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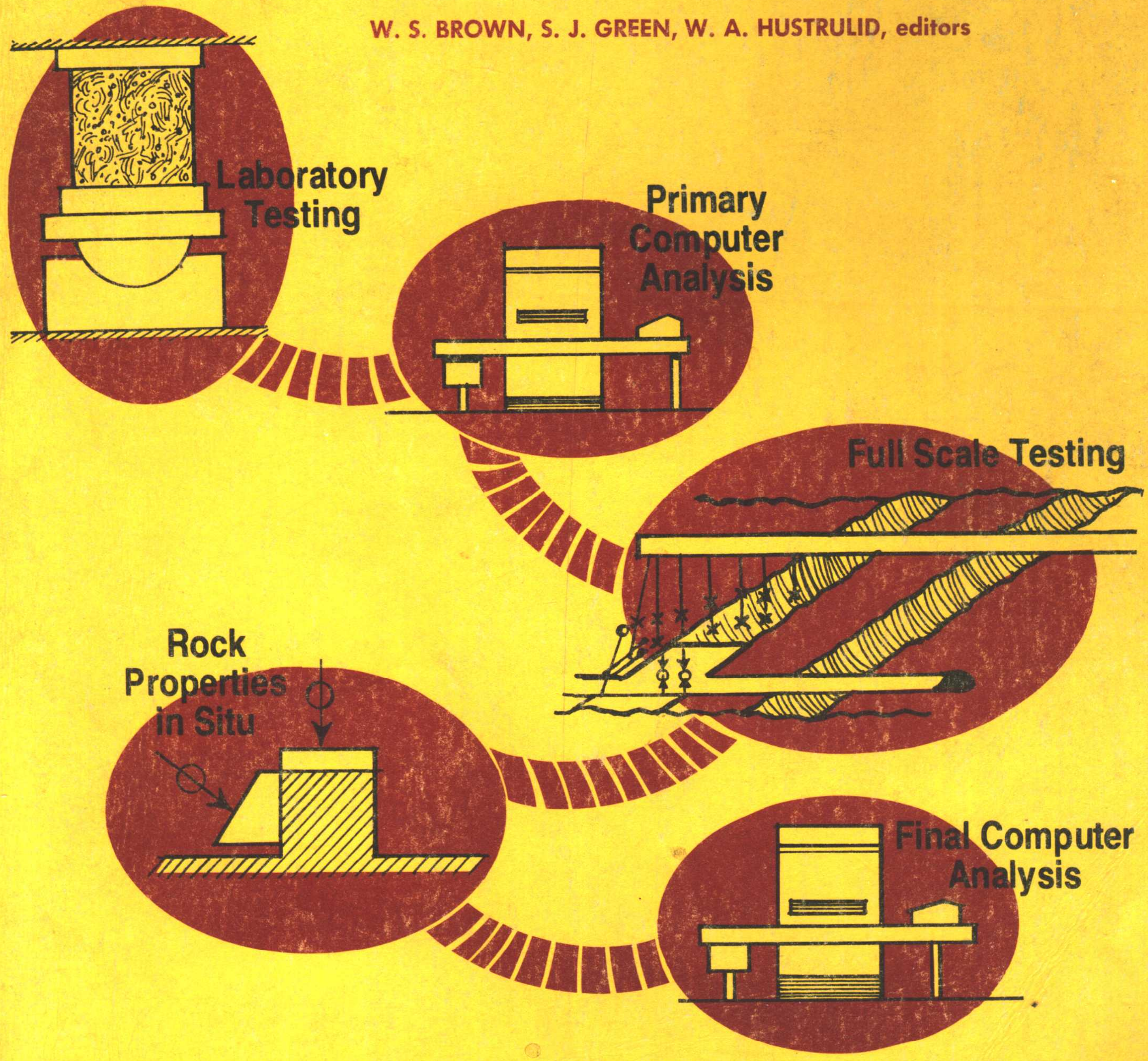
Monograph on Rock Mechanics Applications in Mining

W. S. BROWN, S. J. GREEN, W. A. HUSTRULID, editors



Monograph 1 on
Rock Mechanics Applications in Mining

Papers presented at 17th Symposium on Rock Mechanics
Snowbird, Utah, August 1976

Wayne S. Brown
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PREFACE

The 17th Symposium on Rock Mechanics held at Snowbird, Utah, in August 1976, was sponsored by the University of Utah in cooperation with the U.S. National Committee for Rock Mechanics of the National Academy of Sciences/National Research Council. The general theme of the meeting was *Site Characterization* which, as can be observed from the session titles listed below, was interpreted rather broadly.

- Modeling and Analysis
- Coal Recovery—Thick and Multiple Seams
- Oil and Gas Applications—Porosity, Permeability, Rock Mechanics
- Surface Structures/Slope Stability
- Underground Opening Design
- Geothermal Energy Recovery
- Single Seam Rock Mechanics for Mine Design
- In Situ Methods
- Near Surface Underground Opening Design
- Blasting Design
- Rock Mechanics I
- Rock Mechanics II
- Ground Support

By taking this approach it was hoped to attract as many participants and good papers as possible from the various rock mechanics interest groups so that maximum technology transfer within the field could occur. It was felt that this was accomplished at the meeting.

A Preprint-Proceedings volume containing all the papers presented was prepared and is available at $30.00 per copy from Utah Engineering Experiment Station, University of Utah, Salt Lake City, Utah, 84112.

