Exploitation of Mineral Deposits

Bord & Pillar Mining Methods
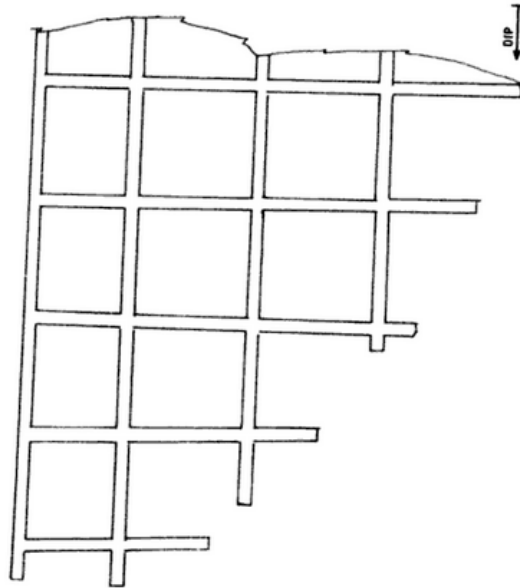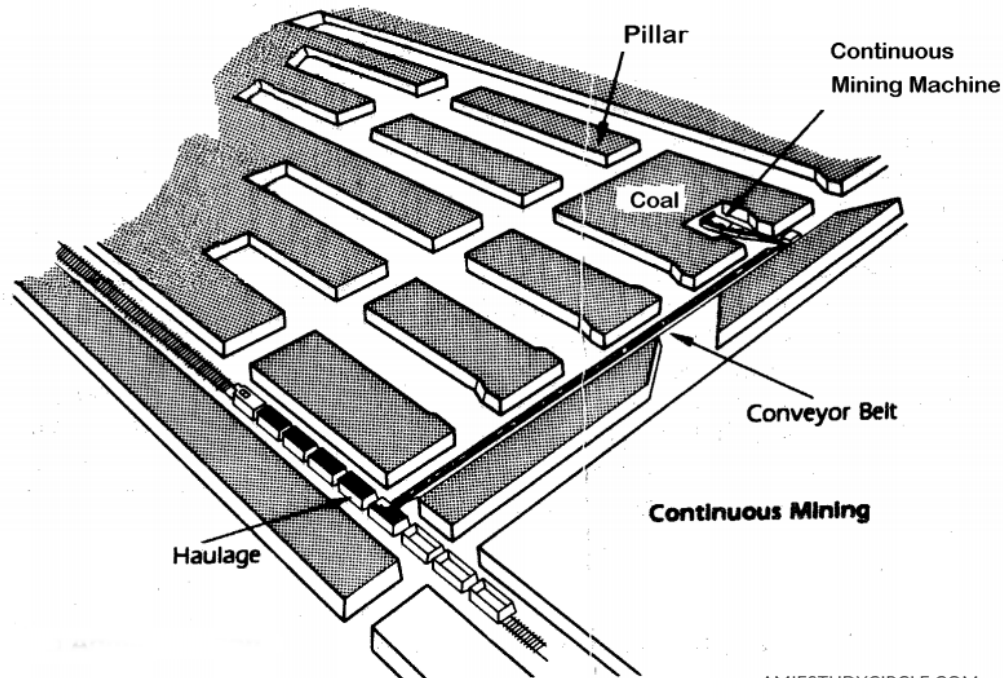
Bord & Pillar Mining Methods

Fundamentally, the bord and pillar method of mining coal seams involves the driving of a series of narrow headings in the seam parallel to each other and connected by cross headings so as to form pillars for subsequent extraction, either partial or complete, as geological conditions or necessity for supporting the surface, may permit. Ideally, the pillars should be square but they are sometimes rectangular or of rhombus shape and the galleries surrounding the pillars are invariably of square cross-section.

The bord and pillar method of mining is suited to work flat coal seams of average thickness and at shallow depths. Coal seams of 1.8 to 3 m thickness are best suited for this method, though the method has been successful in thinner seams also down to a thickness of 1.2 m and in thicker seams up to 4.8 m in thickness. In seams with gradients of more than 1 in 4 difficulties are encountered in manoeuvring machines. Most of the bord and pillar method of coal mining has

been done in depth range less than 300 m as at greater depths pillars experience crush. However, in India in some cases the depth of mining by bord and pillar method has been around 600 m, though mining at such depths is beset with the problems of strata control. Sometimes, low strength of coal limits the depth to which bord and pillar mining can be done.

Seams with bad roof and with high make of gas are unsuitable for bord and pillar method of mining. Also seams highly prone to spontaneous heating should not be worked by bord and pillar methods.

ADVANTAGES

Bord and pillar method of coal mining offers many advantages. The major advantages are:
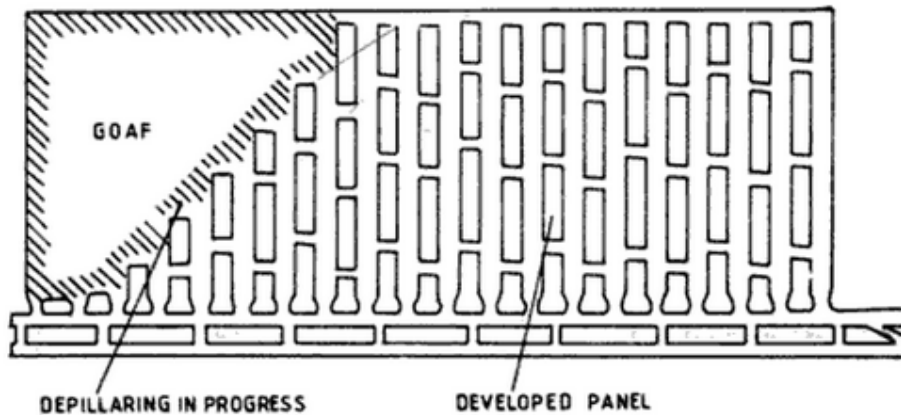
- The area to be immediately worked is proved, and so initial planning may be modified to deal with faults and intrusions without serious loss of output.

- All roadways in the seam are supported by solid coal for as long as they are required, instead of being formed and maintained in the goaf. This results in better and less costly supports.

- Unproductive labour is reduced by the elimination of the packing of the goaf. In thick seams no ripping at all may be necessary and in thinner seams less is required than in unsettled ground. Moreover, the roadways seldom need subsequent enlargement. As unproductive labour is reduced to a minimum, a high OMS (output per manshift) is achieved.

- The system is not dependent upon the completion of specific operations by the end of each shift, and the same operations are continued from one working shift to the next. Multiple shift getting with all its advantages is easily possible.

- Bord and pillar workings attract more labour as the mining operations are rather simpler.

DISADVANTAGES

* The main disadvantages of bord and pillar method are:

* The percentage of extraction is usually less than in longwall mining in similar conditions.

* The need for the constant flitting of machinery from place to place.

* Subsidence in relation to the surface cannot be controlled effectively.

* Strata control is not easy.

* Ventilation is generally poor because of multiple connections and large number of ventilation stoppings which provide sources of leakage.

* Risk of spontaneous heating is more.

ROOM & PILLAR METHOD

Some other variants of bord and pillar method of mining coal seams are known as room and pillar, pillar and stall, chamber and pillar, breast and pillar, post and stall, etc. The basic principles of their design, however, remain almost the same.

Room and pillar method is generally applicable for working thinner coal beds 0.9 - 1.2 m thick. Rooms are generally constructed as wide as possible consistent with the stability characteristic of the roof; common width being 4.5 - 7.5 m and the pillars left between the rooms may be 6 - 12 m wide and 12 - 27.4 m long. The rooms are usually supported by roof bolts. The pillars may or may not be extracted. When the pillars are not extracted, their width is substantially reduced so that the percentage recovery is increased.

GOAF

DEPILLARING IN PROGRESS   DEVELOPED PANEL

Given figure shows the layout of a district developed on room and pillar method.

The advantages of this method are:

* High degree of flexibility

* Improved efficiency in working of thinner seams

* No costly equipment and elaborate arrangements are needed as would be necessary in longwall mining

- As compared to conventional bord and pillar method higher OMS and reduced cost per tonne of coal are obtained in certain conditions.

- Mechanisation is simple and comparatively more efficient

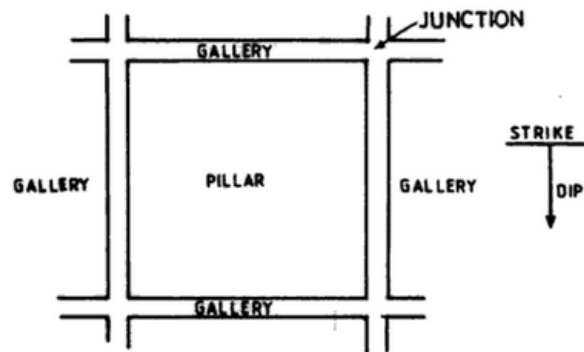- Efficiency of blasting is high

The disadvantages of the room and pillar method are:

- If the strata are not competent, roof falls may take place in the rooms

- If the ribs are left in the goaf deliberately, they may crush and be the cause of spontaneous heating

- Ventilation is difficult, clearance of fumes and suppression of airborne dust may create problems

- In gassy mines, methane layering may take place due to wider galleries and reduced velocity of ventilating air.

