DESIGN OF BORD AND PILLAR METHOD

Swapnil Nagarale[1], Dr. Rajni Kant[2], Pranay Moon[3] and Shailendra Bommanwar[4]
[1]Research Scholar, Department of Mining Engineering, BIT, Ballarpur (MS), India
[2]Principal, Ballarpur Institute of Technology Ballarpur District-Chandrapur (MS)442701
[3]Assistant Professor, Department of Mining Engineering, BIT, Ballarpur (MS)
[4]H.O.D, Department of Mining Engineering, BIT, Ballarpur (MS)

ABSTRACT
The importance of mining is definitely significant to human civilization. In fact, as one of the earliest of human enterprises, mining and its development correlate closely with cultural progress. Mining is the mother industry for other industries. For effectiveness in mining, different methods have been approached keeping in mind the production and safety. One of such methods is the Bord and Pillar method of mining. Bord and Pillar method of mining is one of the oldest methods. 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 issues relating to the stability of pillars and effective extraction from it is a major concern now-a-day. The most important parameter before designing a pillar is the Safety factor. The main purpose of this project is to describe the bord and pillar method's issue and other method to be used in place of board and pillar method.

Keywords: Board and pillar Mining; Safety factor; Mine Panning, Pillar Design.

1) INTRODUCTION

The contribution of mining has played a big part in the development of civilization, more than is usually recognized by the average citizen. In fact, products of the mineral industry pervade the lives of all members of our industrialized society. The chronological development of mining technology bears an important relation to the history of civilization. In fact, as one of the earliest of human enterprises, mining and its development correlate closely with cultural progress. It is no coincidence that the cultural ages of people are associated with minerals or their derivatives (i.e., Bronze Age). Today, products of the mineral industry pervade the lives of all people.

Mining is the extraction of valuable minerals or other geological materials from the earth, usually from an ore body, vein or (coal) seam. Any material that cannot be grown through agricultural processes, or created artificially in a laboratory or factory, is usually mined. Mining in a wider sense comprises extraction of any non-renewable resource (e.g. petroleum, natural gas, or even water). Modern mining processes involve prospecting for ore bodies, analysis of the profit potential of a proposed mine, extraction of the desired materials and finally reclamation of the land to prepare it for other uses once the mine is closed. Coal seams can be mined both by underground methods and opencast methods depending upon certain conditions such as thickness and depth of the seam, dip of the seam, the ratio of overburden to coal (stripping ratio) etc.

The growing needs have been pushing the limits, to which the mining industry has to reach to lift itself to fulfill the demand. The effect can be seen from the methods of mining that have evolved over the years. One of the oldest methods of mining is the Bord and Pillar. It is a method in 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 is usually used for relatively flat-lying deposits, such as those that follow a particular stratum.

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 percentage of material mined varies depending on many factors, including the material mined, height of the pillar, and roof conditions. So proper designing of a pillar is necessary for successful Bord and Pillar working. Many methods are available for designing of pillars. The most important parameter before designing a pillar is the Safety factor. The main purpose of this paper is to describe the board and pillar method's issue and other method to be used in place of board and pillar method.

2) OBJECTIVE

Here there are some objectives that we are going to give a brief explanation regarding the design of board and pillar method and the following objectives that we are going to addresses are:

1. To study the Board and pillar design in terms of pillar size, pillar shape, seam thickness, depth of mining, etc
2. To review other mining methods.

3) LITERATURE REVIEW

Coal seams can be mined both by underground methods and surface mining methods depending on certain conditions like:

a. Thickness of seam
b. Dip of seam
c. Depth of occurrence
d. The ratio of overburden to coal (stripping ratio).

In the U.K, former USSR, France and other European countries longwall method of coal mining is the main method of mining. In India, about 98% of underground output of coal is obtained by Bord and Pillar method and barely about 2% by longwall methods. The other countries where Bord and Pillar method predominates are Australia, The USA and South Africa.

The development of mine by the method of working known as Bord and Pillar consists of driving a series of narrow roads, separated by blocks of solid coal, parallel to one another, and connecting them by another set of narrow parallel roadways driven nearly at right angles to the first set. The stage of formation of a network of roadways is known as development or first working. The coal pillars formed are extracted after the development of the mine leasehold and this later stage of extracting coal from pillars is known as depillaring.

3.1 BORD AND PILLAR WORKING

This method is sometimes called room-and-pillar mining. It is commonly used for flat or gently dipping bedded ores or coal seams. Pillars are left in place in a regular pattern while the rooms are mined out. In many Bord and Pillar mines that are nearing closure, the pillars are taken out, starting at the farthest point from the mine haulage exit, retreating, and letting the roof come down upon the floor. Room-and pillar-methods are well adapted to mechanization. Before the advent of modern pillar design in 1967, or the adoption of special precautions when mining at depths shallower than about 40 m, little was known about what size of pillars to leave behind. Sometimes, in their eagerness to extract the maximum amount of coal, the old miners left pillars too small to support the roof indefinitely. In addition, they sometimes 'robbed' the pillars on their retreat from the exhausted coal faces.

The Bord and Pillar method is adopted for working.

1. A seam thicker than 1.5 m,
2. A seam free from stone or dirt bands. Stone or dirt bands, if present in a seam, can be easily disposed of for strip packing in long wall advancing method of mining.
3. Seams at moderate depth,
4. Seams which are not gassy,
5. Seams with strong roof and floor which can stand for long period after development stage is over,