Contrary to recent practice, however, the volume was not copyrighted. This was done to encourage the authors to obtain a wider readership by publishing in suitable technical journals or through other outlets.

The session developers charged with creating the mining and mining-related sessions had, it was felt, done an excellent job in attracting papers of interest to the mining community as a whole. Therefore, the Book Publishing Committee of SME-AIME was approached and SME-AIME agreed to publish this collection of papers as one of their monograph series.

It is hoped that this attempt at improving the technology transfer from those engaged in rock mechanics to the ultimate users of new technology, the mining industry, will prove useful and popular. For a second volume to appear, a continued active participation is required from the industry.

It is extremely important that the applications of rock mechanics to mining problems—both successful and unsuccessful, simple and complex, inexpensive and expensive—be presented and discussed at such symposia. Only with such a sharing of experiences—particularly by those engaged in field operations—can our ability to design and construct rock structures, whether underground or surface, improve at the maximum rate.

As the mining of ever-deeper ore bodies and lower ore grades proceeds, all possible techniques must be employed to assure an economic operation. The application of rock mechanics principles will be ultimately involved.

The ability to provide meaningful rock mechanics guidance to operations has improved greatly during the past few years. Unfortunately, it is still often unused or misused. Hopefully, through this means of communication, a better understanding of the state-of-the-art can be achieved, and the areas requiring strengthening identified.

WILLIAM HUSTRULID

Salt Lake City, Utah
February 1977

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COAL RECOVERY

THICK AND MULTIPLE SEAMS

Chairman: John W. Wilson
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Chapter 1

DESIGN CONSIDERATIONS FOR MINING THICK SEAMS AND SEAMS LYING IN CLOSE PROXIMITY TO ONE ANOTHER

by

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According to the Project Independence blueprint, a 270 percent increase in coal production is expected from western coal fields compared to an increase of 100 percent for the nation as a whole. Furthermore, 30 percent of the total United States coal reserves lie in the western states, which are classified as beyond the strippable limits and can be recovered only by underground methods. In view of the fact that the majority of the seams in the West are thicker than those presently mined in other parts of the country, it is important to consider the parameters that relate to mining thick seams and the factors that affect such mining systems. Apart from thick seams, a common feature of many western coal fields is the occurrence of multiple seams that lie in close proximity to one another. These multiple seam deposits present difficult mining problems that have not been encountered to any degree in other U.S. coal fields; for example, ground pressure changes in one mine level caused by mining in the other, sudden water or gas influx from the adjacent levels, the danger of spontaneous combustion in gobs and large and complex subsidence displacements on the surface. Perhaps equally important is the fact that the country can ill afford the present systems of underground mining that attain only 50 to 60 percent coal recovery. With the probability of increased thick seam mining, conservation shall be a focal point in future mine design systems. It is possible that in the future it will be forbidden to adopt the present day wasteful mining methods to ensure that coal can be conserved for future generations.

Review of Mining Methods

A number of thick seam mining methods have been successfully tried abroad; notably among them are multi-pass longwall mining with or without packing, room and pillar slicing with hydraulic sandstowing and sublevel caving. The following paragraphs describe the general features of these methods.

(A) The Mining of Thick Seams by Longwall Methods - The most common method of mining is to extract panels of coal in the upper part of the seam first and to either cave the roof or stow the mined out area before mining the second and subsequent panels in the lower parts of the seam. In general, it is necessary to mine the slices or lifts of the seam in descending order so that optimum recovery is possible. There are a number of multi-lift techniques which have been used over the past two decades and these can be summarized as follows:

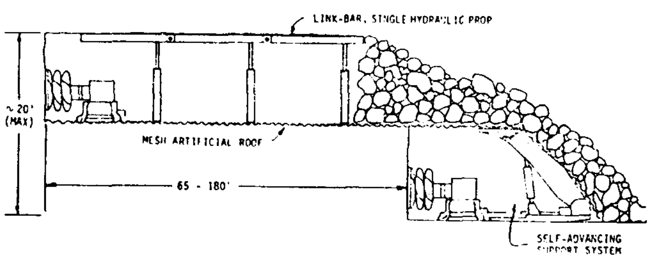
1. Simultaneous - Parallel faces following one another at two horizons in the seam within the same panel of coal. The faces are usually less than 180 feet apart and incorporate:
   - (a) Artificial roof for the lower face (Japan)
   - (b) A thin parting as the lower face roof (Japan)
   - (c) A coal band as the lower face roof (USSR, Europe).
2. Non-Simultaneous - The lower portion of the seam is excavated several years after the upper lift has been taken and time has been allowed to elapse to consolidate the gob area. In this system the roof of lower lifts is created by:
   - (a) Artificial roof for the lower face
   - (b) A thin parting as the lower face roof
   - (c) A coal band as the lower face roof
   - (d) Consolidated gob as the lower face roof
3. Non-Simultaneous - Lower lift taken first.

Details of these techniques will now be discussed.

1. (a) Simultaneous - Artificial Roof

For many years, mining companies in Japan and Europe have operated simultaneous faces with an artificial roof to excavate deep lying coal seams where the thickness of minable coal exceeds 18 feet. An early example of this technique is illustrated in Figure 1. This scheme utilizes a prop and link bar arrangement to support the upper face and self advancing supports for the lower face. As the upper face progresses, an artificial floor is laid between the props to form an artificial roof for the lower face. A variety of materials and composite materials are used for this base, including steel matting alone, matting combined with steel channel, bamboo, and rolled steel sheet stock. In general, the advance of these faces tends to be slow and the production rate often low. The extraction ratio is, however, quite high.