BORD AND PILLAR MINING SYSTEM

Bord and pillar mining method comprises two phases, i.e., development or 'whole working' and depillaring or 'broken working'. Sometimes both these phases proceed simultaneously. In development, pillars are formed by driving a network of galleries, of which one set is generally parallel to the dip and the other set is parallel to the strike cutting the former at right angles.

Given figure shows the basic parameters of bord and pillar mining system.

CLASSIFICATION OF BORD AND PILLAR MINING SYSTEM

The bord and pillar system of mining can be done in three ways, namely :

- 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 starting from the boundary.

Development of entire area followed by pillar extraction

The first system (see figure) is attractive in that more number of working faces can be made available and thus more number of miners can be given employment. Large output can be quickly built up. In the past this system was practised widely in Indian mines and in certain mines with very few coal cutting machines high outputs were obtained. But this system has the following **disadvantages**:

- As the pillars have to stand for a long time before they are extracted, spading takes place and they get weakened. Consequently, they may get crushed and there is the risk of premature collapse.

- Ventilation may be sluggish due to greater percentage of air leakage.

- Treatment of coal dust is costly and difficult.

- There is greater risk of fire spreading in the whole mine.

- Coal dust explosion cannot be contained; if it occurs, it spreads throughout the mine.

- Crush and creep cannot be localised.

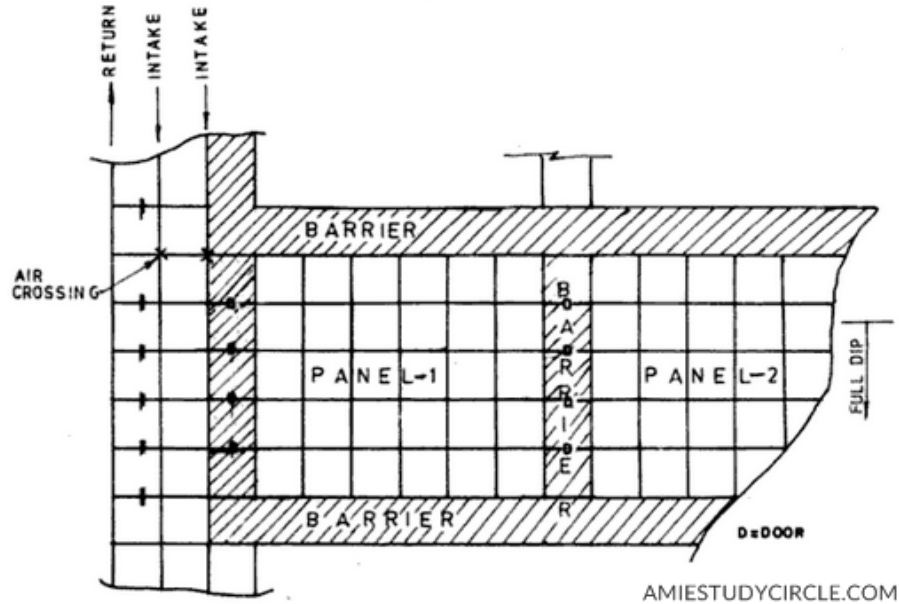- The work is scattered. Consequently, the output per man-shift is low.

Due to these disadvantage this system is not used these days.

Panel system of mining

In the Panel system of mining (see figure) the coal seam is divided into a number of panels separated from one another by solid barrier of coal.

This system offers the following **advantages**:

- Risk of loss of coal through spontaneous heating is limited. In the event of fire occurring, the panel can be isolated from other parts of the workings Similarly, explosions can be limited to the panel of occurrence.

- Crushing of pillars is avoided.

- Creep and thrust (crush) started in any part of the mine are arrested in their course and isolated in their action.

- *'Whole'* and *'broken'* workings can be done at the same time i.e., in one panel development and in another panel depillaring can be done at the same time.

- Ventilation is improved. Each panel can be provided with its separate intake and return. Also number of air stoppings can be substantially reduced.

AMIESTUDYCIRCLE.COM

- Control of subsidence is possible. By working panels of sub-critical width, magnitude of subsidence can be reduced.

- By suitable design using yield pillar techniques percentage extraction can be improved.
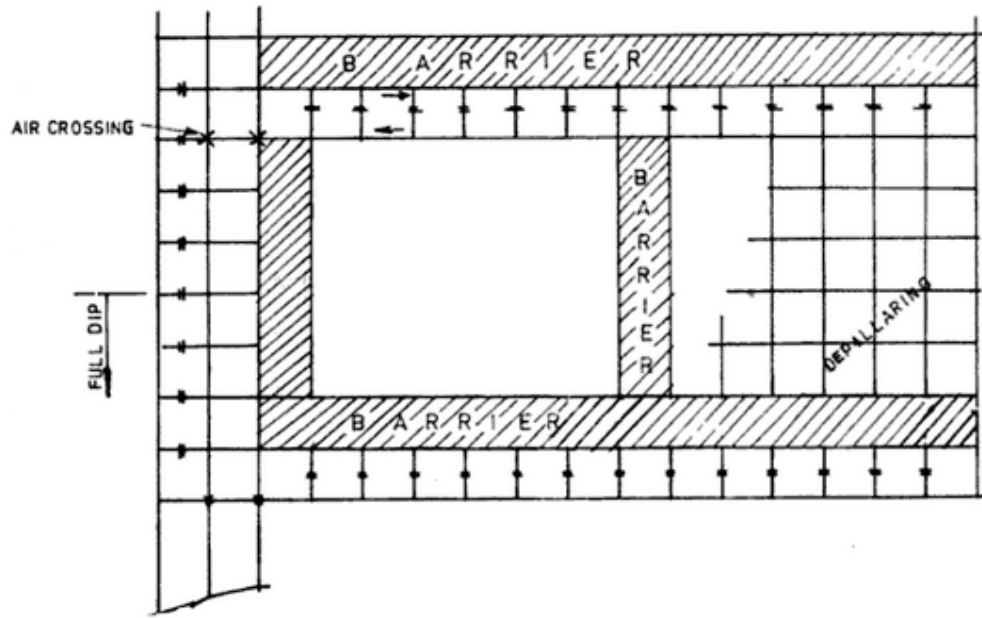
The main **disadvantages** of the panel system of mining are:

- Considerable amount of coal is lost in barriers. Generally, in Indian practice roughly 20% of coal is lost in the barriers.

- More number of air crossings are required for ventilation purposes.

- Each panel must have its own independent coal cutting machine and haulage. Flitting of coal cutting machine from one panel to the other panel is not practicable.

- Crushing of barriers may result in joining of two panels with consequent spread of fire (if it existed in any one of the panels) and delayed and sudden subsidence.

"Whole" followed by "broken" workings

The current trend, however, is to open-out the mine with as few headings as possible (say three to five) and retreat back from the boundary, 'broken* workings following the 'whole' workings (see figure) in suitable size panels. This system is superior over others in the following respects :

- Ventilation is efficient.

- Coal dust treatment is simpler.

- With intensive machine mining high outputs can be obtained. Even in the opening out stage high outputs can be obtained using intensive mechanisation and output per man-shift (OMS) can be high.

- Organisation is simpler.

- Crush and premature collapse of pillars is a remote possibility.

- Haulage can be simpler.

- As the development and extraction of pillars go together, same transport system as for development can be used for extraction work also in its retreating passage.

- Control of fire is comparatively easy.

DESIGN OF BORD AND PILLAR WORKINGS

The main elements of bord and pillar workings are:

- the size of the panel;

- the size of barriers;

- the size of pillars; and

- the width and height of galleries.

Their design must be based on critical techno-economic analysis so as to give maximum operational efficiency and safety.
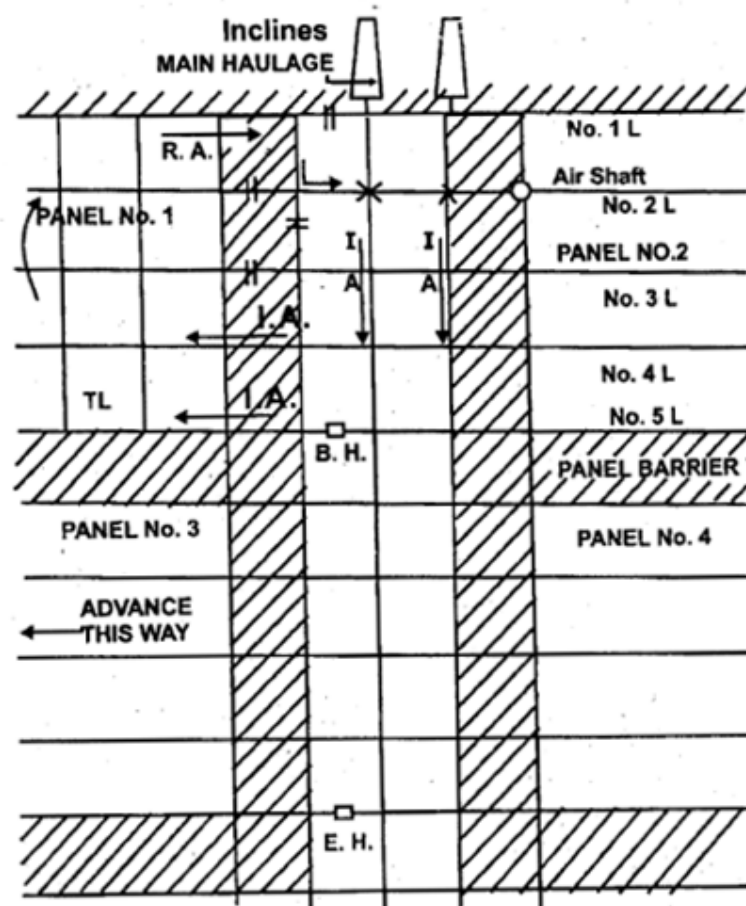
Size of the Panel

In a coal seam which is liable to spontaneous heating development is carried out in panels. A panel is a district separated from other districts by a barrier which may be of solid coal or of

brick stoppings. Between two panels only essential, galleries required for passage of men, ventilation, drainage or stowing are driven. In case of an emergency arising from spontaneous heating, out break of fire in the panel, heavy gas emission, crush of pillars, etc. the panel can be sealed off by brick stoppings and isolated from other workings.