6. Coal of adequate crushing strength.

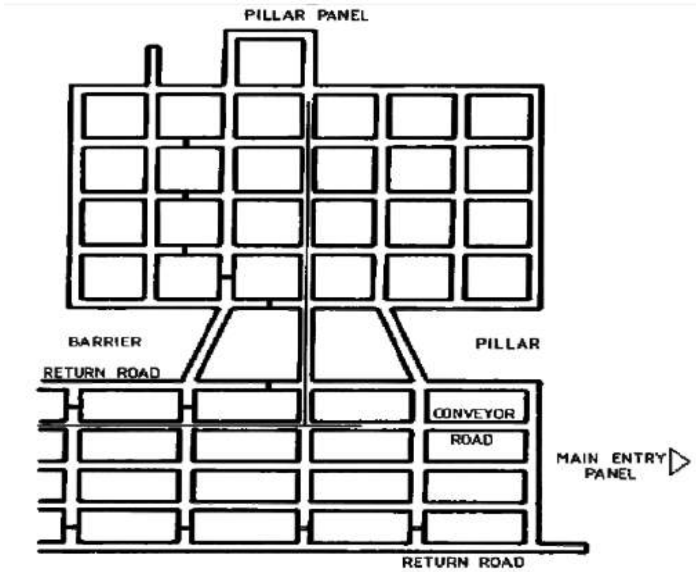


Fig No 1. Cross section of typical Bord and Pillar layout

3.1.1 Classification of 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.

3.1.1.1 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) of the gallery. The ultimate method of pillar extraction presently does not influence shape and size of pillar. However, the ultimate method of pillar extraction should also be taken into consideration while forming these pillars. This is one of the important factors for deciding the size and shape of the pillar. In the present scene of underground mine development by Bord and Pillar system, mostly square pillars are being formed of size dictated only by depth and width of galleries under the Coal Mine Regulations.

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. Such connections should be cut off by having permanent stoppings for complete isolation-of one panel with the other as soon as utility of the few inter connections between the two panels is over. Size of panel depends on many factors, two of which are the incubation period for the coal to be extracted and its rate of extraction.

Normally, formation of pillars in a panel and pillar extraction is separate activities, one after the other, and a long time may pass between the two. Thus, coal pillars may stand for years before they are extracted. In fact, this has become one of the major problems of Indian coal mining industry. It is better to first develop a panel by a pair of galleries each on the rise and dip side of the panel and interconnect these pairs at the panel boundary by a pair of dip-rise galleries. Thereafter, on the retreat, pillars can be formed till just before extraction, the shape and size of the pillar will suit the method of extraction and ventilation and transport during pillar formation and extraction will be common, thus, very much facilitated. Further other advantages associated with concentrated production will be available.

3.1.1.2 Support system during development

Considering that roof falls cause the largest number of mine accidents, it was decided a few years ago to support a 9 m length of a gallery immediately out bye of the working face. These supports may be temporary or permanent in nature. If temporary, they can be replaced by permanent supports, if the roof conditions so dictate or can be taken out completely, if the roof stratum is found to be self-supporting. However, the current trend is to consider that practically no strata is self- supporting for the size of development galleries normally driven. Now, mine managements have to necessarily prepare support plans for the mine as a whole.

The above stipulation and the past experience have encouraged installation of roof bolts in Indian Coal mines. Roof bolting as the sole system of support has been accepted by Directorate of Mines Safety for mine development galleries. Roof bolting, now, is beginning to be accepted as the sole system of support in depillaring areas and for certain geo-mining and operating conditions. Conventional supports in depillaring areas can be reduced if roof bolts are also used. Shiftable hydraulic roof bolting machines are being popular.

In order to determine the system of support to be followed, Rock Mass Rating (RMR) is determined for the immediate roof, say, up to 2 m above gallery height. For this purpose, generally, the following parameters are considered:

• Layer thickness,

• Structural features,

• Rock weathering ability

• Rock strength, and

• Ground water seepage.

By giving different values to the above parameters for possible maximum total of 100, a combined rating for the immediate roof emerges. The weight ages to these parameters are 30, 25, 20, 15, and 10 respectively. An immediate roof is, thus, divided into the five categories. Classification of immediate roof by Rock Mass Rating by the above method is given:

Table No 1. Classification of immediate roof by RMR

Rock mass rating (RMR)	Category of Roof
Less than 20	Very poor
20 to 40	Poor
40 to 60	Fair
60 to 80	Good
80 to 100	Very good

RMR so determined can be further adjusted for factors such as width of excavation (higher RMR for lesser width and vice versa) and depth (lower RMR for depths beyond 250 m or so). From RMR, rock load per sq m is calculated by using an empirical formula as follows:

$$Rock\ load, {}^{t}/_{m^2} = W \times D\,(1.7 - 0.037\,RMR + 0.002\,RMR^2)$$

Where, W is width of gallery in meters and d is mean rock density The support system can be designed giving a factor of safety of 1.5 to 2.0. Using the concept of RMR, as a basic input data in designing support system, is of recent origin and norms are still under evolution. It is a good practice to determine RMR for a few places in a mine, as it may vary from place to place. Life of roadways should also be considered while designing the system. The final method of pillar extraction should also be considered. The system should be such that does not get disturbed during and is merely reinforced, if needed.

In order to keep support cost low, it is essential that the percentage of coal extraction during pillar formation should not be high. It is suggested that, even for shallow depths, this percentage should be within 30. More coal in pillars will indirectly benefit depillaring operations also. For a given percentage of extraction, galleries should be as narrow as the proposed mechanization will permit. Long rectangular pillars should be formed as the number of 4-way junctions considerably reduces with rectangular pillars which will not require splitting before extraction.

3.1.2 Depillaring

After pillars have been formed on the Bord and Pillar system, consideration has to be given to the extraction of coal pillars; the operation is known as pillar extraction. It is also referred to as depillaring. In a method of depillaring, known as the caving method, the coal of pillars is extracted and the roof is allowed to break and collapse into the voids or the de coaled area, known as goaf. As the roof strata about the coal seam break, the ground surface develops cracks and subsides, the extent of damage depending upon depth, thickness of the seam extracted, the nature of strata, thickness of the subsoil and effect of drag by faults.

Depillaring with stowing is a method of pillar extraction in which the goaf is completely packed with incombustible material and generally plasticized where it is necessary to keep the surface and strata above the seam intact after extraction of coal. The following circumstances would require adoption of depillaring with stowing:

1. Presence of water bearing strata above the coal seam being extracted. Enormous quantities of water beyond the economic pumping capacity may enter the mine through cracks in the strata.
2. Railways, rivers, roads, etc. situated on the surface, which cannot be diverted.
3. Presence of fire in a seam above the seam to be extracted.
4. Existence of one or more seams of marketable quality extractable in the near future.
5. Restrictions imposed by local or Government authorities for the protection of the surface.
6. Extraction of the full thickness of a seam thicker than 6 m, as thicker seams cannot be extracted fully by caving method.
7. Extraction of seams very prone to spontaneous heating, of very gassy nature or liable to pumps.
8. Surface buildings which cannot be evacuated.
9. Tanks, reservoirs, etc. which cannot be emptied.