An example of a refinement of this technique is currently used in the Mitsui Collieries in Japan. Here, the upper prop and link bar support system has been replaced with chock-shield self-advancing supports, and strips of steel matting are laid on the floor in a specially designed area between the conveyor and the front leg of the support as shown in Figure 2. Because of the extra space needed for the matting, it can be seen that this technique is best suited to the one web back support system.



ORIGINAL JAPANESE MULTILIFT TECHNIQUE

Figure 1

1. (b) <u>Simultaneous - Rock Parting as the Intermediate Roof</u>

Where a thin rock band separates two economic coal seams, several mining companies use this band as an intermediate roof for a multi-lift mining system. This system is currently in use at depths of 2000 feet below the Pacific Ocean in Japan and where the upper seam varies from 9 to 19 feet thick and the lower seam from 7 to 8 feet. The details of this mining technique are similar to that described earlier with the exception that no artificial roof is required.

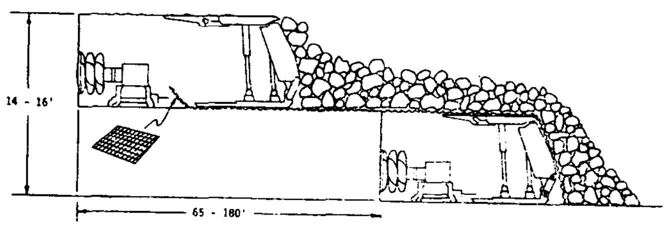
1. (c) <u>Simultaneous - Coal as the Intermediate Roof</u>

There are few differences between this and the method described above. Typically, a two to four foot coal layer is left as the intermediate roof in this system and special care has to be taken to check on possible spontaneous combustion problems due to coal being left in the gob area.

<u>Assessment of Simultaneous Techniques</u>

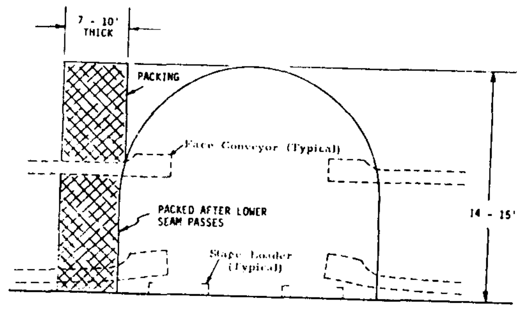
Experience has shown that coal can be mined in simultaneous multiple lifts and significant economies can be achieved in entry development costs if single entries are used; not only two levels of mining in one panel, but also for two adjacent panels.

At deep mines, i.e., below 1,000 feet, entry drivage and maintenance work can become serious problems. However, to minimize these maintenance costs, manufacturers and coal companies have pioneered techniques wherein a single set of development entries can be driven for both the upper and lower lifts as shown in Figure 3. The single entry shown acts as both the headgate for the left panel and the tailgate for the right panel.



MODIFIED JAPANESE MULTILIFT TECHNIQUE

Figure 2



A SINGLE ENTRY MULTILIFT TECHNIQUE

Figure 3

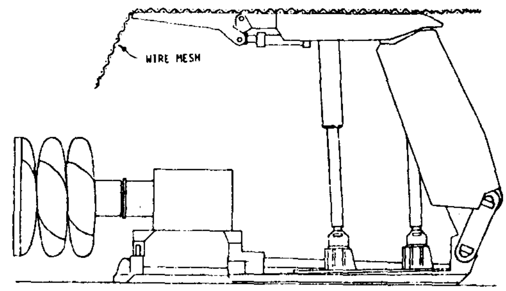
Each such entry is driven in an arched shape and lined with steel arches to withstand the large ground forces. As the upper face (left) passes, a pack is installed to seal the entry from the resulting gob and to provide additional roof support. Similarly, as the lower left lift is taken, a pack is provided to completely seal and stabilize the left side. The lifts are removed from the right panel in a similar fashion. This technique has been used for at least the past six years and presently at least two sections, such as those described above, are operating in Japanese mines. The experience with this technique has been good with a high extraction ratio and relatively minor entry deformation problems.

The economics of increased extraction ratio and decreased development cost is, however, offset by relatively low productivity. This is caused, for the most part, by the fact that two longwall sections are operating in an inter-dependent fashion at a spacing of 100-150 feet. This distance must be maintained between the two units to minimize ground control problems. The operating efficiency of the double section is thus much less than that of each individual section; i.e., if each face has an operational efficiency of 60%, then that of the combined units will be 40% to 50%.

2. Non-Simultaneous Thick Seam Techniques

To eliminate the major production inefficiencies present in the simultaneous mining techniques, several mining companies in Europe and Japan are presently using techniques where the lower lift is removed several years after the gob from the upper seam has fallen, settled and re-consolidated. This results in increased entry development costs since separate entries are normally driven for the top and bottom lifts. However, the productivity is almost always higher since the upper and lower lifts are independent of one another and each can advance at its own pace.

The first three of the non-simultaneous techniques outlined earlier are similar to their simultaneous counterparts, with the exception that both Japanese and European operators have used techniques where the artificial roof is laid by the upper set of supports as they advance. This technique has been used for many years by successfully using one-web back chock type supports with a wire mesh strip unrolled behind the shearer as shown in Figure 4. The wire mesh is required to prevent flushing of roof material through the space between the chock roof members. This method has proven to be successful, though significant extra manpower is required to attach the mesh.