The coal barrier between adjacent panels is usually of the same thickness as the thickness of pillar. A dyke or a fault plane may sometimes serve the purpose of a panel barrier. The number of pillars in a panel is such that during the depillaring stage the coal from the pillars can be extracted to the maximum percentage within the incubation period which varies from seam to seam and is usually between 3 and 10 months. The number of pillars varies from 12 to 30.

A panel is normally longer along the strike and shorter along the dip-rise direction. Long panels are unavoidable where the development is by conveyors or by locomotives and such long panel is sub-divided into small panels during depillaring by construction of isolation stoppings. Given figure shows the general layout of workings in a panel where the panel is approached by an incline.

Where depillaring operations will be in conjunction with stowing, formation of panels is not necessary but may sometimes the demanded by the DGMS.

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 other factor that influences the size is the rate at which extraction is done. With high rates of extraction made possible by mechanisation, the size of the panel can be significantly increased. The extraction rate from depillaring districts in Indian collieries averages about 250-300 tonnes per day per panel (in mechanised depillaring it may be up to 500 tonnes per day). Generally, the size of the panel is about 150 m x 120 m.

Example (Fixing panel size)

Assume incubation period of the seam

$$= 6 \text{ months}$$

Output per day from the panel

$$= 300 \text{ tonnes}$$

Number of working days in a month

$$= 150$$

Total coal obtained from the panel in 6 months

$$= 150 \times 300$$

Assume % recovery in the panel

$$= 80\%$$

Total coal in situ

$$45000 \times (100/80) = 56,250 \text{ tonnes}$$

Coal in a pillar A x A x h x g = T tonnes

Where,

  A = length of a square pillar

  h = height of the pillar

  g = specific gravity of coal = 1.3 - 1.4

Number of pillars in panel = 56250/T

Having determined the number of pillars in the panel, they are *judiciously* placed along the strike (rows) and dip (column). It is a good practice to keep more number of pillars along the strike.

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 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 barrier is not advisable as in that case the barrier may be crushed and two goaves (mines) may get joined, thus endangering safety.

For the determination of the size of barriers around panels in which the pillars are designed on the principle 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.

Size of Pillars

The size of pillars, is influenced by the following:

- Depth from the surface and percentage extraction in the first workings or development.

- Strength of coal : Seams with weak coal require larger pillars. Effect of atmosphere and escape of gas also influence the size of pillars.

- 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 call for larger pillars.

- Geological considerations : In the vicinity of faults, larger pillars are required. Dip and presence of water also influence the decision as to the size of pillars.

- 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.

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 in following table.

Depth of seam from the surface	Where the width of galleries does not exceed 3 m	Where the width of galleries does not exceed 3.6 m	Where the width of galleries does not exceed 4.2 m	Where the width of galleries does not exceed 4.8 m
	The distance between centres of adjacent pillars shall not be less than			
	metres	metres	metres	metres
Not exceeding 60 m	12.0	15.0	18.0	19.5
Exceeding 60 m but not exceeding 90 m	13.5	16.5	19.5	21.0
Exceeding 90 m but not exceeding 150 m	16.5	19.5	22.5	25.5
Exceeding 150 m but not exceeding 240 m	22.5	25.5	30.5	34.5
Exceeding 240 m but not exceeding 360 m	28.5	34.5	39.5	45.0
Exceeding 360 m	39.0	42.0	45.0	48.0

The percentage extraction at different depths during development (formation of pillars) varies between 14.8% and 43.7% (see table).

Depth of the seam from the surface, m.	Where the width of galleries does not exceeds			
	3m	3.6 m	4.2 m	4.8 m
Not exceeding 60 m	43.7	42.2	41.2	43.17
Exceeding 60 m but not exceeding 90 m	39.55	39.8	38.4	40.5
Exceeding 90 m but not excceeding 150 m	33.06	33.5	33.8	34.0
Exceeding 150 m but not exceeding 240 m	24.8	26.2	25.6	25.9
Exceeding 240 m but not exceeding 360 m	9.95	19.7	20.1	20.2
Exceeding 360	14.8	16.4	17.8	19.0

PILLAR DESIGN

Load on Pillars

In order to compute the pressure acting on the pillar the following assumptions are made :

- Any element of the ground at a depth d, below the surface is subjected to a pressure P_0, which depends on the weight of the super incumbent rock so that :

    $P_0 = Wd$

    where, W = weight per unit volume of the super incumbent rock.

- Each pillar supports the volume of the rock over an area which is the sum of the cross-sectional area of the pillar plus a portion of the bord area, the latter being equally shared by all the pillars.

- The load is vertical only and is uniformly distributed over the cross-sectional area of the pillar.

Based on these assumptions,

$$p = p_0 \frac{(a+b)^2}{a^2}$$

and $$R = 1 - \frac{a^2}{(a+b)^2}$$

where

   p = the pressure on the pillar

   p_0 = the initial ground pressure

   a_1, a_2 = the widths of the pillar

   b_1, b_2 = the widths of the bord

   R = percentage extraction

Strength of coal pillars

The formula for pillar strength as modified by Central Mining Research Station is given below

$$S = RK\frac{W^{0.46}}{h^{0.66}}\,lb/inch^2$$

where

K = In situ strength of a 1 ft cube of coal, and

R = the load expressed as the ratio of the failure load at which a final kink occurs in the load determination curve plotted logarithmically and is equal to 0.81 to 0.88 for Indian coals.

Factor of safety

In the design of pillars a factor of safety is provided to take care of the errors in the computation of strength and load on pillars. A factor of safety of about 1.75 should be ample. Here again caution suggests that the factors of safety should be 2.0-2.2. If extensive areas are mined and supported by more or less uniform sized pillars, then this is the only available approach to the design.

Example

Depth of Workings = 200 m (656.17 ft)

Width of galleries = 3 m (9.84 ft)

Height of galleries = 3 m (9.84 ft)

Width of square pillars between centres of boards = 22.5 m (73.82 ft)

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

Solution

Strength of pillars

From Salomon's formula

$$S = 1320\frac{W^{0.46}}{h^{0.66}}$$

where   S = strength of pillars, lb/in^2

W = width of pillars, ft

h = height of galleries, ft

$$\therefore \qquad S = 1320\frac{(73.82 - 9.84)^{0.46}}{(9.84)^{0.66}} = 1976.8672 = 1977\,lb/in^2 = 138.97\,kg/cm^2$$

Load on pillars

$$P = p.dx \frac{1}{1-R}$$

where P = density of strata

d = depth of working

R = percentage extraction

$$R = 1 - \frac{a^2}{(a+b)^2}$$

where a = width of pillars

b = width of bords

$$R = 1 - \frac{19.5^2}{22.5^2} = 0.25$$

∴ Load on pillars

$$= P = \frac{2.306 x 200 x 1000}{100 x 100} x \frac{1}{1-0.25} kg/cm^2 = 61.49 \, kg/cm^2$$

Factor of safety

$$FS = \frac{strength \, of \, pillars}{load \, on \, pillars} = \frac{138.97}{61.49} = 2.26$$

WIDTH OF BORDS (GALLERIES)

Indian Coal Mines Regulations 1957 restrict the width of galleries to a maximum of 4.8 m.

MINING PROCESSES

Modern mining processes and systems may be divided into two classes

- Cyclic mining which comprises cutting, drilling and blasting and loading of coal, and
- Continuous mining in which cutting and loading go on simultaneously.

Cyclic Mining

Broadly, the cyclic mining uses the following combinations of operations

- Drill, blast and load, or
- Cut, drill, blast and load.

Loading of the blasted coal may be done manually or by mechanical means. Amongst the mechanical loaders gathering arm loaders, bucket loaders and scraper loaders are most common these days. For the haulage of coal in the district both track haulages or trackless haulages or conveyors are in use.

Continuous Mining

Continuous mining uses the following equipment: continuous miners (ripping, milling, boring or auger type), shuttle cars and conveyors.

In underground mining, first and foremost in the modernization process are the machines that extract coal: primarily the continuous and longwall miners.