4) DESIGN OF BORD AND PILLAR WORKINGS

The main elements of Bord and Pillar workings are:

4.1 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. The other factors that influences the size is the rate at which extraction is done. With high rates of extraction made possible by mechanization, the size of the panel can be significantly increased. The extraction rate from depillaring districts in Indian coalfield averages about 250-300 tons per day per panel.

Sometimes panel sizes are determined by strata control considerations. For example, in "Yield Pillar" technique the panel size is so fixed as to cause main abutment pressure to be carried by barriers which are made of substantial width and the pillars in the panel are made smaller as to 'yield' and throw the limbs of the main pressure arch on barriers. This way percentage extraction from a panel can be substantially decreased.

4.2 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. In practice, the width of the barrier enclosing pillars in a panel is usually the same as is the width of the coal pillars which are enclosed within the panel. In deep mines the width of the barrier may become quite large (up to 45 m) and so during extraction they are thinned down consistent with safety. Too much reduction in the width of the barrier is not advisable as in that case the barrier may be crushed and two goaves may be joined, thus encouraging safety. For the determination of "Yield Pillar" technique, it is necessary to take into consideration the load at the abutments of the pressure arch and the strength of barrier pillars.

4.3 Size of Pillars

The size of the pillars is influenced by the following:

1. Depth from the surface and percentage extraction in the first workings or development.
2. Strength of the coal: Seams with weak coal require large pillars. Effect of atmosphere and escape of gas also influence the size of pillars
3. The nature of the roof and floor. These influence the liability to crush and creep. A strong roof tends to crush the pillar edges whilst a soft floor predisposes it to creep and both calls for large pillars.
4. Geological Considerations: In the vicinity of faults, large pillars are required. Dip and presence of water also influences the decision as to the size of pillars.
5. Time dependent strain: With time the strain goes on increasing, the load remaining constant and if the size of the pillar is not sufficiently large, then it may fail under the time dependent strain, although initially it might be stable.

Also, with the passage of time, weathering takes place which reduce the strength of coal pillars. In India, the dimensions of pillars and the width and height of galleries are regulated by Regulation 99 of Coal Mines Regulation 1957. It is stipulated that the width of galleries shall not exceed 4.8 m and the height of the galleries shall not exceed 3 m. For width of galleries ranging from 3 m to 4.8 m, the dimensions of pillars for various depths of working are given below:

Table No 2. Dimension of pillars and galleries at different depths

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

It may be seen that the pillar size increases with the increase in depth as well as with the galleries. As the depth of the working increases the strata pressure increases, the rate of increase being 0.2306 kg per cm2 per meter depth in Indian coalfields. Naturally, therefore, to support the increased strata pressure, the size of the pillars must be increased with depth. With the increase in width of galleries, the percentage extraction is increased which in turn results in greater strata pressure per unit area of solid pillar. To counteract that, the size of the pillars again requires to be increased with the increase in the width of the galleries.

Table No 3. Percentage extraction in development at different depths

Depth of seam from surface	Where the width of galleries does not exceed			
	3 m	3.6 m	4.2 m	4.8 m
Not exceeding 60 m	43.7	42.2	41.2	43.17
Between 60-90 m	39.53	39.8	38.4	40.5
Between 90-150 m	33.06	33.5	33.8	34
Between 150-240 m	24.8	26.2	25.6	25.9
Between 240-360 m	9.95	19.7	20.1	20.2
Exceeding 360 m	14.8	16.4	17.8	19.0

4.4 Basic Principles of Pillar design

Pillar loading is of three types, preliminary loading or loading immediately following excavation of opening, subsequent loading or the abutment pressures due to further mining (i.e. when massive extraction, such as longwall or pillaring, is happening near the pillar) and progressive failure theory for post-mining loading.

Tributary Area Concept: According to this concept, a pillar takes the weight of overlying rock up to a distance of half the opening width surrounding it. In the figure, W_0 and W_P- are widths of the opening and pillar respectively, while – L_P is the length of the pillar. For square pillars, - $W_p=L_P$

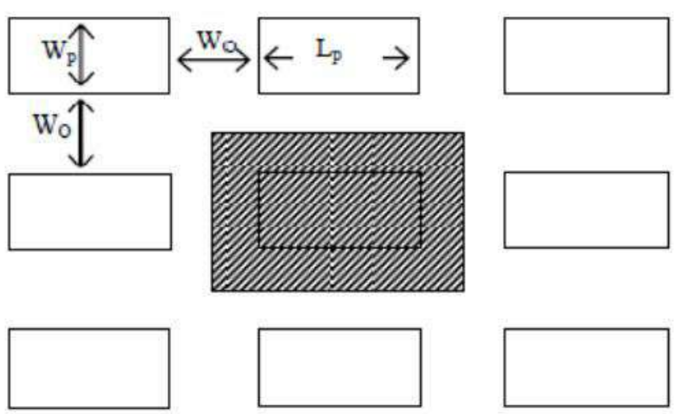


Fig No 3. The tributary area pillar loading concept

(Source: Bieniawski, Z. T., 1984)

The load on the pillar, P, is, therefore,

$$P = (L_p + W_o) \times (W_p + W_o)\gamma \times g \times h$$

Where γg is the weight of the rock per unit volume, and h is the depth of the pillar. The stress on the pillar σ_p is:

$$\sigma_p = \text{P/Area of pillar} = [(L_p + W_o) \times (W_p + W_o)\gamma \times g \times h]/[L_p + W_p]$$

$$= [(L_p + W_o) \times (W_p + W_o) \times \sigma_v]/[L_p + W_p]$$

Where σ_V is the vertical stress γgh. Another formula that works is

$$\sigma_{p=} 1.1 \times h \times [(L_p + W_o) \times (W_p + W_o)/(L_p + W_p)]$$

Pressure Arch Theory: According to this theory, when an opening is made, the stresses shift outward on both sides of pillar, leaving a de-stressed zone, in the shape of an arch, around the pillar. The exact shape and size of the arch depends on the stress levels, age and shape/size of opening, and strata properties. Subsidence occurs when the arch reaches the surface.