ARTIFICIAL ROOF APPLIED BY LOWER LIFT SUPPORTS

Figure 4

The need for the wire mesh or rock parting as an artificial roof for the lower pass has emanated from the use of chock type roof supports which permit roof flushing. The introduction of the full canopy chock-shield support has eliminated this requirement and in Japan, in particular, considerable attention has been given to mining multiple lifts in thick seams without the additional expense of either creating an artificial roof for the lower lift, or leaving a coal or rock layer as an intermediate roof. The use of this technique is dependent on the need to provide immediate forward support of the roof after the passage of the shearer and on having skin-to-skin roof coverage to prevent flushing of loose roof material.

Detailed studies of the subsidence and degree of compaction of gob material in overseas coal mines have demonstrated that the lower portion of the settled gob is generally very dense and tightly packed. Based on these positive observations, it has been shown in Japan that the compacted gob provides an adequate immediate roof for the lower pass without the need for additional artificial or natural roof partings.

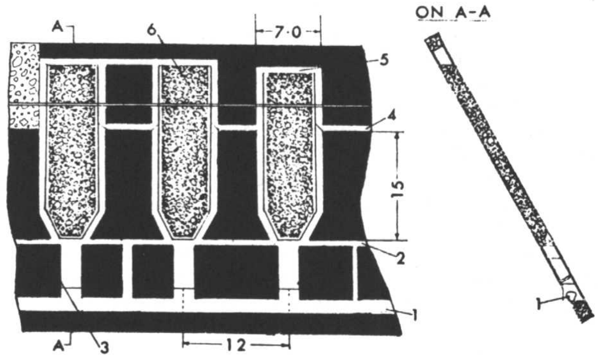
3. Non-Simultaneous - Lower Lift Taken First

Multi-pass mining is currently being used in England where two seams are being worked continuously with the lower seam being mined first. In this operation an artificial roof is formed by laying a wire mesh on top of the powered supports to form a base that prevents the caving of the upper seam. The upper seam then subsides onto the floor of the first face. The intention here is to prevent the fracturing of the inter-seam rock as it bends in subsiding. This system is not efficient and it is understood that current working faces are being phased out. The main reasons given are the inconsistency of output due to the artificial floor collapsing (thus making roof support difficult), and fractures forming in the artificial roof of the first face pass and the coal above it (thus permitting spontaneous heating of the upper seam to occur).

Much of the Polish experience has been with a technique where the lower lift is removed using either shearers or drill/blast methods, while the roof is supported by a prop/bar arrangement. As the lower face advances, the area behind the face is packed as close to the roof as practicable using a sand slurry, and then the upper roof is allowed to settle on this slurry base. After the roof has settled, the upper portion of the seam is excavated by the conventional longwall method. A large labor force is required to mine and backfill the lower lift and the loss of timber into the sand-packed gob area is substantial. Attempts have been made to automate the lower face operation through the use of a modified longwall system; however, to date the attempts have never been carried out to a successful conclusion.

The same methods as those of working thick seams described above are applicable to continguous seams lying in close proximity. The method of extraction depends primarily on the thickness of the parting. If the parting is less than 3 ft., the seams are treated as one thick seam. If the parting is more than three ft. advantage is taken of its presence by leaving the parting as intervening strata and working the independent lifts above and below it.

(B) Room System for Mining Thick Seams - In this system, the seam is extracted to its full thickness in a series of wide rooms that are separated by pillars which are usually left unworked. The system has a wide range of variants that are distinguished on the basis of the method of roof support applied. The roof control may be with caving, with stowing or with shrinkage. The essence of the system is that coal is mined in rooms of 23 - 30 feet in width by driving upwards using drilling and blasting methods. The rooms are driven on approximately 40 foot centers and the broken coal is supported by closely spaced timber posts. Manways are provided on either side of the chute and the room. As fresh coal is broken, a certain portion of the broken coal is drawn off through a chute. The system has been successfully used for working out steeply pitching (45°-85°) seams of a thickness up to 25 feet. When complete stowing is employed as a means of roof control, a rational system of work is one which does not require much timbering and this is achieved by designing the system of work on room patterns to suit different mining and geological conditions (Figure 5).

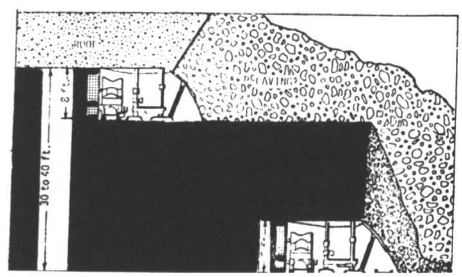


1 - GANGWAY (LEVEL HAULAGE GATE ROAD) 2 - AIRWAY 3 - CHUTE
4 - CONNECTION OR BREAK-THROUGH 5 - BREAST FACE 6 - BLASTED COAL

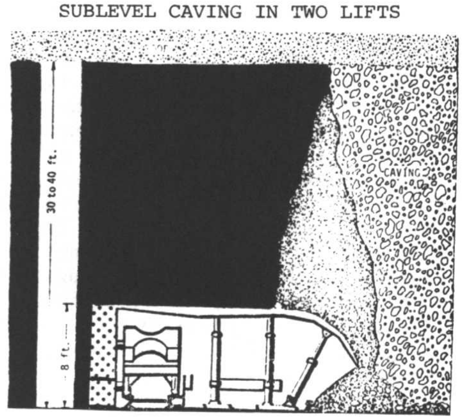
SINGLE CHUTE BATTERY BREASTS

Figure 5

(C) Sublevel Caving - Although sublevel caving is usually associated with metal mining, in recent years the system has been introduced with significant success into the coal industry in Europe and the USSR. It represents a method of working which dispenses with timbering at the working places. As a rule, the system is employed in working steeply inclined coal seams with hard and stable roof and floor rocks. See Figure 6.