DEVELOPMENT

Development of bord and pillar workings **involves drivage of a set of galleries in the seam cut by another set of parallel galleries** generally at right angles to them thus forming pillars surrounded by bords. The drivage of galleries can be done in one of the following ways:
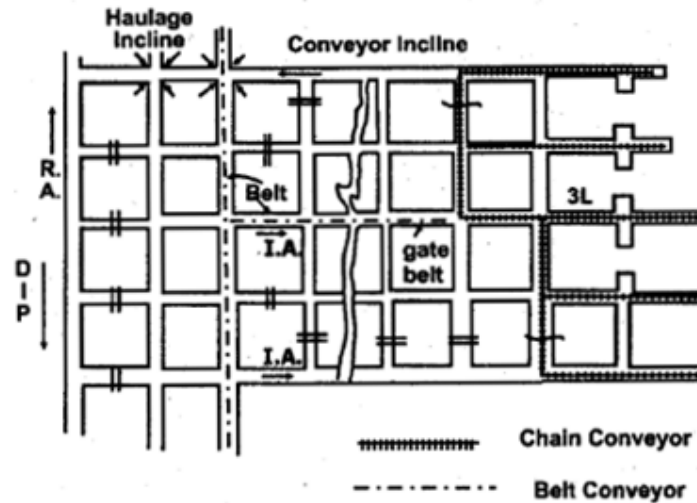
- Manual drivage, this method is now almost non-existent.

- Drill and blast, i.e., blasting off the solid and manual or mechanical loading.

- Cut, drill and blast and manual or mechanical loading.

- Cut and load mechanically by continuous miners.

Development by Blasting off the Solid

In this method, shotholes are placed on the face by electric drills and coal is blasted off the solid, using P5 explosives. On a face 4.2 m wide x 2 .2 m high generally 12 shotholes 1.5 m long each are drilled which yield 10-12 tonnes of coal per round of blasting and give a progress of 1.2 m. Coal thus got is hand-loaded. Blasting off the solid is especially suited for drivages in steep seams in which use of coal cutting machines is difficult.

Development with coal cutting machines

In the development of a panel with five headings on the strike, the headings are undercut by a coal cutting machine and shot holes are then drilled and charged with explosives and blasted. Blasted coal is hand loaded on to scraper chain conveyors which transport the coal from the face to a central belt conveyor. The central belt conveyor conveys the coal to the pit bottom. Each heading can be cut twice a shift, thus making a progress of 3 m per shift.

Development by conveyors

The equipments used are coal cutting machine, hand held electric drill, chain conveyors, and a central belt conveyor which brings coal to a direct rope haulage installed in the main dip of the district to transport coal to the pit bottom.

Development using continuous miners

Standard continuous miners can extract coal at a rate of up to 38 tons a minute depending upon the seam thickness. New, more powerful continuous miners are highly productive and are remotely controlled being designed for a variety of seams and mining conditions. These make possible even fuller recovery of the available coal, while removing the machine operator further from the working area.
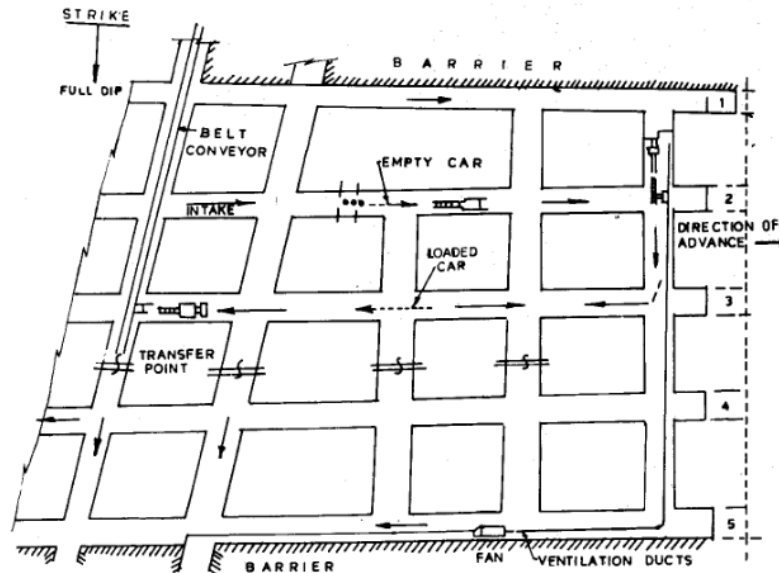
Continuous miners operate a *room and pillar mining system*. A series of 18 to 20 foot wide rooms are driven in the coal bed with pillars or columns of coal left standing to help support the roof. Roof bolts, typically four to six feet long steel bolts, are inserted into holes bored into the roof to bind the strata together support the roof.

Though there are many variations in design, continuous miners mostly consist of five main elements:

- A central body to carry all other components mounted on some type of drive mechanism to provide mobility (most commonly caterpillar tracks).

- A "cutting head" usually rotating drum(s) and/or chains with cutting picks attached

- A loading mechanism to pick up cut coal and deliver it into the central part of the machine

- A conveying system, usually a chain conveyor running in a steel trough from front to rear of the miner

- A rear jib section capable of a degree of vertical and horizontal movement to enable the coal to be delivered into a transport or loaded at a desired point.
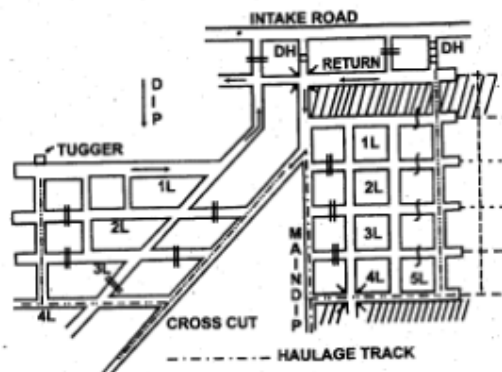
Following figure shows a panel with five headings on the strike in a seam 8.53 in thick dipping at 1 in 14. The galleries were 4.8 m wide x 3 m high driven along the floor and the pillars were 27.4 m x 27.4 m from centre to centre. The miner cut the full width of a gallery in two settings. First, 2.59 m was cut and then the miner was shifted to the next position to cut the other half of the gallery, the overlap being 30 cm.

The coal, thus cut, was loaded into a Torkar, three of which were provided to a miner such that when one was being loaded the other was discharging coal on to the belt conveyor and the third was standing in 'Queue' to be loaded.

Development by cross cuts

Development of the area to the dip side of the shaft level or prominent haulage level by cross cuts is a common practice in many mines as one direct haulage can work in the main dip as well as in the cross cut. The seam should be inclined and the gradient in the cross cut should not be less than 1 in 12, the limiting gradient for direct haulage. On milder gradients the empty tubs, when lowered, are not able to pull the rope of the haulage engine and trammers have to drag it, often on their shoulders. This seriously affects the output.

Development by crosscut

Cross cuts not only save the number of haulage engines but also help to develop the area on the strike when the main dip is advancing and for this reason a cross cut should make a sufficiently large angle with the main dip, provide the gradient of the former is suitable for operation of the direct haulage. In a seam of mild gradient cross cut is not an advantage. Cross cuts to the rise side are uncommon for haulage purposes.

In given figure one direct haulage works along the main dip and the same haulage operates for the crosscut. A panel is opened from the main dip and another from the cross cut so that development on the strike in the panel off the cross out takes place at the same time when the main dip and cross cuts also progress and prove a large area in advance. Two cross cuts, one going East and the other going West, branching off from the main dip at more less the same point are to be avoided as they weaken the pillar formed at the branch-off point.
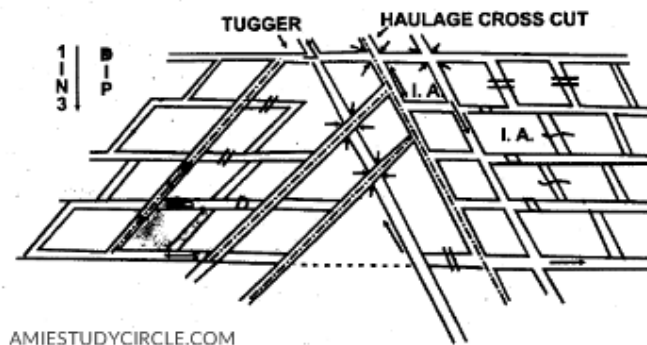
In the district opened on the strike from the cross cut the upper levels have to advance a good distance before a tail rope haulage can be installed in a dip-rise gallery. It is, therefore, common practice to have *only a few pillars* (usually 3 or 4) in the dip-rise direction in a crosscut district.

Development In steep seams

The methods of development by bord and pillar, so far stated, are suitable for working seams upto a gradient of 1 in 4. Special arrangements have to be made in working seams steeper than 1 in 4.

The special arrangements are as follows :

- The main haulage or conveyor should be, not along true dip, but along apparent dip to reduce the gradient of the road (see figure)

Development of steep seam

- The coal pillars should have smaller dimension along the dip and larger dimension along the strike.

- The level galleries should be joined, not along true dip but along apparent dip. The pillars, therefore, become rhombus shaped. The floor area of each pillar should be the same as the area required of a pillar St that particular depth. The acute angle of the rhombus pillar should not be small, otherwise the comers may crush.

- Except the haulage dip the cross-connections between levels should be staggered. Otherwise a sleeper or other material rolling down a cross-connection would roll down to the lowest level without any hindrance.

