987., "Coal pillar design – Can increased extraction be achieved safely?" Paper presented to Mine Safety and Health Congress, Johannesburg.
- Das, M N, 1986., Influence of width to height ratio on post-failure behaviour of coal, International Journal of Mining and Geological Engineering.
- https://images.app.goo.gl/TcFSxPsK5QfhRThRA
- https://images.app.goo.gl/EgXy4z2WtJkgM6qH7
- https://images.app.goo.gl/VmvAP9iFyvkxc9pC6
- https://images.app.goo.gl/RN5obtjvFBdsPNRg8