SUBLEVEL CAVING IN TWO LIFTS



INTEGRAL SUBLEVEL CAVING

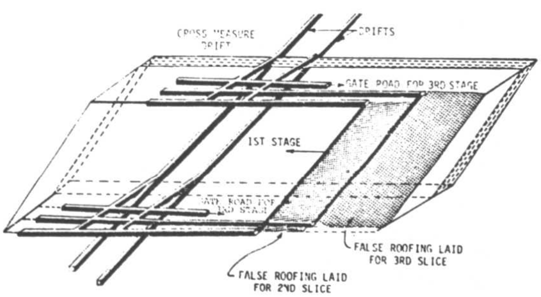
Figure 6

(D) Slicing Methods of Working Thick Seams with Hydraulic Sand Stowing - For the purpose of exploitation, a thick seam can be regarded as being made up of several layers of deposits parallel to the bedding plane of the seam. These layers of seam are termed slices. The inclined slicing method, whereby the extraction of the seam proceeds layer by layer and each layer is extracted parallel to the inclination of the seam, is widely used under a variety of different mining and geological conditions in many countries, notably Poland, India and France. Hydraulic sand stowing, and in a few cases pneumatic and mechanical stowing, are used in the inclined slicing system. There are two main variants of the system with stowing; they are:

1. Variant with longwall faces.

2. Variant with shortwall faces.

Slurry used for stowing gravitates from the surface mixing plants or is directly pumped from the river beds to the worked out areas. The diagonal position of production faces facilitates the filling of the gob area and helps to drain the water away from the working face. However, the cost of back-filling is very high and it is unlikely that such a system can compete with conventional caving in the United States. See Figure 7.



DEVELOPMENT OF INCLINED SLICING

Figure 7

Design Considerations for Mining Thick Seams

There are many complex factors that must be recognized when designing a thick seam mining system. One of the most important factors governing such design is the knowledge of the pattern and relative magnitude of the induced stresses and strains in the strata surrounding the workings, created as a result of the mining activity. The ability to combat and control these stresses and displacements by designing an effective mining geometry and system of strata control is essential. The following design considerations govern the selection of a mining method for working a thick seam:

1. Depth of Seam.
2. Thickness of Seam.
3. Dip of Seam.
4. Nature of Roof and Floor Materials.
5. Extent of Gassiness of Seam.
6. Ventilation Requirements.
7. Proneness to Spontaneous Combustion of Seam and Immediate Roof.
8. Water Content of Strata.
9. Geological Constraints.
10. Surface Subsidence Limitations.
11. Other Design Considerations.

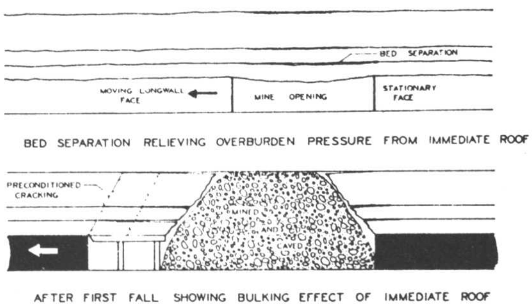
1. In general, as the depth at which coal mining takes place increases, excavations should be designed to be narrow so as to resist the pressure created by this increase in depth. Eventually, a point is reached where the excavation must be so narrow that efficient room and pillar mining cannot take place and a new mining system becomes necessary. At greater depths, the longwall method of mining provides much better recovery than the conventional room and pillar method and more reliable support systems can be used in mining.

2. The extraction of thick seams is generally more difficult than moderately thick seams. The main difficulties encountered in working thick seams are:

   (a) It is difficult to perform effective strata control,
   (b) The cost of supporting working places in productive faces is high,
   (c) A high level of underground coal losses occurs, and
   (d) There is a danger of underground fires due to spontaneous combustion.

   A multilift longwall system appears to cope with the above problems in the safest and most efficient manner.

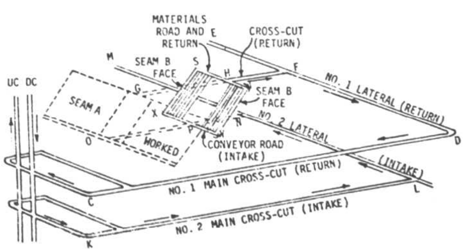
   In longwall mining with caving, as the coal face advances or retreats from the startup point, the immediate roof in the mined out area sags away from the higher strong strata layers. Even though the amount may be small, the immediate roof in the gob area is relieved of all load of the overburden by this action as shown in Figure 8. As the face continues to be mined, the span of the mined out area increases until caving of the roof occurs. The breaking off line is controlled by powered supports properly designed for the condition and provides a protected work area. As mining proceeds and supports are advanced, a new straight breaker line is established at the rear of the supports to create shear action that caves the overhanging shelf.