- From the main haulage road, tram lines should be taken to each level.

- Steps should be provided not only in dip galleries, but also in level galleries as the floor of the seam is steeply inclined and not suitable for walking.

- In the dip or rise galleries where the loaders have to carry coal in baskets to the tramming level, in addition to steps, hand bars should be provided.

- Face pumps should be trolley mounted.

- If chain conveyors are used at the face, the conveyors in the level galleries should be on the rise side. The skid mounted coal cutters and mechanical loaders have a tendency to skid to the dip side during flitting in the "level" gallery. Other equipment like drill transformers, gate end boxes, etc., should also be kept on the rise side, in the level for the same reason.

- The coal tubs or mine cars should be of special design to prevent spillage when hauled along the haulage plane.

PILLAR EXTRACTION

After pillars have been formed on the bord and pillar system, consideration has to be given to the extraction of coal from the pillars; the operation is known as pillar extraction. It is also referred to as **depillaring**, **pillar-cutting or broken working**.

In a method of depillaring, known as the **caving** method, the coal of the pillars is extracted and the roof is allowed to break and collapse into the voids or the decoaled area, known as goaf. As the roof strata about the cola 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.
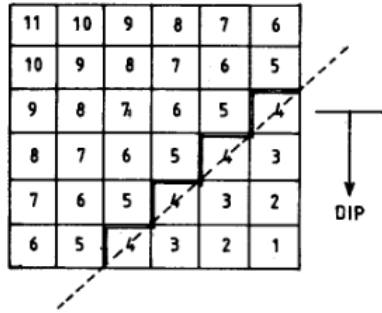
Depillaring with stowing is a method of pillar extraction in which the goaf is completely packed with incombustible material and in generally practised where it is necessary to keep the surface and strata above the seam intact after extraction of coal.

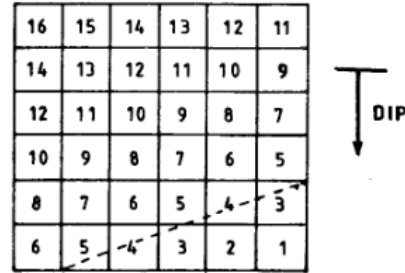## PRINCIPLES OF PILLAR EXTRACTION TECHNIQUES

The principles of designing pillar extraction techniques are as given below:

- Roof exposure at any one time should be minimal. In the Indian coalfields, where caving is practised, 60 - 90 m^2 exposure is normally allowed.

- The size of the panel should be such as depillaring can be completed within the incubation period. This period commonly varies between 6 to 9 months.

- The extraction line should be so arranged as to facilitate roof control. In practice a diagonal line, (Figure a) or step diagonal line of face (Figure b) is common.

(a)   (b)

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 races. It is also claimed that diagonal line of extraction helps in the caving of the roof.

In the panels worked in conjunction with **hydraulic sand stowing** step-diagonal line of face is preferred as it facilitates water drainage without flooding the working faces in the lower level.
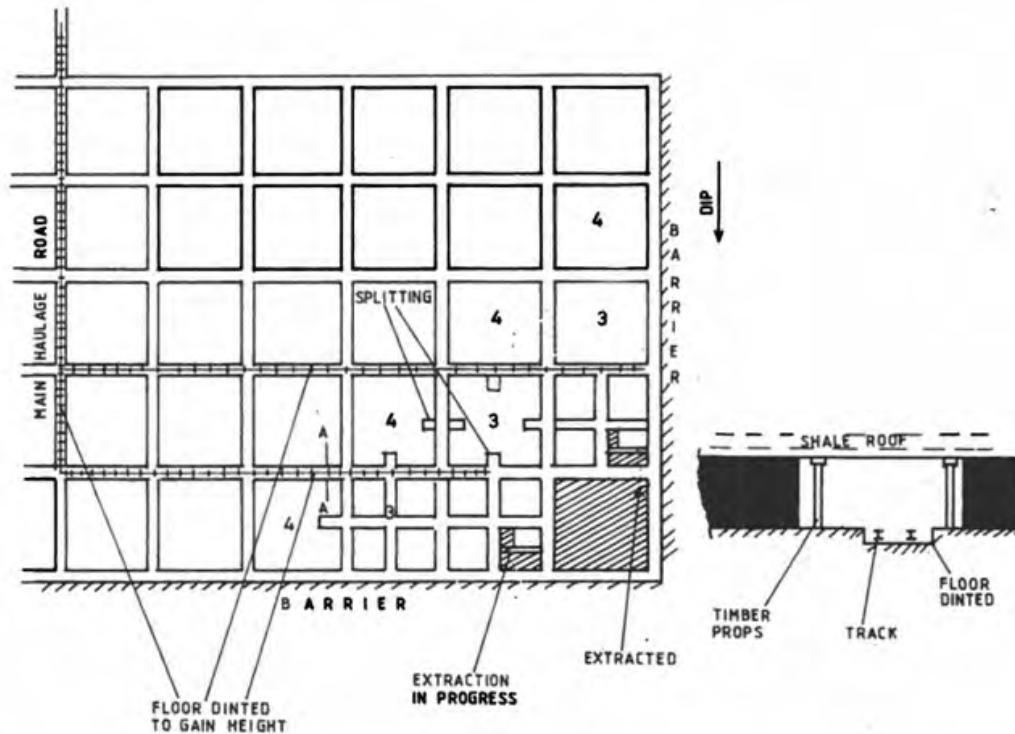
- The single-lift extraction is limited to heights of 4.8 m or less. If the thickness of the seam is more than 4.8 m, the extraction is done in multi-lifts and in that case hydraulic sand stowing is insisted upon. Seams up to 4.8 m thick can be mined by caving in one pass.

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

FACTORS INFLUENCING CHOICE OF PILLAR EXTRACTION TECHNIQUES

- **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.

- **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 the strike.

- **Roof of the Seam** For successful depillaring roof must cave regularly. A roof with compressive strength of less than 500 kg/cm^2 is normally a cavable roof.

- **Incubation Period of the Seam** A coal seam with longer incubation period may be extracted in larger panels. To achieve the same effect, i.e. to make the panel larger, mechanisation of operations are necessary in a seam with shorter incubation period so that rate of extraction is increased.

- **Dip of the Seam** In steeply inclined seams, special techniques of extraction have to be.

PILLAR EXTRACTION TECHNIQUES

Thin Seams

Depillaring in thin seams (say 1.5 m thick) can be done with caving with diagonal line of face. Following figure illustrates the sequence of extraction of pillars.

Transport of coal in the panel was done by hand tramming. Wide, low height tubs were used and the floor was also dented to gain additional height. A pillar was divided into four stooks by driving dip and rise and strike splits. Stooks were extracted by blasting off the solid and the blasted coal was manually loaded into tubs. Roof was supported by wooden props and cogs. In some mines, in Central India, scraper chain conveyors were used with success and gave improved results.

A seam up to 3 m thick is also worked by the same method as above. In this case, however, floor denting is not necessary and tubs of low height need not be used.

Coal Seam 3 to 4.8 m thick

As during development, the height of split galleries are limited to 3 m. Hence in seams more than 3 m thick, the first step is to blast down the roof coal in the splits and in the original galleries before commencing the extraction of the stook (stack). This operation of roof heightening is done in small stretches adjacent to the slice to be extracted as heightening of roof over large area may create the problem of stability. The height of extraction is kept 4.8 m leaving a layer of coal against the roof.

Thick Seams

Caving methods

The major difficulty in extraction of pillars in thick seams is the difficulty of roof control and the spontaneous combustion and both these are aggravated if the extraction is done by caving. All the same some attempts were made in the past to extract the pillars in flat and thick seams by caving.

For example, a seam 14.63 m thick was extracted by caving. It was initially developed in three sections. The first 2.77 m was developed along the floor, over which after leaving a parting of 3 m, the second section (2.76 m high) was developed; the third section (3 m high) was developed along the roof leaving a parting of 3 m below it. During depillaring, the lower sections were joined together by puncturing the parting, thus making a section 8.53 m high which was extracted as a seam. The two sections, i.e., the top 3 m section and the bottom 8.53 m sections were extracted simultaneously by caving and the coal parting (3 m) was left in the goaf. The top section face was kept in advance of the bottom 8.53 m section by about 15 m and the coal was handled by a common haulage.

In seams up to 8.53 m thick the widespread practice has been to divide the pillars in four stooks (equal quarters) and each stook was extracted by blasting off the solid. After the withdrawal of the timber the roof was allowed to cave.

Methods such as the above resulted in heavy losses of coal and quite often led to spontaneous heating of coal. Adverse strata control problems always existed and, in some cases, premature collapses occurred. Hence, *this method is not practised these days*.