The de-stressed area inside the arch is called intradosal ground, while the area outside is called extradosal ground. The stratum at the fringe of the intradosal ground gets compressed as part of

the vertical stress is transferred to the abutments. The height of the intradosal ground is about 2-4 times the width of the extraction. For large excavations, the height is limited to 200 times the excavation height. Regions where pillars are being exploited can be thought of as large excavations. A disadvantage of this theory is that due to a lack of a quantitative estimate of the pressure arch profile, it is difficult to design for (how would you estimate what the intradosal pressure on the roof of an opening is if you do not know where the arch begins). As mentioned earlier, an aspect of the pressure arch theory is subsidence. When an excavation exceeds a certain width, the pressure arch can reach all the way to the surface causing subsidence.

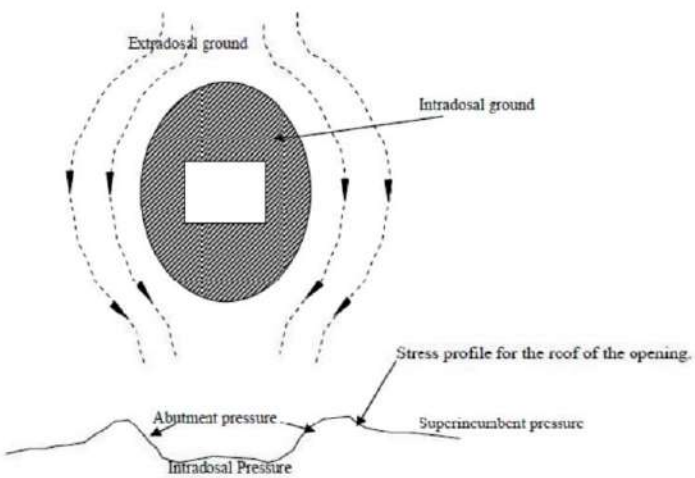


Fig No 4. The Pressure arch theory
(Source: Bieniawski, Z. T., 1984)

The pressure arch theory can be used for design as given below:

If the pressure arch height can be estimated, then multi-seams can be designed so that one mine is within the arch of another, thereby working under lower stresses.

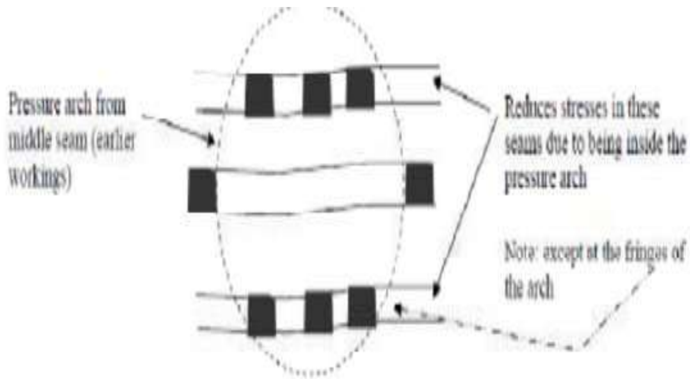


Fig No 5. Multi-seam workings exploiting the intra-dosal region of the pressure arch
(Source: Bieniawski, Z. T., 1984)

Yield pillar design: This concept aims to extend the benefits of the pressure arch theory to the current mining activities rather than to future mining activities. Here, pillars in a panel are designed to not take the full load. Instead, they are slightly under-designed. This obviously causes the pillars to yield, thereby transferring their load to the barrier pillars or to larger pillars in the same panel. Barrier pillars are large pillars that separate one panel from another. Yield pillars are also advantageous for very deep mines. In deep mines, if pillars are designed to support the full load, the pillar dimensions become very large (verify this by using the tributary area method for pillar load and Bieniawski's formula for pillar strength). Besides, pillar stresses are high as well. On the other hand, if pillars are designed to yield, not only do the dimensions remain reasonable, but the pillar stresses are reduced as well.

4.5 Extraction of Pillars

After the formation of pillar, their extraction is done from one end of the panel. If the development was not done in panels, artificial panels of suitable sizes are created by building stoppings around the pillars intended to be extracted such that the extraction of all the pillars of a panel is completed within the incubation period as required under regulation 118 A of the Coal Mine Regulation 1957. Further Regulation 100 of CMR 1957 lays down certain conditions which must be complied with during the extraction. Some of the statutory requirements are given below:

(1)No extraction or reduction of pillars shall be commenced, conducted or carried out except with the permission in writing of the 1[Regional Inspector] and in accordance with such conditions as he may specify therein. An application for permission under this sub-regulation shall be accompanied by two copies of an up-to-date plan of the area where pillars are proposed to be reduced or extracted showing the proposed extend of extraction or reduction of pillars, the manner in which such extraction or reduction is to be carried out the thickness and depth of the seam, the nature of the roof, and the rate and direction of dip.

“(2) The extraction or reduction of pillars shall be conducted in such a way as to prevent, as far as possible the extension of a collapse or subsidence of the goaf over pillars which have not been extracted.

“(3)(a) Save as provided by clause (b), no pillars shall be reduced or split in such a manner as to reduce the dimensions of the resultant pillars below those required by regulation 99 or by any order made there under, nor shall any gallery be so heightened as to exceed three meters.

“(b) During the extraction of pillars, no splitting or reduction of pillars or heightening of galleries shall be affected for a distance greater than the length of two pillars ahead of the pillar that is being extracted or reduced:

Provided that where pillar extraction is about to begin in a district such splitting or reduction of pillars or the heightening of galleries shall be restricted to a maximum of four pillars. The width of the split-galleries shall not exceed the width prescribed for galleries under regulation 99(4).

“(c) The Regional Inspector may, by an order in writing and stating the reasons therefore, relax or restrict the provisions of this sub-regulation in respect of any specified workings to such extend and, on such conditions, as he may specify therein.

“(4) Except where the voids formed as a result of extraction are stowed solid with sand or other incombustible materials, no extraction of pillars in any seam or section shall be commenced until the fire dams or stoppings have been provided on all openings, other than openings essential for ventilation and haulage around the area to be extracted. And in the roads kept open for ventilation and haulage, foundations for such dams or stoppings shall be prepared and bricks and other suitable materials shall be kept readily available in their vicinity. Shale or other carbonaceous material shall not be used in the construction of fire dams or stoppings.