ROCK BEHAVIOR AROUND A LONGWALL FACE

Figure 8

3. The dip of seam plays a major role in determining the method of mining. Highly pitching seams are worked by horizon or modified horizon mining methods. This is a system in which all opening out and preparatory workings for the mining of the seam (the main haulage and ventilation roads) are driven level in the strata so as to provide the best method of transport. See Figure 9.



HORIZON MINING

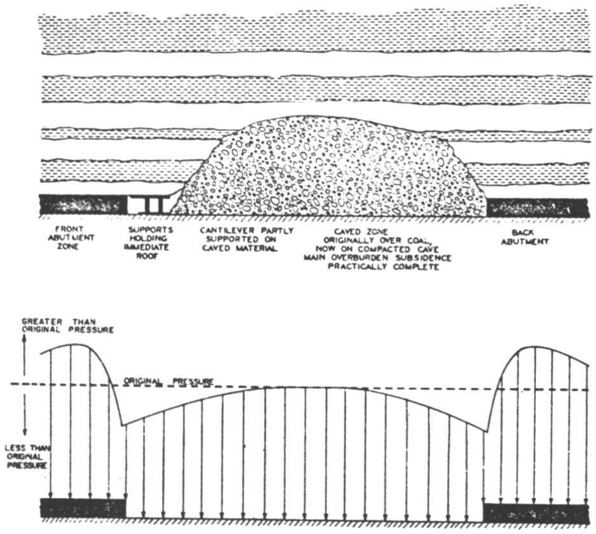
Figure 9

The seams are worked generally on a longwall method or modified room and pillar system. Horizon mining involves driving at least two levels at suitable horizons above and below the area of the seams to be worked, and connections are made in each of the seams lying between the two levels (or horizons). The position of each seam intersected by the levels is then divided into sections of suitable size either by staple or blind shafts. In flat and moderately dipping seams, the dip determines the face alignment and disposition of the coal faces in order to effectively deal with drainage problems in the workings.

4. The nature of the roof and floor strata dictates not only the method of mining but also the type of supports used. For best conditions the immediate roof should be of relatively weak material but of sufficient thickness that it will break without difficulty. Under such conditions, caving the roof will expand to fill the void to permit gradual settling of the higher strata. A roof weakened by excessive fracturing will produce a significant increase in volume of gob when it caves, so that a thickness of caveable roof of not less than two or three times the seam thickness will usually suffice for good gob caving. On the other hand, a strong immediate roof under shallow cover where there has been little induced fracturing from the front abutment pressure, will fall en masse and will thus require a thicker layer of caveable rock immediately above the seam. Under normal conditions, supports with sufficient strength and suitable yielding characteristics maintain the immediate roof intact on the face. With typical coal measure strata, a longwall face may mine 200 to 300 feet before there is a heavy cave. With stronger strata, the distance mined may increase to 400 to 500 feet before effective caving begins.

Under ideal conditions of caving, most of the roof pressure is taken by the solid coal face and surrounding abutment zone. The function of the support at the face is to hold the immediate roof as shown in Figure 10. While the weight of the immediate roof need not be held completely, convergence should be limited to prevent breaking along the face. Advancing the supports immediately after mining is the best method of minimizing convergence, assuming of course, that the supports have an adequate load carrying capacity.

Quick release and advances, adequate capacity and a sufficient number of support units are necessary to limit roof convergence. However, excess support pressure should not be used since this can cause lifting of a friable roof and subsequent premature fracturing of the immediate roof. Loose coal and refuse under a support base and roof coal on top of a support canopy can crush out and destroy the holding ability of the jack.



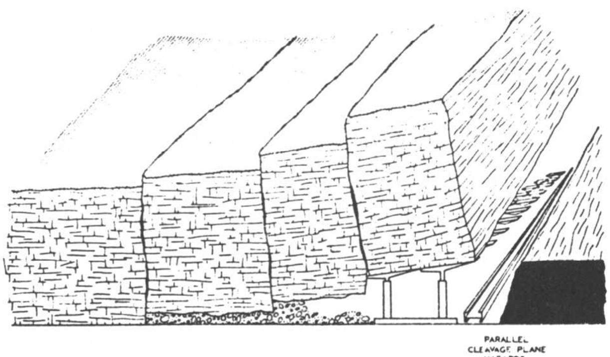
STRESS DISTRIBUTION AROUND A LONGWALL FACE

Figure 10

As with most methods of underground mining, the faster and/or the more regular the face advances, the less time there is for troublesome conditions to develop and, consequently, the better the working conditions.

Various combinations of depth, strength of immediate roof and the presence of cleavage planes can result in poor roof control. For example, when the overburden is shallow and insufficient stresses are induced by mining so as not to cause strong shales and sandstones to prefracture in advance of the coal face, the roof above the seam breaks in large slabs or hangs out behind the face, eventually shearing off from its own weight.

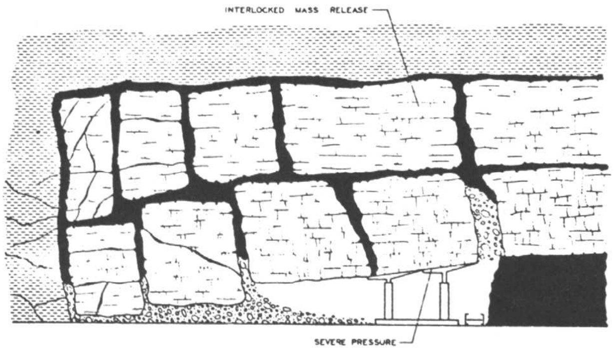
Also, at greater depth when massive sandstone comprises the immediate roof and cleavage planes run parallel to the face, large blocks may interlock and create excessive prop pressures as shown in Figure 11. In the case where the cleavage is at a slight angle to the face, the roof may break in long slabs at the back in the gob area and collapse the rear props or push the prop units toward the face, as shown in Figure 12.