Blasting Gallery Method

Conventional bord and pillar mining in thick seams is associated with very low percentage of extraction [around 30% in a panel] even under favourable conditions. Extensive development of pillars carried out earlier in thick seams also results in large reserves of good quality coal locked up in developed bord and pillar workings. About 50 % of coal reserves in India are in seams with thickness more than 4.5 m which fall under the category of thick seams. Exploitation of thick seams by u/g method poses certain difficulties/problems.
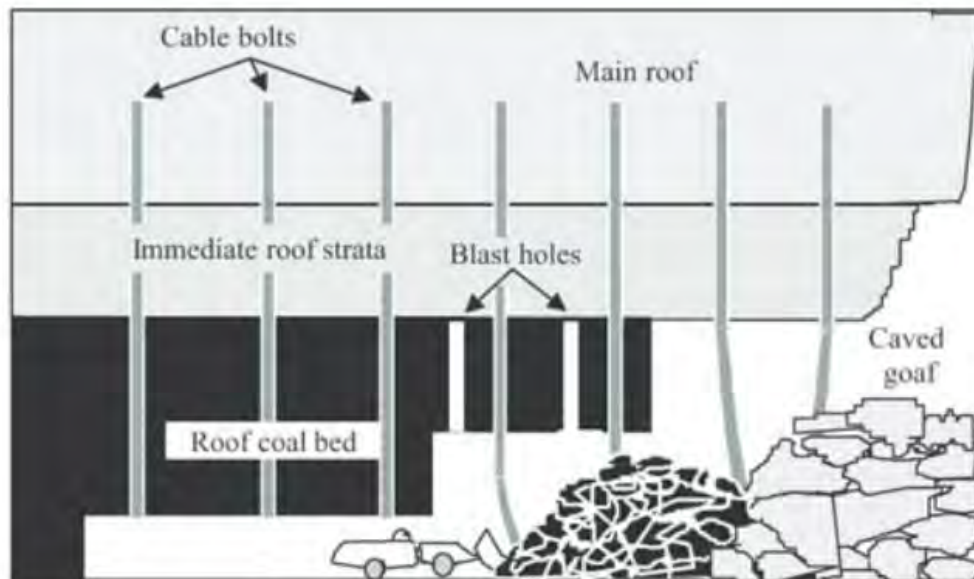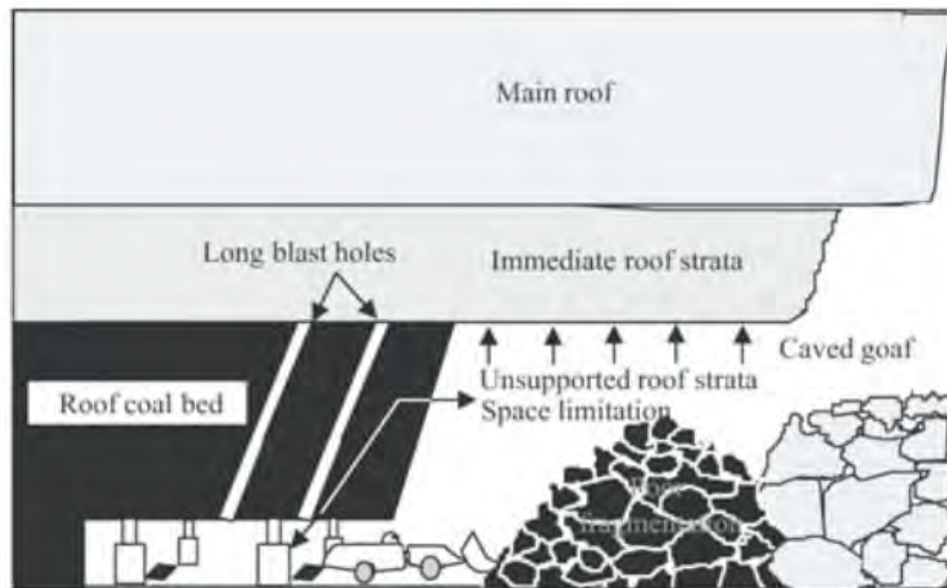
Blasting gallery (BG) method is the appropriate method for the extraction of thick seams up to a thickness of 8 – 11 metres. Mining by BG method produces about 1000 T/day with 85 % of extraction
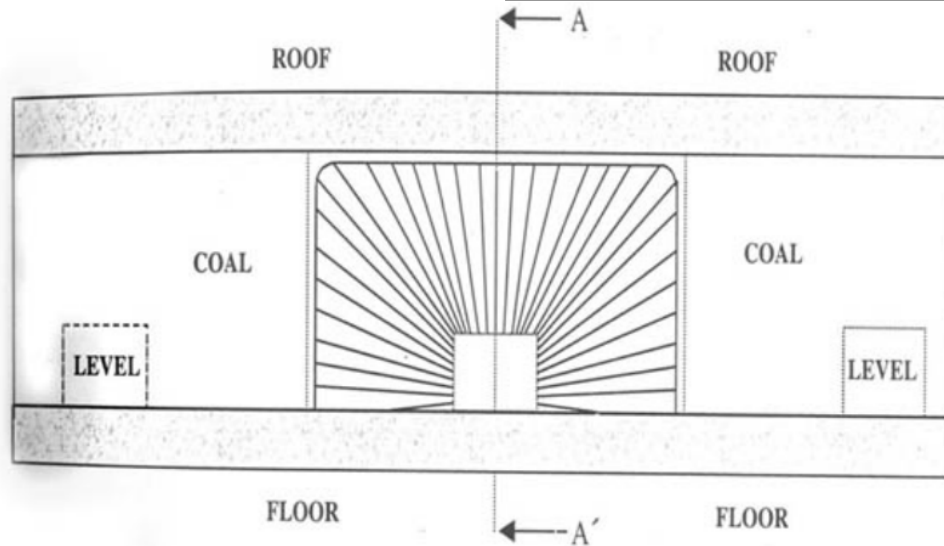
Principles of Blasting gallery method

- The basic principle of BG method is to extract thick coal seams by drilling and blasting of roof and sides of galleries, which are driven at the bottom of the seam at regular intervals.

- Ring holes are drilled in the rooms left between the two adjacent galleries in the roof and sides at regular intervals varying between 0.75 to 1.5 m. by a crawler mounted JUMBO drill.

- Blasting is done using explosive cartridges separated by inert spacers and detonating fuse, so that the explosive spreads all along the length of the hole.

- Load Haul Dumpers (LHDs) with remote control carry out loading of coal enabling the operator to stand under the supported roof and operate the LHD. LHDs carry the coal from the face and discharge into the armoured chain conveyor, which feeds to the belt conveyor network for transport to the surface.

- The development galleries are driven at the floor of the seam.

- It is important that the correct size of rise/dip and rooms are maintained to avoid roof control problems during the retreating of the panel.

Ring pattern of holes is shown in following figure

Advantages of BG method are:

Full thickness of the seam can be extracted in a single lift.

- Higher percentage of extraction i.e. 75 – 85.

- Capital investment is nominal when compared to longwall project.

- Easy to train the man power and easy maintenance of the equipment.

- Extraction is carried under fully supported roof i.e. with remote controlled LHDs.

- Safety of the workmen can be fully ensured

- This method can be also be adopted in virgin/developed seams.

- Most of the equipment and spares are indigenously available

- Loss of production is minimum while shifting the equipment.

- This method is highly flexible as several units are in operation in a district

- Even if one of the units is under break down, production from the district will continue to come.

- The time required for preparation of panel in relation to the total life of the panel is less than other mechanised methods.

Limitations are:

- This method is not suitable for gassy mines and seams with degree-I gassiness are most preferable.

- The method is suitable only for gradient more than 1 in 5 to allow easy movement of tyre mounted LHDs and crawler mounted electro- hydraulic jumbo drills.

- Though the percentage of extraction is around 75-85, still coal left in the goaf is likely to undergo spontaneous heating.

Manner of extraction is

- Each pillar shall be split into two equal parts by level split of width not more than 4.2 m. and height not more than 3m. along bottom section.

- The splitting of pillars shall be restricted to one pillar from the pillar under extraction.

- The long hole blasting shall not be practiced at any place where two free faces are not provided.

- Before practicing long holes blasting (ring holes) the operation of drilling and blasting are carried out in stages to a height of full thickness to expose roof with increasing angle and length of short holes in bye of the galleries i.e., called "Potato blasting".

- The full thickness of the seam is extracted by blasting a ring of shot holes with about 33 shot holes.

- The shot holes are drilled in ring pattern and sloping at an angle of about 300 to 400from the vertical towards the goaf.

- The spacing between consecutive rings at shot holes shall be 1.5 m.

- The shot holes are drilled in a ring spaced 1.5m. apart by means of JUMBO drill from the level rooms in such a way that they cover half the pillar on rise side and half the pillar on the dip side.

- Extraction in level galleries shall be from in bye to out bye forming a diagonal line at an angle of about 600 to the level.

- A curtain of thickness of coal not less than 1.5m shall be left between two adjacent rooms after blasting of rings.

- However, it was observed that this curtain provides protection during remote operation of the LHD in the goaf.

- **Blasting of Ring holes**   After drilling is completed, shot holes are charged with the explosive approved by DGMS.

- The total number of shot holes in a ring are 33.

- The cartridges of explosives are distributed over the whole length of shot holes by spacers tied together by a detonating fuse called RING CORD which are initiated by No. 6 electric detonator.

- About 0.5 – 0.6 in length of all holes are stemmed with clay at the end.

- On completion of charging and stemming of all holes, the circuit is connected in series. Before blasting, the last installed roof support at the goaf line is removed and next support line is reinforced with extra support.