“(5) Whether the method of extraction is to remove all the coal or as much of the coal as practicable and to allow the roof to cave in, the operations shall be conducted in such a way as to leave as small an area of un-collapsed roof as possible. Where possible, suitable means shall be adopted to bring down the goaf at regular intervals

Further, as a precaution against spontaneous combustion in a seam prone to autogenous fire additional precautions have been stipulated in Regulation 11 A which reads as below 118A. – Further precautions against spontaneous heating – The following further precautions shall be taken against the danger of spontaneous heating:

(1)(a) The seam or section shall be worked in panels having independent ventilation in such a manner that it is possible to isolate one from another easily if necessary. Were development has already been made without regard to this factor, artificial panels should be created by the construction of stoppings. In determining the size of the panel due consideration shall be given to the desirability of enabling complete extraction of the pillars therein within the incubation period of the coal.

(b) No coal, shale or other carbonaceous material shall be left or stacked belowground. Where removal of fallen coal out of the mine is not practicable, the area shall be effectively sealed off.

(c) A panel is isolated by adequate stoppings as soon as it has been goaved out.

The essence of the regulations is

(i) To take effective steps for good roof control so as to prevent premature collapse and overriding of pillars and to ensure regular caving of the roof; and

(ii) To take necessary steps against spontaneous heating so as to enable complete extraction of coal without spontaneous district is case spontaneous heating occurs.

4.5.1 Problems in the extraction of pillars

1. The operations of pillar extraction are beset with the problems of strata control. If the operations have not been designed scientifically, there are the dangers of major strata movement setting in, which may result in the overriding of pillars, and premature collapse. In the past and also recent years in the Jharia coalfields and elsewhere during extraction of pillars in thick seams, especially seams developed in multi-sections, premature collapses have occurred involving large areas. In some seams, the roof does not cave in over large areas for quite some time and/when it does cave in, air blasts occur resulting in accidents. In central India, air blasts of high intensity have occurred in the pas causing fatalities to miners.

2. Maintenance of acceptable environment is not easy. Splitting of pillars provides many leakage routes and heightening and widening of galleries increase cross-sectional areas and hence the velocity of ventilating air is reduced. The ventilation in depillaring faces often becomes sluggish. Airborne dust concentrations increase and climatic conditions generally become uncomfortable.

3. Usually, some coal is left in the goaf, which may be 15-20% of the panel reserve. This gets crushed, oxidation sets in and eventually fire may break out. There are numerous cases of fire occurring in depillaring districts in Indian coal mines.

4. Mechanization of coal getting is not easily possible on account of difficulty of roof control.

5. Because of reasons given at 1.2 and 4 above, the production from district is not high and the output per man-shift is low.

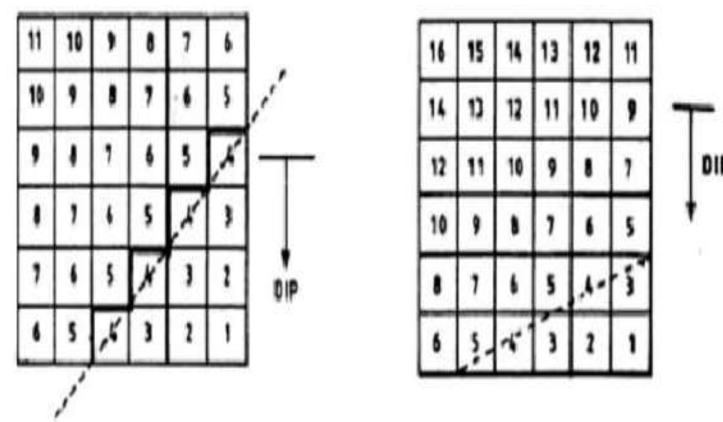
4.5.2 Principles of Pillar extraction techniques

The principles of designing pillar extraction techniques are given below:

1. Roof exposure at one time should be minimal. In the Indian coalfields, where caving is practiced, 60-90 m2 exposure is normally allowed. But in stowing districts the exposure may be increases up to 90-100 m2.

2. The size of the panel should be such as depillaring can be completed within the incubation period. This period commonly varies between 6-9 months. But there are some seams in which fire has not occurred even though depillaring has been going on for more than two years and yet there are some seams in which spontaneous heating has been reported within three to four months of the commencement of depillaring. In a lignite mine spontaneous heating took place within a few weeks only.

3. The extraction line should be so arranged as to facilitate roof control. In practice o diagonal line, or step diagonal line of face is common. In special cases a steep diagonal line of face or even straight line of face has been selected. Diagonal or step diagonal line of face provides protection as the working places are supported by solid pillars and also when the roof caves, there is less risk of goaf flushing into the working faces. It is also claimed that diagonal line of extraction helps in the caving of the roof.



A) Diagonal line of extraction B) Step diagonal line of extraction

Fig No 6. Methods of Pillar extraction

In the panel worked in conjunction with hydraulic sand stowing-diagonal line of face is prepared as it facilitates water drainage without flooding the working faces in the lower level.

4. The single lift extraction is limited to height of 4.8 m or less. If the thickness of the seam is more than 4.8 m, the extraction is done in multi-lifts and in that case hydraulic sand stowing is insisted upon. Seams up to 4.8 m thick can be mined by caving in one pass.