THICK HOMOGENEOUS IMMEDIATE ROOF MATERIAL WITH CLEAVAGE PLANES AT AN ANGLE TO THE FACE MAY BREAK INTO LONG SLABS THAT WILL TEND TO UPSET THE PROP UNITS

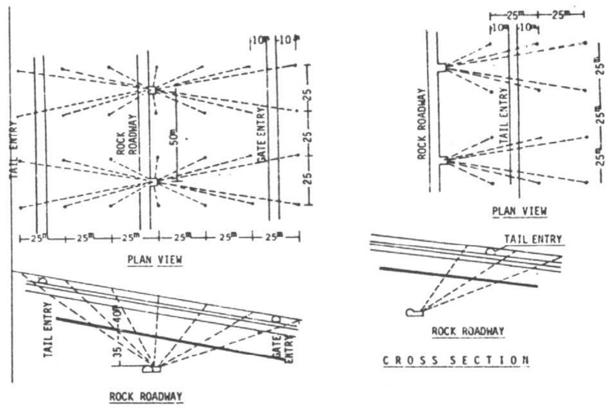
Figure 11

5. The degree of gassiness of the seam to be mined and the amount of fresh air needed to dilute the methane gas to acceptable standards are major factors in planning a mining system. In very gassy seams (such as occur in Japan), a rock road is first excavated under the coal seam before a panel is developed and methane drainage is carried out from this rock road as shown in Figure 13. While the panel is being developed, a pre-determined number of boreholes are drilled for survey and gas drainage. Gas drainage from the gob area is performed by two or three boreholes spaced 100 feet apart along the tailgate entry.



WHERE THE CLEAVAGE PLANS OF THICK HOMOGENEOUS IMMEDIATE ROOF MATERIAL PARALLEL THE FACE, THE BLOCKS MAY INTERLOCK AND PRODUCE SEVERE PRESSURE ON THE PROP UNITS.

Figure 12



METHOD OF METHANE DRAINAGE

Figure 13

6. Due to good ventilation and dust control, the longwall method of mining offers a better choice than other systems for working thick seams. The required ventilation quantities and pressures are provided on a single coal production unit instead of several rooms, and thus fewer air-crossings are required for a given area of coal to be mined.

7. The low level of underground coal recovery is one of the most important and serious drawbacks of working thick seams since coal left in the gob area constitutes a serious threat of underground fires. It is very seldom that thick seams are fully extracted when mined from underground. Factors such as the need for protective coal pillars and the presence of other geological disturbances contribute to significant coal losses.

   In the western United States a large number of thick seams exist, and many of these seams are known to be susceptible to spontaneous combustion. Under the present safety and health regulations, all active worked out areas in a coal mine must be connected to a bleeder system of ventilating entries. Such a bleeder system does not produce a brisk air current to take the heat from the unmined and spillage coal left in the gob, but this ventilating current supplies enough oxygen to encourage the ignition of a seam liable to spontaneous combustion. Any incomplete ventilation system is a serious threat to spontaneous combustion. Many longwall faces are worked overseas in seams prone to spontaneous combustion without maintaining bleeder systems. This experience and the vulnerability of U. S. thick seams to spontaneous combustion needs careful consideration when mining thick seams by underground methods.

8. In multipass mining there can be a danger of water settling and building up in the mined out upper lift of the seam prior to the working of the second or subsequent lifts. Coal faces should be laid out in such a way that the gob becomes self draining or can be drained out at desired intervals. If the coal faces are retreated down dip, there is a possibility that the overlying unconsolidated gob may flush into the lower workings. In terrain where the strata is water bearing, it is advisable to advance or retreat longwall faces on the strike or to the rise.

9. In mining thick coal, due regard must be taken of surrounding rock types and their expected conditions in terms of relative strength, induced and natural fracture patterns, presence of disturbed ground, degree of folding, presence of faulting dikes and faults traversing the seam. For planning purposes, the following can be used to establish the pattern of local geology of a seam in a given area:

   (a) Extrapolation trends from nearby worked areas
   (b) Advance boring
   (c) Exploratory drivages

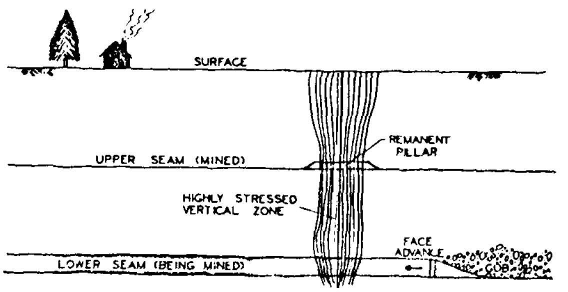
   The latter is the only reliable method when the ground is badly disturbed. Longwall retreating, which is by far the most popular longwall system used in the United States, provides an added advantage of exploring an area to be mined in the future.

10. The present and future workings in a thick seam mine should be planned in relation to the knowledge of the interaction effects from previous workings above, below and in the same seam horizon. A coal face is best protected from the effects of high stress if it is located in the de-stressed zone below the old gob of the upper level workings. An alternative is to locate the lower lift directly below or above the old gob. Note : a face crossing an old solid coal rib edge is susceptible to encountering difficult strata conditions in the pressure abutment zones. The same is true for roadways, although in view of their longer lives the cost of supporting such entries depends on the benefits to be derived.