Support systems in BG method are

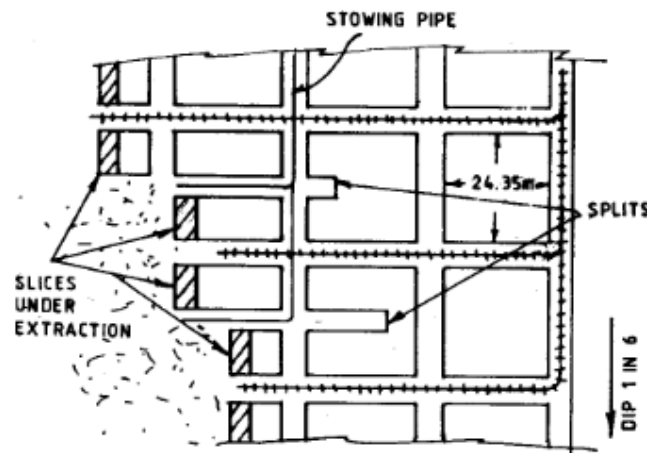- All roof bars set on hydraulic props shall be braced suitably.

- Adequate setting load of not less 6 T shall be provided.

- The distance between two sets along the gallery shall not exceed 1.00 m/1.5 m depending on the roof conditions

- The roof between the bars shall be suitably lagged by wooden sleepers.

- As a precaution against the dislodging of hydraulic props accidentally by moving machinery, the hydraulic props are tied together to roof bars by means of flexible steel wires.

Stowing methods

Pillars in coal seams more than 4.8 m thick are normally extracted in conjunction with hydraulic sand stowing in lifts of 3 m or so. Stowing is adopted for better roof control and as a precaution against spontaneous combustion which are more frequent in thick seams. Also, stowing results in improved percentage recovery, and conservation.

Basically, the method of extraction of pillars with stowing is similar to that with caving excepting that (i) the area of exposed roof at any one time may be slightly more than that exposed with caving; with stowing the exposed are of about 100-150 m^2 may be permitted, and (ii) the line of extraction is usually kept step-diagonal to facilitate drainage of water so that working faces are not flooded.

Following figure illustrates the method of extracting pillars by using stowing method. The seam is overlain by sandstone roof and at the floor it is burnt into 'Jhama'. The dip of the seam is 1 in 6. The seam was developed on bord and pillar method in two sections (a) along the floor, and (b) along the roof with 1.82 m coal left in the roof.

The pillars were 24.35 x 24.35 m from centre to centre. As shown in given figure, a level split was driven in the pillar to be extracted, dip and rise slices approximately 4.8 m wide were then taken from the original level up to half the distance of the pillar.

After extraction of the slice the void was slowed solid with sand leaving a rib of 1.8 m. The next slice was then taken and so on. A diagonal line of face was maintained, the working face in the dip level being kept in advance of the upper level face by half a pillar, i.e. by 12-15 m.
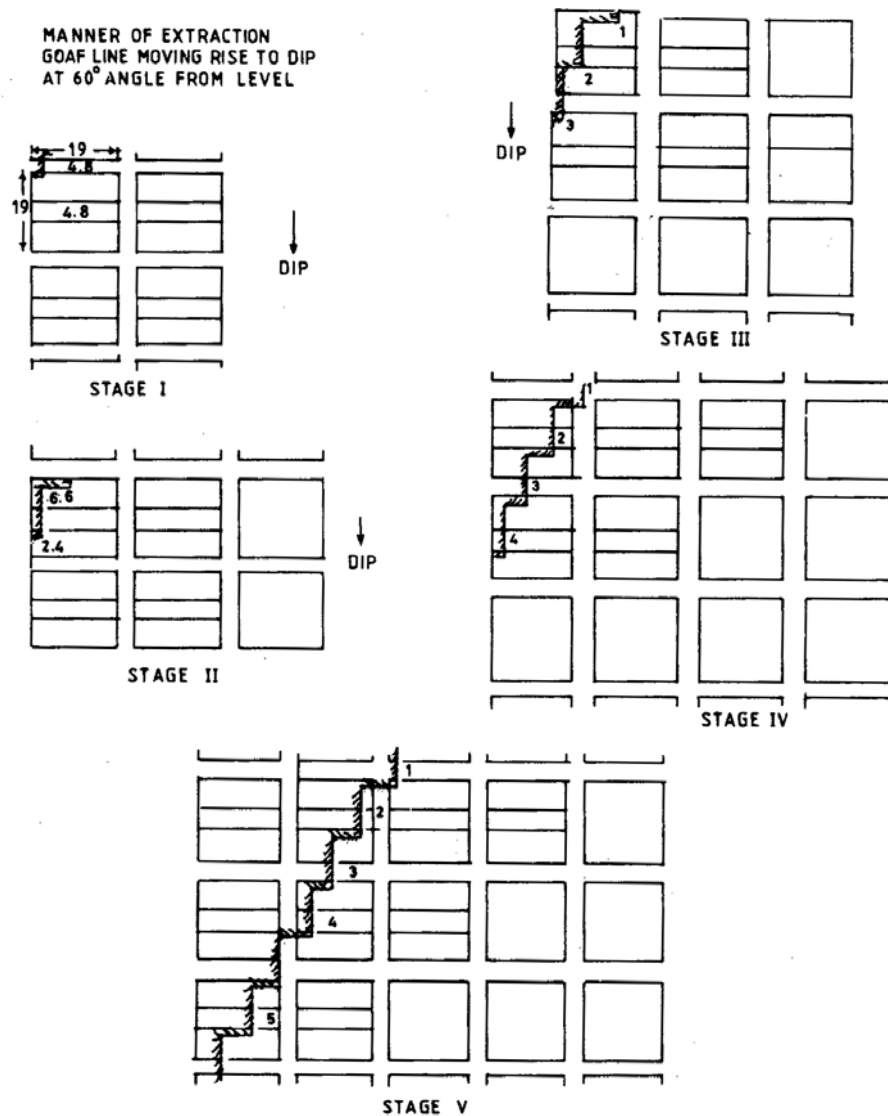
After the first lift of all the pillars in a panel was extracted and coal replaced with sand up to a height of 2.43 m, the second lift was developed over the stowed goaf of the first lift and was extracted in the similar manner followed by the third lift. The fourth lift was extracted from the top section already developed initially, below which about 3 m coal was left to form a solid floor.

Example

Describe blasting gallery method with neat sketches to extract thick coal seam having thickness 7.5 m.

Answer

Following figure shows the manner in which pillar extraction was done at a Colliery in Jharia coalfield using blasting gallery method.

The seam is 7.5 m thick and has a gradient of 1 in 7. It was developed along the floor on bord and pillar method, the pillars being 23 m x 23 m (centre to centre). During extraction, the pillars were divided in two parts by driving a split gallery 4.2 m wide x 3 m high. Splitting of pillars was done up to one pillar ahead of the pillar under extraction. From the galleries 4-5 m long x 42 mm diameter shotholes were drilled in a ring using Jumbo drills at a spacing of 1.4-1.6 m between the successive shotholes leaving 0.6 m coal against the roof. The total number of shotholes in a ring were 22. Each shothole was charged with 2 kg of explosive (including explosive of detonating cord) and all the shotholes of a ring were blasted in open round using short delay detonators. Coal was loaded out using remote controlled LHDs with 3 m^3 bucket.

Extraction was done from rise to dip, the line of face being at approximately 60 to the levels. The roof was supported by grouted cable bolt/steel bolts spaced at 1.2 m in each row and rows we are at 1.4 m intervals. The junctions of galleries were supported by steel joist placed on 40 ion hydraulic props. The first junction from the goaf edge was further reinforced by cogs erected in the dip and rise galleries of a level.

EXTRACTION OF PILLARS IN THICK & STEEP SEAMS WITH STOWING
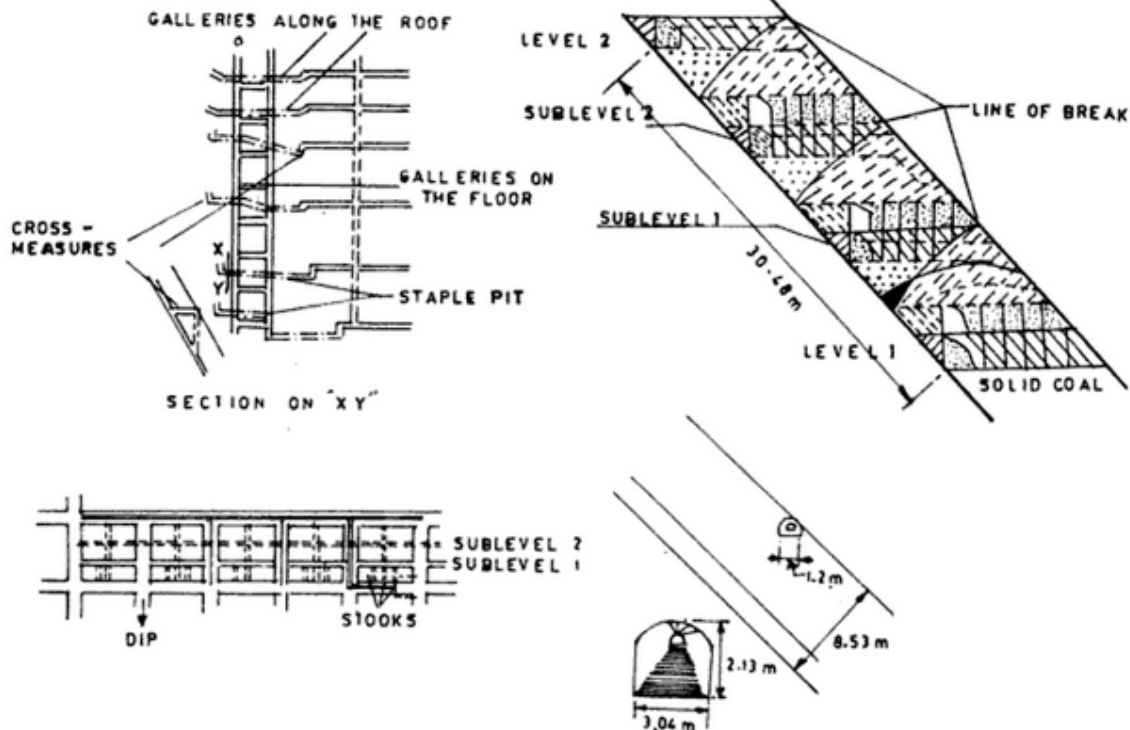
Special techniques are used for the extraction of pillars in thick and steep seams which permit work on the level.