5. Whatever the method of extraction, the working area is systematically supported by cogs and props.

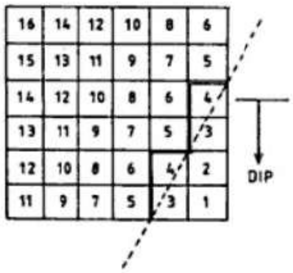


Fig No 7. Steep diagonal line of extraction

(Source: R.D.Singh, 2005)

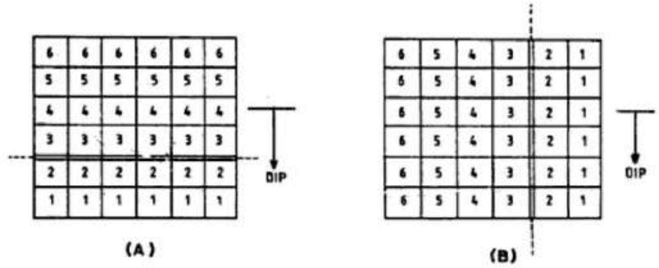


Fig No 8. Straight line of extraction

(Source: R.D.Singh, 2005)

4.5.3 Splitting of pillars

As laid down in the coal mines regulations 1957, splitting of pillars must not be done more than two pillars ahead of the pillar being extracted and at the commencement of depillaring not more than two pillars shall be splitted. This is done to reduce the zone of stress concentration for ensuring stability of the workings. A question arises whether the splits should be dip-rise or on the strike? Dip-rise splits enable the extraction to proceed on the strike. In this case haulage distance is comparatively less, the roof caving is better controlled but if the goaf is to be stowed, stowing is not possible up to the roof. When the pillar is splitted by a strike split, extraction is doing to be the dip. In this case, haulage distance is more than that when the pillar is splitted by the dip-rise splits but stowing of the goaf to the roof is possible. If depillaring is done with caving, the caving of roof is hindered when the pillar is splitted by level split and dip-rise slices are extracted.

4.5.4 Factors influencing choice of pillar extraction techniques

1. Thickness of the seam: If the thickness of the seam is 4.8 m or less, depillaring with caving in one slice may be done. In seams more than 4.8 m thick, pillars must be extracted in lifts in conjunction with stowing. The lifts are normally 3 m thick or so. The last lift may be up to 4.8 m high and could be extracted by stowing or caving
2. Depth of the seam: At greater depths, the pillars must be larger and they are extracted in conjunction with stowing. Splits have to be driven on strike.
3. Roof of the seam: For successful depillaring roof must be cave regularly. A roof with compressive strength of less than 500 kg/ cm2 is normally a capable roof. Massive and strong roofs create problems in caving and blasting may have to be restored to induce caving.
4. Incubation period of the seam: Coal seam with longer incubation period may be extracted in larger panels. To achieve the same effect, i.e. to make the panel larger, mechanizations of operations are necessary in a seam with shorter incubation period so that rate of extraction is increased.
5. Dip of the seam: In steeply inclined seams, special techniques of extraction have to be designed such as Topping method.

5) ADVANTAGE AND DISADVANTAGE OF BOARD AND PILLAR METHOD

Advantages of Board and pillar method:

1. Road and airways are in solid coal and their maintenance cost is low throughout the life of the mine.
2. Coal output is obtained while roadways are being made during the development stage, and naturally during the depillaring stage, thus providing a continuous flow of coal after the seam is touched.
3. Unlike in longwall mining no unproductive work of dining, strip packing, etc, is involved.

4. The development stage reveals the geological disturbances enabling the management to plan accordingly.
5. The working team is usually small at working faces. This helps in simpler methods of calculation of work performance, smoother and more co-ordinate work. The effect of absenteeism is not significant.
6. Surface features like railways, important buildings, rivers, etc. which should not be disturbed by underground methods of mining can be well supported during the development stage by the solid pillars of coal and later by only partially extracting the pillars of coal and later by only partially extracting the pillars if stowing is not practicable.

Disadvantages of Board and pillar method

1. Ventilation in sluggish, as compared to longwall method, at the working places.
2. The extraction losses are generally higher than in other methods of mining.
3. Work is carried on at a number of working places creating problems of supervision.
4. At great depths, the working by this method becomes difficult as effects of roof pressure are not easily controllable; heaving of floor and creeping of roof may result in loss of roadways.
5. The effects of subsidence and interaction on other seams are not even and not easily predicable or controllable.

6) OTHER MINING METHOD'S

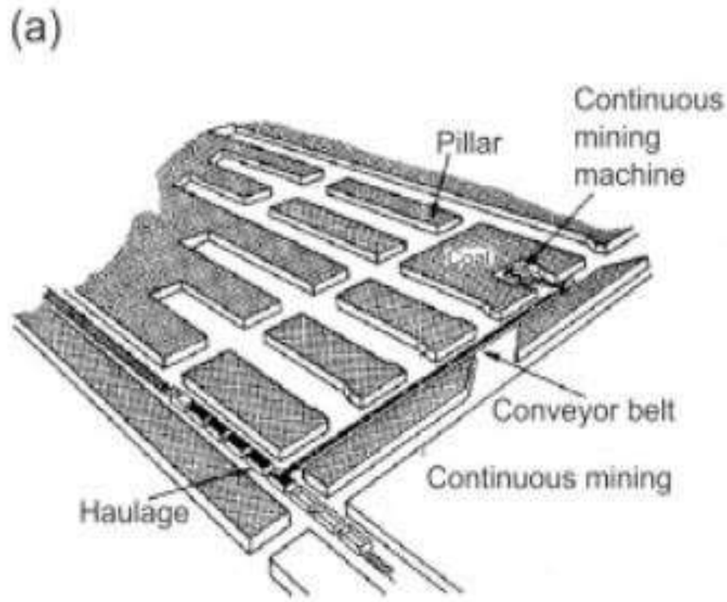
The following methods which are derivatives of the above principal systems have since acquire distinctive nomenclature:

1. Room and pillar Mining
2. Cut and fill mining
3. Horizon Mining
4. Slicing
5. Sublevel Caving

6.1 Room and pillar Mining

The room-and-pillar mining is named after cutting a network of rooms into the coal bed and leaving behind large pillars of coal spaced at regular intervals or grids during mining to provide support to the ceiling or mine roof.

In room and pillar mining, seams of coal are mined partially, leaving large pillars of coal intact to support the overlying layers of rock. Mining by this method creates a network of alternating open spaces and large pillars of coal (Fig. 19.4(a)). When mining in one part of the coal seam has been finished, miners practice "retreat" mining, extracting as much as possible of the coal in the remaining pillars on the way out, while the roof of the seam begins to collapse behind them. coal deposits are mined by cutting a network of 'rooms' into the coal seam and leaving 'pillars' of coal to support the roof of the mine. These pillars can be up to 40% of the total coal in the seam, although this coal can sometimes be recovered at a later stage. This procedure is an inefficient method of resource development but is nevertheless economically suitable for tabular seams, particularly if the seams are narrow. It has been demonstrated in oil shale by the U.S. Bureau of Mines and by several industrial organizations.