A reduced extraction rate must be planned where surface subsidence considerations prevail; for example, in heavily populated areas. Mining by a partial extraction method or the counter-reaction (harmonics) technique can solve this problem. It is worth noting that many cities in Germany, Britain, France and Belgium have undergone several feet of subsidence without serious damage to surface structures. The factors, which have a greater influence on surface subsidence are:

(a) Angle of draw of the strata above the worked seam.
(b) Method of working, thickness of seam and length of panel.
(c) Depth of workings.
(d) Inclination of strata and other geological features.
(e) Effect of time.

It is well known that bad roof conditions exist in an underlying seam if unmined pillars remain in a previously mined overlying seam. High stresses in these pillars cause stress concentrations to accumulate in the underlying seam as shown in Figure 14. When mining takes place in the lower seam in the vicinity of these residual pillars, difficulty is experienced in strata control. For example, at Sunnyside, Utah, such a condition was almost impractical to mine using continuous miners in room and pillar sections, but was subsequently longwalled, albeit with greater difficulty than normal.



EFFECT OF UNMINED PILLARS ON MINING IN OTHER SEAMS

Figure 14

(11) There is much skepticism about the use of analytical methods for designing mining configurations that can obviate, or at least highlight potential rock pressure problems in new mining layouts. Today there is a high degree of sophistication in mathematical models for evaluating mining designs. These models include the use of finite element systems, digital and analog computers based on the theory of elasticity and physical modes. Many of these methods are used in North America on a limited scale to assist mine planning personnel; however, in many overseas countries such techniques are an integral part of mining design with the major mining companies.

Mining Method Considerations

In flat or shallow dipping seams of, say, 50 feet in thickness at a depth too great for strip operations, some form of multipass longwall method is essential if a reasonable rate of extraction is to be achieved. In this case, the use of a chock shield type of support is desirable for mining the lower lifts, since the top canopy of support is stable at all loads up to the predetermined yield load. Weak or thin interseam or inter-pass strata will be less likely to fracture in front of the support when it becomes the roof of the following or lower face, thus reducing the necessity of using wire mesh for strengthening the roof of the lower face or the floor of the upper (leading) face.

It would appear that the use of a simultaneous multilift operation with common entries for up to two lifts seems to be a viable proposition that will give a satisfactory extraction rate. From an economic viewpoint, however, this system may be non-competitive when compared with current mining systems used in the United States (i.e. 5' to 7' seam height). This is due largely to the inefficiencies resulting from the inter-dependence of simultaneous operations of multiple sets of mining equipment. On the other hand, the non-simultaneous techniques appear to provide greater productivity at lower cost. However, the extraction ratio of a method where each successively lower panel is substantially shorter than the one above, will be quite low if several lifts are removed.

Roadway Design

Based on research in Britian and other European countries, the following inferences can be drawn:

1. Interaction - A disturbance of the natural stress field caused by seam extraction is characterized by high strata pressure and the creation of stressed areas. Strata control difficulties are increased as a result of this strata pressure redistribution; this is referred to as interaction. Its effects depend on (a) depth, (b) nature and type of strata, (c) extent of workings and (d) layout and shape of workings.

2. Deformation -

   (a) Arch joint failure is common. The designed yield requires vertical and horizontal capacity to prevent jamming.
   (b) Floor Heave - Problems of extrusion from under a solid rib are increased at depth and where water is present.
   (c) Side Closure - Broken material flows into the roadway as a result of the failure of a narrow coal pillar because of high strata pressures. Poor side resistance allows arch distortion.
   (d) Roof Bed Plastic Flow - High strata pressure acting on weak roof strata above a roadway promotes expansion when stresses are relaxed.
   (e) Roof instability - Shear failures originating at the upper corners occur when high strata pressures exist and/or weak strata are present. This causes expansion and lowering of the roof beds.

3. Requirements of Roadside Supports - The primary purposes of roadside supports are: (a) high resistance to enable roof strata to span the roadway, (b) early provision of adequate support to prevent roof deterioration and (c) sufficient resistance to promote clean breaking off line of the waste-edge, if any.

Need for New Technology

In the future it is probable that there will be immense pressure on the coal mining industry to play a greater part in the national energy development programs, and the only way coal can come up to its expected mark is through solving many of the constraints that have inhibited the utilization of new mining technology. For the underground mining of thick seams (15 ft. and greater) in the United States, the following factors need attention in order to make it an everyday technology for adoption.

1. The clarification of a well-developed ground control theory for the U. S. conditions.
2. A detailed geological understanding of the strata in and around the coal seams.
3. Resolution of the complexities of subsidence laws in various states.
4. A re-assessment of regulations governing

   (a) Mining layouts, such as multiple entries for gate roads, barrier pillar design, bleeder system, etc.
   (b) Environmental conditions in mines, such as regulations governing ventilation and dust control.
5. The study of certain difficult mining conditions, such as thick seams with shallow cover having massive sandstone overlying the seams.
6. Utilization and operational performance research on longwall faces in the country.
7. Public awareness of conservation needs and obligation toward future operations.
8. Greater utilization of geotechnical methods for the design and layout of mining systems. This will need a more practical approach to mining by specialists in geomechanics in order to demonstrate the power of their knowledge to make mine layouts safer and more efficient.

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