A seam 8.53 m thick was developed on bord and pillar system at a colliery in Jharia coalfield and the pillars were extracted by sublevels in conjunctions with hydraulic sand stowing.

For development, two headings 18.28 m apart were driven along the floor of the seam and were connected every 15.24 m as shown in figure.

From the junctions crosscuts were driven towards the roof of the seam and when the roof of the seam was reached level galleries at right angles to the main road were driven on each side of the original crosscut levels. A staple pit was sunk in each of these levels to connect the companion road for the transport of the coal. When these levels in the roof coal were well clear of the two main roads, cross-cut levels were driven again—this time to touch the floor of the seam. When the floor of the seam was met, levels were driven east and west along the floor of the seam. These levels were connected by means of rise and dip galleries 22.86 m apart.
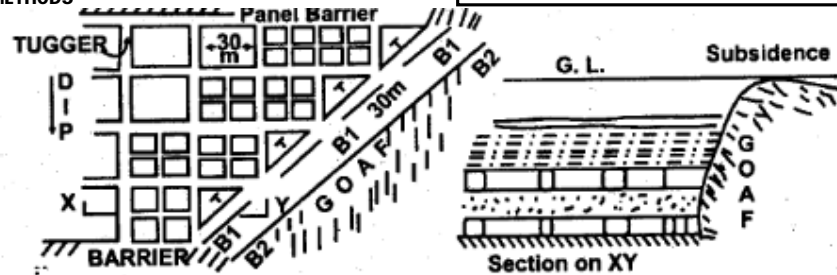
For the extraction of pillars a sublevel was driven between two levels such that one-third of the pillar was left to the dip of the sublevel and two-thirds of the pillar on the rise side. The dip side one-third pillar was subdivided into three stooks which were extracted in conjunction with hydraulic sand stowing. Simultaneously, another sub-level was driven to divide the rise-side two-thirds of the pillar into two parts - also extracted in the same way as the first one-third pillar in conjunction with sand stowing. *Technically, this method was satisfactory but the total output from a district was rather low.*

DEPILLARING OF CONTIGUOUS SEAMS

The method of extraction of contiguous (very close or connected) seams depends primarily on the thickness of the parting. As has been stated earlier, development galleries are driven in the seams such that galleries and pillars are vertically coincident. In some mines, a seam thicker than 7.5 m is developed in two sections, leaving a parting of 3 m and extraction takes place as if there were two contiguous seams.

If the stone in the parting between the two contiguous seams, less than 1 m thick only one seam is developed and the two seams are treated as one seam during pillar extraction. The stone parting is blasted out and thrown in the goaf. If the stone parting is between 1 and 3 metres so that it is not economic to blast out the stone, the seams or sections are depillared simultaneously, that is, the depillaring is conducted in the two seams or sections such that the line of extraction of the lower seam is vertically (or nearly so) below that of the upper seam (see figure).

If one of the seams or sections is not developed, entry is made into the virgin seam through a drift starting at a suitable point in developed seam. The undeveloped seam is partially developed for one or two pillar-lengths at a time and pillar extraction is carried out simultaneously, keeping the supports almost vertically coincident.

The withdrawal of supports is done simultaneously. If the top section supports are withdrawn before those in the lower, the roof fall in the top section punctures the parting and affects the bottom section's supports; if bottom seam supports are withdrawn first, the parting may collapse and supports in the top section may be lost in the collapse. Coal of both the sections is loaded at one point wherever possible.

When the stone parting is thicker than 3 m the two seams are developed with galleries and pillars vertically coincident either throughout the mine or a panel, and extraction proceeds in the two seams at the same time almost simultaneously with line of goaf in the top seam not more than one or two pillars ahead (i.e. outbye) of the bottom seam line of goaf.

SUPPORT SYSTEMS USED IN DEPILLARING AREA OF BOARD AND PILLAR SYSTEM OF WORKING

The present support system for different working places in development and depillaring workings are as follows:

Goaf edges

At goaf edges cogs shall be set skin to skin. Props shall be set in between cogs, cogs & coal sides.

Working faces

- At working faces props shall be set at a maximum interval of 1.2 m between the rows of props or in the same row.

- Cogs shall be set at all entrances to the areas under extraction & also at interval of not more than 2.4m in the area under actual extraction.

- Areas close to the faces where supports are likely to be affected due to blasting shall be supported by cross bars.

Support of galleries

- Props shall be set at interval of 1.2 m between them in the same row & at a max interval between rows of props in all galleries & splits within a distance of 2 pillars from the pillar under extraction or a distance of 30m, which ever greater.

- Cogs shall be set at all junctions.

Wider gallery

Gallery greater than 4.8 meter shall be supported with cogs at interval not exceeding 2.4m between cogs and between rows of cogs.

ASSIGNMENT

Q.1. (AMIE W11, 12 marks): A 2.5 m thick coal seam, dipping at 1 in 10, located at a depth of 100 m from the surface, is to be worked by "Bord and Pillar" method of working. Give the district layout, support system, ventilation arrangements and manpower requirement for a production of 300 ton/day from the district.

Q.2. (AMIE W11, 8 marks): Explain briefly any two methods of extraction of pillars with the help of neat diagram.

Q.3. (AMIE S13, 12 marks): Explain the sequence of pillar extraction in the bord and pillar system of mining for a seam of 3 m thick and lying at a depth of 250 m with suitable sketches. Assume relevant data wherever necessary.

Q.4. (AMIE , 8 marks): Compare Bord and Pillar system with Shortwall system of coal mining.

Q.5. (AMIE S13, W13, 12 marks): What are the applicability conditions for stowing? Discuss and draw a schematic diagram of surface arrangement of hydraulic stowing practiced in India.

Q.6. (AMIE S13, W14, 15, 10 marks): Describe blasting gallery method with neat sketches to extract thick coal seam having thickness 6 m.

Q.7. (AMIE W11, 5 marks): Write a short note on Pillar extraction by hydraulic stowing.

Q.8. (AMIE W13, 12 marks): A Give a layout of depillaring panel producing 600 ton per day. The coal seam is 3.2 m thick lying at a depth of 300 m and developed by Board and Panel method of mining. Explain cycle of operation of this panel in detail. Assume relevant data wherever necessary.

Q.9. (AMIE S14, 6 marks): Explain the principle of continuous mining method for extracting coal.

Q.10. (AMIE S14, 14 marks): Describe the schemes of pillar development and depillaring by using continuous miners with the help of suitable layouts.

Q.11. (AMIE W14, 12 marks): Give a layout of 5 heading mechanised panel producing 400 ton/day coal by Board and Pillar method. The coal seam is 2.8 m thick and lies at a depth of 250 m. The gallery width is 3 m. Explain cycle of operation for this panel. Calculate percentage of extraction during development, roof support requirement and OMS. Assume data wherever required.

Q.12. (AMIE W14, 15, 8 marks): Discuss various support systems used in depillaring area of board and pillar system of working.

Q.13. (AMIE W15, 10 marks): Explain the sequence of pillar extraction in the Bord and Pillar system of mining for a seam of 4.2 m thick and lying at a depth of 320 m with suitable sketches. Assume relevant data.

Q.14. (AMIE W15, 10 marks): Explain the methods used for development with schematic layout, for the Bord and Pillar mining method.

Q.15. (AMIE S16, 20 marks): What are the current trends of mechanisation of bord and pillar method of mining? Give a layout of one such combination to produce 10,000 ton/month for a developed district. Assume your conditions, state the manpower requirement, production per shift and machines used.

Q.16. (AMIE W16, 12 marks): Discuss the sequence of pillar extraction in the bord and pillar system of mining for a seam 2.5 m thick and lying at a depth of 250 m with suitable sketches. Assume relevant data.

Q.17. (AMIE W16, 8 marks): Explain the support system used in roadways and a long the face in Bord and Pillar mining method.

(For online support such as eBooks, video lectures, audio lectures, unsolved papers, online objective questions, test series and course updates, visit www.amiestudycircle.com)