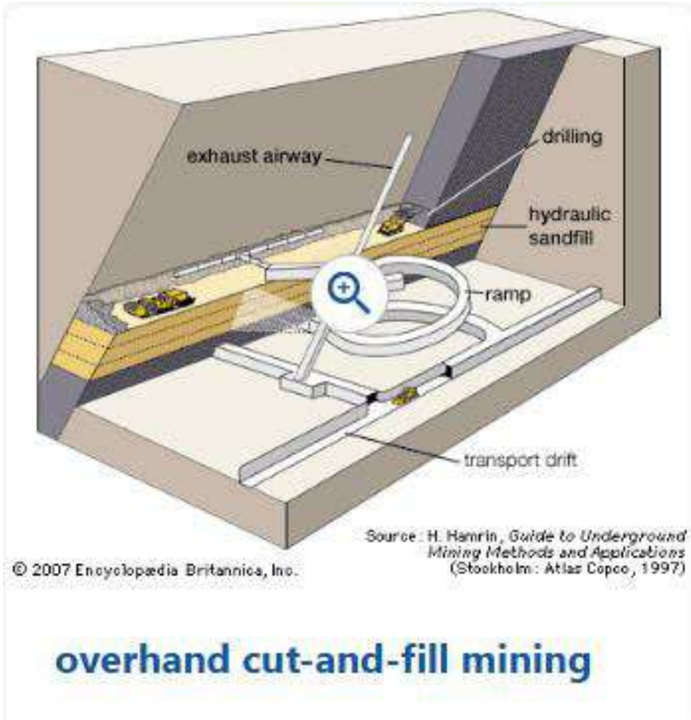


In room-and-pillar mining, coal deposits are mined by cutting a network of ‘rooms’ into the coal seam and leaving ‘pillars’ of coal to support the roof of the mine. These pillars can be up to 40% of the total coal in the seam, although this coal can sometimes be recovered at a later stage. The coal ‘face’ can vary in length from 100 to 350 m. Self-advancing, hydraulically powered supports temporarily hold up (support) the roof while coal is extracted. When coal has been extracted from the area, the roof collapses. Over 75% of the coal in the deposit can be extracted from panels of coal that can extend to 3 km through the coal seam

6.2 Cut and Fill mining

This system can be adapted to many different ore body shapes and ground conditions. Together with room-and-pillar mining, it is the most flexible of underground methods. In cut-and-fill mining, the ore is removed in a series of horizontal drifting slices. When each slice is removed, the void is filled (generally with waste material from the mineral-processing plant), and the next slice of ore is mined. In overhand cut-and-fill mining, the most common variation, mining starts at the lower level and works upward. In underhand cut-and-fill mining, work progresses from the top downward. In this latter case cement must be added to the fill to form a strong roof under which to work. Overhand cut-and-fill mining in a stope with access provided by a ramp is illustrated in the figure. In this particular design raises are constructed in the fill as mining proceeds upward. These perform various functions, such as manways or ore passes, but an alternative would be to load and haul the rock by LHD to an ore pass located in the footwall.

Where ground conditions permit, it is possible to use a combination of cut-and-fill mining and sublevel stopping called rill mining. In this method drifts are driven in the ore separated by a slice of ore two or three normal slices high. As in sublevel stopping, vertical slices are removed by long hole drilling and blasting, but, as the slices are extracted, filling is carried out. In this way the amount of open ground is kept small.



6.3 HORIZON MINING

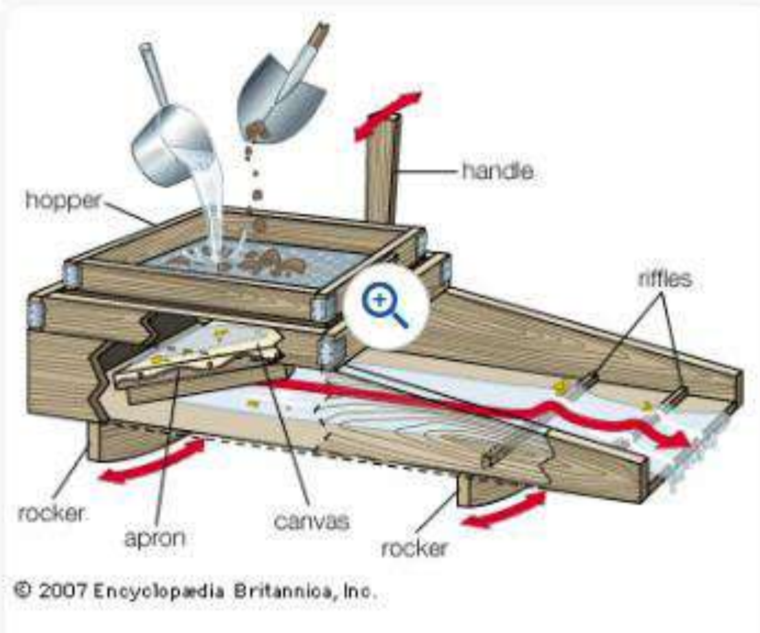
Horizon mining is the system of mining, applicable to inclined or undulating and also to relatively flat seams where these occurs in groups whereby all the coal seams are extracted between predetermined horizon, level or planes. It involves driving main roadways horizontally (or almost so) through the measures or strata from the shaft at pre-arranged intervals of depth, and these roadways form, as it were, the main arteries of the mine, through which coal is transported throughout the life of the mine, or of the horizon concerned. At least two levels are driven at different horizons; lower level, called the haulage level, is used for haulage and serves as intake airway and the upper level called the ventilation or return level, is used as return airway and supply road. Connections are made to each of the seams lying between these two levels and the portion of each seam intersected by the levels is divided into sections of suitable size either by staple or blind shafts or in rare cases by inclined roads.

Lateral drifts or roads, or simply laterals, are those roads driven parallel to the strike from shaft and they may be sited in one of the coal seams or, more usually, in the strata below the lowest coal seam in the borazon concerned. The term cross measure drifts; or simply cross-cuts, is used for all the approximately level main roads driven in rock at right angles to the line of strike, i.e. in the direction of the full dip or rise of the strata. In general, the cross-cuts in the various horizons should be driven directly above one another. A network of these roadways, laterals and cross cuts driven at the same depth of horizon, constitutes a horizon or level. Vertical distance between horizons is 60-200m.

Horizon mining is actually not a method of mining in the sense long wall or bord and pillar is, but is a method of lying out the workings and roadways in a coal seam and cross measure strata for speedy transport. The actual method of mining may be longwall, board and pillar or room and pillar through the method that has been normally adopted has been longwall advancing or longwall retreating as the countries that have first tried horizon mining and later developed it, were accustomed to longwall methods of mining. The usual methods of transport are the conveyors on the faces and gates, spiral chutes in the staple shafts leading to haulage level, and locomotives in the haulage level. Seams are worked in descending order.

6.4 Sluice

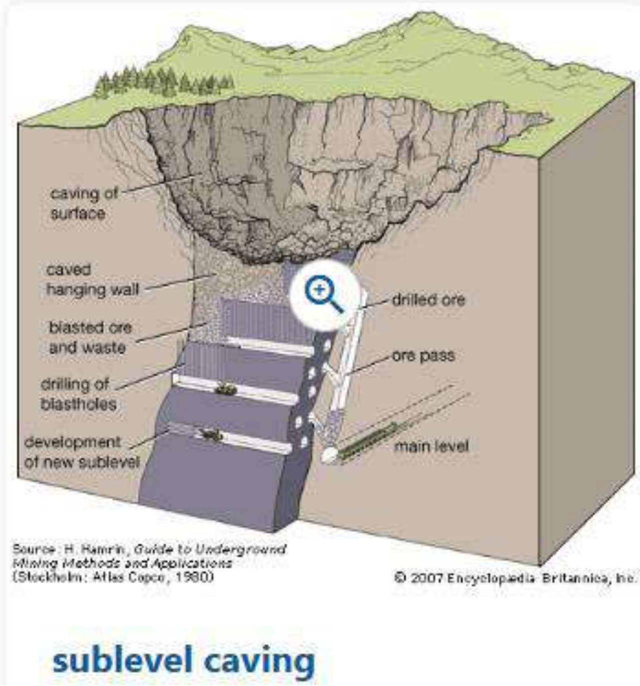
Sluice is a land-based operation. Another hand method involves the use of a sluice box. This is a sturdy rectangular box, nearly always built of lumber, with an open top and a bottom roughened by a set of riffles. The most common riffles are transversely mounted wooden bars, but they may also be made of wooden poles, stone, iron, or rubber. Water and placer dirt are introduced at the upper end of the inclined sluice box, and, as they flow downward, the specially shaped riffles agitate the current, preventing lighter material from settling while retaining the valuable heavy mineral.



6.5 Sublevel caving

After extraction of 2 slices with the artificial roof of wire netting 4.8m thickness of coal on the floor of the seam is still left to be extracted. Out of this 4.8m of coal, the top 2.4m which constitutes 4th slice is not extracted by usual process of coal cutting, drilling, blasting, conveyor, shifting etc. entry is made to the 5th slice (bottom-most slice of 2.4m thickness) by suitable gate roads and the slice is extracted in longwall retreating manner. The roof for the 5th slice is solid coal and not the artificial roof of wire netting. The progress in the main face (5th slice face) is made coal by blasting only. The minimum span of the face is two bars i.e. 2.5m while the maximum span 3bars or 3.75m and each face advance by blasting is 1.25m. When the goaf edge bars and the props are withdrawn, the coal of the 4th slice (called sub level) of 1.25m width and 2.4m height caves down usually by itself in the goaf, through sometimes it is necessary to bring it down by blasting.

At this face second wire netting is added along the roof of the main face (5th slice face) as the face progresses, mainly for the purpose of containing the sub level coal between the 2nd wire netting and the original netting lying below subsided goaf. The roof netting also prevents the immediate splash of broken coal which can inflict injury to the workmen and dislodge the supports inside the face. For extracting the sub level coal, it is necessary to puncture the netting at places or roll it up in sections. Big chunks of the sub level coal need secondary blasting and all the coal cannot be recovered resulting in loss of 10 to 20% (of the sub level coal). The coal remaining in the goaf is a source of spontaneous heating. The second wire netting (along the roof) has to be extended as the face advances.



7) CONCLUSION

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.

Other methods should be used in-place of Board and pillar mining method as per the mining environment.

8) REFERENCE

[1] Singh, R.D., "Principles And Practices Of Modern Coal Mining", New Age International Limited Publishers, 1st Edition, 2005, Chapter 6, pp. 156-18

[2] Deshmukh, D.J., "Elements Of Mining Technology", Denett & Co. Publication, Vol. 1, 7th Edition, 1995, Chapter 12, Page no.367-386

[3] http://www.faculty.uaf.edu/ffrg/min454/Handout4_MIN454.pdf

[4] Lombard, H.E., Fourie, G.A., Cox, A.J., DU Plesis, A.G. and Wilson, R.B. Review of access design and mining method of the 44E room and pillar mine design, Interim Report, SRK-Turgis. 2001. pp. 1–10.

[5] http://www.strataengineering.com.au/client_images/782664.pdf

[6] http://www.maden.org.tr/resimler/ekler/37168031d88451c_ek.pdf

[7] http://researchspace.csir.co.za/dspace/bitstream/10204/1419/1/COL337.pdf

[8] http://www.saimm.co.za/Journal/v091n01p027.pdf

[9] http://www.rokdok.com/mining/pubs/vail.pdf

[10] Bieniawski, Z. T., 1984, Rock Mechanics Design in Mining and Tunneling, A. A Balkema.

[11] Das, M N, 1986. Influence of width to height ratio on post-failure behavior of coal, International Journal of Mining and Geological Engineering, 4:79-87.

[12] Madden, B J, 1987. "Coal pillar design – Can increased extraction be achieved safely?" Paper presented to Mine Safety and Health Congress, Johannesburg

[13] https://www.sciencedirect.com/topics/engineering/room-and-pillar-mining

[14] https://www.britannica.com/technology/mining/Solution-mining